UFC 1-200-01
01 September 2022
Change 4, 17 December 2024

UNIFIED FACILITIES CRITERIA (UFC)

DOD BUILDING CODE

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

DOD BUILDING CODE

Indicate the Military Department Preparing Activity responsible for the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	24 FEB 2023	1-3.3.3 replaced entire paragraph; removed UFC 1-202-01 reference from Appendix C
2	12 JUN 2023	1-4.4 Add paragraph; Chapter 3 and Appendix C: removed references to OUSD Memorandum, Floodplain Management on DoD Installations;
3	26 FEB 2024	1-4.5, Inclusion of NDAA PL 117-263 Sec. 2810 Consideration of Installation of Integrated Solar Roofing. US Army Base name changes, and minor admin.
4	17 Dec 2024	Replaced all references to ICC 2021 codes to ICC 2024. Added anti-ligature requirements for barracks and dormitories. Revised Applicability and Levels of Construction paragraphs.

This UFC supersedes UFC 1-200-01, dated 01 October 2020.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website https://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

PETE G. PEREZ, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Systems Command

DAVID H. DENTINO, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW, SES
Deputy Assistant Secretary of Defense
(Construction)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

TABLES

This Page Intentionally Left Blank

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

Unified Facilities Criteria (UFC) provide common requirements across DoD for safety, sustainability, durability, and functionality for DoD facilities. UFC incorporate a combination of consensus building codes, DoD-defined technical and user requirements, and applicable statutory and regulatory requirements.

1-2 PURPOSE AND SCOPE.

UFC 1-200-01 represents the foundational document of the UFC program in providing general building requirements and overarching criteria, establishing the use of consensus building codes and standards, establishing criteria implementation rules and protocols (including core UFC), and identifying unique military criteria. In accordance with the authority in MIL-STD-3007G, UFC are prepared by DoD committees called Discipline Working Group (DWG), and are published by the Military Services under the authority of the Engineering Senior Executive Panel (ESEP), comprised of the following:

- Deputy Assistant Secretary of Defense (Construction) Office of the Secretary of Defense
- Chief, Engineering and Construction, Headquarters United States Army Corps of Engineers (HQ USACE)
- Chief Engineer, Naval Facilities Engineering Systems Command (NAVFAC)
- Headquarters US Air Force, Deputy Director of Civil Engineers DCS/Logistics, Engineering & Force Protection (HAF/A4C)

1-3 APPLICABILITY.

This UFC applies to the planning, design, construction, sustainment, restoration, and modernization of DoD-owned and DoD-occupied facilities. It is applicable to all methods of project delivery and levels of construction as defined below.

\4 For temporary construction see paragraph 1-3.2.2, for non-permanent DoD facilities in support of military operations see paragraph 1-3.2.3, for Host Nation Facilities see paragraph 1-3.2.4, and for permanent facilities for DoD personnel outside the United States and its territories and possessions see paragraph 1-3.2.5. **/4/**

1-3.1 Implementation, Administration, and Enforcement.

UFC and their referenced codes and Criteria are effective upon issuance for projects as follows:

- Design-Bid-Build projects that have not proceeded beyond 35% design completion.

- Design-Build projects that have not proceeded beyond date of Request for Proposal (RFP) issuance. When an RFP is issued in multiple phases or steps use the date of the last phase of the RFP issuance.
- Projects that have a delay, either planned or unintentional, of more than 18 months between design completion and the solicitation of offers for construction must be re-evaluated to determine if any design revision is necessary due to changes in criteria (including codes and standards) or site infrastructure (for example, water supply for fixed fire suppression systems, water for hose stream allowances, or fire department vehicle access). Note: The evaluation must also include retroactive requirements that have been included in the new editions of the criteria.

1-3.2 Levels of Construction.

1-3.2.1 Permanent Construction.

Permanent facilities must follow Chapter 2 of this UFC, which contains modifications to the IBC. Buildings and facilities are considered permanent construction unless meeting other definitions herein. Permanent construction is intended to address a level of quality and durability to achieve a life expectancy of more than 25 years.

1-3.2.2 Temporary Construction.

\4Temporary construction includes structures erected for a period less than 180 days both inside and outside the United States its territories and possessions**./4/** Temporary structures must conform to the structural strength, fire safety, means of egress, accessibility, light, ventilation, and sanitary requirements of the IBC Section 3103, as modified in Chapter 2 of this UFC. Extension of temporary construction occupancy or usage 180 days or beyond requires a written justification request and approval from the BO/ AHJ. Extension approvals may be renewed at the discretion of the BO/AHJ; however, occupancy or facility usage cannot occur beyond 5 years from date of initial occupancy.

1-3.2.3 Non-permanent DoD Facilities in Support of Military Operations.

Use the following UFC for facilities used in non-permanent DoD facilities support of military operations **\4** both inside and outside the United States its territories and possessions**. /4/** These UFC are self-contained documents and contain all design requirements for the respective subjects. The UFC hierarchy stated in paragraph 1-3.4, and subparagraphs does not apply to these UFC. These UFC apply to all DoD components involved with planning, design, construction and renovation of non-permanent DoD facilities in support of military operations, both new construction and renovations (where renovation does not convert the facility to permanent), used by US military and DoD civilian personnel in support of military operations, actions with written Operation Orders (OPORDS); examples include Kinetic actions, Disaster Recovery, Humanitarian Assistance, and Defense Support to Civil Authorities.

1-3.2.3.1 UFC 1-201-01.

Use UFC 1-201-01 for planning, design, construction, and renovation of non-permanent facilities used by US military and DoD civilian personnel in support of military operations.

1-3.2.3.2 UFC 1-201-02.

Use UFC 1-201-02 to assess existing facilities for life safety and habitability for potential occupancy by DoD personnel in support of military operations. Requirements for preliminary evaluations do not apply when forces occupying the facility are engaged in actual combat operations.

1-3.2.4 \1\ Host Nation Facilities.

\4 Host Nation (HN) facilities are permanent and non-permanent facilities for exclusive use by HN personnel. HN facilities may be funded by the HN or the United States. In either case, follow the appropriate Status of Forces agreements (SOFA), bilateral agreements, or other Host Nation (HN) agreements. If no HN agreement exists, the agreement does not address building codes, or the HN does not address design criteria in the project directive, use the International Building Code® (IBC) for planning, design and construction of all facilities built for HN personnel use**. /4/ /1/**

1-3.2.5 \4\ Permanent Facilities for DoD personnel Outside the United States and its Territories and Possessions.

Permanent facilities for use by one or more DoD personnel outside the United States and its territories and possessions must follow the appropriate Status of Forces agreements (SOFA), bilateral agreements or other Host Nation (HN) agreements. If no HN agreement exists, or the agreement does not address building codes, requirements for permanent facilities that are for use by any DoD personnel follow the applicability of this UFC. **/4/**

1-3.3 Waivers and Exemptions.

A waiver provides authority to deviate from a criteria requirement for a specific period, typically 12 months. An exemption provides authority to deviate from a requirement indefinitely. Refer to MIL-STD-3007 for the waiver and exemption request and approval process.

1-3.4 UFC Hierarchy.

UFC 1-200-01 is the overarching document for buildings and facilities owned by DoD. UFC 1-200-01 directs the use of the International Building Code® (IBC), the International Existing Building Code® (IEBC), International Green Construction Code® (IgCC), Core UFC, other UFC as applicable to the building, facility, structure, or system, and Facility Criteria (FC) as they pertain to the applicable DoD Component.

1-3.4.1 UFC 3- Series.

The UFC 3- Series and FC 3- Series (simply referred to as UFC 3- Series) provide discipline specific criteria requirements for the various engineering disciplines.

- If conflict occurs between two UFC within the UFC 3- Series, the requirements of the UFC that is more detailed pertaining to that specific building, facility, structure, or system take precedence.

1-3.4.2 UFC 4- Series.

The UFC 4- Series and FC 4- Series (simply referred to as UFC 4- Series) provide requirements for multi-disciplinary and facility-specific design.

- If conflict occurs between two UFC within the UFC 4- Series, the requirements of the UFC that is more detailed pertaining to that specific building, facility, structure, or system take precedence.
- If conflict occurs between a UFC 4- Series and a UFC 3- Series, the requirements of the UFC 4- Series take precedence.

1-4 OVERARCHING CRITERIA OR REGULATORY REQUIREMENTS.

Design and Construction must comply with Public Laws (P.L.), Executive Orders (E.O.), Code of Federal Regulations (CFR), Department of Defense Instructions (DoDI), Department of Defense Manuals (DoDM), and Department of Defense Directives (DoDD) or other higher authority documents as applicable.

1-4.1 Vending Facilities for the Blind.

Verify with the using activity the requirement to provide blind-operated vending facilities in compliance with the Randolph-Sheppard Act and DoDI 1125.03. This requirement generally applies in buildings that are over 15,000 square feet (1,400 square meters) that will contain over 100 employees, but may also apply in other situations at the discretion of the using activity.

1-4.2 Nursing and Lactation Rooms.

Provide a private space for nursing mothers as required by the Office of the Undersecretary of Defense (OUSD) Memorandum, Department-Wide Policy for Nursing and Lactation Rooms at military installations and DoD facilities. Use the Office of Personnel Management (OPM) Guide for Establishing a Federal Nursing Mother’s Program to implement best practices for creating a successful nursing mother’s program, consistent with the demand of the workplace and the needs of the mission. This space must not be a bathroom, and must be shielded from view and free from intrusion of others. A nursing mother’s space must be functional, with a private space with a place to sit and a flat surface, other than the floor, to place the breast pump and other supplies. Although there are no size or permanency requirements, this space must provide access to electricity for the use of a breast pump, as well as good lighting, a comfortable temperature, and proper ventilation; and be near a source of hot and cold running water. In addition, comply with any command-specific policy applicable to this requirement or applicable to the establishment of a working mothers program within the facility.

1-4.3 Investigation of Microgrid Feasibility.

Planning and design for military construction projects inside the United States must include consideration of the feasibility and cost-effectiveness of installing an energy microgrid as part of the project, including intentional islanding capability of at least seven consecutive days. **2**\

1-4.4 Government Fleet Electric Vehicle Charging Capability.

Provide adequate electric charging capability, concurrently, for not less than 15 percent of Government motor vehicles planned to be parked at the facility. **/2/ \3**

1-4.5 Photovoltaic Roofs.

Consider the Installation of Integrated Solar Roofing in planning, design, and construction of DoD projects. **/3/**

1-4.6 \4\ Ligature-resistant Design. /4/

\4 Barracks and Unaccompanied Housing. For barracks and unaccompanied housing, prioritize the integration of ligature-resistant fixtures, equipment, and other appurtenances to reduce ligature risk points, as required by the Secretary of Defense memo signed on 26 SEP 2023, titled "New DoD Actions to Prevent Suicide in the Military". Incorporate ligature-resistant features such as rounded edges on furniture and fixtures, tamper-proof fixtures, anti-ligature hardware, weighted furniture, non-removable parts, sloped surfaces, flush-mounted fixtures, and secure windows that cannot be easily manipulated. Incorporate into toilet rooms, bathing facilities, bedrooms, and other living areas, while remaining residential in the nature of the design. These features enhance the safety and well-being of residents. Choose materials for their durability and resistance to tampering to ensure that every aspect of the design minimizes the risk of self-harm. **/4/**

1-5 UFC AUTHORITIES.

1-5.1 ESEP.

The ESEP represents the senior technical facilities engineering leadership within each Military Department as identified in paragraph 1-2 and exercises exclusive authority to issue UFC and FC, and to approve waivers and exemptions thereof.

1-5.2 Building Official / Authority Having Jurisdiction (BO/AHJ).

The terms “Building Official” (BO), “Code Official” and “Authority Having Jurisdiction” (AHJ) used in the UFC or FC criteria, reference codes, and standards are synonymous. The BO/AHJ represents the DoD design and construction agent responsible for accomplishing the project, and exercises authority to interpret and apply criteria to work in progress, evaluate compliance with criteria, and accept finished work that is in compliance. Chapter 2, Section 104, Duties and Powers of the Building Official, defines the authorities of the BO/AHJ. This authority does not include approval of waivers or exemptions to criteria.

1-5.3 Component Technical Representative (CTR).

The CTR represents the project sponsor or customers and exercises authority to establish project requirements on behalf of the user or facility owner in the following cases:

- When the Building Official / Authority Having Jurisdiction (BO/AHJ) has identified more than one option satisfies criteria and allows user preference, such as for different system choices that offer varying levels of performance, durability, compatibility, compatibility with other systems, esthetics, or the like. This authority would not apply where in conflict with requirements for installation-wide networks, architectural standards, or similar standards established by the installation or Component with jurisdiction of the installation.
- When the BO/AHJ has identified an approved equivalent standard that satisfies the intent of criteria (see Chapter 2, paragraph 104.11), such as a material or component meeting a host-nation standard in a foreign location.
- When the BO/AHJ has identified a design option is not specifically addressed in criteria.

1-6 GENERAL BUILDING REQUIREMENTS.

1-6.1 Building Codes.

Use **\4** 2024 IBC and 2024 **/4/** IEBC as follows:

- Use IBC, including all published errata, as the building code for DoD, except as modified by this UFC, other UFC, and FC. Where a paragraph in any chapter of IBC references a paragraph in a different chapter, modify the referenced chapter as described in CHAPTER 2.
- Use IEBC, including published errata, except as modified by this UFC, other UFC, and FC. Where a paragraph in any chapter of IEBC references a paragraph in a different chapter, modify the referenced chapter as described in CHAPTER 3.

1-6.2 Referenced Codes and Substitutions.

Treat references in the DoD Building Code (see Paragraph 2-1.1) and the DoD Existing Building Code (see Paragraph 3-1.1) to other codes as follows:

- Dismiss references to the International Fuel Gas Code® (IFGC), as IFGC is not adopted. UFC 3-430-05 is used for gaseous fuel distribution, UFC 3-460-01 is used for liquid fuel storage and distribution and specific NFPA codes are directly referenced by appropriate application in UFCs.
- References to the International Mechanical Code® (IMC) are references to UFC 3-410-01, which cites IMC.
- References to the International Plumbing Code® (IPC) are references to UFC 3-420-01, which cites IPC.
- Dismiss references to the International Property Maintenance Code® (IPMC), as IPMC is not adopted.
- References to the International Fire Code® (IFC) are references to UFC 3-600-01, which cites NFPA 1.
- References to the International Energy Conservation Code® (IECC) are references to UFC 1-200-02, which cites IECC.
- References to the International Green Construction Code® (IgCC) are references to UFC 1-200-02, which cites IgCC.
- References to NFPA 70, National Electrical Code® (NEC) are references to UFC 3-501-01, which cites NFPA 70.
- References to the International Residential Code® (IRC) are references to the IRC. See also UFC 3-600-01. The DoD adopts the **\4** 2024 **/4/** edition of the International Code Council (ICC) International Building Code® (IBC) and International Residential Code® (IRC) as the primary voluntary consensus standard for DoD Family Housing. Except as augmented or modified in this UFC, design, construct new, and improve Family Housing in accordance with the following:
  - Detached one- and two-family dwellings and multiple attached single-family dwellings (townhouses) not more than three stories above grade plane in height with a separate means of egress and their accessory structures must comply with all sections of the International Residential Code (IRC) and referenced codes and standards (IBC Article 101.2).
  - Other housing types must comply with this UFC, which augments the International Building Code® (IBC). This includes primarily multifamily (i.e., apartment style) housing.

1-6.3 Other Criteria.

In addition to IBC as modified in CHAPTER 2, and IEBC as modified in CHAPTER 3, comply with the following criteria.

1-6.3.1 UFC.

Comply with the UFC (latest version, refer to Paragraph 1-3.1) as noted herein.

1-6.3.1.1 Core UFC.

Core UFC are criteria that provide requirements for the majority of traditional building systems that are prevalent on DoD facility construction projects. Core UFC also identify additional criteria such as Antiterrorism, High Performance, and Sustainable Building requirements mandated by law and policy. Comply with the Core UFC listed here.

- 1-200-02, High Performance and Sustainable Building Requirements
- 3-101-01, Architecture
- 3-110-03, Roofing
- 3-120-10, Interior Design
- 3-190-06, Protective Coatings and Paint
- 3-201-01, Civil Engineering
- 3-201-02, Landscape Architecture
- 3-210-10, Low Impact Development
- 3-220-01, Geotechnical Engineering
- 3-230-01, Water Storage and Distribution
- 3-240-01, Wastewater Collection and Treatment
- 3-301-01, Structural Engineering
- 3-401-01, Mechanical Engineering
- 3-410-01, Heating, Ventilating and Air Conditioning
- 3-420-01, Plumbing Systems
- 3-490-06, Elevators
- 3-501-01, Electrical Engineering
- 3-520-01, Interior Electrical Systems
- 3-530-01, Interior and Exterior Lighting Systems and Controls
- 3-550-01, Exterior Electrical Power Distribution
- 3-560-01, Operation and Maintenance: Electrical Safety
- 3-580-01, Telecommunications Interior Infrastructure Planning and Design
- 3-600-01, Fire Protection Engineering for Facilities
- 4-010-01, DoD Minimum Antiterrorism Standards for Buildings

- 4-010-06, Cybersecurity of Facility-Related Control Systems
- 4-021-01, Design and O&M: Mass Notification Systems

1-6.3.1.2 Other UFC.

In addition to the “Core UFC”, comply with other UFC as applicable to the system, structure, or facility type defined in the scope of the construction project.

1-6.3.2 FC.

The designation "FC" is for criteria that are not applicable to all DoD Components.

For example: FC 4-721-10N "Navy and Marine Corps Unaccompanied Housing" has a final "N" designation because it is used by the Navy, including its Component, the U.S. Marine Corps. FC are applicable only to the DOD Component in the title and are intended for use with unified technical requirements published in UFC. Comply with the FC for the designated facility type and the DoD Component.

1-6.3.3 Specification Requirements.

Use Unified Facilities Guide Specifications (UFGS) for projects, including Design-Build submittals, and in accordance with UFC 1-300-02 no later than 35% design completion for Design-Bid-Build projects or draft Request for Proposals (RFP) completion for Design-Build projects. Download, use, and edit the most current UFGS database available from the Whole Building Design Guide website at https://www.wbdg.org/dod/ufgs. Modify and edit the UFGS as necessary to suit the work required by the specific project, including editing for metric or inch-pound and to reflect the latest proven technology, materials, and methods for the project. Follow Order of Precedence requirements for each Government Design Agent on use of Regional, Agency, Unified, and Other guide specifications. Other guide specifications may be used as a basis for information when not available in the UFGS. Provide these specifications in UFGS format and modified to meet the requirements of UFC 1-300-02.

1-6.3.4 Other Military Criteria.

Military criteria other than those listed in this UFC may be applicable to specific types of structures, building systems, or building occupancies. Such structures, systems, or buildings must meet the additional requirements of applicable military criteria.

1-6.3.4.1 Explosive Safety.

Facilities that involve DoD Ammunition and Explosives (AE) storage, handling, maintenance, manufacture or disposal, as well as facilities within the explosives safety quantity distance (ESQD) arcs of AE facilities, must comply with the requirements found in DoDM 6055.09, as well as implementing Service criteria found in DA PAM 385-64 (Army), NAVSEA OP 5 (Navy and Marine Corps), and DESR6055.09_AFMAN91-201 (Air Force). DoD facilities exposed to potential explosion effects from AE belonging to other nations are also required to meet DoD and Service explosives safety criteria.

Closely coordinate the planning and design of new facilities, and occupation, repair, alteration, and restoration of existing AE-related facilities, or other facilities within ESQD arcs with knowledgeable explosives safety professionals in theater, or with the Services' Explosives Safety Centers. Coordinate as early as possible in the planning and design process to avoid issues or problems and to ensure compliance. Facility construction or use within ESQD arcs requires review for compliance with explosives safety criteria, and must have either an approved explosives safety site plan or an approved explosives safety deviation. Refer to the DoD Service documents mentioned above for further applicable guidance.

1-6.3.4.2 Facility Systems Safety.

Safety is an important component of maintaining and operating DoD facilities. Consider safety during design. Incorporate a hazards review into the regular design review process to ensure systems safety has been considered at the earliest phases of project development to reduce and mitigate unintentional maintenance and operational hazards. For Army projects, incorporate the safety engineering practices delineated under the Facilities Systems Safety (FASS) program as prescribed under DA PAM 385-16, to the extent practicable and feasible. For Air Force projects, incorporate the safety engineering practices delineated in DAFMAN 91-203, to the extent practicable and feasible. For Navy, the Designer of Record must follow the concepts from the most current ANSI/ASSP Z590.3. DoD facilities must comply with DoDI 6055.01 and applicable Occupational Safety and Health Administration (OSHA) safety and health standards.

1-6.3.4.3 Antiterrorism.

Antiterrorism is defined as defensive measures used to reduce the vulnerability of individuals and property to terrorist acts. UFC 4-010-01 sets the minimum requirements for DoD buildings, and the Geographic Combatant Commander Antiterrorism Construction Standards address unique requirements specific to their area of responsibility. Refer to UFC 4-010-01 and the Geographic Combatant Commander Antiterrorism Construction Standards for the minimum antiterrorism requirements.

1-6.3.4.4 Physical Security.

Physical security is defined as that part of security concerned with physical measures designed and placed to safeguard personnel; to prevent unauthorized access to installations, equipment, material and documents, and to safeguard them against espionage, sabotage, damage, and theft. Many buildings require some level of physical security. When required, integrate physical measures into the site, building, room, or area as applicable. DoD requirements for physical security related to specific assets are documented in DoD publications, directives, manuals, and instructions. The Services have related documents that implement the DoD policy for the Services. The main DoD documents that contain the physical security requirements for the protection of specific DoD assets are shown in Table 1-1. This does not include the policy documents associated with the protection of nuclear and chemical assets.

Table 1-1 Policy Related to Physical Security

Asset	Policy and Documents
Classified Information	DoDM 5200.01, Volume 3, *DoD Information Security Program: Protection of Classified Information*; https://www.esd.whs.mil/DD/DoD-Issuances/
Sensitive Compartmented Information (SCI)	DoDM 5105.21-Volume 1, *Sensitive Compartmented Information (SCI) Administrative Security Manual: Administration of Information and Information Systems Security*; https://www.esd.whs.mil/DD/DoD-Issuances/ DoDM 5105.21-Volume 2, *Sensitive Compartmented Information (SCI) Administrative Security Manual: Administration of Physical Security, Visitor Control, and Technical Security*; https://www.esd.whs.mil/DD/DoD-Issuances/ UFC 4-010-05, *SCIF/SAPF Planning, Design, and Construction*; https://www.wbdg.org/dod/ufc/ufc-4-010-05/
Special Access Program (SAP) Information	DoDM 5205.07, Volume 3, *DoD Special Access Program (SAP) Security Manual: Physical Security*; https://www.esd.whs.mil/DD/DoD-Issuances/
Arms, Ammunition, and Explosives	DoDM 5100.76, *Physical Security of Sensitive Conventional Arms, Ammunition, and Explosives (AA&E)*; https://www.esd.whs.mil/DD/DoD-Issuances/
Weapons Systems and Platforms	DoD 5200.08-R, *Physical Security Program*; https://www.esd.whs.mil/DD/DoD-Issuances/
Bulk Petroleum Products	
Communications Systems	
Controlled Inventory Items	

1-6.3.4.5 Corrosion Prevention and Control Requirements.

Use the requirements in 3-18 in conjunction with other UFC requirements to design for durability and provide for a comprehensive corrosion prevention and control strategy.

1-7 CYBERSECURITY.

Plan, design, acquire, execute, and maintain control systems (including systems separate from a utility monitoring and control system) in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-8 NON-GOVERNMENT STANDARD MODIFICATIONS.

CHAPTER 2 modifies IBC and is organized by the chapter of IBC that each section modifies. CHAPTER 3 modifies IEBC and is organized by the chapter of IEBC that each section modifies. The modifications are one of four actions, according to the following legend:

- [Addition] – Add new section, including new section number, not shown in IBC or IEBC.
- [Deletion] – Delete referenced IBC or IEBC section.
- [Replacement] – Delete referenced IBC or IEBC section or noted portion and replace it with the narrative shown.
- [Supplement] – Add narrative shown as a supplement to the narrative shown in the referenced section of IBC or IEBC.

The section modifiers are identified at the end of the paragraph title. Limited commentary has been added in the chapters. Section designations for such commentary are preceded by a “[C]”, and the commentary narrative is shaded.

1-9 GLOSSARY.

APPENDIX B contains a list of acronyms, abbreviations, and definitions.

1-10 REFERENCES.

APPENDIX C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 MODIFICATIONS TO IBC

2-1 CHAPTER 1 – SCOPE AND ADMINISTRATION [SUPPLEMENT].

Use IBC Chapter 1 except as modified below and by UFC 3-301-01.

2-1.1 Section 101 – SCOPE AND GENERAL REQUIREMENTS.

101.1 Title [Replacement]

These regulations are to be known as the DoD Building Code, hereinafter referred to as "this code".

101.4 Referenced codes [Supplement]

Refer to Paragraph 1-6.2 for referenced codes.

101.4.7 Existing buildings [Replacement]

The provisions of the International Existing Building Code® (IEBC), including the amendments in Chapter 3 of this UFC, apply to the repair, alteration, change of occupancy, addition to and relocation of existing buildings.

2-1.2 Section 102 – APPLICABILITY.

102.1 General [Replacement]

Where there is a conflict between a general requirement and a specific requirement, the specific requirement is applicable. Where, in a specific case, different sections of this code specify different materials, methods of construction or other requirements, the most restrictive govern. Refer to Paragraph 1-3.6 for hierarchy of UFC.

102.2 Other Laws [Replacement]

The provisions of this code does not intend to nullify applicable provisions of local, state, or federal law. In overseas locations the SOFA, HNFA, and in some instances, BIA may govern requirements.

102.4 Referenced codes and standards [Supplement]

Refer to Paragraph 1-6.2 and Paragraph 1-6.3 for referenced codes and criteria.

2-1.3 Section 103 – CODE COMPLIANCE AGENCY [Deletion].

2-1.4 Section 104 – DUTIES AND POWERS OF BUILDING OFFICIAL.

104.1 General [Replacement]

The Building Official/AHJ is a person authorized and directed to enforce the provisions of this code, UFC, or FC. They have the authority to render interpretations of this code, UFC, or FC and to clarify the application of the provisions. Such interpretations will be in compliance with the intent and purpose of this code, UFC, or FC and will not have the effect of waiving or exempting requirements specifically provided for in this code, UFC, or FC. For waiver and exemption process and authority refer to Section 104.10 Waivers and exemptions.

104.10 Waivers and exemptions [\4\ Addition /4/]

Where there are practical difficulties involved in carrying out the provisions of this code, UFC, or FC; the Building Official/AHJ must first find that special individual case or reason that makes the strict letter of this code, UFC, or FC impractical resulting in noncompliance with requirements or an increased risk to: health, accessibility, life and fire safety, structural requirements, or operational requirements. Such cases will be treated as a waiver or exemption. Waivers and exemptions to specific UFC or FC requirements are approved by the Service's Chief Engineer, Engineering Senior Executive Panel signature authority for the Service. Refer to MIL-STD 3007 for waivers and exemption definitions and for specific requirements for approval.

[C] 104.10 Waivers and exemptions [**\4** Addition ***/4/***]

Avoid requests for waivers and exemptions if possible. The objective is a criteria- or code-compliant engineering solution for the facility versus a waiver or exemption request. UFC and FC requirements are intended to address code-compliant facility requirements; life, health and safety requirements; property loss prevention; lowest lifecycle cost; and facility operational requirements. For issues dealing with life, health, and safety, cost is not a valid reason to grant a waiver or exemption. Waiving or exempting requirements typically results in increased risk to safety or property loss, increased operational risk, or poor return on investment.

104.11 Alternative materials, design and methods of construction and equipment [\4\ Addition /4/]

The provisions of this code, UFC, or FC are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design, or method of construction may be approved where the Building Official/AHJ finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, UFC, or FC, and that the material, method, or work offered is, for the purpose intended, not less than the equivalent of that prescribed in this code, UFC, or FC in quality, strength, effectiveness, fire resistance, durability, and safety. When the alternative material, design, or method of construction is not approved, the Building Official/AHJ will respond in writing, stating the reasons why the alternative was not approved.

104.11.1 Research reports [\4\ Addition /4/]

Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, UFC, or FC, must consist of valid research reports from approved sources.

104.11.2 Tests [\4\ Addition /4/]

Whenever there is insufficient evidence of compliance with the provisions of this code, or evidence that a material or method does not conform to the requirements of this code, or in order to substantiate claims for alternative materials or methods, the Building Official/AHJ has the authority to require tests as evidence of compliance to be made without expense to the government. Test methods are as specified in this code, UFC, or FC or by other recognized test standards. In the absence of recognized and accepted test methods, the Building Official/AHJ must approve the testing procedures. Perform tests by an approved agency. Building Official/AHJ retains reports of such tests.

104.11.3 Overseas locations [Addition]

In overseas locations where the SOFA, HNFA, OEBGD, or BIA may govern requirements, the Building Official/AHJ will review the situation and determine what, if any, measures are appropriate to take to compensate for measures not allowed by the host nation or that present practical difficulties involved in carrying out the provisions. Measures taken must not lessen quality, strength, effectiveness, fire resistance, durability, and safety. In these instances, formal exemptions are not required. The details of action granting alternative materials, design and methods of construction and equipment will be recorded and entered in the project document files by the Building Official/AHJ. Note that alternative materials, design and methods of construction and equipment must not be misconstrued as a waiver or exemption. Waivers and exemptions are addressed in 104.10.

2-1.5 Section 105 – PERMITS [Deletion].

2-1.6 Section 106 – FLOOR AND ROOF DESIGN LOADS [Deletion].

2-1.7 Section 107 – CONSTRUCTION DOCUMENTS [Deletion].

2-1.8 Section 108 – TEMPORARY STRUCTURES AND USES [Deletion].

2-1.9 Section 109 – FEES [Deletion].

2-1.10 Section 111 – CERTIFICATE OF OCCUPANCY [Deletion].

2-1.11 Section 113 – MEANS OF APPEALS [Deletion].

2-1.12 Section 114 – VIOLATIONS [Deletion].

2-1.13 Section 115 – STOP WORK ORDER [Deletion].

2-1.14 Section 116 – UNSAFE STRUCTURES AND EQUIPMENT [Deletion].

2-2 CHAPTER 2 – DEFINITIONS [SUPPLEMENT].

Use IBC Chapter 2 except as modified by APPENDIX B and by UFC 3-301-01.

> [C] CHAPTER 2 – DEFINITIONS [SUPPLEMENT]
>
> Definitions in IBC Chapter 2 apply to terms used in the model code and are not intended to replace definitions and terms in military and other referenced documents. It is essential that the code defined meaning be known to understand the intent and correctly interpret the code.

2-3 CHAPTER 3 – OCCUPANCY CLASSIFICATION AND USE [SUPPLEMENT].

Use IBC Chapter 3.

> [C] CHAPTER 3 – OCCUPANCY CLASSIFICATION AND USE [SUPPLEMENT]
>
> IBC occupancy classifications are used as they relate to allowable construction type, building height, building area, building separation distance, occupancy separation and associated requirements. NFPA 101 occupancy classifications are used as they relate to fire/smoke resistance rating of interior non-load bearing partitions (other than occupancy separation), means of egress, interior finish, features of fire protection (including vertical openings) and associated requirements.

2-4 CHAPTER 4 – SPECIAL DETAILED REQUIREMENTS BASED ON OCCUPANCY AND USE [SUPPLEMENT].

Use IBC Chapter 4 only as specifically referenced by UFC 3-600-01 and UFC 3-301-01.

2-5 CHAPTER 5 – GENERAL BUILDING HEIGHTS AND AREAS [SUPPLEMENT].

Use IBC Chapter 5 except as modified below and by UFC 3-600-01.

> [C] CHAPTER 5 – GENERAL BUILDING HEIGHTS AND AREAS [SUPPLEMENT]
>
> UFC 3-600-01 gives direction concerning the requirements for fire-rated partitions. Note that the building area for funding and planning purposes is calculated differently than the method defined in IBC Chapter 5 for code compliance calculation.

2-5.1 Section 506 – BUILDING AREA.

2-5.1.1 Table 506.2 – Allowable Area Factor in Square Feet.

Table 506.2: Cell at I-4, S1, Type IA [Replacement]

242,000.

2-6 CHAPTER 6 – TYPES OF CONSTRUCTION [SUPPLEMENT].

Use IBC Chapter 6 except as modified by UFC 3-600-01.

2-7 CHAPTER 7 – FIRE AND SMOKE PROTECTION FEATURES [SUPPLEMENT].

Use IBC Chapter 7 only where specifically referenced by IBC Chapter 5 or 6, otherwise use UFC 3-600-01 and modifications in UFC 3-101-01.

> [C] CHAPTER 7 – FIRE AND SMOKE PROTECTION FEATURES [SUPPLEMENT]
>
> UFC 3-600-01 gives direction concerning the requirements for fire-rated partitions.

2-8 CHAPTER 8 – INTERIOR FINISHES [REPLACEMENT].

Use UFC 3-600-01, UFC 3-120-10 and UFC 3-101-01.

2-9 CHAPTER 9 – FIRE PROTECTION AND LIFE SAFETY SYSTEMS [REPLACEMENT].

Use UFC 3-600-01.

2-10 CHAPTER 10 – MEANS OF EGRESS [REPLACEMENT].

Use UFC 3-600-01. Use IBC Chapter 10 when specifically referenced by US Access Board, Architectural Barriers Act (ABA) Standards and as referenced by UFC 3-600-01.

> [C] CHAPTER 10 – MEANS OF EGRESS [REPLACEMENT]
>
> UFC 3-600-01 references IBC Chapter 10 for requirements for stair to roof access. Where the ABA Standards reference the previous versions of IBC, the applicable requirements of the **\4** 2024 **/4/** IBC are acceptable.

2-11 CHAPTER 11 – ACCESSIBILITY [REPLACEMENT].

Use the ABA Standards and the special provisions of the DoD Deputy Secretary of Defense Memorandum, Subject: Access for People with Disabilities, October 31, 2008. Use the additional requirements listed in the subparagraphs below, in addition to the ABA Standards and Defense Memorandum.

[C] CHAPTER 11 – ACCESSIBILITY [REPLACEMENT]

Refer to APPENDIX C for a link to the ABA Standards and the DoD policy memorandum.

2-11.1 Electrical vehicle charging stations.

Electrical vehicle charging stations provided to serve Group, R-3 and R-4 occupancies are not required to comply with the following sub-sections.

2-11.1.1 Number of accessible vehicle spaces.

Not less than 5 percent of vehicle spaces on the site served by electrical vehicle charging systems, but not fewer than one for each type of electric vehicle charging system, must be accessible.

2-11.1.2 Accessible electric vehicle space size.

Accessible vehicle spaces at electrical vehicle charging stations must include an accessible parking space that is 132 inches (3350 mm) minimum in width with an access aisle on each side of the space that is 60 inches (1525 mm) minimum in width to allow for a pathway around the vehicle to variable locations of charging ports. Two parking spaces are permitted to share a common access aisle.

2-11.2 Water bottle-filling stations.

Where bottle-filling stations are provided, they must be accessible.

Exception: Bottle-filling stations over drinking fountains for standing persons are not required to be accessible, provided that bottle-filling stations are also located over the drinking fountains for persons using wheelchairs.

2-12 CHAPTER 12 – INTERIOR ENVIRONMENT [SUPPLEMENT].

Use IBC Chapter 12 except as modified below and by UFC 3-101-01.

[C] CHAPTER 12 – INTERIOR ENVIRONMENT [SUPPLEMENT]

Refer to other Federal guidance and UFC for additional interior space requirements for ventilation, lighting, acoustics, and other environmental characteristics.

2-12.1 Section 1203 – TEMPERATURE CONTROL.

1203.1 Equipment and systems [Replacement]

Use UFC 3-410-01.

1203.1 Equipment and systems, Exceptions [Deletion]

2-12.2 Section 1206 – SOUND TRANSMISSION.

1206.2 Airborne sound [Replacement]

Use UFC 3-101-01 and UFC 3-120-10. For Navy and Marine Corps Unaccompanied Housing facilities, only use FC 4-721-10N.

1206.3 Structure-borne sound [Replacement]

Use UFC 3-101-01 and UFC 3-120-10. For Navy and Marine Corps Unaccompanied Housing facilities, only use FC 4-721-10N.

2-12.3 Section 1207 – ENHANCED CLASSROOM ACOUSTICS [REPLACEMENT].

Use UFC 3-101-01.

2-12.4 Section 1208 – INTERIOR SPACE DIMENSIONS.

\4\ 1208.3 Dwelling Unit Size [Replacement] /4/

\4\ 1208.4 /4/ Room area [Replacement]

Use UFC 3-101-01 and UFC 3-120-10. For Navy and Marine Corps Unaccompanied Housing facilities, only use FC 4-721-10N.

\4\ 1208.5 /4/ Efficiency dwelling units [Replacement]

Use UFC 3-101-01 and UFC 3-120-10. For Navy and Marine Corps Unaccompanied Housing facilities, only use FC 4-721-10N.

2-13 CHAPTER 13 – ENERGY EFFICIENCY [REPLACEMENT].

Use UFC 1-200-02.

\3 As per Public Law 117-263 Sec. 2810, consider the installation of integrated solar roofing to improve energy resiliency of military installation inside of the United States. Consideration includes feasibility and cost-effectiveness of installing the system. **/3/**

2-14 CHAPTER 14 – EXTERIOR WALLS [SUPPLEMENT].

Use IBC Chapter 14 except as modified by UFC 3-101-01.

2-15 CHAPTER 15 – ROOF ASSEMBLIES AND ROOFTOP STRUCTURES [SUPPLEMENT].

Use IBC Chapter 15 except as modified by UFC 3-110-03 and UFC 3-600-01.

2-16 CHAPTER 16 – STRUCTURAL DESIGN [SUPPLEMENT].

Use IBC Chapter 16 except as modified below and by UFC 3-301-01 and 3-301-02.

2-16.1 Section 1604 – GENERAL DESIGN REQUIREMENTS.

1604.11 Fall prevention and protection [Addition]

Provide fall protection features such as fixed ladders, roof hatches, handrails, guardrails and other building fall arrest systems in compliance with section titled “Hazard Prevention” in UFC 3-101-01. For fall protection features specific to roofing systems, provide in compliance with UFC 3-110-03. The anchorages and the structural elements that support these anchorages must meet the requirements of Section 1607.10.4, as modified by UFC 3-301-01. Where fall protection is required in the vicinity of weight-handling equipment, prevent conflicts between the weight-handling equipment and the fall protection measure.

2-16.2 Section 1612 – FLOOD LOADS [Supplement].

Use Section 1612 except as modified by UFC 3-201-01.

1612.3 Establishment of flood hazard areas [Supplement]

Comply with UFC 3-201-01.

2-17 CHAPTER 17 – SPECIAL INSPECTIONS AND TESTS [SUPPLEMENT].

Use IBC Chapter 17 except as modified below and by UFC 3-220-01, UFC 3-301-01, and UFC 3-600-01.

2-17.1 Section 1701 – GENERAL.

1701.1 - Scope [Supplement]

Contractual relationships and the composition of the architect / engineer / construction (AEC) team differ from that contemplated by the language of **\4** 2024 **/4/** IBC, when doing DoD construction. When performing design or construction using typical methods for in-house design, architect-engineer design, and contracting for construction, **\4** 2024 **/4/** IBC/ASCE 7-16 terms of Authority Having Jurisdiction and Building Official are to be as defined in UFC 1-200-01.

[C] 1701.1 - Scope [Supplement]

The context of the IBC terms “permit”, “permit application”, “permit applicant”, and “owner” must be modified for DoD projects. Refer to Paragraph 1-5. DoD functions as the building department/jurisdiction and the AHJ functions as the building official. When DoD advertises a project, the building permit is effectively implied/granted. However, the overall project may still require other permits related to site storm water, air quality, demolition disposal, etc.

2-17.2 Section 1704 – SPECIAL INSPECTIONS AND TESTS, CONTRACTOR RESPONSIBILITY AND STRUCTURAL OBSERVATION.

1704.2 Special inspections and tests [Replacement]

The contractor must employ one or more approved agencies to perform inspections during construction on the types of work listed under Section 1705. These inspections are in addition to the inspections defined in Section 110. The inspecting agency must provide reports of the special inspections directly to the government.

2-18 CHAPTER 18 – SOILS AND FOUNDATIONS [SUPPLEMENT].

Use IBC Chapter 18 except as modified below and by UFC 3-101-01, UFC 3-201-01, UFC 3-220-01, and UFC 3-301-01.

2-18.1 Section 1804 – EXCAVATION, GRADING, AND FILL.

1804.4 Site grading [Supplement]

Ensure that the grading and associated storm water runoff do not adversely affect surrounding sites. Establish finished floor elevations a minimum of 6 inches (150 mm) above finished grade at the perimeter of the building and provide site grading in accordance with UFC 3-201-01. Comply with UFC 3-600-01 for design of entrances and exits from buildings.

1804.4 Site grading, Exception 1 [Deletion]

1804.4 Site grading, Exception 2 [Replacement]

Impervious surfaces are permitted to be sloped less than 2 percent where the surface is a door landing or ramp that is required to comply with UFC 3-600-01.

2-19 CHAPTER 19 – CONCRETE [SUPPLEMENT].

Use IBC Chapter 19 except as modified by UFC 1-200-02 and UFC 3-301-01.

2-20 CHAPTER 20 – ALUMINUM [SUPPLEMENT].

Use IBC Chapter 20 except as modified by UFC 3-101-01 and except for aluminum use in Heating, Ventilation, and Air Conditioning (HVAC) systems. For aluminum use in HVAC systems, use UFC 3-410-01.

2-21 CHAPTER 21 – MASONRY [SUPPLEMENT].

Use IBC Chapter 21 except as modified by UFC 3-101-01 and UFC 3-301-01.

2-22 CHAPTER 22 – STEEL [SUPPLEMENT].

Use IBC Chapter 22 except as modified by UFC 3-101-01 and UFC 3-301-01.

2-23 CHAPTER 23 – WOOD [SUPPLEMENT].

Use IBC Chapter 23 except as modified below and UFC 3-101-01 and UFC 3-301-01.

2-23.1 Section 2301 – GENERAL.

2301.3 Composite Wood [Addition]

Composite wood containing materials (e.g. Plywood, Particle Board, MDF) must be specified to be moisture resistant or exterior glue grade.

2-23.2 Section 2303 – MINIMUM STANDARDS AND QUALITY.

2-23.2.1 2303.2 Fire-retardant-treated wood.

\4\ 2303.2.10 Type I and II Construction Applications [Deletion] / 4/

\4\ 2303.2.11 /4/ Roof construction [Addition]

Do not use fire-retardant-treated plywood in any part of the roof or roofing system.

2-24 CHAPTER 24 – GLASS AND GLAZING [SUPPLEMENT].

Use IBC Chapter 24 except as modified by UFC 4-010-01.

2-25 CHAPTER 25 – \4\ GYPSUM PANEL PRODUCTS AND PLASTER /4/

Use IBC Chapter 25 except as modified by UFC 3-101-01.

2-26 CHAPTER 26 – PLASTIC [SUPPLEMENT].

Use IBC Chapter 26 except as modified by UFC 3-600-01.

2-27 CHAPTER 27 – ELECTRICAL [SUPPLEMENT].

Use IBC Chapter 27 except as modified below and by UFC 3-501-01.

- Use UFC 3-520-01 for interior electrical systems criteria.
- Use UFC 3-530-01 for interior and exterior lighting and controls criteria.
- Use UFC 3-540-01 for engine-driven generator criteria.
- Use UFC 3-550-01 for exterior power distribution systems criteria.
- Use UFC 3-560-01 for electrical safety and electrical Operations and Maintenance (O&M) criteria.
- Use UFC 3-580-01 for building telecommunications criteria.
- Use UFC 3-600-01 for fire protection criteria.
- Use UFC 4-021-01 for mass notification systems criteria.

[C] CHAPTER 27 – ELECTRICAL [SUPPLEMENT].

IBC references NFPA 70, NEC. In addition, IBC Chapter 27, Section 2702 EMERGENCY AND STANDBY POWER SYSTEMS, which addresses emergency and standby power requirements, references IFC. Per Paragraph 1-6.2, this must be considered a reference to UFC 3-600-01, which cites NFPA 1.

2-28 CHAPTER 28 – MECHANICAL SYSTEMS [SUPPLEMENT].

Use IBC Chapter 28 except as modified by UFC 3-401-01. Use UFC 3-600-01 for fire protection features for mechanical systems.

[C] CHAPTER 28 – MECHANICAL SYSTEMS [SUPPLEMENT].

IBC Chapter 28 provides references to IMC which has been modified by UFC 3-410-01. However, IFGC has not been adopted. The DoD uses NFPA 54 (ANSI Z223.1), National Fuel Gas Code, for the design and installation of fuel gas piping systems.

2-29 CHAPTER 29 – PLUMBING SYSTEMS [SUPPLEMENT].

Use IBC Chapter 29 except as modified by UFC 3-420-01.

2-30 CHAPTER 30 – ELEVATORS AND CONVEYING SYSTEMS [REPLACEMENT].

Use UFC 3-490-06.

2-31 CHAPTER 31 – SPECIAL CONSTRUCTION.

Use IBC Chapter 31.

2-32 CHAPTER 32 – ENCROACHMENTS INTO THE PUBLIC RIGHT-OF-WAY.

Use IBC Chapter 32.

2-33 CHAPTER 33 – SAFEGUARDS DURING CONSTRUCTION [SUPPLEMENT].

Use IBC Chapter 33.

2-34 CHAPTER 34 – RESERVED [DELETION].

2-35 CHAPTER 35 – REFERENCED STANDARDS [SUPPLEMENT].

Use IBC Chapter 35 except as modified by Paragraph 1-6.2.

2-36 APPENDICES [DELETION]

CHAPTER 3 MODIFICATIONS TO IEBC

This Chapter covers project requirements for existing facilities. In many cases, there are project parameters that trigger discipline-specific or facility-type requirements for renovation projects.

3-1 CHAPTER 1 – SCOPE AND ADMINISTRATION.

Use IEBC Chapter 1 except as modified below. The terms "Code Official", "Building Official" (BO), and "Authority Having Jurisdiction" (AHJ) used in the UFC or FC criteria, reference codes, and standards are synonymous. The terms "Owner" and "Owner's Authorized Agent" are synonymous with "Component Technical Representative" for the DoD. See Section 1-5 of this UFC for additional information on these terms.

3-1.1 Section 101 – SCOPE AND GENERAL REQUIREMENTS.

101.1 Title [Replacement]

These regulations are to be known as the DoD Existing Building Code, hereinafter referred to as "this code."

3-1.2 Section 102 – APPLICABILITY.

102.1 General [Replacement]

Where there is a conflict between a general requirement and a specific requirement, the specific requirement is applicable. Where, in any specific case, different sections of this code specify different materials, methods of construction or other requirements, the most restrictive govern. Refer to Paragraph 1-3.6 for hierarchy of UFC.

102.4 Referenced codes and standards [Supplement]

Refer to Paragraph 1-6.2 and Paragraph 1-6.3 for referenced codes and criteria.

3-1.3 Section 103 – CODE COMPLIANCE AGENCY [Deletion].

3-1.4 Section 104 – DUTIES AND POWERS OF CODE OFFICIAL [Deletion].

3-1.5 Section 105 – PERMITS [Deletion].

3-1.6 Section 106 – CONSTRUCTION DOCUMENTS [Deletion].

3-1.7 Section 108 – FEES [Deletion].

3-1.8 Section 110 – CERTIFICATE OF OCCUPANCY [Deletion].

3-1.9 Section 112 – MEANS OF APPEALS [Deletion].

3-1.10 Section 113 – VIOLATIONS [Deletion].

3-1.11 Section 114 – STOP WORK ORDER [Deletion].

3-1.12 Section 115 – UNSAFE STRUCTURES AND EQUIPMENT [Supplement].

Use Section 115 except as modified below.

115.4 Method of service [Deletion]

3-1.13 Section 116 – EMERGENCY MEASURES [Deletion].

Use Section **\4** 116 **/4/** except as modified below.

116.2 Temporary Safeguards [Replacement]

Notwithstanding other provisions of this code, whenever, in the opinion of the BO/AHJ, there is imminent danger due to an unsafe condition, the BO/AHJ must order the necessary work to be done, including the boarding up of openings, to render such structure temporarily safe; and as the code official requires other actions as deemed necessary to meet such emergency.

116.4 Emergency repairs [Deletion]

116.5 Costs of emergency repairs [Deletion]

116.6 Hearing [Deletion]

3-1.14 Section 117 – DEMOLITION [Deletion].

3-2 CHAPTER 2 – DEFINITIONS [SUPPLEMENT].

Use IEBC Chapter 2 except as modified by APPENDIX B.

> [C] CHAPTER 2 – DEFINITIONS [SUPPLEMENT]
>
> Definitions in IEBC Chapter 2 apply to terms used in the model code and are not intended to replace definitions and terms in military documents. It is essential that the code defined meaning be known to understand the intent and correctly interpret the code.

3-3 CHAPTER 3 – PROVISIONS FOR ALL COMPLIANCE METHODS [SUPPLEMENT].

Use IEBC Chapter 3 except as modified below.

3-3.1 Section 302 – GENERAL PROVISIONS.

302.1.1 Existing Building Minimum Requirements [Addition]

Facilities, as they exist, must meet the requirements within the applicable occupancy chapter of NFPA 101. Facilities that do not meet the requirements of NFPA 101 for existing occupancies must conform to one of the following:

a. Upgrade the deficiency to meet the existing occupancy requirements, or

b. Establish management protocols to provide a level of life safety equivalent to that required by NFPA 101 for existing occupancies, until an upgrade project can be completed. Management protocols must be in writing and approved by the BO/AHJ.

[C] 302.1.1 Existing Building Minimum Requirements [Addition]

The areas of the facility where no work is being performed must meet the applicable existing occupancy chapter of NFPA 101. Thus, if the work involves 5,000 ft^2 of an existing 15,000 ft^2. office building, then the remaining 10,000 ft^2 not involved in the project must be brought up to meet the applicable existing occupancy chapter of NFPA 101 before beginning the project or be included as part of the project.

302.2.2 Requirements for High Performance and Sustainable Building Features and Systems [Addition]

For existing buildings undergoing renovations, the systems and components included in the scope of the project must meet the requirements of UFC 1-200-02. Refer to UFC 1-200-02 Table 1-1 and Chapter 2 paragraph titled “Work in Existing Buildings” for project requirements.

302.2.3 Antiterrorism Upgrades for Inhabited Buildings [Addition]

Incorporate antiterrorism upgrades as required to bring entire existing inhabited buildings into compliance with UFC 4-010-01 for all building renovations, modifications, repairs, revitalizations, and restorations where project costs exceed 50% of the replacement cost of the existing building in accordance with UFC 3-701-01 except as stated otherwise in UFC 4-010-01. The project costs used to compare against the 50% threshold are exclusive of the additional costs identified to meet these antiterrorism standards. Where project costs do not exceed the 50% threshold, compliance with the antiterrorism standards is recommended, but not required.

Incorporate antiterrorism upgrades as required in UFC 4-010-01 whenever any building, or portion of a building, is converted from low occupancy to inhabited occupancy.

302.2.4 Requirements for New Fire Protection and Life Safety Systems [Addition]

Where the Building Rehabilitation chapter of NFPA 101 requires newly constructed elements, components, and systems to comply with new construction requirements in NFPA 101, then it must also comply with new construction requirements in UFC 3-600-01.

302.2.5 Fire Protection and Life Safety Upgrades [Addition]

Where project costs exceed 50 percent of the replacement cost of the existing building in accordance with UFC 3-701-01, then the entire building must be brought up to the fire protection and life safety system requirements for new construction in UFC 3-600-01. Project costs to bring the building more into compliance with NFPA 101 do not count towards the 50 percent threshold.

[C] 302.2.5 Fire Protection and Life Safety Upgrades [Addition]

The intent of meeting requirements for new construction in this UFC is that this also applies to any requirements in applicable UFC 4-series, unless the UFC 4-series states otherwise.

302.2.6 Re-Use of Vacant Buildings [Addition]

When a vacant building is considered for reuse, the building must be evaluated for the occupancy that is planned to be in the building and all deficiencies must be corrected prior to occupancy. This includes a building to be reused for the same occupancy; for example, the last use was a warehouse and the new use will be a warehouse.

The vacant building must be evaluated to the requirements for new construction.

302.2.7 Phased Projects [Addition]

Projects or programs involving floor plan reconfiguration that will encompass more than 50 percent of the area of a floor, or project or program costs exceeding 50 percent of the replacement cost of the existing building in accordance with UFC 3-701-01, that are planned in a phased approach or have separate projects to improve various parts of the facility must conform to the requirements for new construction.

These requirements are not applicable if the time from the start of design of the first phase to the start of design of the phase involving floor plan reconfiguration that exceeds 50 percent of the area, or project cost exceeds 50 percent of the replacement cost of the existing building in accordance with UFC 3-701-01, is greater than five years.

302.2.8 Low Impact Development Requirements [Addition]

For projects in the United States, United States Territories and Possessions of the United States involving the expansion of one or more buildings as part of its primary scope (i.e., primary facilities **\4** versus ***/4/*** supporting facilities) with a “footprint” greater than 5,000 gross square feet (464.5 square meters), incorporate the low impact development (LID) requirements in UFC 3-210-10. “Footprint” does not include existing building area to be renovated or existing impervious surfaces.

For Navy only: Use UFC 1-300-09N for renovation projects exceeding $5 million with a stormwater component.

3-3.2 Section 304 – STRUCTURAL DESIGN LOADS AND EVALUATION AND DESIGN PROCEDURES.

304.3 Seismic evaluation and design procedures [Replacement]

Use UFC 3-301-01 Chapter titled “Seismic Evaluation and Retrofit of Existing Buildings” for seismic retrofit scope requirements.

3-3.3 Section 306 – ACCESSIBILITY FOR EXISTING BUILDINGS [Replacement].

Use the ABA Standards and the special provisions of the DoD Deputy Secretary of Defense Memorandum, Subject: Access for People with Disabilities, October 31, 2008.

[C] SECTION 306 – ACCESSIBILITY FOR EXISTING BUILDINGS [REPLACEMENT]

Refer to APPENDIX C for a link to the ABA Standards and the DoD policy memorandum.

3-3.4 Section 307 – SMOKE ALARMS [Replacement].

Use UFC 3-600-01.

3-3.5 Section 308 – CARBON MONOXIDE DETECTION [Replacement].

Use UFC 3-600-01.

3-4 CHAPTER 4 – REPAIRS [SUPPLEMENT].

Use IEBC Chapter 4 except as modified below.

3-4.1 Section 401 – GENERAL.

401.3 Flood hazard areas [Supplement]

\2 Use IEBC except as modified in UFC 3-201-01. ***/2/***

3-4.2 Section 403 – FIRE PROTECTION [Replacement].

Use UFC 3-600-01.

3-4.3 Section 404 – MEANS OF EGRESS [Replacement].

Use UFC 3-600-01.

3-5 CHAPTER 5 – PRESCRIPTIVE COMPLIANCE METHOD [SUPPLEMENT].

Use IEBC Chapter 5 except as modified below and by UFC 3-301-01 and UFC 3-600-01.

3-5.1 Section 502 – ADDITIONS.

\4\ 502.2 /4/ Flood hazard areas [Supplement]

\2 Use IEBC except as modified in UFC 3-201-01. **/2/**

502.6 Enhanced Classroom Acoustics [Replacement]

Use UFC 3-101-01.

3-5.2 Section 503 – ALTERATIONS.

503.2 Flood hazard areas [Supplement]

\2 Use IEBC except as modified in UFC 3-201-01. **/2/**

\4\ 503.12 Roof Diaphragms Resisting Wind Loads in High-wind Regions [Replacement]

Use UFC 3-301-01. **/4/**

3-5.3 Section 506 – CHANGE OF OCCUPANCY.

506.6 Enhanced Classroom Acoustics [Replacement]

Use UFC 3-101-01.

3-5.4 Section 507 – HISTORIC BUILDINGS.

507.3 Flood hazard areas [Supplement]

\2 Use IEBC except as modified in UFC 3-201-01. **/2/**

3-6 CHAPTER 6 – CLASSIFICATION OF WORK.

Use IEBC Chapter 6.

3-7 CHAPTER 7 – ALTERATIONS – LEVEL 1 [SUPPLEMENT].

Use IEBC Chapter 7 except as modified below.

3-7.1 Section 701 – GENERAL.

701.3 Flood hazard areas [Supplement]

\2 Use IEBC except as modified in UFC 3-201-01. **/2/**

3-7.2 Section 702 – BUILDING ELEMENTS AND MATERIALS [Supplement].

Use IEBC Section 702 except as modified below and by UFC 3-600-01.

702.4 \4\ Window Fall Protection /4/ [Supplement]

For family housing facilities, operable windows must comply with UFC 4-711-01.

702.8 Window, Skylight, Glazing and Door Replacements [Addition]

Use products/materials meeting antiterrorism requirements when projects include replacement of windows, skylights, glazing or doors in existing inhabited buildings. This applies to installation of supplemental windows behind existing windows (inside face) and to installation of windows in new openings. Refer to UFC 4-010-01 for requirements.

702.9 HVAC Systems and Associated Controls [Addition]

Incorporate antiterrorism upgrades as required in UFC 4-010-01 whenever HVAC systems including outside air intakes are being replaced or modified. Modifications include, but are not limited to, modifications such as complete air handling unit replacement, outside air control damper replacement, major ductwork reconfiguration, control system replacement, and control system reprogramming.

3-7.3 Section 703 – FIRE PROTECTION [Replacement].

Use UFC 3-600-01.

3-7.4 Section 704 – MEANS OF EGRESS [Replacement].

Use UFC 3-600-01.

3-7.5 Section 706 – STRUCTURAL.

706.3.2 Roof Diaphragms Resisting Wind Loads in High-wind Regions [Replacement]

Use UFC 3-301-01.

3-8 CHAPTER 8 – ALTERATIONS – LEVEL 2 [SUPPLEMENT].

Use IEBC Chapter 8 except as modified below.

3-8.1 Section 802 – BUILDING ELEMENTS AND MATERIALS [Supplement].

Use IEBC Section 802 except as modified by UFC 3-600-01.

3-8.2 Section 803 – FIRE PROTECTION [Replacement].

Use UFC 3-600-01.

3-8.2.1 Upgrades Required When Reconfigurations Exceed 50 Percent of the Area of a Floor.

Floor plan reconfigurations that exceed 50 percent of the area of a floor require that the entire floor be brought up to the requirements for new construction in UFC 3-600-01. The notification appliances for the fire alarm and mass notification system must be upgraded throughout the remainder of the building as required to provide a uniform notification strategy.

Floor plan reconfigurations that bring the building more into compliance with UFC 3-600-01 does not count towards the 50 percent floor area threshold.

[C] **\4** 3-8.2.1 **/4/** Upgrades Required When Reconfigurations Exceed 50 Percent of the Area of a Floor.

The intent of upgrading fire alarm and mass notification devices throughout the remainder of the building is to provide a uniform notification strategy. For example, a facility has existing clear and amber strobes throughout with no **\4** textual **/4/** signs. The new requirement may be only clear strobes with **\4** textual **/4/** signs. The floor being brought up to UFC 3-600-01 new construction requirements, and means of egress serving this floor, will require clear strobes and **\4** textual **/4/** signs installed per the new criteria. The remainder of the floors will be modified so there are only clear strobes and **\4** textual **/4/** signs, and the work must not make these other floors less conforming to UFC 3-600-01 requirements.

3-8.3 Section 804 – MEANS OF EGRESS [Replacement].

Use UFC 3-600-01.

3-8.3.1 Upgrades Required When Reconfigurations Exceed 50 Percent of the Area of a Floor.

Floor plan reconfigurations that exceed 50 percent of the area of a floor require that the entire floor be brought up to the requirements for new construction in UFC 3-600-01. The means of egress serving this floor, including portions not located on this floor, must conform to the requirements for new construction in UFC 3-600-01.

Floor plan reconfigurations that bring the building more into compliance with NFPA 101 does not count towards the 50 percent floor area threshold.

3-9 CHAPTER 9 – ALTERATIONS – LEVEL 3 [SUPPLEMENT].

Use IEBC Chapter 9 except as modified below.

3-9.1 Section 903 – BUILDING ELEMENTS AND MATERIALS.

Use IEBC Section 903 except as modified below and by UFC 3-600-01.

903.4 Enhanced Classroom Acoustics [Replacement]

Use UFC 3-101-01.

3-9.2 Section 904 – FIRE PROTECTION [Replacement].

Use UFC 3-600-01.

3-9.3 Section 905 – MEANS OF EGRESS [Replacement].

Use UFC 3-600-01.

3-10 CHAPTER 10 – CHANGE OF OCCUPANCY [SUPPLEMENT].

Use IEBC Chapter 10 except as modified below. UFC 3-600-01 replaces all references to Chapter 9 of the IBC.

3-10.1 Section 1001 – GENERAL.

1001.2.1 – Change of use [Supplement].

When a change in use occurs for the building, correct any deficiencies prior to the new occupants occupying the space. When any building with an occupant load of less than 11, is changed to a building with an occupant load greater than 10, for one year or more, the building must meet the requirements for new construction in UFC 3-600-01.

1001.2.2 – Change of Occupancy classification \4\ /4/ [Supplement].

When a change in occupancy occurs for the building **to support a mission that will exist for one year or more**, the building and its means of egress, must comply with the requirements for new construction in UFC 3-600-01. When any building with an occupant load of less than 11, is changed to a building with an occupant load greater than 10, for one year or more, the building must meet the requirements for new construction in UFC 3-600-01.

1001.2.2.1– Partial change of occupancy [Supplement].

When a partial change in occupancy occurs **to support a mission that will exist for one year or more**, the area of the change, and its associated means of egress, must comply with the requirements for new construction in UFC 3-600-01.

3-10.2 Section 1002 – SPECIAL USE AND OCCUPANCY [Replacement].

When a change in occupancy occurs **to support a mission that will exist for one year or more**, the area of change and its means of egress, must comply with the requirements for new construction in UFC 3-600-01.

3-10.3 Section 1007 – ELECTRICAL.

1007.1 Special Occupancies [Supplement]

Follow UFC 4-510-01 for design of health care facilities.

3-10.4 Section 1009 – PLUMBING.

1009.1 Increased Demand, Exception [Replacement]

Follow UFC 3-420-01 for determination of plumbing fixture quantities.

1009.5 Group I-2 [Replacement]

If the occupancy group is changed to Group I-2, follow UFC 3-420-01 for design of the plumbing systems and UFC 4-510-01 for design of medical gas systems.

3-10.5 Section 1011 – CHANGE OF OCCUPANCY CLASSIFICATION [Replacement].

Use UFC 3-600-01 except as modified below.

1011.4 Enhanced Classroom Acoustics [Replacement]

Use UFC 3-101-01.

3-11 CHAPTER 11 – ADDITIONS [SUPPLEMENT].

Use IEBC Chapter 11 except as modified below.

3-11.1 Section 1101 – GENERAL.

\4\ 1101.6 /4/ Enhanced Classroom Acoustics [Replacement]

Use UFC 3-101-01.

3-11.2 Section 1102 – HEIGHTS AND AREAS.

1102.3 Fire Protection Systems [Replacement]

Use UFC 3-600-01.

3-12 CHAPTER 12 – HISTORIC BUILDINGS [SUPPLEMENT].

Use IEBC Chapter 12 except as modified below.

3-12.1 Section 1201 – GENERAL.

1201.4 Flood hazard areas [Supplement]

\2 Use IEBC except as modified in UFC 3-201-01. **/2/**

3-12.2 Section 1203 – FIRE SAFETY [Replacement].

Use UFC 3-600-01.

3-12.3 Section 1204 – CHANGE OF OCCUPANCY [Supplement].

Use IEBC Section 1204 except as modified by UFC 3-600-01.

3-13 CHAPTER 13 – PERFORMANCE COMPLIANCE METHODS [SUPPLEMENT].

Use IEBC Chapter 13 except as modified below and by UFC 3-600-01.

3-13.1 Section 1301 – GENERAL.

\4\ 1303 /4/ Acceptance.

\4\ 1303.1.3 /4/ Compliance with flood hazard provisions [Supplement]

\2 Use IEBC except as modified in UFC 3-201-01. **/2/**

3-14 CHAPTER 14 – RELOCATED OR MOVED BUILDINGS.

Use IEBC Chapter 14.

3-15 CHAPTER 15 – CONSTRUCTION SAFEGUARDS.

Use IEBC Chapter 15.

3-16 CHAPTER 16 – REFERENCED STANDARDS [SUPPLEMENT].

Use IEBC Chapter 16 except as modified by Paragraph 1-6.2.

3-17 APPENDICES [DELETION].

3-18 RESOURCES [DELETION].

CHAPTER 4 CORROSION PREVENTION AND CONTROL

4-1 GENERAL.

Provide design detailing, and use materials, systems, components, and coatings that are durable and minimize the need for preventative and corrective maintenance over the life-cycle of a facility. Refer to Paragraph 1-6.3.4.5.

Many UFGS specifications include materials, coatings, or protective measures that are more durable for use in corrosive environments. However, even in benign environments, where options are stated in UFC and UFGS, use the more corrosion-resistant option whenever possible. Considerations include life-cycle maintenance costs and potential for corrosive microenvironments (for example, deicing salt effect on steel doors). General guidance and training on corrosion prevention and control issues is available at the Corrosion Prevention & Control (CPC) Source webpage at https://www.wbdg.org/dod/cpc-source.

4-1.1 Definition of Corrosion.

Corrosion is defined in 10 USC §2228(f) (1) as, "The deterioration of a material or its properties due to a reaction of that material with its chemical environment." While traditionally thought of only as deterioration of metal (for example, rusting of steel), some nontraditional examples include rotting of wood, degradation of concrete (for example, carbonation and alkali-silica reaction phenomena), and degradation of composite materials due to reaction with the environment.

4-1.2 Identification of Project Environmental Severity Classification.

Identify and use the Environmental Severity Classification (ESC) in APPENDIX A, **\4** Table A-1 ESC for United States, Its Territories and Possessions or Table A-2 ESC for Outside United States, Its Territories and Possessions **/4/**, as the basis for project design requirements. The ESC for each military location is based on ISO 9223. Also, use the ESC factor and descriptions provided in ISO 9223 to classify and design for interior, environmentally severe conditions.

Categories C1 and C2 are mildly corrosive while categories C3, C4, and C5 require added corrosion protection. Note that a project site may have a different ESC than the installation (especially in locations near the coast). Any project site within 1 mile (1.61 km) of seawater is ESC C5. Any project site within 1 to 6 miles (1.61 to 9.66 km) of seawater is ESC C4, unless the installation ESC as stated in APPENDIX A is higher. If the calculated ESC of the project site is different from the ESC of the installation, use and design to the higher of the two ESC values. A resource to determine the ESC on a site-specific basis is the ISO Corrosivity Category Estimation Tool (ICCET); it can be found at the following location: https://www.wbdg.org/ar/tools/corrosion-toolbox.

4-1.3 Corrosion Prone Locations.

Corrosion prone locations are locations with one or more of the following characteristics:

- Exterior exposed metallic elements at a location with an ESC of C3, C4, or C5. Includes areas open to the exterior (for example, mechanical rooms and hangars), and spaces that are not conditioned by design or may not be conditioned during prolonged periods due to deployment or occupancy.
- Exterior exposed nonmetallic elements at a location with an ESC of C4 or C5.
- Locations where micro-environmental factors (for example, prevailing winds, ventilation, waterfront environments, industrial emissions, deicing salt application, possible chemical splash/spillage, adverse weather events such as flooding or wind-driven rain, and penetrations of the building envelope) create a locally corrosive environment regardless of ESC.
- Humid locations identified in ANSI/ASHRAE/IES 90.1 as climate zones 0A, 1A, 2A, 3A, 3C, 4C, and 5C.
- High humidity interior areas (for example, bathrooms, locker rooms, laundry rooms, pools, natatoriums, and aquatic training facilities).

4-1.4 Requirements for Corrosion Prone Locations.

For corrosion prone locations defined in Paragraph 4-1.3, provide added corrosion protection to the design such as, but not limited to, the following:

- Where material options are provided in a UFGS, use the most durable options.
- Provide higher level of corrosion protection as defined in the appropriate corresponding UFGS.
- Do not use unprotected ferrous metal unless there are no alternatives.
- Coat galvanized steel with an industrial coating.
- Where stainless steels are used, select ones which will resist pitting and surface rusting in the intended application, and include the associated ASTM standard and stainless steel type in the contract documents. For process systems or specialized applications, refer to industry sources for recommended stainless steels to provide corrosion protection.
- Coat aluminum with an industrial protective coating or a heavy-duty anodized coating.
- Isolate dissimilar metals (for example, aluminum and steel, stainless steel and carbon steel, and zinc-coated steel and uncoated steel) by

appropriate means to avoid the creation of galvanic cells which occur when dissimilar metals come in contact.

4-1.5 Design Geometries.

Detail designs to prevent accelerated deterioration of facility components. Design geometries that prevent collection of debris, allow water to readily drain in all situations, incorporate sealed joints between components, are protected from mechanical coating damage, and avoid dissimilar materials in direct contact with each other. Follow best engineering and design practices to prevent galvanic corrosion. Slope surfaces such as windows and pavements to drain away from the structure.

Avoid designs that tend to direct corrosive elements to any specific area of a structure. Minimize the flow of water, airborne contaminants (for example, salts and pollutants), and humid air over susceptible materials when designing facility components, systems, and assemblies.

4-1.6 Environmental Severity Factors.

Design based on the Environmental Severity Factors present in the project location and application, including the following.

4-1.6.1 Elevated Temperatures.

Design projects to prevent corrosion in applications where elevated temperatures are present. Elevated temperatures have adverse effects on building materials such as paints, woods, and many asphalt-based products. High temperatures combined with high humidity cause severe deterioration.

4-1.6.2 Ultraviolet Radiation.

Use materials that are resistant to, or protected from, ultraviolet radiation. High ultraviolet exposure results in rapid deterioration of most nonmetallic roofing materials, paints, sealants, elastomeric coatings, and wood.

4-1.6.3 Humidity Resistance.

Use materials that withstand high humidity or incorporate efforts to eliminate humidity in humid locations.

Ensure vapor barrier locations prevent moisture buildup. Do not use building materials that exhibit hygroscopic properties and potentially lose their structural and functional properties when exposed to sustained humidity.

4-1.6.4 Biological Corrosivity.

When selecting materials (for example, wood), design for the presence of insects, fungi, and marine borers as applicable to the location.

4-1.7 System, Component, and Material Design Requirements.

4-1.7.1 Piping and System Corrosion.

Protect water and wastewater systems, fire water systems, and other piping from internal and external corrosion. Design factors include water quality and composition (for example, pH, alkalinity, and dissolved oxygen), ferric scale, flow conditions, biological activity, and the presence of disinfectants and corrosion inhibitors. Provide corrosion control treatment in accordance with UFC 3-230-01, UFC 3-230-03, and UFC 3-240-01.

4-1.7.2 Structural Members.

Use galvanized steel or stainless steel for structural members embedded in concrete, exterior railings, handrails, fences, guardrails, and anchor bolts.

Design systems that can be maintained over the life of the facility. Avoid concealed and inaccessible members.

4-1.7.3 Hardware and Fasteners.

Specify galvanized ferrous metals, stainless steel, brass, bronze, copper, aluminum, or other corrosion resistant metals for hardware and fasteners. Do not use ferrous metal as finishing strips or as components of other securement systems, even if a protective coating is provided.

4-1.7.4 Dissimilar Metals in Close Contact.

Protect against galvanic corrosion when dissimilar metals are in close contact. Metals such as magnesium, steel, zinc, and aluminum (anodes) tend to corrode when in contact with copper, stainless steel, and nickel (cathodes). When relatively incompatible metals must be assembled in the design, apply the following methods to minimize or prevent galvanic corrosion.

- Design metal couples where the surface area of the cathode is smaller than the surface area of the anode metal and only when the anode metal can afford loss due to local corrosion. For example, only use stainless steel bolts to fasten carbon steel parts when bolt removal is frequent and necessary, and when the loss of carbon steel at the bolt hole is acceptable. Interpose a non-absorbing, inert gasket or washer between the dissimilar materials prior to connecting them. This is applicable to couples that are not to serve as electrical conductors.
- Seal faying edges to preclude the entrance of liquids.
- Apply corrosion-inhibiting pastes or compounds under the heads of screws or bolts inserted into dissimilar metal surfaces, whether or not the fasteners had been previously plated or otherwise treated, in addition to applying an organic coating to the faying surfaces prior to assembly. In

situations where large faying surfaces are involved it may be feasible to insert a thicker barrier such as dried adhesive or sealant material. This applies to joints that are not required to be electrically conductive.

- Where practicable or where it will not interfere with the proposed use of the assembly, coat the joint externally with an effective paint system or sealant.
- Coat welded or brazed dissimilar metal assemblies with a paint system or other suitable protective coatings to at least 0.4 inch (1 cm) beyond the heat-affected zone.

4-1.7.5 Protective Coatings.

Use UFC 3-190-06 for protective coatings and paints requirements. Factory applied coatings are more life-cycle cost effective than field painting procedures most of the time. The cost to maintain protective coating systems often includes significant fixed costs (for example, scaffolding and rigging, environmental protection, and disposal of debris). This usually means that the system with the highest attainable life is the best choice. Avoid concealed and inaccessible members.

Provide coating systems durable enough to withstand mechanical damage in service. This includes gouging or chipping during normal activities in a facility. In environments such as desert climates, blowing sand can accelerate deterioration of surface coatings and lead to corrosion of materials earlier in the life cycle process.

4-1.7.6 Buried or Submerged Structures and Systems.

Include a combination of cathodic protection (CP) systems, protective coatings, proper material selection, encasement, or other methods for overall corrosion protection of buried or submerged structures or systems. For buried structures or systems, design for the corrosivity of the soil, including soil pH, resistivity, moisture content, and presence of chlorides, sulfides, and bacteria. Design for differences in soil composition, stray electrical currents, and effects of connections of new to existing structures. Use UFC 3-570-01 to determine where CP is required.

For immersed structures, consider the corrosivity of the water (primarily influenced by salinity, but also affected by pH, dissolved oxygen, temperature, current, and microbiological activity). Tidal and splash zones will experience higher corrosion than continuously immersed or atmospherically exposed zones. For submerged or partially submerged structures, account for differences in corrosion potential associated with each zone (for example, atmospheric, splash, tidal, submerged, and subsoil).

4-1.7.7 Waterfront and Coastal Structures and Systems.

For structures proximate or at the waterfront, in addition to atmospheric corrosion, design for the presence of hydrostatic forces, wind, salt spray, currents, tides, waves, ice, marine borers, insects, and pollution from waterfront operations. Some common grades of stainless alloy such as Type 304 or 316 are susceptible to corrosion when immersed in salt or brackish water.

APPENDIX A ESC FOR DOD LOCATIONS

Table A-1 ESC for United States, Its Territories and Possessions

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Alabama	Alabama National Guard	C3[1]
	Alabama Reserves	C3[1]
	Anniston AR Depot	C3[1]
	Fort McClellan	C3[1]
	Fort Novosel	C3[1]
	Maxwell AFB	C3[1]
	Redstone Arsenal	C3[1]
Alaska	Alaska National Guard	C4[3]
	Alaska Reserves	C4[3]
	Clear AF Station	C2[1]
	Eareckson Air Station	C4[3]
	Eielson AFB	C2[1]
	Fort Greely	C2[1]
	Fort Wainwright	C2[1]
	Joint Base Elmendorf-Richardson	C3[3]
	NAF Adak	C5[3]
Arizona	AF Plant 44 Armed Force Plant	C2[1]
	Arizona National Guard	C2[1]
	Arizona Reserves	C2[1]
	Davis-Monthan AFB	C2[1]
	Fort Huachuca	C2[1]
	Luke AF Base	C2[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Arizona (continued)	MCAS Yuma	C2[1]
	Yuma Proving Ground	C2[1]
Arkansas	Arkansas National Guard	C3[1]
	Arkansas Reserves	C3[1]
	Little Rock AFB	C3[1]
	Pine Bluff Arsenal	C3[1]
California	AF Plant 42 Armed Forces Plant	C2[1]
	Beale AFB	C2[1]
	California National Guard	C3[2]
	California Reserves	C3[2]
	Defense Distribution Depot San Joaquin	C2[1]
	Edwards AFB	C2[1]
	Fort Hunter Liggett	C2[1]
	Fort Ord	C5[3]
	FRC North Island	C4[3]
	Hunters Point Annex	C5[3]
	Los Angeles AFB	C4[2]
	MCAGCC Twenty-nine Palms	C2[1]
	MCAS El Toro Santa Ana	C3[1]
	MCAS Miramar	C4[3]
	MCAS Tustin	C3[1]
	MCB Camp Pendleton	C4[3]
	MCLB Barstow	C2[1]
	MCRD San Diego	C4[3]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
California (continued)	Military Ocean Terminal Concord	C3[2]
	NAF El Centro	C2[1]
	NAS Alameda	C5[3]
	NAS Lemoore	C2[1]
	National Training Center And Fort Irwin	C2[1]
	Naval Base Point Loma	C4[3]
	Naval Base Ventura City Pt Mugu	C5[3]
	Naval Weapons Station Seal Beach	C4[3]
	NAVSTA San Diego	C4[3]
	NAWS China Lake	C2[1]
	NRC Stockton	C2[1]
	NS Treasure Island	C5[3]
	NSA Monterey	C5[3]
	NSY Mare Island	C4[3]
	Presidio Of Monterey	C5[3]
	PWC San Francisco	C5[3]
	Sacramento AR Depot	C3[1]
	Sierra AR Depot	C2[1]
	Travis AFB	C3[1]
	Vandenberg AFB	C4[2]
Colorado	Buckley AFB	C2[1]
	Cheyenne Mountain AF Station	C2[1]
	Colorado National Guard	C2[1]
	Colorado Reserves	C2[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Colorado (continued)	Fort Carson	C2[1]
	Peterson AFB	C2[1]
	Pueblo Chemical Depot	C2[1]
	Rocky Mountain Arsenal	C2[1]
	Schriever AFB	C2[1]
	USAF Academy	C2[1]
Connecticut	Connecticut National Guard	C3[1]
	Connecticut Reserves	C3[1]
	NWIRP Bloomfield	C3[1]
	Stratford AR Engine Plant	C3[2]
	Subase New London	C4[3]
Cuba	NAVSTA Guantanamo Bay	C5[3]
Delaware	Delaware National Guard	C3[1]
	Delaware Reserves	C3[2]
	Dover AFB	C3[2]
District of Columbia	District Of Columbia National Guard	C3[1]
	Joint Base Anacostia-Bolling	C3[1]
	MARBKS Washington DC	C3[1]
	Naval Station Washington Navy Yard	C3[3]
	Washington DC Reserves	C3[1]
Florida	Blount Island Command	C4[3]
	Cecil Field FL NAS	C3[1]
	Eglin AFB	C5[3]
	Florida National Guard	C5[3]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Florida (continued)	Florida Reserves	C5[3]
	FRC Jacksonville	C4[2]
	Hurlburt Field	C5[3]
	Macdill AFB	C5[3]
	NAS Key West	C5[3]
	NAS Pensacola	C5[3]
	NAS Whiting Field Milton	C3[1]
	NAVSTA Mayport	C4[3]
	NOMI Pensacola	C5[3]
	NSA Orlando	C3[1]
	NSA Panama City	C5[3]
	Orlando Ntc	C3[1]
	Patrick AFB	C5[3]
	Tyndall AFB	C5[3]
	USAG Miami	C4[2]
Georgia	Fort Eisenhower	C3[1]
	Fort Mcpherson	C3[1]
	Fort Moore	C3[1]
	Fort Stewart	C3[1]
	Ft Mcpherson Brac/Excess Sites	C3[1]
	Georgia National Guard	C3[1]
	Georgia Reserves	C3[1]
	MCLB Albany	C3[1]
	Moody AFB	C3[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Georgia (continued)	NAS Athens	C3[1]
	NSA Atlanta	C3[1]
	Robins AFB	C3[1]
	Subase Kings Bay	C4[3]
Hawaii	Fort Shafter	C4[3]
	Hawaii National Guard	C4[3]
	Hawaii Reserves	C4[2]
	Joint Base Pearl Harbor-Hickam	C4[3]
	Kaena Point Satellite Tracking Station	C5[3]
	MCB Hawaii Kaneohe	C5[3]
	NAS Barbers Pt	C4[3]
	Pacific Missile Range Facility	C4[3]
	Schofield Barracks	C4[2]
	Wheeler AR Airfield	C4[2]
Idaho	Idaho National Guard	C2[1]
	Idaho Reserves	C2[1]
	Mountain Home AFB	C2[1]
Illinois	Illinois National Guard	C3[1]
	Illinois Reserves	C3[1]
	NAVSTA Great Lakes Il	C3[1]
	Rock Island Arsenal	C3[1]
	Scott AFB	C3[1]
Indiana	Crane AR Ammunition Activity	C3[1]
	Fort Benjamin Harrison	C3[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Indiana (continued)	Indiana National Guard	C3[1]
	Indiana Reserves	C3[1]
	Newport Chemical Depot	C3[1]
	NSA Crane	C3[1]
Iowa	Iowa AR Ammunition Plant	C3[1]
	Iowa National Guard	C3[1]
	Iowa Reserves	C3[1]
Kansas	Fort Riley	C2[1]
	Fort Leavenworth	C3[1]
	McConnell AFB	C3[1]
	Kansas National Guard	C2[1]
	Kansas Reserves	C3[1]
Kentucky	Blue Grass AR Depot	C3[1]
	Fort Campbell	C3[1]
	Fort Knox	C3[1]
	Kentucky National Guard	C3[1]
	Kentucky Reserves	C3[1]
	Louisville NSWC	C3[1]
Louisiana	Barksdale AFB	C3[1]
	Fort Johnson	C3[1]
	HQ 4Th MAW New Orleans	C4[2]
	Louisiana AR Ammunition Plant	C3[1]
	Louisiana National Guard	C4[3]
	Louisiana Reserves	C4[3]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Louisiana (continued)	New Orleans NAS Annex	C3[1]
	NSA New Orleans	C4[2]
Maine	Maine National Guard	C3[3]
	Maine Reserves	C3[3]
	NAS Brunswick	C3[2]
Mariana Islands	Agana Guam NAS	C5[3]
	Guam National Guard	C4[2]
	Guam Reserves	C4[2]
	Joint Region Marianas	C5[3]
Maryland	Aberdeen Proving Ground	C2[1]
	Fort Detrick	C3[1]
	Fort George G Meade	C3[1]
	Joint Base Andrews	C3[1]
	Maryland National Guard	C3[1]
	Maryland Reserves	C3[1]
	NAS Patuxent River	C3[1]
	NSA Annapolis	C3[1]
	NSA South Potomac	C3[1]
	NSA Thurmont	C3[1]
	NSWC Carderock	C3[1]
	US AR Research Laboratory Adelphi	C3[1]
	Walter Reed National Military Medical Center	C3[1]
	Washington DC National Guard	C3[1]
	Washington Headquarters	C3[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Massachusetts	Cape Cod AF Station	C3[3]
	Fort Devens	C2[1]
	Hanscom AFB	C3[1]
	Massachusetts National Guard	C3[1]
	Massachusetts Reserves	C3[1]
	NWIRP Bedford	C3[1]
	Soldier Systems Center	C3[1]
	South Weymouth NAS	C3[1]
Michigan	Detroit Arsenal	C2[1]
	Michigan National Guard	C2[1]
	Michigan Reserves	C2[1]
	USAG Selfridge	C2[1]
Minnesota	Minnesota National Guard	C2[1]
	Minnesota Reserves	C2[1]
Mississippi	CBC Gulfport	C5[3]
	Columbus AFB	C3[1]
	Keesler AFB	C5[3]
	Mississippi National Guard	C3[1]
	Mississippi Reserves	C3[1]
	NS Pascagoula	C4[3]
Missouri	Fort Leonard Wood	C3[1]
	Lake City AR Ammunition Plant	C3[1]
	MCSPTACT Kansas City	C2[1]
	Missouri National Guard	C3[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Missouri (continued)	Missouri Reserves	C3[1]
	NAS Meridian	C3[1]
	Whiteman AFB	C3[1]
Montana	Ellsworth AFB	C2[1]
	Malmstrom AFB	C2[1]
	Montana National Guard	C2[1]
	Montana Reserves	C2[1]
Nebraska	Cornhusker AR Ammunition Plant	C2[1]
	Nebraska National Guard	C2[1]
	Nebraska Reserves	C2[1]
	Offutt AF Base	C3[1]
Nevada	Hawthorne AR Depot	C4[2]
	NAS Fallon	C2[1]
	Nellis AFB	C2[1]
	Nevada National Guard	C2[1]
	Nevada Reserves	C2[1]
New Hampshire	New Boston AF Station	C2[1]
	New Hampshire National Guard	C2[1]
	New Hampshire Reserves	C2[1]
	NSY Portsmouth	C3[3]
New Jersey	Fort Monmouth	C3[2]
	Joint Base Mcguire-Dix-Lakehurst	C3[1]
	Naval Weapons Station Earle	C3[2]
	New Jersey National Guard	C3[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
New Jersey (continued)	New Jersey Reserves	C3[1]
	Picatinny Arsenal	C3[1]
New Mexico	Cannon AFB	C2[1]
	Holloman AFB	C2[1]
	Kirtland AFB	C2[1]
	New Mexico National Guard	C2[1]
	New Mexico Reserves	C2[1]
	White Sands Missile Range	C2[1]
New York	Fort Drum	C3[1]
	Fort Hamilton	C3[3]
	MARCORPS Dist 1 Garden City	C3[2]
	NAVSUPPU Saratoga Springs	C2[1]
	New York National Guard	C2[1]
	New York Reserves	C2[1]
	NWIRP Bethpage	C3[2]
	NWIRP Calverton	C3[2]
	Rome Laboratory	C3[1]
	Seneca AR Depot Activity	C3[1]
	USMA	C3[1]
	Watervliet Arsenal	C2[1]
North Carolina	Fort Liberty	C3[1]
	FRC/MCAS Cherry Point	C4[3]
	MCB Camp Lejeune	C4[3]
	Military Ocean Terminal Sunny Point	C5[3]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
North Carolina (continued)	North Carolina National Guard	C3[1]
	North Carolina Reserves	C3[1]
	Pope AFB	C3[1]
	Seymour Johnson AFB	C3[1]
North Dakota	Cavalier AF Station	C2[1]
	Grand Forks AFB	C2[1]
	Minot AF Base	C2[1]
	North Dakota National Guard	C2[1]
	North Dakota Reserves	C2[1]
Ohio	Defense Supply Center Columbus	C3[1]
	Joint System Manufacturing Center Lima	C3[1]
	Ohio National Guard	C3[1]
	Ohio Reserves	C3[1]
	Wright-Patterson AFB	C3[1]
Oklahoma	Altus AFB	C2[1]
	Fort Sill	C2[1]
	Oklahoma National Guard	C3[1]
	Oklahoma Reserves	C3[1]
	Tinker AFB	C3[1]
	Vance AFB	C3[1]
Oregon	Oregon National Guard	C3[1]
	Oregon Reserves	C3[2]
	Umatilla Chemical Depot	C2[1]
Pennsylvania	Carlisle Barracks	C3[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Pennsylvania (continued)	Defense Distribution Depot Susquehanna	C2[1]
	Defense Supply Center Philadelphia	C3[1]
	Fort Indiantown Gap	C3[1]
	Letterkenny AR Depot	C3[1]
	NSA Mechanicsburg	C3[1]
	Ord Research Lab University Park	C3[1]
	Pennsylvania National Guard	C3[1]
	Pennsylvania Reserves	C3[1]
	Philadelphia NS	C3[1]
	Scranton AR Ammunition Plant	C2[1]
	Tobyhanna AR Depot	C2[1]
	Warminster NAWC-AD	C3[1]
Puerto Rico	Fort Buchanan	C5[2]
	Naval Activity Puerto Rico	C5[3]
	Puerto Rico National Guard	C5[2]
	Puerto Rico Reserves	C5[3]
	Roosevelt Roads	C5[3]
Rhode Island	Davisville CBC	C3[2]
	NAVSTA Newport	C3[3]
	Rhode Island National Guard	C3[2]
	Rhode Island Reserves	C3[2]
South Carolina	Fort Jackson	C2[1]
	Joint Base Charleston	C4[3]
	MCAS Beaufort	C4[3]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
South Carolina (continued)	MCRD Beaufort Parris Island	C4[3]
	Shaw AF Base	C3[1]
	South Carolina National Guard	C3[1]
	South Carolina Reserves	C3[1]
South Dakota	South Dakota National Guard	C2[1]
	South Dakota Reserves	C2[1]
Tennessee	Arnold AFB	C3[1]
	Defense Depot Memphis	C3[1]
	Holston AR Ammunition Plant	C3[1]
	Milan AR Ammunition Plant	C3[1]
	NSA Midsouth Memphis	C3[1]
	Tennessee National Guard	C3[1]
	Tennessee Reserves	C3[1]
Texas	Applied Research Lab Austin	C3[1]
	Brooks City Base	C3[1]
	Corpus Christi AR Depot	C5[3]
	Dyess AFB	C2[1]
	Fort Bliss	C2[1]
	Fort Cavazos	C3[1]
	Goodfellow AFB	C2[1]
	Joint Base San Antonio	C3[1]
	Laughlin AFB	C3[1]
	Longhorn AR Ammunition Plant	C3[2]
	McAlester AR Ammunition Plant	C3[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Texas (continued)	NAS Corpus Christi	C5[3]
	NAS Kingsville	C3[1]
	NAVSTA Ingleside	C5[3]
	NWIRP Dallas	C3[1]
	NWIRP Mcgregor	C3[1]
	Red River AR Depot	C3[1]
	Sheppard AFB	C2[1]
	Texas National Guard	C3[1]
	Texas Reserves	C3[1]
United States Virgin Islands	Virgin Islands National Guard	C5[3]
	Virgin Islands Reserves	C5[2]
Utah	Deseret Chemical Depot	C2[1]
	Dugway Proving Ground	C2[1]
	Hill AFB	C2[2]
	Tooele AR Depot	C2[1]
	Utah National Guard	C2[2]
	Utah Reserves	C2[2]
Vermont	Vermont National Guard	C2[1]
	Vermont Reserves	C2[1]
Virginia	Arlington National Cemetery	C3[1]
	Dam Neck Naval Station	C4[3]
	Defense Supply Center Richmond	C3[1]
	Fort Belvoir	C3[1]
	Fort Gregg-Adams	C3[1]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
Virginia (continued)	Fort Myer	C3[1]
	Fort Moore	C3[1]
	Fort Pickett	C3[1]
	Fort Walker	C3[1]
	HQBN HQMC Arlington	C3[1]
	Joint Base Langley–Eustis	C3[3]
	Joint Base Myer-Henderson Hall	C3[1]
	Joint Expeditionary Base Little Creek-Fort Story	C4[3]
	MCB Quantico	C3[1]
	NAS Oceana	C3[2]
	Naval Weapons Station Yorktown	C3[3]
	NAVMEDCEN Portsmouth	C4[3]
	NAVSTA Norfolk	C4[3]
	Norfolk NSY Portsmouth	C4[3]
	NOSTRA Yorktown	C3[3]
	NSA Northwest	C3[1]
	Radford AR Ammunition Plant	C3[1]
	Virginia National Guard	C3[1]
	Virginia Reserves	C3[1]
Washington	Applied Physics Lab Seattle	C4[3]
	Fairchild AF Base	C2[1]
	Joint Base Lewis-McChord	C3[2]
	MCRC Yakima	C2
	NAS Whidbey Island	C5[3]

United States, Its Territories and Possessions		
State/Territory/Possession	**Installation Master Name**	**ESC***
	Naval Base Kitsap	C4[3]
	NAVMAG Indian Island	C5[3]
	NAVSTA Everett	C5[3]
	NS Puget Sound	C4[3]
	Washington National Guard	C3[2]
	Washington Reserves	C3[2]
West Virginia	Allegany Ballistics Lab	C3[1]
	NSA Sugar Grove	C3[1]
	West Virginia National Guard	C3[1]
	West Virginia Reserves	C3[1]
Wisconsin	Badger AR Ammunition Plant	C2[1]
	Fort McCoy	C2[1]
	Wisconsin National Guard	C2[1]
	Wisconsin Reserves	C2[1]
Wyoming	Wyoming National Guard	C2[1]
	Wyoming Reserves	C2[1]

*ESC Value Notes:

1. ESC value is based on installation location greater than 6 miles (9.66 km) from a saltwater source. If the project site is less than 6 miles (9.66 km) from a saltwater source, use next highest ESC or verify category with ICCET. If the project site is proximate to a pollution source, use the next highest ESC.

2. ESC value is based on installation location greater than 1 mile (1.61 km) from a saltwater source and less than 6 miles (9.66 km). If the project site is less than 1 mile (1.61 km) from a saltwater source, use the next highest ESC. If the project site is proximate to a pollution source, use the next highest ESC.

3. ESC value is based on installation location less than 1 mile (1.61 km) from a saltwater source. If the project site is proximate to a pollution source, use the next highest ESC if available.

Table A-2 ESC for Outside United States, Its Territories and Possessions

Outside United States, Its Territories and Possessions			
Continent/Region	**Country/Territory**	**Installation Master Name**	**ESC***
Africa	Djibouti	Camp Lemonnier	C4[2]
	Egypt	NAMRU Three Cairo Egypt	C3[2]
Asia	Afghanistan	Bagram AF Base	C3[1]
		Camp Eggers	C2[1]
		Camp Marmal	C2[1]
	Bahrain	NSA Bahrain	C3[1]
	Iraq	Al Taqaddum Army Base	C2[1]
		Camp Fallujah	C2[1]
		Camp Taji	C2[1]
	Israel	Attache Israel	C3[2]
	Japan	Camp Zama	C3[2]
		COMFLEACT Kadena Okinawa Ja	C5[1]
		COMFLEACT Sasebo Ja	C3[1]
		COMFLEACT Yokosuka Ja	C3[1]
		Fort Buckner	C5[1]
		Kadena Air Base	C5[1]
		MCAS Iwakuni Ja	C4[3]
		MCB Camp S D Butler Okinawa Ja	C5[3]
		Misawa Air Base	C3[1]
		NAF Atsugi Ja	C3[1]
		NAF Misawa Ja	C3[1]
		Sagami Depot	C3[1]
		Shariki Communication Site	C3[1]

Outside United States, Its Territories and Possessions			
Continent/Region	**Country/Territory**	**Installation Master Name**	**ESC***
Asia (continued)	Japan (continued)	Yokota Air Base	C3[1]
	Kuwait	Ahmed Al Jaber Air Base	C2[1]
	Kyrgyzstan	Manas International Airport	C2
	Qatar	Al Udeid Air Base	C3[1]
		As Sayliyah Army Base	C2[1]
	Singapore	NAVREGCONTRCTR Singapore	C5[3]
	South Korea	Area 1, Korea	C3[1]
		Area 2, Korea	C3[1]
		Area 3, Korea	C5[1]
		Area 4, Korea	C3[1]
		Taegu Air Base	C3[1]
	Turkey	Incirlik Air Base	C3[2]
		Izmir Air Station	C3[3]
		Kurecik AF Base	C2[1]
	United Arab Emirates	Al Dhafra AF Base	C3[1]
Europe	Belgium	USAG Benelux	C3[1]
	Bosnia	Camp Bedrock	C2[1]
	Germany	Germersheim AR Depot	C3[1]
		Landstuhl	C3[1]
		Ramstein Air Base	C3[1]
		Spangdahlem Air Base	C3[1]
		Taylor Barracks	C3[1]
		USAG Ansbach	C2[1]
		USAG Bamberg	C3[1]

Outside United States, Its Territories and Possessions			
Continent/Region	**Country/Territory**	**Installation Master Name**	**ESC***
Europe (continued)	Germany (continued)	USAG Baumholder	C3[1]
		USAG Darmstadt	C3[1]
		USAG Franconia	C2[1]
		USAG Giessen	C3[2]
		USAG Grafenwoehr	C2[1]
		USAG Heidelberg	C3[1]
		USAG Hessen	C3[1]
		USAG Hohenfels	C2
		USAG Kaiserslautern	C3[1]
		USAG Mannheim	C3[1]
		USAG Schinnen	C3[1]
		USAG Schweinfurt	C3[1]
		USAG Stuttgart	C3[1]
		USAG Wiesbaden	C3[1]
		Wuerzburg Tng Areas	C3[1]
	Greece	NSA Souda Bay Gr	C3[1]
	Iceland	NAS Keflavik	C4
	Italy	Aviano Air Base	C3[1]
		NAS Sigonella It	C3[1]
		NSA Naples It	C3[1]
		USAG Livorno	C3
		USAG Vicenza	C3
	Kosovo	Camp Bondsteel	C2[1]
		Camp Monteith	C2[1]

Outside United States, Its Territories and Possessions			
Continent/Region	**Country/Territory**	**Installation Master Name**	**ESC***
Europe (continued)	Netherlands	JFC North	C3[1]
	Portugal	Lajes Field	C5
	Spain	Moron Air Base	C3[1]
		NAVSTA Rota Sp	C4[3]
	United Kingdom	Alconbury Royal AF Station	C3[1]
		Croughton Royal AF Station	C3[1]
		Fairford Royal AF Station	C3[1]
		Lakenheath Royal AF Station	C3[1]
		Mildenhall Royal AF Station	C3[1]
Indian Ocean	British Indian Ocean Territory	Navsuppfac Diego Garcia Io	C5
North America	Greenland	Thule Air Base	C2[1]
	Honduras	Enrique Soto Cano AF Base	C3[1]
Oceania	Australia	Navcommsta H E Holt Exmouth As	C3[1]
	Marshall Islands	US AR Kwajalein Atoll	C5[3]
South America	Peru	Navmedrschcen Det Lima Peru	C5[3]

*ESC Value Notes:

1. ESC value is based on installation location greater than 6 miles (9.66 km) from a saltwater source. If the project site is less than 6 miles (9.66 km) from a saltwater source, use next highest ESC or verify category with ICCET. If the project site is proximate to a pollution source, use the next highest ESC.

2. ESC value is based on installation location greater than 1 mile (1.61 km) from a saltwater source and less than 6 miles (9.66 km). If the project site is less than 1 mile (1.61 km) from a saltwater source, use the next highest ESC. If the project site is proximate to a pollution source, use the next highest ESC.

3. ESC value is based on installation location less than 1 mile (1.61 km) from a saltwater source. If the project site is proximate to a pollution source, use the next highest ESC if available.

This Page Intentionally Left Blank

APPENDIX B GLOSSARY

B-1 ACRONYMS

AA&E	Arms, Ammunition, and Explosives
ABA	Architectural Barriers Act
AE	Ammunition and Explosives
AEC	Architect / Engineer / Construction
AFCEC	Air Force Civil Engineer Center
AFMAN	Air Force Manual
AHJ	Authority Having Jurisdiction
BO	Building Official
BIA	Bilateral Infrastructure Agreement
CCR	Criteria Change Request
CECW-EC	Corps of Engineers Civil Works, Chief of Engineering and Construction Division
CP	Cathodic Protection
CPC	Corrosion Prevention & Control
CFR	Code of Federal Regulations
CTR	Component Technical Representative
DAFMAN	Department of the Air Force Manual
DCS	Deputy Chief of Staff
DoDD	DoD Directive
DoDI	DoD Instruction
DoDM	DoD Manual
DUSD (I&E)	Deputy Under Secretary of Defense for Installations and Environment
DWG	Discipline Working Group

EI&E	Energy, Installations, and Environment
ESC	Environmental Severity Classification
ESEP	Engineering Senior Executive Panel
ESQD	Explosives Safety Quantity Distance
E.O.	Executive Order
FASS	Facilities Systems Safety
FC	Facilities Criteria
HQ	Headquarters
HQMC	Headquarters, U.S. Marine Corps
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
HVAC	Heating, Ventilation, and Air Conditioning
IBC	International Building Code®
ICC	International Code Council
ICCET	ISO Corrosivity Category Estimation Tool
IEBC	International Existing Building Code®
IECC	International Energy Conservation Code®
IE&E	Installations, Energy, and Environment
IE&L	Installations, Environment, and Logistics
IFC	International Fire Code®
IFGC	International Fuel Gas Code®
IgCC	International Green Construction Code®
IMC	International Mechanical Code®
IPC	International Plumbing Code®
IPMC	International Property Maintenance Code®

IRC	International Residential Code®
LPG	Liquified Petroleum Gas
MCM	Metal Composite Materials
MDF	Medium Density Fiberboard
NAF	Naval Air Facility
NAVFAC	Naval Facilities Engineering Systems Command
NEC	National Electrical Code®
O&M	Operations and Maintenance
OEBDG	Overseas Environmental Baseline Guidance Document (DoDM 4715.05)
OSHA	Occupational Safety and Health Administration
OASD	Office of the Assistant Secretary of Defense
OUSD	Office of the Under Secretary of Defense
P.L.	Public Law
RFP	Request for Proposal
RMF	Risk Management Framework
SAP	Special Access Program
SCI	Sensitive Compartmented Information
SOFA	Status of Forces Agreements
SOH	Safety and Occupational Health
TOC	Total Ownership Costs
USACE	U.S. Army Corps of Engineers
USC	United States Code
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications

USD (AT&L) Under Secretary of Defense for Acquisition, Technology, and Logistics

B-2 DEFINITION OF TERMS

Discipline Working Group: Representatives from the DoD components responsible for the unification and maintenance of criteria documents. (MIL-STD-3007)

Engineering Senior Executive Panel: Panel established by the DoD Installations Policy Board to implement the UFC and UFGS system for DoD. The ESEP consists of a representative from the Office of the Secretary of Defense and the three Service Chiefs of Engineering. (MIL-STD-3007)

Facilities Criteria: A criteria document that is not adopted by all services and will be used only by services indicated in the document

Technical Representative: Author of a particular criteria document or the working-level representative from another participating organization for a particular document. (MIL-STD-3007)

APPENDIX C REFERENCES

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS

https://www.ashrae.org

ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings* (Refer to chapter 2 of UFC 1-200-02, for applicable publication date)

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

https://www.asme.org

AMERICAN SOCIETY OF SAFETY PROFESSIONALS

https://www.assp.org

ANSI/ASSP Z590.3, *Prevention through Design: Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes*

CODE OF FEDERAL REGULATIONS

https://www.osha.gov/laws-regs/regulations/standardnumber/1910

29 CFR 1910, *Occupational Safety and Health Standards*

INTERNATIONAL CODE COUNCIL

https://www.iccsafe.org

IBC, *International Building Code*®, **\4** 2024 ***/4/***

IEBC, *International Existing Building Code*®, **\4** 2024 ***/4/***

IECC, *International Energy Conservation Code*® (Refer to Chapter 2 of UFC 1-200-02 for applicable edition)

IgCC, *International Green Construction* ,**\4** (Refer to UFC 1-200-02 for applicable edition) ***/4/***

IMC, *International Mechanical Code*®, **\4** 2024 ***/4/***

IPC, *International Plumbing Code*®, **\4** 2024 ***/4/***

IRC, *International Residential Code*®, **\4** 2024 ***/4/***

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

https://www.iso.org/

ISO 9223, *Corrosion of Metals and Alloys – Corrosivity of Atmospheres – Classification, Determination and Estimation*

NATIONAL FIRE PROTECTION ASSOCIATION

https://www.nfpa.org

NFPA 1, *Fire Code*

NFPA 54 (ANSI Z223.1), *National Fuel Gas Code*

NFPA 58, *Liquefied Petroleum Gas Code*

NFPA 70, *National Electrical Code®*

NFPA 101, *Life Safety Code®*

NFPA 285, *Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 1-201-01, *Non-Permanent DoD Facilities in Support of Military Operations*

UFC 1-201-02, *Assessment of Existing Facilities for Use in Military Operations*

\2\ /2/

UFC 1-300-02, *Unified Facilities Guide Specifications (UFGS) Format Standard*

FC 1-300-09N, *Navy and Marine Corps Design Procedures*

UFC 3-101-01, *Architecture*

UFC 3-110-03, *Roofing*

UFC 3-120-10, *Interior Design*

UFC 3-190-06, *Protective Coatings and Paints*

UFC 3-201-01, *Civil Engineering*

UFC 3-201-02, *Landscape Architecture*

UFC 3-210-10, *Low Impact Development*

UFC 3-220-01, *Geotechnical Engineering*

UFC 3-230-01, *Water Storage and Distribution*

UFC 3-230-03, *Water Treatment*

UFC 3-240-01, *Wastewater Collection and Treatment*

UFC 3-301-01, *Structural Engineering*

UFC 3-301-02, *Design of Risk Category V Structures, National Strategic Military Assets*

UFC 3-401-01, *Mechanical Engineering*

UFC 3-410-01, *Heating, Ventilating, and Air Conditioning Systems*

UFC 3-420-01, *Plumbing Systems*

UFC 3-430-05, *Natural Gas and Liquefied Petroleum Gas (LPG) Distribution Pipelines*

UFC 3-460-01, *Design: Petroleum Fuel Facilities*

UFC 3-490-06, *Elevators*

UFC 3-501-01, *Electrical Engineering*

UFC 3-520-01, *Interior Electrical Systems*

UFC 3-530-01, *Interior and Exterior Lighting Systems and Controls*

UFC 3-540-01, *Engine-Driven Generator Systems for Prime and Standby Power Applications*

UFC 3-550-01, *Exterior Electrical Power Distribution*

UFC 3-560-01, *Operation and Maintenance: Electrical Safety*

UFC 3-570-01, *Cathodic Protection*

UFC 3-580-01, *Telecommunications Interior Infrastructure Planning and Design*

UFC 3-600-01, *Fire Protection Engineering for Facilities*

UFC 3-701-01, *DoD Facilities Pricing Guide*

UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings* **\3**

UFC 4-010-05, *SCIF/SAPF Planning, Design, and Construction* **/3/**

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

UFC 4-021-01, *Design and O&M: Mass Notification Systems*

UFC 4-510-01, *Design: Military Medical Facilities*

UFC 4-711-01, *Family Housing*

FC 4-721-10N, *Navy and Marine Corps Unaccompanied Housing*

UNITED STATES ACCESS BOARD

\2 Architectural Barriers Act **/2/** (ABA) Standards
https://www.access-board.gov/files/aba/ABAstandards.pdf

UNITED STATES AIR FORCE

https://www.e-publishing.af.mil

DESR6055.09_AFMAN91-201, *Explosives Safety Standards*

DAFMAN 91-203, *Air Force Occupational Safety, Fire and Health Standards*

UNITED STATES ARMY

https://armypubs.army.mil/

DA PAM 385-64, *Ammunition and Explosives Safety Standards*

DA PAM 385-16, *System Safety Management Guide*

UNITED STATES DEPARTMENT OF DEFENSE

Deputy Secretary of Defense Memorandum for Secretaries of the Military Departments, et al. Subject: Access for People with Disabilities, October 31, 2008
https://www.access-board.gov/aba/background/dod-policy-memo.html

DoDM 4715.05, *Overseas Environmental Baseline Guidance Document*
https://www.esd.whs.mil/Directives/issuances/dodm/

DoD 5200.08-R, *Physical Security Program*
https://www.esd.whs.mil/DD/DoD-issuances/OUSD

DoDI 6055.01, *DoD Safety and Occupational Health (SOH) Program*
https://www.esd.whs.mil/DD/DoD-issuances/

DoDM 6055.09, *DoD Ammunition and Explosives Safety Standards*
https://www.esd.whs.mil/DD/DoD-issuances/

DoDI 1125.03, *Vending Facility Program for the Blind on DoD-Controlled Federal Property*
https://www.esd.whs.mil/DD/DoD-issuances/

DoDM 5100.76, *Physical Security of Sensitive Conventional Arms, Ammunition and Explosives (AA&E)*
https://www.esd.whs.mil/DD/DoD-issuances/

DoDM 5200.01, *DoD Information Security Program*
https://www.esd.whs.mil/DD/DoD-issuances/

DoDM 5205.07 Volume 3, *DoD Special Access Program (SAP) Security Manual: Physical Security*
https://www.esd.whs.mil/DD/DoD-issuances/

MIL-STD-3007G, *Standard Practice for Unified Facilities Criteria, Facilities Criteria and Unified Facilities Guide Specifications*, 1 November 2019
https://www.wbdg.org/FFC/FEDMIL/milstd3007g.pdf

OUSD Memorandum. Subject: Department-Wide Policy for Nursing and Lactation Rooms, 1 November 2016
https://www.wbdg.org/FFC/DOD/DOD_NursingMothersMemo_110116.pdf

OUSD Memorandum for Assistant Secretary(s) of the Army (IE&E), Navy (EI&E), Air Force (IE&L), Directors of Defense Agencies, Directors of Defense Activities, Director, Washington Headquarters Service. Subject: Floodplain Management on Department of Defense Installations, 11 February 2014
https://www.wbdg.org/FFC/DOD/DUSDIE_Memo_FloodplainMgmt.pdf

UNITED STATES NAVY

NAVSEA OP 5, *Ammunition and Explosives Safety Ashore*
https://nossa.dc3n.navy.mil/nrws3/ (must be registered user)

UNITED STATES OFFICE OF PERSONNEL MANAGEMENT

OPM Guide for Establishing a Federal Nursing Mother's Program
https://www.opm.gov/policy-data-oversight/worklife/reference-materials/nursing-mother-guide.pdf

UFC 1-200-02
01 DECEMBER 2020
Change 02, 01 JUNE 2022

UNIFIED FACILITIES CRITERIA (UFC)

HIGH PERFORMANCE AND SUSTAINABLE BUILDING REQUIREMENTS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

UFC 1-200-02
01 DECEMBER 2020
Change 02, 01 JUNE 2022

HIGH PERFORMANCE AND SUSTAINABLE BUILDING REQUIREMENTS

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING **\1** SYSTEMS **/1/** COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
01	03 Jan 2022	Replaced “renovation” with “comprehensive replacement” or “SRM” as appropriate, defined; minor changes Table 1-1; revised “Component” and “Service” throughout, defined; Metering policy updates to paras 2-3.3, 2-4.4, 3-4.2.2, 2-4.3, 3-3.3, 3-4.2, 3-4.3.2, 3-4.4, updated Reference; replaced “compounds” with “substances” paras 2-6.1.3 and 3-6.1.3; App A added sentence to 1st para and replaced flowchart.
02	01 June 2022	Minor changes para 1.1 and 1.2; language change for ASRHAE 90.1-2019 and IECC 2021 in paras 2-2.2, 2-3; addressed CCRs.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering **\1** Systems **/1/** Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

CHRISTINE T. ALTENDORF, PhD, P.E., SES
Chief, Engineering and Construction

U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering **\1** Systems **/1/** Command

NANCY J. BALKUS, P.E., SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering & Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL MCANDREW
Deputy Assistant Secretary of Defense (Construction) and Acting Deputy Assistant Secretary of Defense (Housing) Office of the Assistant Secretary of Defense (Sustainment)

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 1-200-02, *High Performance and Sustainable Building Requirements*

Superseding: UFC 1-200-02, dated 01 December 2016, with Changes 1-4.

Description: This revision addresses the following:

- Required update cycle
- Approved Criteria Change Requests (CCRs) changes
- Updates that reflect “Implementing Instructions for Executive Order 13834 Efficient Federal Operations”
- Additional life cycle cost analysis guidance.

Impact: Improved mission capability through:

- Reduced total ownership costs of buildings
- Improved energy and water efficiency, and security
- Enhanced building performance and sustainability
- Promoting sustainable resource and environmental stewardship, occupant health, and productivity

Unification Issues: None

TABLE OF CONTENTS

TABLES

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

The Energy Policy Act of 2005, Energy Independence Security Act of 2007, and **\2** Executive Order (EO) 14057 ***/2/*** require Federal agencies to increase efficiency, optimize performance, eliminate unnecessary use of resources, and protect the environment. The Federal requirements collectively are referred to as the "Guiding Principles", and are detailed in *Guiding Principles for Sustainable Federal Buildings and Associated Instructions*, February 2016, which replaces "Guiding Principles for Federal High Performance and Sustainable Buildings", 2008. Consistent with UFC program requirements, this UFC integrates DoD requirements (DoDI 4170.11 and other DoD Policies) with High Performance and Sustainable Building (HPSB) Guiding Principles and industry standards for high performance and sustainable buildings.

1-2 PURPOSE AND SCOPE.

This UFC provides minimum requirements and guidance to achieve high performance and sustainable buildings. This UFC is organized around the HPSB Guiding Principles. Per *Department of Defense Sustainable Buildings Policy*, when a building meets the requirements of this UFC, it is considered compliant with the HPSB Guiding Principles.

\2 ***/2/*****\1** ***/1/*** This UFC incorporates the sections of the **\2** International Green Construction Code (IgCC) ***/2/*** mentioned herein when appropriate and determined to be life cycle cost effective. Where the provisions of the IgCC meet the intent of the HPSB Guiding Principles, the provisions of the IgCC are referenced in this UFC as a means of compliance or provided as an alternative compliance pathway. These requirements are applicable to all new work**\1** , comprehensive replacement, and sustainment, restoration, and modernization (SRM) ***/1/*** projects, regardless of building type or configuration.

1-3 ORGANIZATION.

- CHAPTER 1 introduces the scope of this document and overall requirements
- CHAPTER 2 provides requirements for building design and construction activities.
- CHAPTER 3 details Federal HPSB Guiding Principles Existing Building Assessment requirements that must be met in order for an existing building to be reported as a High Performance and Sustainable Building (HPSB).
- CHAPTER 4 defines HPSB compliance and details tracking and reporting.
- APPENDIX A details the energy optimization and LCCA process.
- APPENDIX B contains preferred methods of execution for cited topics.

- APPENDIX C contains project requirements impacted by historic buildings, historic districts and those near historic facilities, **\1\/1/** and other designated cultural resources.
- APPENDIX D contains acronyms, abbreviations, and terms.
- APPENDIX E contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

1-4 APPLICABILITY.

This UFC applies to all planning, design and construction, **\1** comprehensive replacement, SRM, **/1/** repair, operations and maintenance, and affixed equipment installation in new and existing buildings, regardless of funding source, that result in DoD real property assets. Table 1-1 "Building Compliance Requirements and Thresholds" is applicable to all methods of project delivery and levels of construction (as defined in UFC 1-200-01, paragraph titled "Levels of Construction".)

Apply this UFC to the following construction activities to the greatest extent practical:

- Buildings outside of United States and U.S. territories
- Buildings supporting contingency operations (Refer to UFCs 1-201-01, 1-201-02, and 1-202-01)
- Non-permanent buildings
- Projects with DD1391 marked "austere"
- Military Operations in Urban Terrain (MOUT) and similar training buildings (examples: mock villages, shoot-houses)

This UFC does not apply to:

- Buildings to be demolished or deconstructed, except for demolition waste diversion reporting
- Buildings that have a status of Report of Excess (ROE) submitted, ROE accepted, or Determination to Dispose
- Unoccupied buildings, which are occupied one hour or less per person per day on average; AND have total building energy consumption (including receptacle and process loads) from all sources less than 12.7 kBTU / SF/ Yr.; AND have annual average water consumption (including process water) of less than 2 gallons per day for the building.
- Structures and linear construction that do not meet the definition of a building.

Comply with Table 1-1:

Table 1-1 Building Compliance Requirements and Thresholds

Requirements	Thresholds\1\ (Refer to each chapter's "Overview" for details) /1/
Chapter 1	All design and construction activity Assessments of existing buildings ≥10,000 GSF.
Chapter 2	All design and construction activity
Chapter 3	Assessments of existing building assets ≥10,000 GSF.
Chapter 4 For **\1**Service**/1/** policy and guidance documents, refer to paragraph titled "DoD Service Policy."	HPSB Guiding Principles Compliance Tracking and Reporting (use Service HPSB Checklist): 1. For Army and Navy, new building or stand-alone addition ≥10,000 GSF; for Air Force, all new buildings or stand-alone additions. 2. Comprehensive replacement in an existing building that is ≥10,000 GSF, with total cost >$3M and 50% or more Estimated Replacement Cost (ERC) 3. Assessments of existing building assets ≥10,000 GSF **\1\/1/** Addition of **\2** Third-Party **/2/** Certification: 1. New building or stand-alone addition ≥10,000 GSF, with construction cost >$3M 2. Comprehensive replacement in an existing building that is ≥10,000 GSF, with total cost greater than $3M and 50% or more ERC
Appendix A	All buildings that meet statutory threshold.[1]
Appendix B	All buildings as applicable.
Appendix C	All buildings as applicable.
Appendix D	All buildings as applicable.
Appendix E	All buildings as applicable.
\1\ All Chapters and Appendices	New building or additions <10,000 GSF, sustainment, modernization, and restoration building improvements must comply with UFC requirements relevant to the scope of the project/work, as determined by the Project Delivery Team as early as possible during project process. Comprehensive replacement to a building includes significant opportunities for improvement in: energy and water efficiency (such as HVAC, lighting, building envelope, and other building components); indoor air quality; other requirements in this UFC; and additions that are part of the comprehensive replacement. Total cost for comprehensive replacement includes addition, operations and maintenance, sustainment, restoration, and modernization associated with an existing building comprehensive replacement. **/1/**

[1] In addition to the new building requirements, all existing building large capital energy investments (all projects for which the cost of the systems that impact energy consumption exceeds $250K, which constitutes a capital investment, per National Defense Authorization Act) are to employ the most energy efficient designs, systems, equipment, and controls that are life cycle cost effective.

1-5 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, *DoD Building Code*. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-6 LIFE-CYCLE COST ANALYSIS (LCCA).

The purpose of the LCCA methodology as detailed in 10 CFR Part 436 Subpart A is to identify and compare life-cycle cost-effective (LCCE) building energy and water systems that will in total achieve the energy and water requirements stated in this document. LCCA and energy optimization (paragraph titled "Energy Compliance Analysis (ECA)") work together to determine the resulting savings, and provide the information for the required narrative (paragraph titled "ECA Narrative Requirements".) An LCCA is required for the following:

1. Systems contributing to the energy footprint of the building including, but not limited to, HVAC**\1** domestic hot water ***/1/*** and the building envelope[2]

2. Renewable energy generating systems (example: photovoltaic panels)

3. When LCCE is selected as the reason any requirement of this document is "Partially compliant" or "Not Applicable" (reference paragraph "Compliance with Federal Requirements").

The LCCA methodology may also be used to evaluate multiple options, such as selecting the building construction type and comparing compliant materials; and is at the discretion of the project team. For process to develop LCCA, refer to Appendix A.

1-6.1 LCCA Format.

Prepare the LCCA in accordance with 10 CFR Part 436, Subpart A and NIST Handbook 135 Life-Cycle Costing Manual for the Federal Energy Management Program. The LCCA must be prepared using the Building Life-Cycle Costing (BLCC) program, available from the National Institute of Standards and Technology. The implied long-term inflation rate and discount rates identified in the Annual Supplement to NIST Handbook 135 must be used. A link to BLCC can also be found at the Department of Energy's building energy tools web site: Building Life Cycle Cost Programs. When needed, refer to UFC 3-410-01 for requirements to obtain weather data. The NIST handbook focuses on determining an LCCA for each design alternative modeled by acceptable software. In order to be fully acceptable, the selected design alternative must also comply with federally-mandated ASHRAE 90.1 baseline, and achieve 30%

[2] In addition to the new building requirements, all existing building large capital energy investments (all projects for which the cost of the systems that impact energy consumption exceeds $250K, which constitutes a capital investment, per National Defense Authorization Act) are to employ the most energy efficient designs, systems, equipment, and controls that are life cycle cost effective.

energy efficiency below the baseline when LCCE. Refer to Energy Optimization and LCCA Process Integration which details the mandatory framework for determining systems that contribute to the energy and water footprint of the building; and paragraph Energy Efficiency, which provides analysis details.

1-6.2 LCCA Building-Level (Whole Building) Analysis.

Any building-level LCCA must be calculated using a 40-year expectant life. Individual components or systems life expectancies must be reflected by inclusion of appropriate replacement and salvage values in the appropriate year of this analysis.

1-6.3 LCCA Individual Component or System Alternatives Analysis.

LCCAs comparing at least three individual component or system alternatives must use a life expectancy of 40 years from the beginning of beneficial use. All alternatives, along with their sub-systems, must meet mission requirements. Include the appropriate replacement and salvage values for each of the alternatives. Acceptable alternatives must not degrade the overall building performance. They must be sound technical alternatives that are user comfort-compatible, reliable, locally serviceable, user friendly, ensure safety, and at a minimum are neutral with regard to occupant productivity and design aesthetics.

Perform this analysis based on the actual conditions expected over the life of the facility including anticipated occupancies, scheduled hours of operation, and process loads. Include actual values for location utility costs and for sources used; modeled energy usage and efficiencies; realistic operations, maintenance, repair and replacement costs; and all costs or savings associated with recovered energy, solar heat, solar photovoltaic energy and any other renewable or waste heat applications. Credit any alternative funding such as rebates in the LCCA.

1-7 CYBERSECURITY.

All **\2** facility ***/2/*** control systems (including systems separate from **\2** a utility-monitoring and ***/2/*** control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

This Page Intentionally Left Blank

CHAPTER 2 BUILDING DESIGN AND CONSTRUCTION

2-1 OVERVIEW.

The requirements of this chapter apply to all building design and construction, as well as each building within a project. Refer to Table 1-1 "Building Requirements Compliance and Thresholds" to determine applicability of this chapter to each building within a project. Refer to Chapter 4 for additional requirements.

2-1.1 New Construction and \1\ Comprehensive Replacement /1/.

New construction and **\1** comprehensive replacement **/1/** must comply with all requirements; or must clearly identify and provide justification when requirements are not applicable or fully achievable. Refer to paragraph titled "Compliance with Federal Requirements" for additional guidance and requirement applicability.

2-1.2 Work in Existing Buildings.

In some of the paragraphs that follow, there are specific requirements provided for **\1** sustainment, restoration, and modernization (SRM) projects **/1/**. For existing building **\1** SRM **/1/**, the goal is to improve the performance of the existing building inventory with every investment. The systems and components included in the scope of the project must meet the requirements of this UFC, by providing the most resource-efficient solutions. This UFC does not apply to systems and components not included in the scope of the project. The intent is not to expand the scope of the project.

2-2 EMPLOY INTEGRATED DESIGN PRINCIPLES.

Integrated design is the most important requirement in achieving a high performance building. A design team must have strong, consistent representation from all stakeholders throughout the project phases to maximize opportunities to improve building performance and to realize increased savings potential.

2-2.1 Integrated Design.

Incorporate the following planning and evaluation into the integrated design, as described in IgCC F101.1.1 (F1.1.1) *Charrette Process*.

Exception: subparagraph b. does not apply.

2-2.1.1 Integrated Planning.

Use a collaborative, integrated planning and design team composed of users, government support staff, and appropriate professionals, to identify requirements and to establish performance goals for siting, energy, water, materials, indoor environmental quality, and other comprehensive design goals. Ensure incorporation of these goals throughout design and construction.

2-2.1.2 Evaluation for Design Strategies

Evaluate the site and building components to determine whether passive and natural design strategies and features are cost effectively incorporated before designing the active and mechanical systems. Incorporate these features where applicable.

Take into account site attributes, including climate and local and regional context, which impact the design of the building.

2-2.1.3 Evaluation of the Site.

During the site selection process, comply with the requirements of UFC 2-100-01.

2-2.1.4 Site Integration and Design of the Building.

Use the following site development considerations and passive strategies:

- Meet the requirements of UFC 3-201-02.
- Site design elements that ensure safe and convenient pedestrian access.
- Incorporate results of site analysis in order to design the building, focusing on orientation, configuration, and massing.
- Orient building to maximize energy efficiency, passive solar, and daylighting potential.
- Select, design, and integrate into the overall building, high performance and sustainable systems (examples: HVAC, plumbing, water heating systems, lighting systems, control systems, elevators, building envelope, and fire protection systems).
- Consider opportunities for occupants to voluntarily increase physical activity early in the design process. Refer to Appendix B "Best Practice" for examples.

2-2.2 Commissioning.

In order to verify design and performance, and ensure that the Government requirements are met, employ commissioning practices appropriate to the size and complexity of the building and its system components. This must include an experienced commissioning provider, who should be independent of the project design and construction team, and from the operations team. The choice of either contracted services or Government personnel to serve as the commissioning provider will be determined at project level.

\2 To the extent practicable, based on LCCA and DoD policy[3], meet the following:

For all projects with design starts before 7 April 2023, ***/2/*** meet the requirements of IgCC 1001.3.1.2 (10.3.1.2) *Building Project Commissioning*, with the following modifications:

- For buildings and systems that are less complex, commissioning may be tailored as determined by the DoD Service AHJ. For Army projects, refer to Army policy for determination of systems to commission. For Air Force and Navy projects, the Project Delivery Team must determine the level of commissioning activities required.
- "Schematic design" is the design charrette or similar conceptual design activity prior to completion of 35% design.
- Documentation as described in ASHRAE 55 Section 6.2 is not required.

\2 For commercial and multi-family high-rise buildings with design starts on or after 7 April 2023, meet the requirements of ASHRAE 90.1-2019. For low-rise residential buildings with design starts on or after 5 April 2023, meet the requirements of 2021 IECC. ***/2/***

Exception: For Medical Treatment Facilities, refer to UFC 4-510-01 *Medical Military Facilities* for commissioning requirements.

Refer to UFGS 01 91 00.15 **\1** 10 ***/1/*** Total Building Commissioning **\1** (Army executed) or UFGS 01 91 00.15 20 Total Building Commissioning (Navy executed ***/1/***) for commissioning requirements prior to project award.

2-3 OPTIMIZE ENERGY PERFORMANCE.

Base energy efficiency design decisions on LCCA, as indicated in Chapter 1 of this UFC. The LCCA includes a minimum of three energy efficient alternatives to the baseline standard (ASRHAE 90.1, IECC, etc.) For **\1** details ***/1/***, refer to Appendix A.

2-3.1 Energy Efficiency.

2-3.1.1 Commercial and Multi-Family High-Rise Residential Buildings

\2 To the extent practicable, based on LCCA and DoD policy[4], meet the following: ***/2/***

- Meet the requirements of ASHRAE 90.1 **\2** Use ASHRAE 90.1-2013 for all projects with design starts before 7 April 2023. Use ASHRAE 90.1-2019 thereafter. ***/2/***
- Design the building to achieve at least 30% energy consumption reduction from ASHRAE 90.1 baseline.

[3] **\2** Includes any DoD policies that relate to commissioning. **/2/**
[4] **\2** Includes any DoD policies that relate to energy.

- If a 30% reduction is not LCCE, modify the design of the proposed building to achieve an energy consumption level at the highest level of energy efficiency that is LCCE.

- **\2** When using ASHRAE 90.1-2013, ***/2/*** determine energy consumption levels for both the ASHRAE Baseline Building and proposed building alternatives by using the Performance Rating Method found in Appendix G of ASHRAE 90.1, except for the formula for calculating the Performance Rating. Replace the formula in G1.2 with the following:

  Percentage improvement = 100 × ((Baseline building consumption − Receptacle and process loads) − (Proposed building consumption − Receptacle and process loads)) / (Baseline building consumption − Receptacle and process loads)[5]

- **\2** When using ASHRAE 90.1-2019: Determine energy consumption levels for both the ASHRAE Baseline Building 2019 and proposed building alternatives by using the Performance Rating Method found in Appendix G of ASHRAE 90.1-2019[6]. The formula for determining the percentage improvement is:

  Percentage Improvement = 100 x (1-PCI/PCIt)

  Where

  PCI = Performance Cost Index calculated in accordance with section G1.2 of ASHRAE 90.1-2019

  PCIt = Performance Cost Index Target calculated by formula in section 4.2.1.1 of ASHRAE 90.1-2019 ***/2/***

2-3.1.2 Low-Rise Residential Buildings

\2 To the extent practicable based on LCCA and DoD policy[7], meet the following: ***/2/***

- Meet the requirements of International Energy Conservation Code (IECC). **\2** Use 2015 IECC for all projects with design starts before 5 April 2023. Use 2021 IECC thereafter. ***/2/***

---

[5] Energy consumption for the purposes of calculating the 30 percent savings requirements in 10 CFR Part 433, §433.100 shall include the building envelope and energy consuming systems normally specified as part of the building design by ASHRAE 90.1-2013 such as space heating, space cooling, ventilation, service water heating, and lighting, but shall not include receptacle and process loads not within the scope of ASHRAE 90.1 such as specialized medical or research equipment and equipment used in manufacturing processes.

[6] **\2** Energy consumption for the purposes of calculating the 30 percent savings requirements in 10 CFR Part 433, §433.100 shall include the building envelope and energy consuming systems normally specified as part of the building design by ASHRAE 90.1-2019 such as space heating, space cooling, ventilation, service water heating, and lighting, and all process and receptacle loads, except for energy-intensive process loads that are driven by mission and operational requirements, not necessarily buildings, and not influenced by conventional building energy conservation measures.

[7] Includes any DoD policies that relate to energy. **/2/**

- Design the building to achieve at least 30% energy consumption reduction from the IECC baseline using the Simulated Performance Alternative found in Section 405 of the IECC.
- If a 30% reduction is not LCCE, modify the design of the proposed building alternatives to achieve an energy consumption level at the highest level of energy efficiency that is LCCE.

2-3.1.3 \1\ Comprehensive Replacement and SRM /1/.

\2 To the extent practicable based on LCCA and DoD policy[8], meet the following: ***/2/***

- **\1\/1/**Projects that replace everything above the foundation **\1** (comprehensive replacement) ***/1/*** must apply either paragraph "Commercial and Multi-Family High-Rise Residential Buildings" or "Low-Rise Residential Buildings".
- **\1** SRM projects ***/1/*** choose one of the following options:

  1. Reduce measured building energy use by at least 30%, below FY 2003, or earlier, energy use baseline[9].

  2. Reduce measured building energy use by at least 20% below FY 2015 energy use baseline.

  3. Reduce modeled energy use (from all sources including renewable energy) by 30% compared to the ASHRAE 90.1 baseline building design for Commercial or Multi-Family High-Rise Residential Buildings, or the IECC baseline (using the Simulated Performance Alternative found in Section 405 of the IECC) for Low-Rise Residential buildings. (Refer to paragraph "Commercial and Multi-Family High-Rise Residential Buildings" for calculation of energy consumption reduction.)

2-3.1.4 Energy Efficient Products.

If none of the reduction choices is life-cycle cost effective, modify the design of the proposed building system(s) to achieve an energy consumption level at the highest level of energy efficiency that is life-cycle cost effective.

Per EISA 2007 Section 525, acquire products that are ENERGY STAR®-qualified or meet FEMP-designated Energy-Efficient Products requirements in all covered product categories, considering cost-effectiveness and availability.

2-3.1.5 Standby Power Devices.

Per EISA 2007 Section 524, provide commercially available, off-the-shelf products that use no more than 1 watt in their standby mode, provided it is life-cycle cost effective, practicable, and performance is not compromised.

---

[8] **\2** Includes any DoD policies that relate to energy.

[9] Consult with Installation Energy Manager to determine if building metered data is available. If it isn't, this option cannot be pursued. **/2/**

2-3.2 On-Site Renewable Energy.

Provide on-site renewable energy systems in accordance with IgCC 701.4.1.1 (7.4.1.1) *On-Site Renewable Energy Systems* and UFC 3-440-01 where LCCE, considering climate, infrastructure condition, mission compatibility, and effects on base-wide electrical system (grid) power quality. When available, utilize Installation-specific studies to determine LCCE renewable energy systems. Studies must be dated within five years of project design start.

- For Army projects, if not LCCE, utilize IgCC **\2** 701.3.2 ((7.3.2) ***/2/*** *On-Site Renewable Energy Systems* for future installation of on-site renewable energy systems.
- Services may choose LCCE centralized or Installation-wide renewable energy development, in lieu of building-by-building application. Meet the requirements of UFC 3-540-08.

Exception: Do not use purchase of renewable energy certificates (RECs) as a substitute for IgCC 701.4.1.1 **\2** (7.4.1.1) ***/2/*** new building requirement.

2-3.2.1 Solar Domestic Hot Water (SDHW).

Per EISA 2007 Section 523, meet at least 30% of the annual domestic hot water requirement through the installation of solar water heating unless SDHW is not LCCE.

2-3.3 Metering.

\1 Provide meters as required by DoDI 4170.11, and as amended by DoD Utilities Meter Policy, in the standard units of measure. Where base-wide energy and utility monitoring and control systems exist, meters must be connected using the installation's advanced metering protocols. Meter configuration must comply with the requirements of UFC 4-010-06, and as required by individual Service's meter implementation policy. ***/1/***

2-4 PROTECT AND CONSERVE WATER.

2-4.1 Indoor Water.

Base water efficiency design decisions on life-cycle cost as indicated in paragraph "Life-Cycle Cost Analysis (LCCA)".

- Meet the requirements of IgCC 601.3.2 (6.3.2) *Building Water Use Reduction*, which incorporates EPA WaterSense-labeled products. Water closet replacements**\1*/1/*** may have a flush value of up to 1.6 GPF (6.1 LPF) to accommodate existing plumbing infrastructure. Fixtures used for sanitizing potential biohazards are exempt from low-flow and WaterSense labeling requirements.
- Meet the requirements of IgCC 601.3.3 (6.4.3) *Special Water Features*.

Exception: Paragraph 601.3.2.1.j is not mandatory, but encouraged.

2-4.1.1 Indoor Water Metering.

\1 Provide meters to monitor building indoor water consumption, as required by DoDI 4170.11, and as amended by DoD Utilities Meter Policy, in the standard units of measure. Where base-wide energy and utility monitoring and control systems exist, meters must be connected using the installation's advanced metering protocols. Meter configuration must comply with the requirements of UFC 4-010-06, and as required by individual Service's meter implementation policy. **/1/**

2-4.2 Outdoor Water.

2-4.2.1 Landscaping.

- In accordance with DoD Memo *Water Use for Landscape Architecture on Department of Defense Installations/Sites*, potable water use is prohibited for irrigating new landscaping, other than for plant establishment.
- For existing systems, if a building has a single water meter, reduce combined indoor and outdoor potable water use by at least 20% compared to building water use in 2007. Compare results to a baseline building, using the EPA WaterSense landscape water budget tool version 1.01 or later, or a Service approved tool.
- Show preference for irrigation contractors who are certified through a WaterSense labeled program, or other industry-recognized credentialing programs.
- Refer to UFC 3-201-02 for additional requirements

2-4.2.2 Outdoor Water Metering.

\1 Where LCCE, provide meters to monitor existing irrigation systems serving more than 25,000 square feet of landscape, as required by DoDI 4170.11, and as amended by DoD Utilities Meter Policy, in the standard units of measure. Where base-wide energy and utility monitoring and control systems exist, meters must be connected using the installation's advanced metering protocols. Meter configuration must comply with the requirements of UFC 4-010-06, and as required by individual Service's meter implementation policy. **/1/**

For all other existing irrigation systems using potable water, meters are encouraged.

2-4.3 Alternative Water.

Where life-cycle cost-effective and permitted by state and local laws and regulations, use alternative water sources for non-potable applications.**\1** Where LCCE, provide meters to monitor alternative water consumption, as required by DoDI 4170.11, and as amended by DoD Utilities Meter Policy, in the standard units of measure. Where base-wide energy and utility monitoring and control systems exist, meters must be connected using the installation's advanced metering protocols. Meter configuration must comply with the requirements of UFC 4-010-06, and as required by individual Service's meter implementation policy. **/1/**

2-4.4 Stormwater Management.

Meet the requirements of UFC 3-210-10.

2-5 ENHANCE INDOOR ENVIRONMENTAL QUALITY.

2-5.1 Ventilation and Thermal Comfort.

Comply with UFC 3-410-01 for ventilation and thermal comfort criteria. Consider the use of passive (non-mechanical) thermal comfort methods as described in paragraph entitled, "Integrated Design" in this UFC.

Exception: For Medical Treatment Facilities, refer to UFC 4-510-01 *Medical Military Facilities* for ventilation and thermal comfort criteria.

2-5.2 Daylighting and Lighting Controls.

Locate all employee work areas, such as classrooms and offices, on exterior walls or other locations where it is feasible to maximize daylighting. Maximize daylighting in break rooms and other gathering areas where feasible. **\1** For those spaces on the exterior of the building where it is feasible to maximize daylighting, m**/1/**eet the requirements of IgCC 801.4.1.2 (8.4.1.2) *Minimum Sidelighting Effective Aperture for Office Spaces and Classrooms*. Provide automated lighting, including daylighting, controls in accordance with UFC 3-530-01. For Medical Treatment Facilities, refer to UFC 4-510-01 Medical Military Facilities for additional daylighting criteria.

Exceptions: Under IgCC 801.4.1.2, Exceptions: Number 2, "for more than four daytime hours per day" does not apply.

2-5.3 Indoor Air Quality.

2-5.3.1 Moisture Control.

Establish and implement a moisture control strategy for controlling moisture flows and condensation to prevent building damage, minimize mold contamination, and reduce health risks related to moisture. Meet the requirements of IgCC 1001.3.1.6 (10.3.1.5) *Moisture Control* by including and implementing these requirements in the IAQ construction management plan; UFC 3-410-01, Chapter 3, *Ventilation Air*; and UFC 3-101-01 Chapter 3, *Building Envelope Requirements*. Refer to Appendix B "Best Practices" for Protect Indoor Air Quality.

2-5.3.2 Reduce Volatile Organic Compounds (VOC) (Low-Emitting Materials).

Specify materials and products with low or no pollutant emissions, including composite wood products, adhesives, sealants, interior paints and finishes, carpet systems, and furnishings. Meet the requirements of IgCC 801.4.2 (8.4.2) *Materials*.

Exception: Exclude compliance with the first sentence.

2-5.3.3 Protect Indoor Air Quality during Construction.

For new construction and for **\1** work in **/1/** an existing building that will be unoccupied during construction, develop and implement an IAQ construction management plan that complies with IgCC 1001.3.1.5 (10.3.1.4) *Indoor Air Quality (IAQ) Construction Management*, with maximum outdoor air consistent with achieving relative humidity no greater than 60%.

For **\1** work in **/1/** an existing building that will be occupied during construction, comply with ANSI/SMACNA 008-2008, 2nd Edition, SMACNA IAQ *Guidelines for Occupied Buildings Under Construction*. Refer to Appendix B "Best Practices" for "Protect Indoor Air Quality."

2-5.3.4 Environmental Tobacco Smoke Control.

Prohibit smoking[10] within the building and within a minimum of 50 feet (15.24 meters) of all building entrances, operable windows, and building ventilation intakes. Verify if more stringent facility criteria or Installation policy applies.

2-5.4 Occupant Health and Wellness.

Promote opportunities for occupants to voluntarily increase physical activity, as part of the Integrated Design Process.**\1** Refer to Appendix B "Best Practices" for examples.**/1/**

2-6 REDUCE ENVIRONMENTAL IMPACT OF MATERIALS.

2-6.1 Environmentally Preferable Products.

The following paragraphs require procurement of construction materials and building supplies that have a lesser or reduced effect on human health and the environment over their lifecycle, when compared with competing products or services that serve the same purpose.

2-6.1.1 Recycled Content.

Use RCRA Section 6002 compliant products that meet or exceed EPA's recycled content recommendations, available on EPA's Comprehensive Procurement Guideline (CPG) Program.

[10] Refer to Service-specific policies (may need to copy and paste hyperlink in Browser): Army: ARMY HEALTH PROMOTION Navy: NAVY AND MARINE CORPS TOBACCO POLICY Air Force: AIR FORCE INSTRUCTION 40-102

2-6.1.2 Biologically-Based Products.

Per Section 9002 of the Farm Security and Rural Investment Act, specify products composed of the highest percentage of biobased content consistent with the USDA Biopreferred Program, if products meet performance requirements and are available at a reasonable cost. Document deviation from using biobased product procurement. Include a preference for purchasing products with the highest biobased content per USDA recommendations for designated product categories in all applicable solicitations. USDA's biobased product designations and biobased content (which includes certified sustainably-harvested and rapidly renewable resources) recommendations are available on USDA Biopreferred website.

2-6.1.3 Ozone-Depleting \1\ Substances /1/.

Do not use ozone-depleting **\1** substances **/1/** and high global warming potential (GWP) chemicals where EPAs Significant New Alternatives Policy (SNAP) Program has identified acceptable substitutes or where other environmentally preferable products are available for use in construction, repair or end-of-life replacements.

Exceptions: Refer to UFC 3-600-01 for fire protection system requirements.

2-6.2 Waste and Materials Management.

2-6.2.1 Storage and Collection of Recyclables.

Meet the requirements of IgCC 901.3.4.1 (9.3.4.1) *Recyclables*, where markets or onsite recycling exist.

2-6.2.2 Waste Diversion.

Divert a minimum of 60% of the nonhazardous construction and demolition waste material from landfills.

2-7 ADDRESS CLIMATE CHANGE RISK.

Provide building design solutions responsive to any Government-provided projections of climate change and determination of acceptable risk, typically evaluated and documented in the planning process.

See UFC 2-100-01 and UFC 3-201-01 for potential climate risk considerations and requirements for work on existing buildings.

CHAPTER 3 EXISTING BUILDINGS HPSB COMPLIANCE ASSESSMENT

3-1 OVERVIEW.

3-1.1 Federal Guiding Principles Assessment.

Use this chapter when assessing the HPSB Guiding Principles compliance of an existing building, independent of design and construction activities. The assessment is used to assist in identifying opportunities to increase performance of the building until it reaches full compliance. This assessment can also be used to inform future design and construction activities in the building. Some HPSB Guiding Principles can be addressed at the Installation, Service, or DoD Agency level, versus the building level (example: no smoking policy). Align DoD Service programs that target building energy and water efficiency improvements with the requirements of this UFC. Include consideration of whole building, maintainability, and energy and water efficient solutions. Refer to Table 1-1 for requirements for compliance. HPSB tracking and reporting procedures are covered in Chapter 4, paragraph entitled, "Building Compliance Tracking" and "Building Compliance Reporting".

3-1.2 Assessment Requirements.

Use the following questions-based assessment elements to assess Guiding Principles compliance of an existing building. Each element has two designations noted under the element title: 1) "Required" or "Additional" and 2) "Installation-wide" or "Building-specific". Designation definitions are:

- "Required" means the element must be met to be in compliance.
- "Additional" means the element is an optional part of the assessment. Forty percent of these elements must be met to be in compliance.
- "Installation-wide" means the element can be met through Installation policy/specifications/contracts (where the building is located.)
- "Building-specific" means the element must be met at the building level.

3-2 EMPLOY INTEGRATED ASSESSMENT, OPERATION, AND MANAGEMENT PRINCIPLES.

3-2.1 Integrated Assessment, Operation, and Management.

(Required; Installation-wide)

a. Are sustainable operations and maintenance practices incorporated into the Installation Environmental Management System (EMS)?

Through an integrated process and team, identify and implement operations and maintenance policies that improve building environmental performance; protect natural, historic, and cultural resources; support occupant health and wellness; and improve the resiliency of facilities and operations.

b. Has there been an assessment of existing conditions and operational procedures of the building and/or major building systems, and have areas been identified for improvement?

Assess existing condition and operational procedures of the building and major building systems. Consider electric vehicle charging infrastructure and appropriate energy resiliency measures, in accordance with applicable laws and regulations. Identify areas for improvement.

c. Are there established operational performance goals for energy, water, material use, recycling, and indoor environmental quality; and is incorporation of the goals ensured throughout the lifecycle of the building?

Establish: operational performance goals for energy and water; product compliance goals for material use, recycling, and indoor environmental quality; and ensure goals are incorporated throughout the remaining life cycle of the building, including a verification process.

d. Is there a building management plan to ensure that operating decisions and user/tenant education are carried out with regard to integrated, sustainable building operations and maintenance?

Incorporate goals into building management to ensure that operating decisions and tenant education are carried out with regard to integrated building operations and maintenance.

e. In addition to the work order program/Facilities Managers, are building operations and maintenance augmented as needed, using Building Manager/occupant/user feedback on workspace satisfaction?

Engage building occupants with building environmental performance information. Augment building operations and maintenance as needed using occupant feedback on workspace satisfaction.

3-2.2 ReCommissioning and RetroCommissioning.

(Required; Building-specific)

Has the building been commissioned, recommissioned, or retrocommissioned within the last four years?

In order to verify performance and ensure that the Government requirements are met, employ retrocommissioning and recommissioning activities, tailored to the size and complexity of the existing building and its system components. Recommissioning must be led by an experienced commissioning agent, who should be independent of the facility operations team.

Use IgCC 1001.3.1.2 (10.3.1.2) *Building Project Commissioning* to assist in defining appropriate commissioning activities. For buildings and systems that are less complex, commissioning activities may be tailored as determined by the DoD Service AHJ. For Army assessments, refer to Army policy for determination of systems to commission. For Air Force and Navy assessments, the Assessment Team must determine the level of commissioning activities required.

3-3 OPTIMIZE ENERGY PERFORMANCE.

3-3.1 Energy Efficiency.

3-3.1.1 Commercial and Multi-Family High-Rise Residential Buildings or Low-Rise Residential.

(Required; Building-specific)

\1 When LCCE, h **/1/** as energy usage met any of the following performance options?

- Option 1: Reduce measured building energy use by at least 30% below the FY 2003, or earlier, energy use baseline[11].
- Option 2: Reduce modeled building energy use (from all sources including renewable energy) by at least 20% below the FY 2015 energy use baseline.
- Option 3a: Reduce modeled building energy use (from all sources including renewable energy) by at least 30% below ASHRAE 90.1 standard. (Refer to paragraph "Commercial and Multi-Family High-Rise Residential Buildings" for calculation of energy consumption reduction.)
- Option 3b: Reduce modeled building energy use (from all sources including renewable energy) by at least 30% below IECC standard.

3-3.1.2 Energy Efficient Products.

(Required; Installation-wide)

Do acquisition documents require the purchase of **\1** ENERGY STAR® **/1/** and/or FEMP-designated Energy Efficient products?

Per EISA 2007 Section 525, acquire products that are ENERGY STAR®-qualified or meet FEMP-designated Energy-Efficient Products requirements in all covered product categories, considering cost-effectiveness and availability.

3-3.2 On-Site Renewable Energy.

(Additional; Building-specific or Installation-wide)

a. Has building-level or centralized renewable energy generation been evaluated?

[11] **\2** Consult with Installation Energy Manager to determine if building metered data is available. If it isn't, this option cannot be pursued. **/2/**

b. When found to be LCCE, has renewable energy generation been implemented or planned for implementation?

Implement renewable energy generation projects on agency property for agency use, where lifecycle cost effective and when there are no adverse effects on base-wide electrical system (grid) power quality or mission. Implementation must comply with the requirements in UFC 3-440-01. When available, utilize Installation-specific studies to determine LCCE of renewable sources. Studies must be dated within five years of project design start.

Services may choose centralized renewable energy development in lieu of building-by-building application. Meet the requirements of UFC 3-540-08.

3-3.3 Metering.

(Additional; Building-specific)

a. Is there a building meter for electricity?

b. Is there a building meter for gas?

c. Is there a building meter for steam?

\1 Provide meters as required by DoDI 4170.11, and as amended by DoD Utilities Meter Policy, in the standard units of measure. Where base-wide energy and utility monitoring and control systems exist, meters must be connected using the installation's advanced metering protocols. Meter configuration must comply with the requirements of UFC 4-010-06, and as required by individual Service's meter implementation policy. **/1/**

3-3.4 \1\/1/Benchmarking (Verification).

(Additional; Building-specific)

a. Is electric metered data gathered on a monthly basis?

   If Yes: Is the data analyzed?

b. Is gas metered data gathered on a monthly basis?

   If Yes: Is the data analyzed?

c. Is steam metered data gathered on a monthly basis?

   If Yes: Is the data analyzed?

Compare annual performance data with previous years' performance data, by entering annual performance data in a measurement and tracking tool.

3-4 PROTECT AND CONSERVE WATER

3-4.1 Indoor Water.

(Required; Building-specific or Installation-wide)

Do acquisition documents require the purchase of water-conserving products (ex: EPA's WaterSense-labeled products where available for toilets, showers, urinals, faucets)?

3-4.2 Indoor Water Metering

(Required; Building-specific)

a. Is there a building meter for potable water sources?

b. Is there a measured 20% reduction in water usage from 2007 baseline; OR has a 20% reduction in water usage been determined by a Service approved method; OR has an analysis been conducted of water use, leaks been identified and repaired, single pass cooling been eliminated, cooling tower operations optimized, and water efficient products installed?

\1 Provide meters to monitor building indoor water consumption, as required by DoDI 4170.11, and as amended by DoD Utilities Meter Policy, in the standard units of measure. Where base-wide energy and utility monitoring and control systems exist, meters must be connected using the installation's advanced metering protocols. Meter configuration must comply with the requirements of UFC 4-010-06, and as required by individual Service's meter implementation policy **/1/**

3-4.3 Outdoor Water.

3-4.3.1 Water for landscaping.

(Additional; Building-specific)

If potable water is used for existing irrigation, has 20% reduction been demonstrated by metered data or modeling (such as the EPA WaterSense Landscape Water Budget Tool, version 1.01 or later, or a Service approved tool) OR is water efficient landscaping used?

3-4.3.2 Outdoor Water Metering

(Additional; Building-specific)

For irrigation systems serving more than 25,000 SF of landscaping, is an outdoor water meter installed?

\1 Where LCCE, provide meters to monitor existing irrigation systems serving more than 25,000 square feet of landscape, as required by DoDI 4170.11, and as amended by DoD Utilities Meter Policy, in the standard units of measure. Where base-wide energy and utility monitoring and control systems exist, meters must be connected using the installation's advanced metering protocols. Meter configuration must comply with the requirements of UFC 4-010-06, and as required by individual Service's meter implementation policy. **/1/**

3-4.4 Alternative Water.

(Additional; Building-specific or Installation-wide)

a. Have building-level or centralized alternative water sources been evaluated?

b. When found to be LCCE, have alternative water sources been implemented or planned for implementation?

Where life-cycle cost-effective and permitted by state and local laws and regulations, use alternative water sources for non-potable applications.**\1** Where LCCE, provide meters to monitor building alternative water consumption, as required by DoDI 4170.11, and as amended by DoD Utilities Meter Policy, in the standard units of measure. Where base-wide energy and utility monitoring and control systems exist, meters must be connected using the installation's advanced metering protocols. Meter configuration must comply with the requirements of UFC 4-010-06, and as required by individual Service's meter implementation policy. **/1/**

3-4.5 Stormwater Management.

(Additional; Building-specific or Installation-wide)

Are the requirements of UFC 3-210-10 incorporated into projects that include expansion of one or more existing buildings, and disturbance of greater than 5000 SF?

3-5 ENHANCE INDOOR ENVIRONMENTAL QUALITY.

3-5.1 Ventilation and Thermal Comfort.

(Required; Building-specific)

Does the building comply with the ventilation and thermal requirements of UFC 3-410-01?

3-5.2 Daylighting and Lighting Controls.

(Additional; Building-specific)

Are automated lighting controls, including occupancy/vacancy sensors with manual-off capability and daylighting controls, provided for appropriate spaces in accordance with UFC 3-530-01? (Appropriate spaces include: restrooms, conference and meeting rooms, employee lunch and break rooms, training classrooms, and offices.)

Maximize opportunities for daylighting within the existing structure, except where not appropriate because of building function, mission, or structural constraints. Maximize: the use of automatic dimming controls; task lighting where life cycle cost-effective; and appropriate shade and glare control. Provide automated lighting controls in accordance with UFC 3-530-01.

3-5.3 Indoor Air Quality.

3-5.3.1 Moisture Control.

(Additional; Installation-wide)

Is there a policy or specification requiring moisture control strategy for moisture flows and condensation to prevent building damage, minimize mold contamination, and reduce health risks related to moisture?

Establish and implement a moisture control strategy for controlling moisture flows and condensation to prevent building damage, minimize mold contamination, and reduce health risks related to moisture.

3-5.3.2 Reduce Volatile Organic Compounds (VOC) (Low-Emitting Materials).

(Additional; Installation-wide)

a. Is there a policy or specification requiring low emitting materials (low Volatile Organic Compounds (VOCs)) for building repairs/modifications?

b. Is there a policy or specification requiring the use of low emitting materials (low Volatile Organic Compounds (VOCs)) for cleaning?

Use reduced volatile organic compounds (VOC) (low emitting materials) for building modifications, maintenance, and cleaning. In particular, specify the following materials and products to have low or no pollutant emissions: composite wood products, adhesives, sealants, interior paints and finishes, solvents, carpet systems, janitorial supplies, and furnishings.

3-5.3.3 Integrated Pest Management.

(Additional; Installation-wide)

Is there an Integrated Pest Management Plan (IPMP) in place?

Use integrated pest management techniques as appropriate to minimize pesticide usage. When pesticides are needed, only use EPA-registered pesticides.

3-5.3.4 Environmental Tobacco Smoke Control.

(Additional; Installation-wide)

> Do all smoking structures comply with Service policy to be 50 feet from openings?

Prohibit smoking[12] within the building and within a minimum of 50 feet (15.24 meters) of all building entrances, operable windows, and building ventilation intakes. Verify if more stringent facility criteria or Installation policy applies.

3-5.4 Occupant Health and Wellness.

(Additional; Installation-wide)

> Do occupants have access to infrastructure, buildings, and interior attributes that promote voluntary increased physical movement?

Promote opportunities for occupants to voluntarily increase physical movement. Refer to Appendix B "Best Practice" for examples.

3-6 REDUCE ENVIRONMENTAL IMPACT OF MATERIALS.

3-6.1 Environmentally Preferable Products.

The following paragraphs require procurement of construction materials and building supplies that have a lesser or reduced effect on human health and the environment over their lifecycle when compared with competing products or services that serve the same purpose.

3-6.1.1 Recycled Content.

(Required; Installation-wide)

> Is there a policy or specification requiring products to meet or exceed EPA's recycled content recommendations for all building repairs/modifications?

Use RCRA Section 6002 compliant products that meet or exceed EPA's recycled content recommendations, available on EPA's Comprehensive Procurement Guideline (CPG) Program.

Encourage reuse of building materials, components, and furnishings that are in refurbishable condition and meet the quality standards of the government.

---

[12] Refer to Service-specific policies (may need to copy and paste hyperlink in Browser): Army: ARMY HEALTH PROMOTION Navy: NAVY AND MARINE CORPS TOBACCO POLICY Air Force: AIR FORCE INSTRUCTION 40-102

3-6.1.2 Biologically-Based Products.

(Required; Installation-wide)

> Is there a policy or specification requiring use of products listed by USDA's biobased content site?

Per Section 9002 of the Farm Security and Rural Investment Act, specify products composed of the highest percentage of biobased content consistent with the USDA Biopreferred Program, if products meet performance requirements and are available at a reasonable cost. Document deviation from using biobased product procurement. Include a preference for purchasing products with the highest biobased content per USDA recommendations for designated product categories in all applicable solicitations for building modifications, operations and maintenance, and cleaning. USDA's biobased product designations and biobased content (which includes certified sustainably-harvested wood products and rapidly renewable resources) recommendations are available on USDA Biopreferred website.

3-6.1.3 Ozone-Depleting \1\ Substances /1/.

(Required; Installation-wide)

> Is there a CFC management plan that includes reducing Ozone-Depleting **\1** Substances **/1/**?
>
> If Yes: does the plan include a phase out of ODCs, or have CFCs already been phased out?

Eliminate the use of ozone-depleting **\1** substances **/1/** and high global warming potential (GWP) chemicals where EPAs Significant New Alternatives Policy (SNAP) Program has identified acceptable substitutes or where other environmentally preferable products are available for use in construction, repair or end-of-life replacements.

Exception: Refer to UFC 3-600-01 for fire protection system requirements.

3-6.2 Waste and Materials Management.

3-6.2.1 Storage and Collection of Recyclables.

(Required; Installation-wide)

a. Is there reuse or recycling service for building occupants?

b. Is there policy/specifications requiring salvage, reuse, or recycling services for waste generated from building operations and maintenance, as well as discarded furnishings, equipment, and property?

Provide salvage, reuse and recycling services for waste generated from building operations, maintenance, repair and **\1** SRM projects **/1/**, where markets or on-site recycling exist.

3-6.2.2 Waste Diversion.

(Additional; Installation-wide)

> Is there policy/specifications requiring salvage, reuse, or recycling services for waste generated from **\1** work in existing buildings **/1/**?

Divert a minimum of 60% of the nonhazardous construction and demolition waste material from landfills. Provide recycling services for paper, corrugated cardboard, glass, plastics, and metals, at a minimum, where local markets or on-site recycling exist.

3-7 ADDRESS CLIMATE CHANGE RISK.

(Required; Building-specific or Installation-wide)

> Where climate change risk factors have been identified, is there a process to implement associated actions?

Provide building design solutions responsive to any Government-provided projections of climate change projection and determination of acceptable risk (typically determined, evaluated and documented in the planning process.)

See UFC 2-100-01 and UFC 3-201-01 for potential climate risk considerations and requirements for work on existing buildings.

CHAPTER 4 HPSB COMPLIANCE TRACKING, REPORTING, AND POLICIES

4-1 OVERVIEW.

Federal agencies are required to target and report annual progress toward HPSB Guiding Principles compliance, with the ultimate goal of 15% compliance of the existing building inventory by 2025. Refer to Table 1-1 "Building Requirements Compliance and Thresholds" to determine applicability of this chapter to each building within a project.

4-2 COMPLIANCE WITH FEDERAL REQUIREMENTS.

The focus of compliance with the HPSB Guiding Principles is to meet the requirements of Table 1-1 "Compliance Requirements/Thresholds." HPSB Checklist requirements are met (marked "YES") when each requirement demonstrates one of the following:

- Fully compliant – the requirement is in full compliance and is marked "Yes".
- Partially compliant – the requirement is compliant to the greatest degree possible, based on LCCE (example: SDHW serves only 20% of water use, per LCCE); mission restriction (example: 24/7 operation); location/regional restriction (example: availability of high-efficiency equipment service); locale restriction (example: proximity of existing buildings restricts daylighting), or safety (example: building orientation restriction for anti-terrorism due to existing infrastructure), and is marked "Yes" with justification.
- Not applicable – the requirement is not applicable, based on LCCE (example, LCCE excludes use of Alternative Water); mission exclusion (example, no daylighting in a theater); location/regional exclusion (example, Host Nation Agreement or no local recycling facility); locale exclusion (example, there is no steam to meter), or safety (example, building orientation restriction for AT/FP due to existing infrastructure), and is marked "Not Applicable" with justification.

Per *Department of Defense Sustainable Buildings Policy*, if a newly constructed building or renovated existing building complies with all the requirements of this UFC, it is considered compliant with all federal sustainability requirements.

\2 Guiding Principles Validation (GPV), as used in UFGS 01 33 29, is project delivery team self-assessment of compliance, and required tracking and reporting. ***/2/***

4-2.1 Compliance HPSB Checklists.

Use the DoD Service-level HPSB checklists to track and report compliance with the requirements of this UFC, found on the Tri-Services Sustainability Program "Required Tracking – Reporting" page. Additional requirements:

- Air Force –Tracking and reporting includes revising and submitting the Air Force Sustainability Requirements Scoresheet and the design analysis to

<AFCEC.CF.SustainableRpt@us.af.mil> at each design submittal and when construction is complete.

- Army – Track and report compliance by completing and submitting, per the instructions, the checklist(s) hosted under USACE Sustainable Tracking.
- Navy – Tracking includes revising and submitting the NAVFAC HPSB Checklist with the project's Final Design Submittal and as a Construction Submittal when all construction HPSB requirements are complete.

Use the Checklist of the Service that will maintain the building asset in their Real Property Record. Check with the user Command for additional requirements.

4-2.1.1 Compliance Documentation.

Compliance documentation demonstrates appropriate analysis and compliance with each of the HPSB requirements. Examples of compliance documentation are cited in the following paragraphs. Provide and update Compliance documentation in the design phase with each design submittal, preferably consolidated into a "sustainability" chapter in the Basis of Design, Scope of Work, or Design Analysis, and retained in the project folder.

Compliance documentation also includes the "S" submittals. The "S" Submittal is a required specification submittal that proves a particular sustainability requirement has been met by the post-award construction contractor. These submittals support the requirements in UFGS 01 33 29, are part of the electronic organization system called the Sustainability eNotebook, and are also used to obtain required documentation for third-party certifications. Many of the UFGS templates contain the standard language and tagging for the "S" submittals, with notes on how to edit each tagged submittal phrase. "S" submittals appear on the Submittal Register.

4-2.1.1.1 Energy Compliance Analysis (ECA).

In the design analysis, include an ECA that demonstrates compliance with all energy related requirements in this UFC. Identify the specific energy efficiency criteria that apply to the project, the software used to prepare the necessary calculations, a summary of all input to and output from the calculations, and the calculated energy consumption of the baseline and alternatives. Include in the ECA a completed "Performance Rating Report" as shown in Appendix G of the ASHRAE 90.1 *User's Manual*. Building-level energy consumption calculations (typically the responsibility of the design mechanical engineer) must be performed using a computer program or programs that integrate architectural features (such as the building envelope), air-conditioning, heating, lighting, and other energy producing or consuming systems. These programs must be capable of simulating the features, systems, and thermal loads used in the design. Include the energy savings and any parasitic energy loads associated with the utilization of recovered energy, solar heat, solar photovoltaic energy and other renewable or waste heat applications. The program must be capable of performing 8,760 hourly calculations. The Department of Energy (DoE) maintains a list of building energy tools for design (such as eQuest).

4-2.1.1.2 ECA Narrative Requirements.

ECA LCCA narratives must be prepared by each of the following individuals: Lead Project Architect, Lead Project Mechanical Engineer, and Lead Project Electrical Engineer. List in each of the three narratives the conservation features considered for that discipline, conservation measures adopted in the design, and any supporting LCCA calculations. Use the results of this analysis for design decision-making in reducing total Life Cycle Cost, while meeting mission objectives.

4-2.2 Existing Buildings, HPSB Assessment.

Existing building assessment is detailed in Chapter 3. Code an existing building meeting the HPSB Guiding Principles (all "Required" and 40% of "Additional" elements) as "Yes (1)". Indicate the appropriate sustainability status when the asset record is created, assessed, or updated.

For reporting requirements, refer to the paragraph entitled, "Compliance Reporting".

4-2.3 Building Compliance Tracking.

Refer to Table 1-1 for building compliance tracking thresholds. During the project definition, design, and construction phases of a project, compliance with requirements is tracked using DoD Service HPSB checklist referenced in the paragraph entitled, "Compliance Checklists". Individual building performance is reported in the Annual Energy Management and Resilience Report to Congress. Refer to each DoD Service for guidance on reporting systems and instructions.

Once the project is complete, track the final status for each building's HPSB Guiding Principles compliance in each Service's reporting system as detailed above.[13] A new building or **\1** comprehensive replacement **/1/** meeting the HPSB Guiding Principles also meets the existing building HPSB Guiding Principles and can be coded as "Yes (1)". Indicate the appropriate sustainability status at the completion of the project when the asset record is created or updated.

4-2.4 Building Compliance Reporting.

Compliance with this UFC is considered compliance with the HPSB Guiding Principles. DoD Services report their building compliance with HPSB Guiding Principles via the Real Property Inventory Submission, as provided in guidance promulgated by the Office of the Assistant Secretary of Defense (OASD) Energy, Installations & Environment (EI&E), Business System Integration Directorate (BSI). View policy regarding this reporting requirement in DoDI 4165.14.

BSI maintains the real property inventory data standards needed for the Enterprise Energy Information Management capability in the Real Property Information Model. The

[13] Buildings greater than 10,000 SF are reported to Congress.

specific data element identified with this reporting requirement is "RPA Sustainability Code".

The reporting codes are:

- Yes (1) – asset has been evaluated and meets HPSB Guiding Principles
- No (2) – asset has been evaluated and does not meet HPSB Guiding Principles
- Not Yet Evaluated (3) – asset has not yet been evaluated on whether or not it meets HPSB Guiding Principles
- Not Applicable (4) – One of the following:
    - Buildings that have a status of Report of Excess (ROE) submitted, ROE accepted, or Determination to Dispose:

      OR ARE
    - Unoccupied: The building is occupied one hour or less per person per day on average;

      AND

      Low/No Energy Use: The total building energy consumption from all sources is less than 12.7 kBTU / SF/ Yr.;

      AND

      Low/No Water Use: Annual average water consumption is less than 2 gallons per day for the building.

Code existing buildings ≥ 10,000 GSF (929 GSM) that have not had an HPSB Guiding Principles assessment "Not yet evaluated (3)". Code existing buildings ≥ 10,000 SF (929 SM) that have had an HPSB Guiding Principles assessment as either "Yes (1)" or "No (2)" using the guidance herein.

4-3 DOD SUSTAINABILITY POLICY REQUIREMENTS.

4-3.1 Office of Secretary of Defense Guidance.

OUSD AT&L Memorandum, *Department of Defense Sustainable Buildings Policy* requires compliance with this UFC, in alignment with Federal policy. The memo also requires the use of auditable processes to track and report this compliance.

4-3.2 Sustainable Third-Party Certification (TPC).

The requirement for TPC is in addition to tracking and reporting HPSB Guiding Principles Compliance in accordance with Table 1-1 "Building Compliance Requirements and Thresholds". Per *Department of Defense Sustainable Buildings Policy*, DoD projects must "…include green-building certification of those buildings through any of the systems approved for federal use…" The green-building rating system is also known as Third-Party Certification (TPC), and is an additional requirement to this UFC compliance, tracking, and reporting. TPC is the generic term for a third-party product that provides either certification of the third party's specific product or a validation program by the third party that this UFC's requirements have been met. TPC is required for applicable DoD **\1** Component **/1/** buildings in the US and US territories. For all other DoD building locations, apply TPC to the greatest extent practical, when not in conflict with mission objectives and Host Nation agreements. Apply TPC to each applicable building in a project. Use the TPC of the supporting Service who will maintain the building asset in their Real Property Record. See guidance for supporting Service in DoD Policy[14].

4-3.2.1 Service-Specific TPC

\1\/1/Refer to Component policy for exemption requirements if the following cannot be met:

- Air Force: Project delivery teams may use either Green Business Certification, Inc.(GBCI) "Guiding Principles Assessment for Department of Defense" program or Green Building Initiative's (GBI) "Department of Defense Guiding Principles Compliance" program.

- Army: Projects must use USGBC's LEED rating system at the minimum Silver level.

- Navy: Project delivery teams may use one of the following: Green Business Certification, Inc.(GBCI) "Guiding Principles Assessment for Department of Defense" program; USGBC's "LEED" rating system; Green Building Initiative's (GBI) "Department of Defense Guiding Principles Compliance" program; or GBI's "Green Globes" rating system.

4-3.3 Prohibition of Sharing Energy and Water Usage Data.

No energy or water usage data sharing with private, sustainable third-party certification vendors is allowed for any DoD project. The DoD has complete exemption from sharing energy or water with any third-party certifier. Some certifiers have specific procedure for registering projects to include waiver language. Contact DoD Service or Third-Party Certification provider for specific procedures.

4-3.4 DoD Service Policy.

DoD and Service-specific implementation requirements and guidance documents may be viewed at Tri-Services Sustainability Program "Policy and Mandates" page.

[14] Memorandum, Department of Defense Supplemental Guidance for Implementing and Operating a Joint Base, April 15, 2008: Facilities Investment Joint Base Supplemental Guidance (CAC with Authentication certificate required)

4-4 DOD SUSTAINABILITY REPORT AND IMPLEMENTATION PLAN (SRIP).

EO 13834 requires each Federal agency to "report…agency implementation and progress toward the goals of this order and relevant statutory requirements." The DoD SRIP provides an organized approach to meeting the requirements of the EO, including HPSB.

APPENDIX A ENERGY OPTIMIZATION AND LCCA PROCESS INTEGRATION

This appendix contains mandatory provisions for performing LCCA, unless otherwise stated. This appendix replaces Appendix "HVAC System Selection Flow Chart" in UFC 3-410-01. Execute LCCA by following the NIST Handbook 135 and utilizing the BLCC software program.**\1** DOE COMcheck-web or COMcheck desktop programs might be useful to gain energy credit, improve energy efficiency, reduce energy cost, and comply with IECC and ASHRAE 90.1. **/1/**

A-1 LCCA PROCESS INTEGRATION STEPS

Use the Process flowchart "Energy Optimization and LCCA Process" when performing the Energy Optimization and LCCA.

For projects that meet the minimum requirements of paragraph "Life-Cycle Cost Analysis (LCCA)", perform energy optimization and LCCA during parametric design process to 35% Design or earlier. Identify energy enhancements that are life-cycle cost effective (LCCE) and supported by the LCCA to meet energy efficiency requirements. Where such enhancements increase costs, request additional funds for the project prior to budget lock. Ensure that all processes, decisions, and the resultant recommended course of action are properly documented.

A-1.1 Identify Alternatives

Identify the highest efficiency building systems and features from those that are feasible. Perform energy modeling on at least three alternative sets of building envelope, and mechanical, and electrical design solutions. Exercise good engineering judgment and use past experience in identifying the best alternatives for analysis for a given project. Perform LCCA to determine which alternatives are LCCE. When appropriate, consider additional alternatives. Document all alternatives considered in the Design Analysis for the record, including those that were not pursued.

- For Navy and Air Force projects, select the most LCCE alternative out of the set of alternatives that provide at least 30% energy savings from the ASHRAE 90.1 Appendix G baseline. Refer to Chapter 2, paragraph titled "Energy Efficiency" for calculation methodology.

- For Army projects, select the alternative that provides the highest energy efficiency while remaining LCCE as the proposed design solution for the project.

A-1.2 Chosen Alternative Justification

When the LCCA process does not identify an LCCE solution that meets or exceeds 30% below baseline, provide an explanation in the Design Analysis file. For example, justification may relate to unique mission requirements, historic building requirements, resiliency requirements, operation and maintenance considerations, or factors that cannot be quantified to be included in the LCCA.

A-1.2.1 Balance Energy with O&M

Balance increases in energy efficiency against operating and maintenance (O&M) costs and initial costs. LCCE means that the proposed design solutions have a lower life-cycle cost than the life-cycle cost of the baseline.

A-1.2.2 Building Envelope

For existing buildings, the LCCA baseline for the building envelope is the existing building envelope system type with ASHRAE 90.1 Section 5 compliant U-factors, etc. Example: if an existing building has masonry wall construction, the baseline envelope will have masonry wall construction with the associated U-factors from ASHRAE 90.1 Section 5. Do not use the ASHRAE 90.1 Appendix G requirement for steel-framed wall for the baseline for LCCA in this example.

A-1.2.3 Preferred Features

In selecting alternatives for analysis, give preference to durable features and systems with lower complexity and maintenance burden. Where alternatives were considered, but not analyzed, identify those alternatives and provide an explanation in the Design Analysis. When there are less than three feasible alternatives for the project, include a justification in the documentation.

A-1.2.4 Lighting Systems

When included in the design, LED and high-intensity RF Induction lighting systems do not require LCCAs because long life, efficiency, and environmental sustainability is inherent in these technologies.

A-1.2.5 Installation Preferences

Installation preferences do not supersede service policies or this UFC without an approved exemption in accordance with MIL-STD-3007. Incorporate realistic operational and maintenance considerations into the LCCA. When non-quantitative considerations may impact alternatives selected, provide justification as noted above.

A-1.2.6 Funding of Features and Systems

Where the DD Form 1391 for a Congressionally approved project requires a particular feature or system, such feature or system must be included in the design. In such cases, a LCCA for that feature or system is not required during design. Cite the reason for no LCCA in the Design Analysis. Example: Where funding is identified for solar photovoltaic systems or ground source heat pump systems in the DD Form 1391, they will be included in the project without the need for an additional LCCA, since a required LCCA was completed in order for those systems to be added to the DD form 1391. Where connection to a central energy plant is required in the DD form 1391, LCCA for the central heating/cooling plants for a building is not required. However, a LCCA for the air systems is required. When central plant data is available, energy optimization calculations should be conducted and documented in the design analysis.

A-1.3 Energy Modeling

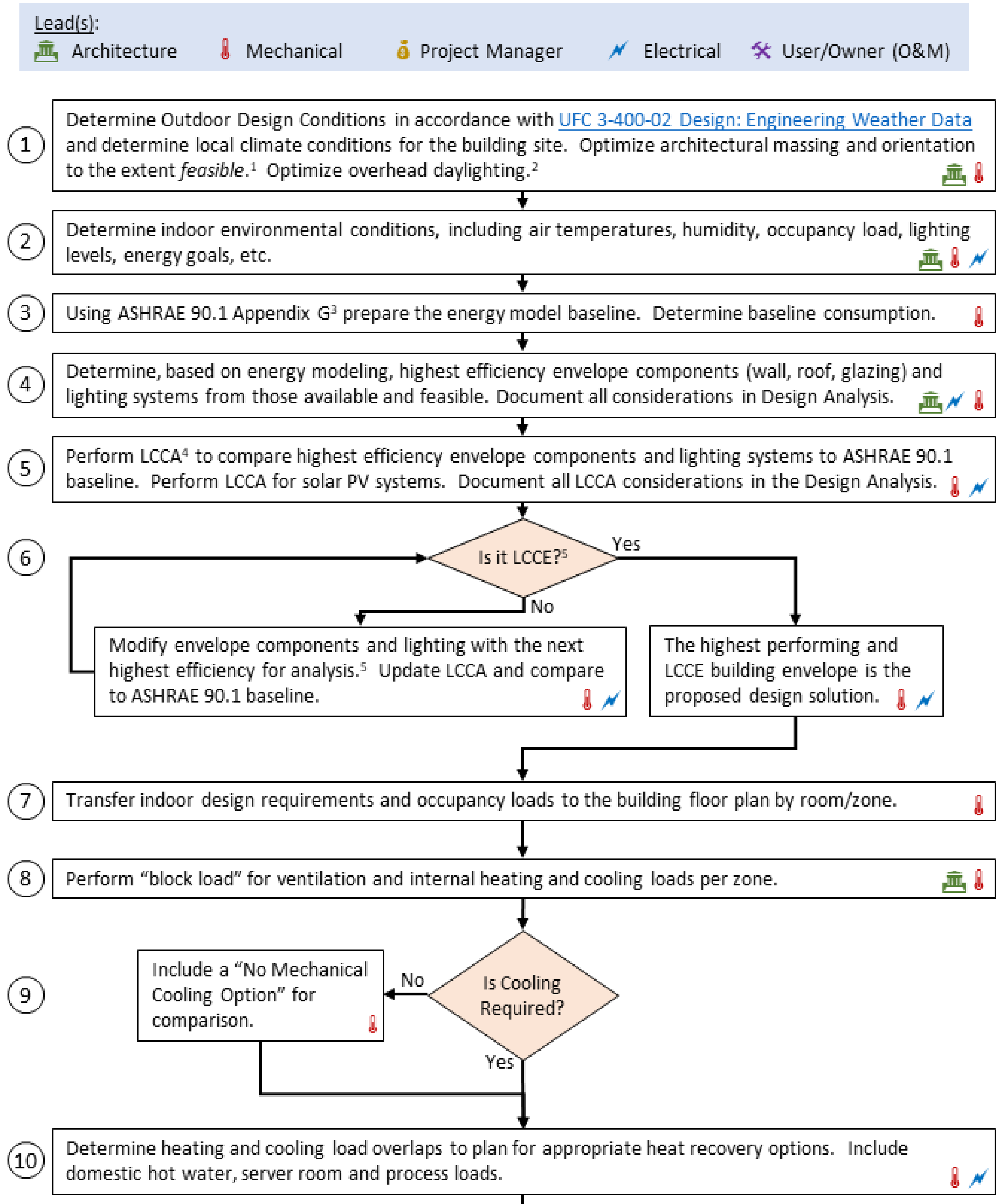
Complete the documentation of the energy optimization and LCCA, including the associated energy modeling, no later than the parametric design phase (5-35%). Any significant changes to the project scope beyond initial design that impact energy savings or project cost require an updated LCCA and energy model. Place all documentation in the Design Analysis and keep it readily available for a third-party review. The LCCA documentation forms a part of the Energy Compliance Analysis required for the project.

A-2 DESIGN BUILD PROJECTS

In Design Build (DB) projects, the LCCA is prepared during the development of the solicitation package, or Request for Proposal (RFP). The resulting system and feature selections are incorporated as requirements in the DB RFP. The DB selection criteria must require that any deviation provided by the offeror that increases energy efficiency is supported by an energy optimization and LCCA. Deviations that decrease the energy efficacy are not acceptable.

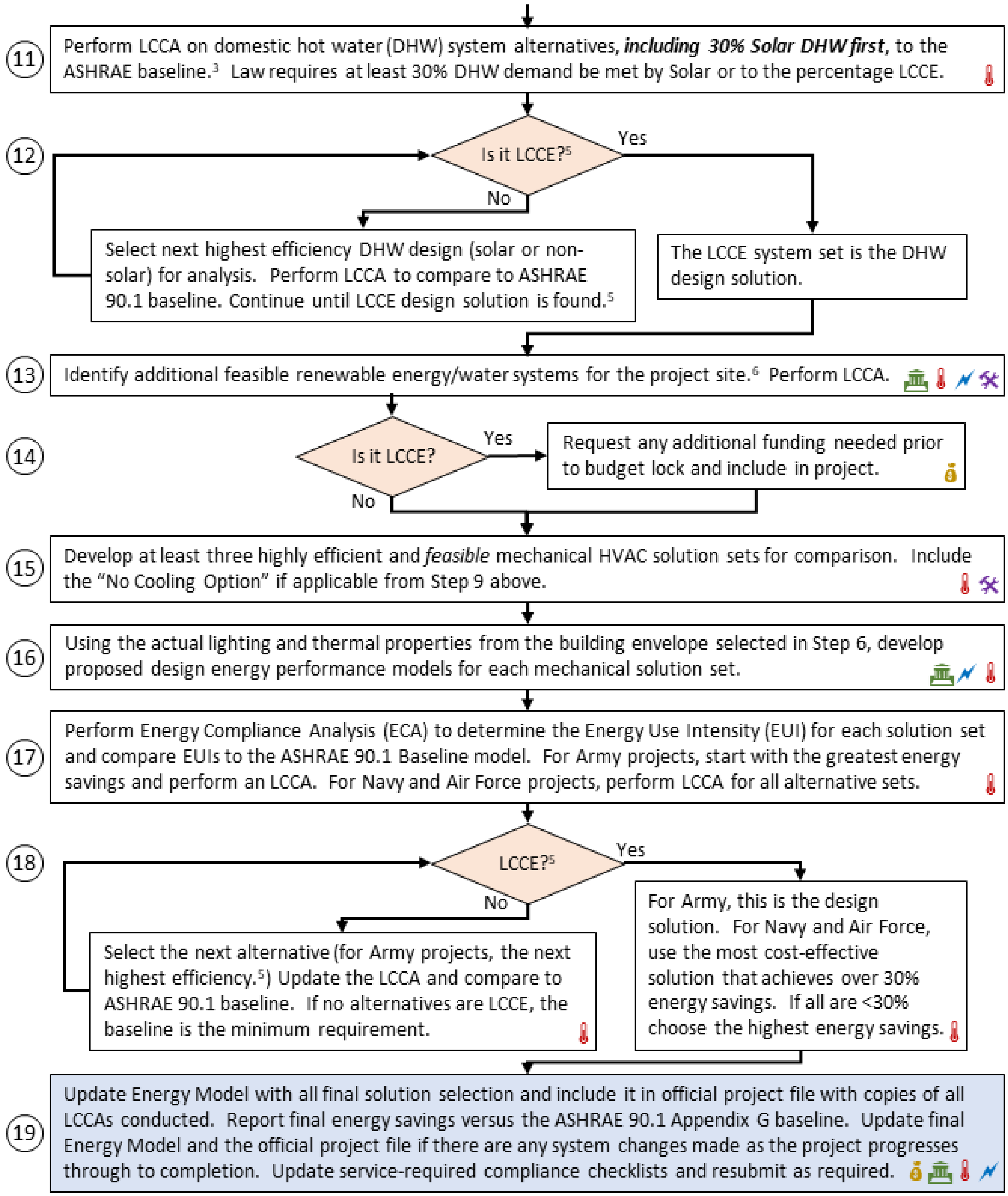
A-3 ENERGY OPTIMIZATION AND LCCA PROCESS CHART

\1\



Continued next page...

...continued from previous page.



Flowchart Footnotes:

1. The term “feasible” throughout the flow chart means technically viable alternatives that are: 1) available in the project market; meet mission/functional requirements; 2) comply with Federal Laws and applicable Government regulations, policy, codes, and criteria (UFCs, AT/FP, etc.); and 3) realistically and economically maintainable by local facility operation and maintenance staff or contractors. Justify design solutions found to be “not feasible” in the Design Analysis for the record with documentation.

2. “Optimize daylighting” means improvement to user environmental quality, as well as providing opportunity to save energy through instantaneous automatic electronic light dimming. Optimize to the extent feasible per Footnote 1. Consider the extent of energy savings available based on most likely selected lighting system alternative. Daylighting is most effective from above. Refer to UFC 3-101-01, Architecture for guidance on Daylighting.

3. ASHRAE 90.1 Appendix G prescribed systems are the baseline and minimum energy performance requirement (presumed to be cost-effective) based on the latest version adopted in 10 CFR §433.100 Energy Efficiency Performance Standard. All Federal facilities are required to achieve at least 30% energy savings from this baseline, if life-cycle cost effective.

4. Perform Life-Cycle Cost Analysis (LCCA) in accordance with 10 CFR 436 and the NIST Handbook 135, using present-value method. Include realistic maintenance costs, based on Installation O&M capabilities.

5. Life-Cycle Cost Effective (LCCE) as determined by a Life-Cycle Cost Analysis (LCCA). LCCA are required to demonstrate that savings beyond the baseline are LCCE. A minimum of three alternative solutions to the baseline is required for a complete analysis. If none of the alternative solutions with savings beyond the baseline are LCCE, then the baseline is the design solution.

6. The consideration of solar energy systems is required by mandate. There are other forms of renewable energy that can enhance the performance and resiliency of the facility. Use the current, local Installation utility costs, to include savings attributable to demand and time-of-day charge reductions from the inclusion of renewable energy and energy storage. Evaluate the project location for available alternative renewable energy sources. Some locations may have significant wind, waste heat recovery, microhydro, biomass, cogeneration, or other options that may be included economically as a package. Based on 1391, enhance building resiliency, and when feasible (per Note 1), consider these systems to supplement critical power circuits to reduce fuel consumption by backup generators during service disruptions. Request additional funding for a line item was not included or underestimated on the DD Form 1391 that has not yet been enacted or locked. Document funding request approvals and disapprovals in the Design Analysis. **/1/**

APPENDIX B BEST PRACTICES

B-1 PROMOTE SUSTAINABLE LOCATION AND SITE DEVELOPMENT.

Coordinate with UFC 2-100-01 requirements and guidance.

B-1.1 Mitigation of Heat Island Effect.

- For Site Hardscapes – Consider the use of IgCC 501.3.5.1 (5.3.5.1) *Site Hardscape* for sidewalks, courtyards and POV parking areas
- For Walls – Consider the use of IgCC 501.3.5.2 (5.3.5.2) *Walls*.

B-2 PROTECT INDOOR AIR QUALITY (IAQ).

IAQ is a quality-of-life issue in every enclosed building. Due to lack of good IAQ, occupant absenteeism and poor performance has drawn a lot of attention over the years. In addition to moisture control, IAQ should be of concern in every project.

B-2.1 IAQ for \1\ Work in Existing Buildings /1/.

IAQ is of particular concern in **\1** work **/1/** that occur in occupied buildings.

When **\1** work occurs **/1/** in occupied buildings, include in the sequencing consideration for the occupants who remain in the building during the **\1** work **/1/**.

- Pay additional attention to sealed edges of barriers that prevent escaping dust from the construction area into corridors and other occupied areas
- Require fans and additional ventilation when potential off-gassing materials are installed
- To the greatest degree possible, plan construction activities after business hours or over weekends, for demolition or installation of materials with potential off-gassing or dust-producing properties. Examples: all dust-producing tear-outs; painting; drywall cutting; mixing and application of adhesives, caulking, and other glues; placement of insulation; asphalt (exterior that is near air intake louvers); poured or broadcast floor finishes; or any material that takes hours or days to cure, set, or dry.

B-3 OCCUPANT HEALTH AND WELLNESS.

B-3.1 Sit-Stand Workstations.

Consider the design of office space for either immediate or future addition of sit-stand workstations for all occupants. Examples:

- Consider systems furniture that allows easy adjustment of work surface height

- Consider overhead cabinet locations, relative to future work surface height changes, or addition of desktop sit-stand equipment
- Work with end users to determine type of furniture to support sit-stand environment.

B-3.2 Promoting Voluntary Physical Activity.

Include discussion and decisions in project charrettes related to how buildings address voluntary physical activity. No two projects will result in the same decisions. Always consider less mobile occupants during the decision process. The following examples are suggestions and do not comprise a complete list of possible solutions:

- Location of common use zones
- Use of under-utilized spaces as common gathering areas
- Visibility of stair locations
- Corridor locations and lengths
- Proximity and configuration of exterior walkways and bicycle commuter facilities, as promoted by UFC 2-100-01 and UFC 3-201-02.

B-3.3 Connection to Nature

Include discussion and decisions in project charrettes related to design for location for plantings. Consider strategies to extend daylighting and exterior views beyond minimum requirements, Examples:

- Low walls to allow penetration of daylighting
- Occupants' ability to have proximity to exterior views
- Locations for planters

B-4 DOMESTIC SOLAR HEATING.

Consider implementation of solar heating for domestic hot water in the 60 to 85 percent range, when determined to be life-cycle cost-effective.

B-5 OTHER SUSTAINABLE PRODUCTS.

Purchase products that meet Federally Recommendations of Specifications, Standards, and Ecolabels for Federal Purchasing; or are on the Federal Green Procurement Compilation.

B-6 TPC.

For applicable projects, the addition of TPC is required (refer to paragraph Sustainable Third-Party Certification (TPC) and Table 1-1.)

B-6.1 Design Submittal.

It is preferred that each project that applies a TPC requires a design review by the TPC at final design submittal, rather than a combined design and construction review (applies to both design-build and design-bid-build.)

B-6.2 TPC Training.

It is highly recommended that all designers and construction managers take online training webinars for third-party certification or validation programs, offered by third-party vendors.

This Page Intentionally Left Blank

APPENDIX C PROJECTS IMPACTING A HISTORIC BUILDING OR DISTRICT

C-1 APPLICABILITY TO SUSTAINABILITY GOALS.

C-1.1 Applicability.

Many buildings listed in or eligible for listing in the National Register of Historic Places are capable of meeting the HPSB Guiding Principles and should work toward compliance. Following the National Historic Preservation Act of 1966 (NHPA) Section 106 implementing regulations, 36 CFR Part 800, will facilitate the consultation needed to meet sustainability goals in proposed construction/rehabilitation/repair projects. This process will also take into account indirect impacts that the project could have on other cultural resources that could trigger project delays.

C-1.2 Building Analysis.

Sustainably rehabilitating historic buildings conserves the invested-cost of energy and materials as well as encouraging the preservation of these resources and cultural landscapes. The design, materials, type of construction, size, shape, site orientation, surrounding landscape and climate all play a role in how buildings perform. Before implementing any energy conservation measures to enhance the sustainability of a historic building, the existing energy-efficient characteristics of the building should be assessed as historic construction methods and materials often maximized natural sources of heating, lighting, and ventilation to respond to local climate conditions.

C-1.3 Consultation.

For DoD’s historic facilities, certain generic sustainable upgrades may not be the most appropriate solution. To avoid later delays, early inclusion of the DoD Service-specific Installation Cultural Resource Manager and the State Historic Preservation Office (SHPO) ensures meeting the Secretary of Interior Professional Standards. Take into consideration the character-defining features of the buildings during the design process. Historic buildings represent a previous long-term investment of resources and energy and as such these buildings were often constructed using methods and materials that maximized natural sources of heating, lighting, and ventilation to respond to local climatic conditions. Work with the Installation Cultural Resource Manager and SHPO to identify these elements of historic buildings that are functional passive design components, or inherently sustainable in nature.

C-1.4 Daylighting.

If windows, skylights and other elements allowing for daylighting are character-defining features on the historic building, discuss options with the Installation Cultural Resource Manager.

If daylighting principles do not cause an adverse effect to the historic facilities, employ them to the fullest extent practicable.

C-1.5 Cistern Use.

The use of cisterns, either sub-grade or above-ground, was a frequently used mechanism for water storage in many historic buildings and structures and may be an appropriate addition when**\1** executing work in an existing building. **/1/**

If a historic cistern is available at the site, reuse the location and equipment, as practical.

C-1.6 Reclaimed/Salvaged Materials.

When repairing or renovating historic buildings, reclamation of salvaged materials must be used instead of procurement of, or repair to, assets to meet current requirements, when timely and economical to do so (DoDI 4715.16 Paragraph 6.1). Monetary value may not be considered a limitation if reclamation will satisfy critical item requirements, or if new procurement/production is impractical. See DoD 4160.21-M Chapter 13 (Reclamation) for more information.

C-1.7 Historical Landscapes.

Consider historic landscapes when planning water efficient landscapes. Refer to UFC 3-201-02.

APPENDIX D GLOSSARY

D-1 ACRONYMS

≥	greater than or equal to
<	less than
AFCEC	Air Force Civil Engineer Center
AFARS	Army Federal Acquisition Regulation Supplement
AFFARS	Air Force Federal Acquisition Regulation Supplement
AHJ	Authority Having Jurisdiction
APF	Appropriated Funding
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASTM	American Society of Testing and Materials
BEAP	Base Exterior Architecture Plan
BSI	Business Systems Integration Directorate (EI&E Office)
CF	Cubic Feet
CFR	Code of Federal Regulations
CONUS	Continental United States
DFARS	Defense Federal Acquisition Regulation Supplement
DOE	Department of Energy
DoD	Department of Defense
DoDI	Department of Defense Instruction
ECA	Energy Compliance Analysis
EEIM	Enterprise Energy Information Management
EISA	Energy Independence and Security Act
EMS	Environmental Management System
EO	Executive Order
EPA	Environmental Protection Agency

EPAct	Energy Policy Act
EPEAT	Electronic Product Environmental Assessment Tool
ERC	Estimated Replacement Cost
FAR	Federal Acquisition Regulation
FEMP	Federal Energy Management Program
GBCI	Green Business Certification Incorporated
GBI	Green Building Initiative
GPF	Gallons per Flush
GSA	General Services Administration
GSF	Gross Square Feet
GSM	Gross Square Meters
HPSB	High Performance Sustainable Building
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
ICC	International Code Council
IECC	International Energy Conservation Code
IESNA	Illuminating Engineering Society of North America
KWh	Kilowatt Hour
LCC	Life-Cycle Cost
LCCA	Life-Cycle Cost Analysis
LCCE	Life-Cycle Cost Effective
LEED	Leadership in Energy and Environmental Design
LPF	Liters per Flush
MIL-STD	Military Standard
MOU	Memorandum of Understanding

NAF	Non-Appropriated Funding
NAVFAC	Naval Facilities Engineering **\1** Systems **/1/** Command
NIST	National Institute of Standards and Technology
NMCARS	Navy Marine Corps Acquisition Regulation Supplement
OCONUS	Outside Continental United States
ODS	Ozone Depleting Substances
OMB	Office of Management and Budget
PL	Public Law
RCRA	Resource Conservation and Recovery Act
RPA	Real Property Accountability
SDHW	Solar Domestic Hot Water
\1 SF	Square Foot **/1/**
SHPO	State Historic Preservation Office
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SNAP	Significant New Alternatives Policy
TPC	Third-Party Certification
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
USGBC	U.S. Green Building Council
US	United States
USACE	U.S. Army Corps of Engineers
USC	U.S. Code
USDA	United States Department of Agriculture
WBDG	Whole Building Design Guide

D-2 DEFINITION OF TERMS

Acquisition: A multidisciplinary process encompassing a variety of functions that involve all facets of life-cycle management, including determination of need, planning; design; construction, lease, or purchase; sustainment, modernization, and disposal of military installations and facilities as well as other goods and services. Acquiring supplies and services is a process governed by Federal, Defense, and service branch specific Acquisition Regulations (FAR, DFARS, and AFFARS, AFARS, or NMCARS) and Public Law (PL). Together there are more than 4,000 documents controlling the acquisition process. The acquisition process depends upon: (1) who the customer is, (2) the source of the item to be acquired, and (3) what type of funds are to be used, Appropriated (APF) or Non-Appropriated (NAF). In general, the Military Construction Program process is funded by Appropriated Funds. However, projects for Non-Appropriated Funds activities (commissaries, bowling centers, etc.) use NAF funds for building construction, upgrades, special equipment, and furnishings. APF funding is used most typically for demolition and environmental work on NAF activity sites. A combination of APF and NAF funds may be used.

Alternative Water Sources: Non-potable water from sources such as harvested rainwater (refer to UFC 3-210-10), treated wastewater, air handler condensate capture, grey water, or reclaimed water. The use of alternative water sources must comply with applicable codes and standards.

Authority Having Jurisdiction (AHJ): The term "Authority Having Jurisdiction" (AHJ) as used in the codes and standards referenced in this UFC means the **\1** Service **/1/** office of responsibility, i.e., U.S. Army, HQ USACE/CECW-CE; U.S. Navy, NAVFACENGCOM HQ Code CHE; U.S. Marine Corps, HQMC Code LFF-1; and U.S. Air Force, AFCEC. The enforcement of the codes and standards as they pertain to facility projects can be delegated to the local **\1** Service **/1/** Office's Chief Engineer's Technical Representative at the discretion of the **\1** Service's **/1/** aforementioned office.

Building: Per UFC 1-300-08, "A roofed and floored facility enclosed by exterior walls and consisting of one or more levels that is suitable for single or multiple functions."

Charrette: An intensive creative work session in which a design team focuses on a particular design problem and arrives at a collaborative solution with stakeholders from the project area. A charrette can be a breakthrough event that helps create a meaningful master plan or facility design. Properly executed, this technique can produce a master plan or facility design that is more useful, better understood, and more quickly produced than one formed by any other method.

Climate Change: Per DoD Directive 4715.21, variations in average weather conditions that persist over multiple decades or longer that encompass increases and decreases in temperature, shifts in precipitation, and changing risk of certain types of severe weather events.

Commercial and Multi-Family High-Rise Residential Buildings: All buildings, other than low-rise residential buildings.

Commissioning: Per DOE Guidance 42 USC 8253(f), “The commissioning process ensures that all of the equipment and systems within a facility are currently operating and functioning properly, and identifies items that need to be fixed or adjusted, typically in a low or no cost fashion.”

\1\ Component: One of the Military Departments, Defense Agencies, or DoD Field Activities, per USD (AT&L) Memorandum dated 29 May 2002.

Comprehensive Replacement: Comprehensive replacement to a building includes significant opportunities for improvement in: energy and water efficiency (such as HVAC, lighting, building envelope and other building components); indoor air quality; other requirements in this UFC; and additions that are part of the comprehensive replacement. **/1/**

DD Form 1391: A programming document used by the Department of Defense to submit requirements and justifications in support of funding requests for military construction to Congress.

Employee Work Areas: Per International Building Code 2015: “All or any portion of a space use by employees and only for work. Corridors, toilet rooms, kitchenettes and break rooms are not employee work areas.”

Energy Compliance Analysis (ECA): The ECA must identify specific energy conservation criteria that applies to the project, the software used to prepare the necessary calculations, a summary of all input to and output from the calculations, and the calculated energy consumption of the proposed design.

Energy Modeling: The process by which conceptual designs, including size; material choices; factors such as site, solar, and wind orientations; daylighting percentages; and energy system choices (solar water heat, underfloor vs. overhead air distribution systems) are analyzed to show how to optimize these factors for efficient building operation and resource consumption.

Energy Resiliency: Per DoDI 4170.11, “The ability to prepare for and recover from energy disruptions that impact mission assurance on military installations.”

Environmental Management System (EMS): A framework that helps to achieve environmental goals through consistent control of operations. The assumption is that this increased control will improve environmental performance.

Environmentally Preferable Products: Products or services having a lesser or reduced effect on human health and the environment when compared with competing products or services serving the same purpose. This comparison may consider raw materials acquisition, production, manufacturing, packaging, distribution, reuse, operation, maintenance, or product or service disposal.

Estimated Replacement Cost (ERC): ERC is the cost listed in the project’s DD1391 “Economic Analysis.” ERC is the cost of replacing the current physical plant with modern facilities built at today’s construction costs using today’s construction standards.

Facility: Per UFC 1-300-08, a building, structure, or linear structure out to an imaginary line surrounding a facility at a distance of five feet from the foundation that, barring specific direction to the contrary such as a utility privatization agreement, denotes what is included in the basic record for the facility (examples: landscaping, sidewalks, utility connections). This imaginary line is commonly referred to as the "five-foot line."

Historic Properties: Properties that are included in the National Register of Historic Places or that meet the criteria for the National Register.

Life-Cycle Costing (LCC): An important economic analysis used in the selection of alternatives that impact both pending and future costs. It compares initial investment options and identifies the cost alternatives for a 40-year period. As applied to building design energy conservations measures, the process is mandated by law and is defined in 10 CFR Part 436, Subpart A: *Methodology and Procedures for Life-Cycle Cost Analysis*. The National Institute of Standards and Technology has established the Building Life-Cycle Cost (BLCC) computer program to perform LCC analyses. The program incorporates user entered data for and compares the following: Sunk Costs, First Costs, Salvage Value, Future Investment, Residual Value, Annually Recurring Fixed Costs, Annually Recurring Escalating Costs, and Energy (Fuel Costs) Escalation Rates.

Life-Cycle Cost Analysis (LCCA): Assessment of the direct, indirect, recurring, nonrecurring, and other related costs incurred or estimated to be incurred in the design, development, production, operation, maintenance, support, and final disposition of a major system over its anticipated useful life span. LCCA considers all costs (capital, operating, and decommissioning expenses for the duration of a project) for various alternative approaches, including inflation and discount rates.

Life-Cycle Cost Effectiveness (LCCE): A documented statement of costs to be incurred to complete all stages of a project from planning through acquisition, maintenance, operation, remediation, disposition, long-term stewardship, and disposal. The results of a LCCA.

Low-Rise Residential Buildings: All buildings three stories or less in height above grade that include sleeping accommodations where the occupants are primarily permanent in nature (30 days or more).

Planning: Initiated by a using entity whose facility needs are driven by mission requirements. The insertion of facility projects into the official budget is based on the requirement for mission support. As mission priorities change, projects can be moved ahead of their initial scheduled fiscal year or alternatively, be dropped altogether.

Process load: The load on a building resulting from energy consumed in support of a manufacturing, industrial, or commercial process. Process loads do not include energy consumed maintaining comfort and amenities for the occupants of the building (including space conditioning for human comfort).

Programming: The data collection process done by the military project management team in order to achieve a conceptual design in enough detail to prepare a viable cost estimate. Programming data is reported on DD Form 1391 for design-bid-build and design-build projects, and is scrutinized from Installation-level through the Office of Management and Budget (OMB), Congress, and signed by the President before it is approved as a project.

Project Definition: As the military programming process often predates actual design by two to five years or more, when the design services portion of a project is funded, the project design team must validate stated project requirements and personnel assignments based upon updated mission criteria. This process is sometimes referred to as Project Definition to distinguish it from the usual private sector A/E reference to "programming."

Project Scope: Refers to the physical size, cost, and mission of a project. With historical data on facilities for various missions, experienced programmers will formulate the conceptual design for the DD Form 1391 based upon the required size of a facility to accommodate mission functions. Once the scope for a project has been enacted by Congress, changing the scope of a project will delay a project until the revision has been justified and approved. This is true whether or not the costs have also changed. Reductions of project scope (by no more than 25%) will require Congressional notification, review, and authorization before proceeding. Increasing the project scope is not authorized without reprogramming. See USC Title 10 Section 2853 for more information.

Real Property Asset: An individual building, structure, linear structure or land parcel, owned by the Department of Defense.

Receptacle Load: The load on a building resulting from energy consumed by all equipment plugged into electrical outlets.

Recommissioning: Per DOE Guidance 42 USC 8253(f), "The process of commissioning a previously commissioned facility or system after expiration of the project development and warranty phase. The primary goal of recommissioning is to optimize facility performance, in accordance with design or operating needs, over the useful life of the facility."

Resiliency: The ability to prepare for and recover from disruptions that impact mission assurance on military installations.

Resource-efficient solutions: Solutions that minimize energy, water, natural, and human resources required.

Retrocommissioning: Per DOE Guidance 42 USC 8253(f), "The retroactive commissioning of equipment or a system that was not commissioned at the time of installation or during the warranty phase. Typically, retrocommissioning is performed long after the facility is constructed and placed into service."

\1\ Service: When used to describe a DoD entity, one of the three Military Departments under the DoD, per USD (AT&L) Memorandum dated 29 May 2002. **/1/**

Stand-Alone Additions: Stand-alone additions are scoped to function like stand-alone new buildings. Although the addition is attached to an existing building, all of its new systems operate separately from the existing building.

Structure: Per UFC 1-300-08, a facility, other than a building or linear structure (road, fence, etc.), that is constructed on or in the land.

Sustainable Site: Based on the selection process, a site is considered sustainable when it uses less energy, water, and natural resources, generates less waste, and minimizes the impact on land compared to conventional design, construction, and maintenance techniques.

\1\ Sustainment, Restoration, and Modernization (SRM): Per the Office of the Assistant Secretary of Defense for Sustainment, Construction:

- Sustainment activities include scheduled and unscheduled inspection, maintenance and repair to ensure facilities remain in good working order throughout their service lives.
- Restoration activities include repair and replacement efforts to renovate facilities damaged by inadequate sustainment, excessive age, natural disaster, fire, accident, or other causes.
- Modernization activities include implementation of new or higher standards; accommodating new functions; or replacing building components that typically last more than 50 years. **/1/**

Third-Party Certification (TPC): TPC is the generic term for a third-party product that provides either certification of the third-party vendor's proprietary product requirements (examples: LEED, Green Globes), or a validation program by the third-party vendor that this UFC's requirements have been met (examples: Guiding Principles Assessment, Guiding Principles Compliance.)

Total Ownership Cost (TOC): Total of all direct and indirect costs associated with an asset or acquisition over its entire life cycle.

Tracking: Method by which each Service internally validates HPSB Guiding Principles compliance, with the use of HPSB Checklist.

\1\/1/

APPENDIX E REFERENCES

(Note: If a web link does not work the first time, close Internet and try again. Also try a different internet platform. This is a persistent issue with Government devices.)

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS (ASHRAE)

http://www.ashrae.org/

NOTE: Include all references Errata, except Errata for Addenda. Include Interpretations, except Interpretations for Addenda. Do not include Addenda.

ANSI/ASHRAE/IESNA Standard 90.1-2013 (ASHRAE 90.1), *Energy Standards for Buildings Except Low Rise Residential Buildings*, 2013

\2 ANSI/ASHRAE/IESNA Standard 90.1-2019 (ASHRAE 90.1), Energy Standards for Buildings Except Low Rise Residential Buildings, 2019 ***/2/***

ENVIRONMENTAL PROTECTION AGENCY

Comprehensive Procurement Guideline (CPG) Program, https://www.epa.gov/smm/comprehensive-procurement-guideline-cpg-program

Energy Independence and Security Act (EISA), 19 December 2007, https://www.epa.gov/laws-regulations/summary-energy-independence-and-security-act

Energy Policy Act of 2005 (EPAct 2005), https://www.epa.gov/laws-regulations/summary-energy-policy-act

ENERGY STAR®, http://www.energystar.gov/Resource Conservation and Recovery Act (RCRA), 21 October 1976, https://www.epa.gov/laws-regulations/summary-resource-conservation-and-recovery-act

WaterSense Program, https://www.epa.gov/watersense

GENERAL SERVICES ADMINISTRATION

Guiding Principles for Sustainable Federal Buildings and Associated Instructions (February 2016), https://sftool.gov/Content/attachments/guiding_principles_for_sustainable_federal_buildings_and_associated_instructions_february_2016.pdf

INTERNATIONAL CODE COUNCIL

https://codes.iccsafe.org/search/

International Energy Conservation Code, 2015

International Green Construction Code, 2018

\2 International Energy Conservation Code, 2021 ***/2/***

MILITARY STANDARDS

MIL-STD-3007G Standard Practice Unified Facilities Criteria, Facilities Criteria And Unified Facilities Guide Specifications, 2019, https://www.wbdg.org/FFC/FEDMIL/milstd3007g.pdf

NATIONAL INSITUTE OF BUILDING SCIENCES, WHOLE BUILDING DESIGN GUIDE

http://www.wbdg.org/

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

https://www.wbdg.org/ffc/nist/criteria

NIST Handbook 135, Life-Cycle Costing Manual for the Federal Energy Management Program

The Annual Supplement to NIST Handbook 135 and SP 709, Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis

SHEET METAL AND AIR CONDITIONING CONTRACTOR'S NATIONAL ASSOCIATION (SMACNA)

https://www.smacna.org/ SMACNA *Indoor Air Quality (IAQ) Guidelines for Occupied Buildings Under Construction*, 2nd Edition, 2008

UNITED STATES CODE

https://www.govinfo.gov/app/collection/uscode

USC Title 10 Section 2853, *ADMINISTRATION OF MILITARY CONSTRUCTION AND MILITARY FAMILY HOUSING – Authorized Cost and Scope of Work Variations*

USC Title 16 Section 106, *National Historic Preservation Act*

UNITED STATES CODE OF FEDERAL REGULATIONS

https://www.govinfo.gov/collection/cfr-index

10 CFR Part 433, *Energy Efficiency Standards for New Federal Commercial and Multi-Family High-Rise Residential Buildings*

10 CFR Part 436, Subpart A: *Methodology and Procedures for Life-Cycle Cost Analysis*

36 CFR Part 800, *Protection of Historic Properties*

UNITED STATES DEPARTMENT OF AGRICULTURE

BIOPREFERRED PROGRAM, HTTP://WWW.BIOPREFERRED.GOV/ UNITED STATES DEPARTMENT OF DEFENSE

http://www.esd.whs.mil/dd/

DoD Directive 4715.21, *Climate Change Adaptation and Resilience*, 14 January 2016

DoD 4160.21-M, *Defense Materiel Disposition Manual*, 28 May 2004

DoDI 4165.14, *Real Property Inventory (RPI) and Forecasting*, 17 January 2014

DoDI 4170.11, *Installation Energy Management*, 31 August 2018

DoDI 4715.16, *Cultural Resources Management*, 18 September 2008

DoD Memo, *Water Use for Landscape Architecture on Department of Defense Installations/Sites*, 10 March 2017

DoD *Utilities Meter Policy*,**\1** 14 January 2021, https://www.acq.osd.mil/eie/Downloads/IE/DoD%20Utilities%20Meter%20Policy%2014%20Jan%202021.pdf **/1/**

Department of Defense *Sustainable Buildings Policy*, 10 November 2013, https://www.denix.osd.mil/sustainability/dodpolicy/unassigned/dod-sustainable-buildings-policy-current-as-of-nov-2013/DoD-Sustainable_Buildings_Policy_-10-Nov-2013.pdf

Memorandum, Department of Defense Supplemental Guidance for Implementing and Operating a Joint Base, April 15, 2008

\1 Office of the Assistant Secretary of Defense for Sustainment, Construction: https://www.acq.osd.mil/eie/FIM/FIM_Program_Areas.html **/1/**

UNITED STATES DEPARTMENT OF DEFENSE, UNIFIED FACILITIES CRITERIA PROGRAM

http://dod.wbdg.org/

UFC 1-200-01, *DoD Building Code*

UFC 1-201-01, *Non-Permanent DoD Facilities in Support of Military Operations*

UFC 1-201-02, *Assessment of Existing Facilities for Use in Military Operations*

UFC 1-202-01, *Host Nation Facilities in Support of Military Operations*

UFC 1-300-08, *Criteria for Transfer and Acceptance of DoD Real Property*

UFC 2-100-01, *Installation Master Planning*

UFC 3-101-01, *Architecture*

UFC 3-201-01, *Civil Engineering*

UFC 3-201-02, *Landscape Architecture*

UFC 3-210-10, *Low Impact Development*

UFC 3-410-01, *Heating, Ventilation, and Air Conditioning Systems*

UFC 3-440-01, *Renewable Energy Systems – Facility*

UFC 3-530-01, *Interior and Exterior Lighting Systems and Controls*

UFC 3-540-08, *Utility-Scale Renewable Energy Systems*

UFC 3-600-01, *Fire Protection Engineering for Facilities*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

UFC 4-510-01, *Design: Military Medical Facilities*

U.S. DEPARTMENT OF ENERGY

Federal Energy Management Program (FEMP), https://energy.gov/eere/femp/federal-energy-management-program

UNITED STATES EXECUTIVE ORDERS

https://www.federalregister.gov/presidential-documents/executive-orders

\2 Executive Order 14057, *On Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability*, 08 December 2021 **/2/**

UFC 1-201-01
4 March 2022
Change 4, 08 August 2023

UNIFIED FACILITIES CRITERIA (UFC)

NON-PERMANENT DOD FACILITIES IN SUPPORT OF MILITARY OPERATIONS

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

NON-PERMANENT DOD FACILITIES IN SUPPORT OF MILITARY OPERATIONS

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	16 May 22	4-4.5.5 Updated language.
2	01 Sep 22	2-2.6.5, 3-4.1, and 4-4.1 Updated language.
3	09 Nov 22	4-3.1.5 Removed list, updated reference.
4	08 Aug 23	3-4.7 through 3-4.7.4 Updated language, and 4-4.7 through 4-4.7.4 updated language.

This UFC supersedes UFC 1-201-01, dated 01 January 2013.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website https://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

PETE G. PEREZ, P.E., SES

Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Systems Command

NANCY J. BALKUS, P.E., SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW
Deputy Assistant Secretary of Defense
(Construction)
Office of the Secretary of Defense

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 1-201-01, *NON-PERMANENT DOD FACILITIES IN SUPPORT OF MILITARY OPERATIONS*

Superseding: UFC 1-201-01 dated 1 January 2013

Description: This UFC provides life safety and habitability-related design requirements for non-permanent facilities designed and constructed for use by the Department of Defense (DoD) in support of military operations.

Reasons for Document:

- This UFC was developed to establish the minimum requirements for the Life Safety and Habitability aspects of non-permanent facilities in support of military operations.

Impact:

- The criteria established in this UFC may result in Doctrine, Organization, Training, Material, Leadership and Education, Personnel, Facilities, and Policy (DOTMLPF-P) impacts across the Services. Services should conduct DOTMLPF-P analysis to determine the impacts on their ability to execute construction in support of military operations.

- Review of standard facility designs for compliance with criteria in this UFC.

Unification Issues

There are no unification issues in this document.

This Page Intentionally Left Blank

TABLE OF CONTENTS

This Page Intentionally Left Blank

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

This UFC was developed in response to US Code Title 10, "Policy and Requirements to Ensure the Safety of Facilities, Infrastructure, and Equipment for Military Operations", cited below for clarity and information.

It shall be the policy of the Department of Defense that facilities, infrastructure, and equipment that are intended for use by military or civilian personnel of the Department in current or future military operations should be inspected for safety and habitability prior to such use, and that such facilities shall be brought into compliance with generally accepted standards for the safety and health of personnel to the maximum extent practicable and consistent with the requirements of military operations and the best interests of the Department of Defense, to minimize the safety and health risk posed to such personnel.

US Code Title 10 requires addressing the following:

- Fire protection
- Structural integrity
- Electrical systems
- Plumbing
- Water treatment
- Waste disposal
- Telecommunications networks

1-2 PURPOSE AND SCOPE.

Consistent with the requirements of Public Law 111-84 Section 807 this UFC establishes the minimum design criteria for the following areas:

- Fire protection
- Structural integrity
- Electrical systems
- Plumbing and mechanical systems
- Water treatment, storage and distribution
- Wastewater collection and treatment
- Telecommunications networks

1-2.2 Exceptions and Exclusions.

The following exceptions and exclusions apply.

1-2.1.1 Ammunition and Explosives Safety.

This document does not contain requirements for explosives safety.

All facilities that involve DoD Ammunition and Explosives (AE) storage, handling, maintenance, manufacture or disposal, as well as any facilities within the Explosives Safety Quantity Distance (ESQD) arcs of AE facilities, must comply with the minimum DoD explosives safety criteria given in DoD Manual 6055.09-M, as implemented in DA PAM 385-64 (Army), NAVSEA OP5 (Navy and Marine Corps), and AFMAN 91-201 (Air Force). DoD facilities exposed to potential explosion effects from AE belonging to other nations are also required to meet DoD and Service explosives safety criteria.

It is essential that the planning and design of new facilities and occupation and renovation of existing AE-related facilities or any facilities within ESQD arcs be accomplished in close coordination with knowledgeable explosives safety professionals in theater or with the Services' explosives safety centers. This coordination should occur as early as possible in the planning/design process to avoid issues/problems and ensure compliance.

All facility construction or use within ESQD arcs requires review for compliance with explosives safety criteria and must have either an approved explosives safety site plan or an approved explosives safety deviation. Refer to the DoD and Service documents mentioned above for further guidance in this area.

1-2.1.2 Antiterrorism / Force Protection.

Expeditionary structure stand-off distances are incorporated from Chapter 4, UFC 4-010-01 DoD Minimum Antiterrorism Standards for Buildings. All other antiterrorism and force protection requirements are excluded for initial and temporary construction. Semi-permanent construction follows the complete requirements of UFC 4-010-01.

The mass notification system must comply with the requirements of UFC 4-010-01 (*DOD Minimum Antiterrorism Requirements for Buildings)* excluding the requirement for remote activation and the requirements of UFC 4-021-01.

1-2.1.3 Accessibility.

Facilities for use in military operations are designed for combat capable, able-bodied personnel. However, special use facilities, such as medical facilities, may employ more stringent requirements IAW (In Acceptance With) "Accessibility" requirements in UFC 1-200-01.

1-2.1.4 Solid Waste Disposal.

Solid waste disposal is addressed in UFC 3-240-11 Landfills In Support Of Military Operations.

The following disposal functions, must comply with the respective chapters from TM 3-34.56, MCIP 4-11.01 Waste Management for Deployed Forces:

- Non-hazardous Solid Waste
- Hazardous and Special Waste
- Medical Waste

Regulated hazardous and medical waste disposal facilities must reference host-nation final governing standards (FGS) or where the FGS does not exist, then the Overseas Environmental Baseline Guidance Document (OEBGD) prevails (DOD 4715.05-G).

1-3 APPLICABILITY.

This UFC applies to all DoD components involved with planning, design, construction and renovation of non-permanent facilities, both new construction and renovations to non-permanent facilities (where the renovation does not convert the facility to permanent), used by US military and DoD civilian personnel in support of Military Operations, actions with written Operation Orders (OPORDS), examples include Kinetic, Disaster Recovery, Humanitarian Assistance, Defense Support to Civil Authorities, etc. See JP 3-0 and JP 3-34 for more complete definition, description and guidance on operations. This UFC establishes the minimum requirements for initial, temporary, and semi-permanent construction levels.

1-3.1 Waivers and exemptions.

Section 807 of Public Law 111-84, "Policy and Requirements to Ensure the Safety of Facilities, Infrastructure, and Equipment for Military Operations" required the Department of Defense to establish minimum design criteria for the safety and health of military or civilian personnel of the Department of Defense.

Waivers are for the facility design to not comply with the requirements of this UFC for a period of time as designated by the approval authority. This time period allows for use of the facility, with mitigating measures in place, while awaiting full compliance. Treat waivers considered for an indefinite period of time as exemptions and follow the exemption approval process. An exemption provides authority to deviate from a UFC requirement indefinitely.

The procedures and requirements for the submission of a waiver are described in MIL-STD 3007, Appendix A. Lack of funds is not considered sufficient justification for a waiver.

In accordance with DFAR Clause 246.270-3, the combatant commander may waive compliance when it is impracticable to comply with such standards under prevailing operational conditions. Any waiver for reasons other than operational conditions must be approved by the appropriate Service Chief Engineer as outlined in MIL-STD- 3007.

1-3.2 Standard Designs

Standard designs are available for the construction of non-permanent facilities. These standard designs accommodate a wide range of site conditions, missions and other parameters. The use of these designs is encouraged when the project requirements can be met by the standard design.

The review of these standard designs should be completed prior to embarking upon the design of a unique non-permanent facility.

Standard Designs are available from the following sources:

- Center of Standardization for Non-Permanent Facilities (US Army Corps of Engineers, CETAM-DP-EX) https://mrsi.dren.army.mil/cos/tam/
- Joint Construction Management System (JCMS) https://jcms.army.mil requires a CAC

1-4 GENERAL BUILDING REQUIREMENTS.

Comply with 1-3.5.1 of UFC 1-200-01, *DoD Building Code*. UFC 1-200-01 provides general building requirements and overarching criteria, establishing the use of consensus building codes and standards, establishing criteria implementation rules and protocols (including core UFC), and identifying unique military criteria.

The requirements of the UFC sections cited in this document are mandatory. Other UFCs may be used as guidance but are not mandatory.

This document must be used in conjunction with Status of Forces Agreements (SOFA), bilateral agreements, and other Host Nation (HN) agreements.

1-4.1 Facility Design.

Facility Design efforts must be performed by Qualified Personnel.

1-4.2 Alterations to Facility Designs.

1-4.2.1 Standard designs for temporary facilities (Chapter 3)

Construction by military personnel - Any modification requires review and approval by qualified personnel in the discipline applicable to the feature being modified

AND

Notification of the designer of record

Construction by contractor personnel - any modifications require approval by the Contracting Officer or the Contracting Officer’s representative.”

AND

Notification of the designer of record

1-4.2.2 Standard designs for Semi-permanent facilities (Chapter 4)

The Designer of Record for a Facility Design must review and approve all alterations, outside of the parameters identified in the design prior to implementation.

1-4.3 Corrosion Protection.

Provide durability and protection from corrosive environments for systems, components, and connections required by this UFC appropriate for the life expectancy of the facility.

Protection and surface finishing will be as indicated in drawings, specifications, and/or contracts as applicable for semi-permanent facilities.

If included, DoDI 5000.67 Prevention and Mitigation of Corrosion on DoD Military Equipment and Infrastructure directs that trade-off decisions include cost, useful service life, and effectiveness.

1-4.4 Alternative Design Approaches.

Alternative design approaches that comply with the criteria in this UFC are encouraged.

1-4.5 Fuel Systems.

Follow approved technical manuals or manufacturer instructions.

1-4.6 Water Treatment, Storage, and Distribution.

Design and operate all potable water (drinking water) facilities and systems to ensure protection of health and safety. Requirements for systems may be addressed in COCOM or coalition guidance or international agreements.

Army, Navy, Marine Corps must comply with the respective chapters from ATP 4-44/MCRP 3-17.7Q Water Support Operations and NTRP 4-04.2.13/FM 3-34.469/AFMAN 32-1072, Water-Well Drilling Operations:

- Water Treatment
- Water Storage, Distribution and Issue

Air Force must comply with the respective chapters from AF TTP 3-32.33 V1.

1-4.7 Structural / Seismic.

Where site specific information is unknown, the following may be considered:

- Occupancy Category II

- Soil Site Class: D
- Mapped Seismic Spectral Response Coefficients: Ss=0.64g / S_1=0.18g

1-4.8 Equipment Used as Facilities.

Equipment (such as tents and prepackaged structures requisitioned through the supply system (*Department of Defense Dictionary of Military and Associated Terms*)), Table of Organizational Equipment, Commercial off the Shelf procurements, Relocatable Buildings, and all DOD program of record solutions will be deployed IAW all relevant manufacture specifications, technical manuals and bulletins, and with regard to the requirements of this UFC

1-4.9 Quality Management.

Combatant/Service Component Commands must establish and maintain a Quality Management (QM) system through the duration of the project life cycle to ensure that facilities comply with the requirements of this UFC.

1-4.10 Facility Data Placards.

Include a data plate on entry doors for all buildings. Data plates must include: year of construction, facility construction level, occupancy type (per basis of design or per NFPA 101 Chapter 6),

Update the data plate when the intended use of the building changes and/or to include building modifications.

See Appendix D for data plate example.

1-4.11 Inspections.

Inspect buildings prior to initial occupancy, at unit transfer, or when reaching buildings initial design life. Inspections must follow UFC 1-201-02 Assessment of Existing Facilities for Use in Military Operations.

1-5 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-6 GLOSSARY.

APPENDIX B-1 contains acronyms.

The authorities for the definition are included where applicable.

1-6.1 Authority Having Jurisdiction/Building Official/Code Official.

The terms above as used in the codes and standards referenced in this UFC are the stated entities as defined in UFC 1-200-01 1-5.

1-6.2 Billeting.

Any building or portion of a building, regardless of population density, in which 11 or more unaccompanied DoD personnel are routinely housed, including Temporary Lodging Facilities and military family housing permanently converted to unaccompanied housing. Billeting also applies to expeditionary structures with similar populations and functions. (UFC 4-010-01).

Billeting does not include sleeping spaces in facilities with 24 hour operations such as HQ, TOCs, JOCs or Air Terminals.

1-6.3 Base Operating Support Integrator (BOS-I).

BOS-I Is responsible for planning and synchronizing the efficient application of resources and contracting to facilitate unity of effort and the coordination of sustainment functions at designated contingency locations (JP 4-0).

1-6.4 Building.

A structure, usually enclosed by walls and a roof, constructed to provide support or shelter for an intended occupancy. Note that other structures, such as canopies, are not considered buildings for the purposes of these standards. (UFC 4-010-01).

1-6.5 Designer of Record

The entity that performed the original design and maintains ownership of the design. This is noted in the title block of the design drawings.

1-6.6 Exemption.

An exemption provides authority to deviate from a UFC requirement indefinitely.

1-6.7 Facility.

A real property entity consisting of one or more of the following: a building, a structure, a utility system, pavement, and underlying land (*Department of Defense Dictionary of Military and Associated Terms*).

1-6.8 Facility Construction Levels.

1-6.8.1 Organic construction level.

Organic construction level is a subset of the Initial construction level.

Intended for use up to 90 days, it may be used for up to six months. See JP 3-34.

1-6.8.2 Initial construction level.

Initial construction level is intended for immediate use by units upon arrival in theater for up to twenty-four months. See JP 3-34.

1-6.8.3 Temporary construction level.

Temporary construction level buildings and facilities are designed and constructed to serve a life expectancy of five years or less. See JP 3-34.

1-6.8.4 Semi-Permanent construction level.

Buildings and facilities designed and constructed to serve a life expectancy of less than 10 years. With maintenance and upkeep of critical building systems, the life expectancy of a facility can be extended to 25 years. See JP 3-34.

1-6.9 Occupancy Type.

The category description of a facility based on the usage.

1-6.10 Qualified Personnel.

A professionally registered technical expert.

1-6.11 Range of Military Operations.

The military instrument of national power can be used in a wide variety of ways that vary in purpose, scale, risk, and combat intensity. These various ways can be understood to occur across a continuum of conflict ranging from peace to war. (JP 1).

1-6.12 Structure Group

A cluster of independent structures, including tents, trailers, containerized housing units, or similar construction typically occupied by 200 or fewer personnel except in the case of the DEPMEDS (Deployable Medical Systems).

1-6.13 Waiver.

A waiver provides authority to deviate from an UFC requirement for no more than twelve months or for a length of time as designated by the approval authority

1-7 REFERENCES.

APPENDIX C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 INITIAL FACILITY CONSTRUCTION LEVEL

2-1 APPLICABILITY.

The Initial Construction Level encompasses two sublevels defined in Joint Publication (JP) 3-34 Joint Engineer Operations:

Organic – intended for use up to 3 months (90 days) which can be extended to a maximum of 6 months (180 days).

Initial – Structures with an expected use not to exceed 24 months (2 years)

Construction requirements for Initial Facility Construction Level rely primarily on manufacturers' instructions provided with Government-approved systems, Service-specific Field Manuals, and Handbooks developed for pre-packaged assemblies and equipment. This Chapter addresses requirements that affect life safety and health of personnel when establishing base operations. Typical to transient mission activities, it may require system upgrades or replacement by more substantial or durable facilities during the course of operations.

2-1.1 Organic Construction Level.

The Organic construction level is a subset of the Initial construction level intended for use up to 90 days, it may be used for up to six months. See JP 3-34.

Organic equipment is a program of record system provided under a unit's table of authorized distribution allowances. Organic Facility construction must follow manufacturers' instructions, Service- specific Manuals and Handbooks developed for pre-packaged assemblies and equipment.

2-1.2 Initial Construction Level.

The Initial construction level is intended for immediate use by units upon arrival in theater for up to twenty-four months. See JP 3-34.

Fabric shelters are Initial construction level facilities.

Container Housing units are Initial level facilities, unless specifically designed to a higher construction level.

2-2 PRIMARY CRITERIA.

The following sections must be used as criteria for organic and initial facility construction. Where conflicts existing between the UFCs, other industry codes and standards, this UFC takes precedence.

For unit organic tentage used in establishing base operations, comply with Sections 2-2.1 thru 2-2.14 of this document.

2-2.1 CIVIL/SITE.

The requirements for site water treatment, storage and distribution, and waste disposal may be included in Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA) and as required by the Military Command having jurisdiction over the operation. The information below is a listing of some, but not necessarily all of those requirements. It is the responsibility of the user to determine which criteria are to be utilized for the operation.

2-2.2 Stormwater.

Locate facilities and equipment away from areas subject to stormwater runoff and flooding. Avoid low lying, tidal, and tributary areas. Consider adjacent facilities or functional areas when planning stormwater runoff control. Control water flow with surface drainage and trenches. When available, place surface laid / shallow buried culverts.

2-2.3 Structural.

Follow manufacturers' instructions for Government-approved systems for assembly of pre-packaged shelters in theater. The authority for Government-approved shelter systems is the Joint Committee on Tactical Shelters (JOCOTAS).

2-2.4 Electrical.

Follow manufacturers' instructions for installation of Government-approved pre-packaged electrical equipment in theater.

If pre-packaged systems are not available:

- Comply with the requirements of UFC 3-550-01, *Exterior Electrical Power Distribution*, Section 3-2, "General Electrical Requirements".
- Comply with the requirements of UFC 3-520-01, Interior Electrical Systems, Section 3-12, "Grounding, Bonding, and Static Protection".
- Comply with UFC 3-550-01, Exterior Electrical Power Distribution, Section 3-14, "Distribution System Grounding".

2-2.4.2 Grounding.

Ground all electrical systems in accordance with manufacturer recommendations.

2-2.4.3 Power Cable Installation.

Surface lay or protect cables from vehicular and foot traffic over power cables where appropriate.

2-2.4.4 Circuit Lockout Requirements.

Follow manufacturers' instructions for installation of Government-approved pre-packaged electrical equipment in theater.

Non-government pre-packaged circuit breakers, disconnect switches, and other devices that are electrical energy isolating must be lockable or protected from unauthorized access.

2-2.5 Plumbing and Mechanical.

2-2.5.1 Water Treatment, Storage, and Distribution.

Design and operate all potable water (drinking water) facilities and systems to ensure protection of health and safety. Requirements for systems may be addressed in COCOM or coalition guidance or international agreements.

Army, Navy, Marine Corps must comply with the respective chapters from ATP 4-44/MCRP 3-17.7Q Water Support Operations and NTRP 4-04.2.13/FM 3-34.469/AFMAN 32-1072, Water-Well Drilling Operations:

- Water Treatment
- Air Force must comply with the respective chapters from AF TTP 3-32.33 V1.

2-2.5.2 Waste Water.

All waste water facilities and systems must be designed and operated to ensure protection of health and safety. Requirements for systems may be addressed in international agreements, COCOM or coalition guidance.

2-2.5.3 Heating, Ventilating and Air-Conditioning (HVAC).

Install ventilation and environmental control systems in accordance with manufacturers' instructions and service technical manuals for pre-packaged heating, ventilating, and air-conditioning (HVAC) systems.

2-2.6 Fire Protection.

The overarching requirement is for Life Safety.

Property Protection is a consideration only if specifically required by the facility owning entity.

Fire protection requirements for Initial Construction Level assume no active fire protection or site water supplies are to be provided.

Provide an alarm initiating device at each exit by either:

a. Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

OR

b. Combined standalone sounder and strobe battery powered push button stations with interconnection capability.

2-2.6.1 Allowable Area / Population.

No more than 200 persons shall be located within a billeting structure group. Occupant loads for this determination must be calculated based on the number of beds.

See UFC 4-010-01 for antiterrorism/force protection requirements related to space separation.

2-2.6.2 Structure Separation.

Where this document uses the term structure group, this is defined as a cluster of independent structures, including tents, trailers, containerized housing units, or similar construction.

Separation of structures within structure groups consisting of fabric structures, containers, trailers, or similar structures must comply with the following:

a. The minimum separation between individual structures within a row of a billeting structure group consisting of fabric structures must be 12 ft (3.7 m).

b. The minimum separation between rows of structures within a billeting structure group must be 30 ft (9.1 m). This distance may be used for vehicle traffic, but must not be used for vehicle parking, storage, or vegetation other than a lawn.

c. The minimum separation between billeting structure groups must be 59 ft (18 m). The separation distance may be used for vehicle traffic (including emergency response vehicles), but must not be used for vehicle parking, storage or vegetation other than a lawn.

d. The minimum separation between billeting structure groups and other structures must be 100 ft (30.5 m). The separation distance may be used for vehicle traffic (including emergency response vehicles), but must not be used for vehicle parking, storage or vegetation other than a lawn.

2-2.6.3 Use of Revetments.

See UFC 4-010-01 for a diagram of the space separation requirements. If the space separations between individual structures given above cannot be achieved due to existing site constraints, then revetments may be used to reduce allowable separation distances between structures. Revetments may consist of engineered hardened walls, concrete barriers, HESCO type barriers, or similar separating barriers. Revetments adjacent to tents or other structures must be at least as tall as the height of the tent wall, or the lower eave of the building. In the event revetments are provided, adjacent structures need to be separated as stated in UFC 4-010-01.

2-2.6.4 Fire Safety Analysis for Constrained Sites

If site constraints do not permit compliance with the above space separation requirements, a fire-safety analysis must be done. This evaluation must be performed or reviewed by the Unit Safety Officer and this analysis must be approved by the first O-6 level officer in the chain of command.

2-2.6.5 Interior Finishes / Fabric Coverings

Fabric coverings for tents or membrane structures must be in accordance with NFPA 701 requirements. Typically, compliance with NFPA 701 is achieved using fire retardant chemically treated fabrics.

Other structures must comply with NFPA 101 requirements. Compliance with NFPA 101 can be achieved using painted or unpainted finishes of concrete masonry units, gypsum wallboard, sheet metal, or 3/8-inch (9.5 mm) plywood. Fabric covering or textile coverings must be fire retardant as established by the manufacturer through testing in accordance with NFPA requirements.

Use or installation of exposed Urethane foam or other exposed plastic insulations on walls or ceilings is not allowed. **\2** Use of pre-insulated panels (with any surface – metal, wood, plastic or other) containing foam insulation is not allowed. **/2/**

2-2.6.6 Fire Extinguishers.

All facilities must be provided with listed portable fire extinguishers consistent with the occupancy of the facility (see NFPA 10, Standard for Portable Fire Extinguishers). If traditional listed/approved extinguishers are not available, the use of extinguishers with equivalent rating from EU, Asian, or other countries is permitted.

2-2.7 Telecommunications.

- Army requirements are contained in FM 4-20.07, paragraphs 2-79 and 4-25.
- Air Force requirements are in AFH 10-222, Volume 1, Table 2.8, and Attachment 6.
- Navy/Marine Corps must follow assembly instructions for installation of pre-packaged equipment in theater.
- If pre-packaged systems are not available and when fabricating a grounding system from components:
- Follow UFC 3-580-01, *Telecommunications Interior Infrastructure Planning and Design*, Section 2-9, “Grounding, Bonding and Static Protection”.

- Follow UFC 3-580-01, Appendix A, Item 19: TIA-J-STD-607-B, *Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises*.
- Follow UFC 3-580-01, Appendix A, Item 23: MIL-STD-188-124B, *Grounding, Bonding And Shielding for Common Long Haul/Tactical Communication Systems Including Ground Based Communications-Electronics Facilities and Equipments*.
- Follow UFC 3-580-01, Appendix A, Item 24: MIL-HDBK-419A, *Grounding, Bonding, and Shielding For Electronic Equipments and Facilities*.

2-2.8 Cybersecurity.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

CHAPTER 3 TEMPORARY FACILITY CONSTRUCTION LEVEL

3-1 APPLICABILITY.

The Temporary Facility Construction level applies to structures with an expected use not to exceed 60 months (5 years) and a design life up to 60 months (5 years).

3-2 CIVIL.

The requirements for site water treatment, storage and distribution, and waste disposal may be included in Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA) and as required by the Military Command having jurisdiction over the operation. The information below is a listing of some, but not necessarily all of those requirements. It is the responsibility of the service component engineer staff to determine which criteria are to be utilized for the operation.

3-2.1 Potable Water Supply Source Selection and Testing.

Use TB MED 577, Sanitary Control and Surveillance of Field Water Supplies, Chapter 5 “Water Source Selection and Basic Testing for Potability”, Chapter 6 “Advanced Water Surveillance and Testing”, Chapter 7 “Evaluation of Field Tests and Analytical Results (Health Guidelines)” for water supply source selection and testing. Use UFC 3-230-03A, Water Supply, Chapter 5, “Groundwater Supplies” for construction of wells for groundwater supplies.

3-2.2 Potable Water Treatment and Disinfection.

All drinking water facilities and systems must be designed and operated to ensure protection of personnel health and safety. The environmental annex (i.e., Annex L) of the applicable CCMD OPLAN/OPORD must be reviewed and updated as required to ensure appropriate force health protection standards for drinking water are included. Additional criteria may be applied in accordance with COCOM guidance, any applicable DoD policies, or international agreements. Facilities must also comply with TB MED 577, Chapter 9 Water Treatment and Disinfection, for potable water treatment and disinfection.

3-2.3 Gray Water Collection and Disposal.

Use Army FM 4-20.07, Chapter 2, Section I, “Gray Water Collection and Disposal”; Army FM 4-20.07, Chapter 3, Section II, “Gray Water Collection Subsystem”; AFH 10-222, Volume 4, Section 2.8, “Wastewater”; and AFH 10-222, Volume 4, Section 3.4.1, “Gray Water”.

3-2.4 Black Water Collection and Disposal.

Use Army FM 4-20.07, Chapter 2, Section I, “Black Water Disposal”; AFH 10-222, Volume 4, Section 2.8, “Wastewater”; and AFH 10-222, Volume 4, Section 3.4.2, “Black Water”.

3-2.5 Stormwater.

Locate facilities and equipment away from areas subject to stormwater runoff and flooding.

3-2.6 Design Documentation

3-2.6.1 Civil Submittals

Drawings: Site plan showing location of water source supply, sanitary sewer facilities, solid waste disposal areas, and all other facilities critical to life safety and health.

Calculations: Showing compliance with potable water testing requirements contained in referenced standards.

3-3 STRUCTURAL SYSTEMS.

3-3.1 Structural Design.

Structural Design must be in accordance with the International Building Code (IBC), Chapters 16, 17, 18, 19, 20, 21, 22, and 23 as modified by the Unified Facilities Criteria 3-301-01 Structural Engineering, except as modified herein.

3-3.1.1 Serviceability [Supplement].

Frame drift discussed in UFC 3-301-01 Section 2-1.2.1 need not be limited to prevent damage to non-structural elements provided any damage sustained does not create unsafe conditions for personnel in or around the structure.

3-3.1.2 Deflections [Replacement].

Modify UFC 3-301-01 Sections 2-1.2.2 and 2-1.2.3 as follows: Deflections of structural members may exceed the limitations of IBC Sections 1604.3.2 through 1604.3.5, Table 1604.3, and Table 2-1 of UFC 3-301-01 provided: (1) The increased deflection does not cause excessive rotations in connections at ends of members that could result in connection failure or, (2) The increased deflection does not create an unsafe condition where finishes or other non-structural items could become dislodged and fall on personnel. Under no circumstances are member deflections to exceed L/120 where L is the member span in inches. Members supporting mission critical equipment sensitive to excessive member deflection or vibration must be designed to meet equipment requirements.

3-3.1.3 Live Loads [Supplement].

It is not permissible to design structures for live loads less than those shown in UFC 3-301-01 Table D-1 or IBC Table 1607.1. Additionally, the minimum design uniform floor live load is 50 psf (245 kg/m^2), even if the occupancy classification for these codes allows a lower value. Similarly, for site specific designs, the minimum design uniform roof live load is 20 psf (98 kg/m^2), even if the location map allows a lower value.

Live load reductions are not permissible.

Dead Load shall be computed from material weights and partitions, safes, equipment, etc.

3-3.1.4 Wind Loads [Supplement].

It is permissible to multiply the basic wind speed, V, as identified in UFC 3-301-01, by a reduction factor of 0.78 for structures that meet the definition of temporary construction except in regions defined as Hurricane Prone Regions.

Site Specific:

- Values in UFC 1-301-01 section 1609.1.1.

Unrestricted:

With a minimum of:

- Basic wind speed (3-sec gust) 95 mph (153 km/hr)
- Exposure category C
- Importance factor I_w = 1.0

3-3.1.5 Earthquake Loads [Supplement].

For structures that meet the definition of temporary construction, it is permissible to multiply design loads calculated per the above referenced code sections by a reduction factor of 0.6 for structures that meet the following requirements:

1. For Risk Category I, II, or III structures, Ss does not exceed 0.55 and S_1 does not exceed 0.13.
2. For Risk Category IV structures, Ss does not exceed 0.32 and S_1 does not exceed 0.08.

Site Specific:

- Within the United States use IBC Section 1613
- Outside the United States use IBC Section 1613

Unrestricted:

- Within the United States use IBC Section 1613
- Outside the United States use IBC Section 1613

With a minimum of:

- For Risk category I, II, III or IV structures,
- Short period acceleration S_s = 0.55g
- One second acceleration S_1 = 0.13g
- Site class (assumed) D
- Importance factor I_e = 1.0

3-3.1.6 Structural Test and Special Inspections [Revision].

Delete IBC Chapter 17 Structural Tests and Special Inspections. The DOR must delineate all testing and inspection requirements in the construction drawings or specifications to ensure performance of the structural system. The DOR is responsible to provide an appropriate design in which the testing and inspection requirements specified in IBC Sections 1713, 1714, and 1715 can be met based on field capability and resources. Testing and inspections should include, but not be limited to, the following:

The UFC indicates the DOR must specify, however does not indicate limits of QC, nor any QA for the manufacturing process.

1. All Materials: Inspection of suitable sub-surface conditions. Visual inspection of member sizes, locations, spacing, and configuration. Visual inspection of splice/cold joint locations, connections, and adequate bearing.
2. Wood structures: In addition to the inspections for All Materials also perform visual inspection of connector (e.g. nails, screws, bolts) sizes, spacing and locations. Visual inspection of size and location of plate connections. Visual inspection of all straps, hold downs, and connection hardware. Visual inspection of overlapping lengths at splices. Visual inspection of member material grades. Visual inspection of sheathing thickness, sheathing material grades, shear wall locations, and cross bracing.
3. Masonry: In addition to the inspections for All Materials also perform visual inspection of grout placement. Visual inspection of reinforcing steel sizes, locations, clearances, configuration, embedment, and splice lengths. Grout cylinder compression tests, CMU compression tests, and verification of mortar and grout proportions.
4. Steel: In addition to the inspections for All Materials also perform visual inspection of deck profiles, diaphragm sizes and locations, and diaphragm connections. Visual inspection of completed welds. Visual inspection of connector (e.g. bolts, screws) number and patterns, and connector sizes. Inspection confirming proper tightening of the nuts. Visual inspection of cross bracing.

5. Concrete: In addition to the inspections for All Materials also perform visual inspection of formwork. Visual inspection of reinforcing steel sizes, locations, clearances, configuration, embedment, and splice lengths. Concrete anchors and embed sizes and locations. Concrete cylinder compression test, and water/cement ratio measurement.

3-3.1.7 Geotechnical Investigations, General [Supplement].

Add exception: The DOR or qualified DoD personnel must accept simplified geotechnical investigations in lieu of the full requirements of sections 1803.3 through for one-story, simple span structures without basements that bear on shallow foundations and meet the following requirements:

1. For Risk Category I, II, or III structures, Ss does not exceed 0.55 and S_1 does not exceed 0.13.
2. For Risk Category IV structures, Ss does not exceed 0.55 and S_1 does not exceed 0.13.

In the absence of a Geotechnical Report, the DOR must design foundations for presumptive bearing capacities per IBC Section 1806.

3-3.1.8 Reporting [Supplement].

The DOR must stipulate the required items, if any, to be included in a written report of the geotechnical investigations, which need not include any or all of IBC Section 1803.6, items 1 through 10.

3-3.1.9 Permanent Wood Foundation Systems [Supplement].

Delete preservative treatment requirements except in regions with a known significant risk of destructive insect infestations.

3-3.1.10 Foundations [Supplement].

Modify second sentence to read, “Deflection and racking of the supported structure must be limited to that which will not compromise the strength or stability of the structure.”

3-3.1.11 Frost Protection [Supplement].

Add exception: One-story, simple span structures that bear on shallow foundations need not be protected.

3-3.1.12 Timber Footings [Supplement].

Delete preservative treatment requirements except in regions with a known significant risk of destructive insect infestations.

3-3.1.13 Durability Requirements [Delete].

Delete IBC Section 1904.

3-3.1.14 Corrosive Environments [Delete].

Delete UFC 3-301-01 and IBC Section 1907.7.6.

3-3.1.15 Protection [Delete].

Delete IBC Section 2203.2.

3-3.1.16 Bolting [Delete].

Delete UFC 3-301-01.

3-3.1.17 General [Supplement].

Delete UFC 3-301-01. Members supporting mission critical equipment sensitive to excessive vibration must be designed to meet equipment requirements.

3-3.1.18 Steel Structures in Corrosive Environments [Supplement].

Delete UFC 3-301-01 except for steel sections with elements thinner than 3/8”.

3-3.1.19 Floor Vibrations [Supplement].

Delete UFC 3-301-01. Members supporting mission critical equipment sensitive to excessive vibration must be designed to meet equipment requirements.

3-3.1.20 Protection Against Decay and Termites [Delete].

Delete UFC 3-301-01 section except in regions with a known significant risk of destructive insect infestations.

3-3.2 Design Documentation

Provide as a minimum:

- Drawings:
  - General Notes
  - Inspection Requirements
  - Foundation Plans
  - Framing Plans, all levels

- Roof Framing Plans
- Details
- Schedules as required (footings, columns, beams, shear walls)

- Calculations:
  - Basis of Design; summary of applicable codes, live loading, snow loading, wind and seismic loads, and dead load assumptions Gravity design; design of floor and roof framing members - beams, slabs, joists, decks, composite slabs, etc.
  - Column and bearing wall design
  - Foundation design
  - Lateral design; design of diaphragms and collectors, distribution of loads to lateral forces resisting elements (frames, walls), design of shear walls, moment frames, and braced frames, design of foundations at lateral force resisting elements, design of hold downs, straps, etc.
  - Design for AT/FP; confirm setbacks, wall construction types, and progressive collapse mitigation design requirements, check window designs, jambs and sills for AT/FP window loading requirements

- Additional Requirements:
  - Load combinations used
  - Materials used with properties and section properties
  - Connection design and details – bolted and welded
  - Wind load analysis applied to structure
  - Seismic load analysis
  - Serviceability check (deflections and overturning)
  - Wall panel design (building envelope) and connection to superstructure
  - Stated structure life-span
  - Erection plan(s)

3-4 FIRE PROTECTION.

The overarching requirement is for Life Safety.

Property Protection is a consideration only if specifically required by the facility owning entity.

The intent of this document is to provide buildings that are limited in size (overall building height and floor area) so as to not require installed active fire protection or fire alarm systems, except where explicitly required by the criteria of an allowable occupancy in this UFC.

Any installed fire alarm system shall be a local alarm only and shall not require visual appliances (strobes), unless specifically required by the facility owning entity.

An acceptable alternate local alarm system:

- Consisting of an alarm initiating device at each exit by either:
  - Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

    OR

  - Combined standalone sounder and strobe battery powered push button stations with interconnection capability.

3-4.1 General requirements

Use of Spray Plastic Foam Insulation (SPFI) is not allowed. **\2** Use of pre-insulated panels (with any surface – metal, wood, plastic or other) containing foam insulation is not allowed. **/2/**

3-4.1.1 Mission Critical Facilities

For mission critical facilities, see Figure E-1 in Appendix E for a decision tree with guidance on protection of assets for these facilities.

3-4.1.2 Antiterrorism Separation Distance

Refer to UFC 4-010-01 for antiterrorism/force protection requirements related to space separation compliance.

For all buildings, provide access to at least one side of any building for the largest emergency response vehicle serving the site.

3-4.1.3 Unenclosed Vertical Openings

Unenclosed vertical openings are generally not permitted. Vertical openings include but are not limited to atriums, stairways; hoist ways for elevators, dumbwaiters, or inclined and vertical conveyors (escalators); shafts used for light, ventilation or building services.

Mezzanines shall comply with requirements for mezzanines herein and in IBC Chapter 5, General Building Heights and Areas, and are not treated as vertical openings.

All vertical openings shall be enclosed or protected with shafts constructed as fire barriers as called for by the IBC Chapter 7, Fire and Smoke Protection Features, or NFPA 101 Chapters 7, Means of Egress, and 8, Features of Fire Protection, for the fire resistance rating of the barrier.

Any planned unenclosed vertical opening needs to be approved by the AHJ.

3-4.2 Construction Level and Space Separation Requirements per Occupancy.

Classifications of buildings within this section are based on occupancy. As defined by NFPA 101, Chapter 3, Definitions, the occupancy is the purpose for which a building or other structure, or part thereof, is used or intended to be used. The occupant load of these areas is calculated per NFPA 101, Chapter 7, Means of Egress.

3-4.2.1 Fire Separation Distance

This document provides requirements for allowable fire separations between structures by occupancy classification.

3-4.2.2 Area Limits

Area limits stated within this UFC are for a stand-alone building as defined in the IBC Chapter 5, General Building Heights and Areas. If larger building areas than stated herein are needed to meet the needs of users, then the following guidance is provided to facilitate the construction of buildings with larger areas, in order of preference:

1. Provide fire separation distance between separate structures in accordance with IBC Chapter 6, Types of Construction, requirements for fire separation between buildings.
2. Provide pedestrian walkways between buildings individually compliant with IBC Chapter 31, Special Construction, fire separation requirements to provide separate buildings interconnected with enclosed, conditioned walkways.
3. Provide fire rated exterior walls or fire walls between buildings in accordance with IBC Chapter 6, Types of Construction, requirements.

4. Provide buildings of an area or height to require fixed fire protection systems in accordance with IBC Chapter 5, General Building Heights and Areas requirements, and provide these fixed protection systems.

3-4.3 Assembly Occupancy

Assembly occupancy is an occupancy used for a gathering of 50 or more persons for deliberation, worship, entertainment, eating, drinking, amusement, awaiting transportation or similar uses; or used as a special amusement building, regardless of occupant load. Assembly occupancies include but are not limited to: dining facilities, clubs, chapels, conference rooms, and morale welfare, and fitness centers for general personnel use.

3-4.3.1 Building Construction.

Buildings must be constructed in accordance with one of the following options (a or b):

a. Buildings must be limited to one story high.

    i. Buildings constructed of combustible construction must be limited to 6,000 sq. ft. (557 sq. m.) in area.

    ii. Buildings constructed of non-combustible or fire-resistive construction must be limited to 9,500 sq. ft. (883 sq. m.) in area.

b. Buildings must be provided with a sprinkler system designed in accordance with the fire sprinkler requirements of this document. Buildings provided with this protection must be constructed in accordance with IBC Chapter 5, General Building Heights and Areas, limits on building areas. Building height must be limited to 2 stories.

3-4.3.2 Building Separation.

Buildings must be separated from other buildings by one of the following options (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings. The clear space may be used for vehicle roadways or pedestrian walkways, but not for parking, storage or vegetation other than lawns.

b. If fire separation distances as noted in Option (a) cannot be provided due to site constraints, one of the following must be provided:

    i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, requirements.

ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other similar type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Adjacent buildings must be separated by at least twice the height of the taller building.

3-4.3.3 Egress Requirements.

Comply with NFPA 101, Chapters 7, Means of Egress, and 12, New Assembly Occupancies, for egress, except as follows:

a. For buildings without sprinkler protection in accordance with this document, provide exits 100% above the number required by NFPA 101, Chapters 7, Means of Egress, and 12, New Assembly Occupancies. Exits must be evenly distributed along at least three sides of the building.

3-4.3.4 Fire Alarm System

Provide local fire alarm notification throughout the space for evacuation in the event of an emergency. The fire alarm notification system must be activated by manual stations at each exit. The fire alarm notification system may be integrated with the mass notification system for the building. Fire alarm systems must comply with NFPA 72 requirements.

3-4.3.5 Kitchen Requirements.

Provide an exhaust hood with a listed kitchen hood fire protection system for any commercial-type cooking operation.

Provide one-hour rated fire barrier separation between any cooking/serving operations and the seating area(s).

3-4.4 Business Occupancy.

Business occupancy is an occupancy used for the transaction of business other than mercantile. Business occupancies include the following: general offices and administrative facilities, outpatient clinics, doctors' offices, detention facilities, and fitness centers that are located within an office, solely for office personnel use (no public or common use).

Business Occupancy can include sleeping spaces in facilities with 24 hour operations such as HQ, TOCs, JOCs or Air Terminals.

3-4.4.1 Building Construction.

Buildings must be constructed in accordance with one of the following options (a or b):

a. Buildings must be limited to 3 stories above grade.

   i. Buildings constructed of combustible construction must be limited to 9,000 sq. ft. (836 sq. m.) per floor.

   ii. Buildings constructed of non-combustible or fire-resistive construction must be limited to 23,000 sq. ft. (2,137 sq. m.) per floor.

b. Buildings must be provided with a sprinkler system designed in accordance with the fire sprinkler requirements of this document. Buildings provided with this protection must be constructed in accordance with 2009 IBC Chapter 5, General Building Heights and Areas, limits on floor areas. Building height must be limited to 3 stories.

3-4.4.2 Building Separation.

Buildings must be separated from other buildings by one of the following (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings within the same contingency compound. A clear space of 100 ft. (30.5 m) must be provided between the building and other buildings not associated with the contingency compound. Clear space must not be used for vehicle parking, storage, or vegetation other than lawns.

b. If fire separation distances as noted in Option (a) cannot be provided, one of the following must be provided:

   i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, requirements.

   ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other similar type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Buildings must be separated by at least twice the height of the taller building.

Comply with NFPA 101, Chapters 7 and 38, for egress except that all exits, including grade level exit doors, exit stairs, and fire-rated exit passageways must discharge directly to the exterior to public ways.

3-4.4.3 Fire Alarm System.

Provide local fire alarm notification throughout the space where any of the following conditions occur:

a. Levels of the building located on other than grade level exceed 5,000 sq. ft. (465 sq. m.) per floor.

b. The total area of all floors exceeds 30,000 sq. ft. (2,787 sq. m.).

The notification system must be activated at each exit by either:

- Manual pull stations

  OR

- Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

  OR

- Combined standalone sounder and strobe battery powered push button stations.

The fire alarm notification system may be integrated with the mass notification system for the building. Fire alarm systems must comply with the installation requirements of NFPA 72.

3-4.4.4 Detention Facilities.

Detention Facilities are classified as Business Occupancy with special population requirements. Detention facilities are those buildings and structures where persons are under restraint or where security is closely supervised and are not capable of self-preservation because the conditions of confinement are not under their control (i.e. they require assistance by the facility's staff to reach safety in an emergency situation). For occupancy classification purposes the population refers only to the number of persons being secured or restrained. The number of guests or staff is not counted.

3-4.4.4.1 Detention Facilities Allowable Population.

The allowable population of a detention facility, building or structure is no more than five (5) persons who are under restraint or security.

3-4.4.4.2 Detention Facilities Fire Separation Distance.

Buildings must be separated from other buildings by one of the following (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings within the same contingency compound. A clear space of 100 ft. (30.5 m) must be provided between the building and other buildings not associated with the contingency compound. Clear space must not be used for vehicle parking, storage, or vegetation other than lawns.

b. If fire separation distances as noted in Option (a) cannot be provided, one of the following must be provided:

i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, requirements.

ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other similar type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Buildings must be separated by at least twice the height of the taller building.

3-4.4.5 Fire Alarm System

The fire alarm notification system must be activated at each exit by either:

a. Manual pull stations

OR

b. Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

OR

c. Combined standalone sounder and strobe battery powered push button stations

The fire alarm notification system may be integrated with the mass notification system for the building. Fire alarm systems must comply with the installation requirements of NFPA 72.

3-4.5 Industrial Occupancy.

A factory-industrial occupancy is an occupancy in which products are manufactured or in which processing, assembling, mixing, packaging, finishing, decorating, or repair operations are conducted. This occupancy includes factories, laundries, power plants, maintenance shops, and pumping stations.

3-4.5.1 Building Construction.

Buildings must be constructed in accordance with one of the following options (a or b):

a. Buildings constructed of combustible construction must be limited to 8,500 sq. ft (790 sq. m.) and one story above grade.

b. Buildings constructed of non-combustible or fire-resistive construction must be limited to 15,500 sq. ft. (1,440 sq. m.) per floor and two stories above grade.

c. Buildings must be provided with a sprinkler system designed in accordance with NFPA 13. Buildings provided with this protection must be constructed in accordance with IBC Chapter 5, General Building Heights and Areas, requirements for floor areas and heights.

3-4.5.2 Building Separation.

Buildings must be provided fire separation from other buildings by one of the following (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings. Clear space must not be used for vehicle parking, storage, or vegetation other than lawns.

b. If fire separation distance as noted in Option (a) cannot be provided, one of the following must be provided:

   i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC requirements.

   ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other approved type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Fire separation distance between these buildings must be at least twice the height of the taller building.

3-4.5.3 Fire Alarm System

The fire alarm notification system must be activated at each exit by either:

a. Manual pull stations

   OR

b. Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

   OR

c. Combined standalone sounder and strobe battery powered push button stations

The fire alarm notification system may be integrated with the mass notification system for the building. Fire alarm systems must comply with the installation requirements of NFPA 72.

3-4.5.4 Egress Requirements.

Comply with NFPA 101, Chapters 7, Means of Egress, and 40, Industrial Occupancies, for egress in accordance with one of the following options (a or b):

a. Provide a minimum of two means of egress from every story or section, and not less than one exit shall be reached without traversing another story

OR

b. Provide a single means of egress from any story or section in low and ordinary hazard industrial occupancies, provided that the exit can be reached within the distance permitted as a common path of travel.

3-4.5.5 Mezzanines.

Mezzanines within industrial buildings cannot be used for normally occupied spaces (such as offices). Mezzanines must be limited to storage rooms and/or mechanical/electrical rooms only.

3-4.5.6 Fire Alarm System.

Provide local fire alarm notification throughout the space where a floor area more than 7500 sq. ft. (697 sq. m.) is located above or below grade, or if the total building area of all floors exceeds 30,000 sq. ft. (2,787 sq. m.). The fire alarm notification system must be activated by manual stations at each exit. The fire alarm notification system may be integrated with the mass notification system for the building. Fire alarm systems must be installed in accordance with NFPA 72.

3-4.5.7 Hazardous Areas.

Hazardous areas such as flammable painting operations, combustible dust producing operations, areas with combustible hydraulic fluid systems over 100 gallons (379 liters), or other industrial operations with significant flammable liquid or gas storage and/or use must be protected by one of the following (a or b):

a. Provided protection in accordance with NFPA 13, 30, and 101 requirements.

b. These areas must be located in buildings with a minimum 100 ft (30.5 m) fire separation distance from adjacent buildings.

3-4.6 Residential Occupancy.

The residential occupancy is defined as an occupancy that provides sleeping accommodations for purposes other than health care or detention and correctional. Residential occupancies include one- and two-family dwellings, dormitories, barracks, billeting, Bachelor Enlisted Quarters and Bachelor Officer’s Quarters, apartment buildings, relocatable buildings and converted shipping containers.

Residential Occupancy does not include sleeping spaces in facilities with 24 hour operations such as Headquarters (HQs), Tactical Operations Center (TOCs), Joint Operation Centers (JOCs), Air Terminals or any other facility with 24 hour operations.

3-4.6.1 Building Construction.

Buildings must be constructed in accordance with one of the following requirements (a or b):

a. Buildings constructed of combustible construction must be limited to 7,000 sq. ft. (650 sq. m.) per floor, and 2 stories in height.

   i. Buildings constructed of non-combustible construction must be limited to 15,000 sq. ft. (1,394 sq. m.) per floor, and 4 stories in height.

b. Buildings must be provided with a sprinkler system designed in accordance with NFPA 13R and the fire sprinkler requirements of this document. Buildings provided with this protection must be constructed in accordance with IBC Chapter 5, General Building Heights and Areas, requirements for floor areas. Building heights must be limited to 4 stories.

3-4.6.2 Building Separation.

Buildings must be separated from other buildings by one of the following (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings. Clear space must not be used for vehicle parking, storage, or vegetation other than lawns.

b. If fire separation distances as noted in Option (a) cannot be provided due to site constraints, one of the following must be provided (i, ii or iii):

   i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, requirements.

   ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other similar type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Fire separation distance must be at least twice the height of the taller building.

   iii. The residential building must be provided with sprinkler protection by a system designed in accordance with NFPA 13R and the fire sprinkler requirements of this document.

3-4.6.3 Fire/Smoke Alarms.

Multiple station type smoke alarms must be provided throughout each room of the living quarters. Actuation of any smoke alarm must cause all smoke alarms within the living unit to generate an audible signal.

A manual fire alarm system must be provided throughout each building, with notification appliances provided in each living unit.

The fire alarm notification system must be activated at each exit by either:

a. Manual pull stations

OR

b. Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

OR

c. Combined standalone sounder and strobe battery powered push button stations

3-4.6.4 Range-Top Extinguishing Systems.

For all living units with residential range-top cooking units, an approved residential range-top extinguishing system must be provided. Actuation of the residential range-top extinguishing system must cause a general building alarm, and automatically shut off all sources of fuel and electrical power to the cooking unit.

3-4.6.5 Egress Requirements.

Comply with NFPA 101, Chapters 7, Means of Egress, and 28, New Hotels and Dormitories, for egress, except as modified below:

Means of egress from sleeping rooms must be provided in accordance with one of the following (a or b):

a. A secondary means of escape must be provided, consisting of a door or window readily operable from inside with no special tools or knowledge. The window must be sized at a minimum of 5.7 sq. ft, (0.53 sq. m.) with a width of at least 20 inches (508 mm) and an open height of at least 24 inches (610 mm). The secondary means of escape must be located on a different exterior wall than the main entrance door to the sleeping room.

b. For sleeping rooms where it is not practical to provide a secondary means of escape as noted in (a), the following must be provided (i and ii):

   i. Walls between sleeping rooms must be rated at a minimum of 30 minutes.

ii. Sprinkler protection must be provided throughout the building installed in accordance with NFPA 13R or NFPA 13D requirements.

3-4.7 \4\ Storage.

Storage occupancy is an occupancy used primarily for the storage or sheltering of goods, merchandise, products, or vehicles. Storage occupancies include barns, cold storage, freight terminals, parking structures, truck and marine terminals, and warehouses. See section 3-4.9 of this document for requirements of fuel and hazardous materials storage areas.

3-4.7.1 Building Construction.

Buildings must be constructed in accordance with one of the following requirements (a, b, or c):

a. Buildings of combustible construction must be limited to 9,000 sq. ft. (836 sq. m.) in area and one story. Storage heights must be limited to 12 ft. (3.66 m) maximum.

b. Buildings of noncombustible or fire resistive construction must be limited to 17,500 sq. ft. (1,626 m.) and one story. Storage heights must be limited to 12 ft. (3.66 m) maximum.

c. Sized based on IBC Chapter 5, General Building Heights and Areas, and provided with sprinkler protection in accordance with UFC 3-600-01 and NFPA 13 requirements.

3-4.7.2 Building Separation.

Storage buildings must be provided with fire separation distance from surrounding buildings by one of the following options (a or b):

a. Fire separation distance of at least 60 feet (18.3 m) from any adjacent building must be provided.

b. Exterior walls must be rated at two hours or more, in accordance with IBC Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, with 1-1/2 hour opening protectives provided for all openings on building sides where fire separation is less than 60 feet (18.3 m).

3-4.7.3 Egress Requirements.

Comply with NFPA 101, Chapters 7, Means of Egress, and 42, Storage Occupancies, for egress.

3-4.7.4 Mezzanines.

Mezzanines cannot be used for occupied spaces (such as offices). Any mezzanines can only be used for storage or mechanical/electrical equipment. ***/4/***

3-4.8 Aircraft Hangars.

Aircraft hangars must be protected as follows:

a. Single hangars over 15,000 sq. ft. (1,394 sq. m.) must be provided with fire protection as called for by UFC 3-600-01 Section 6-16, “Aircraft Facilities”.

b. Multiple hangars less than 15,000 sq. ft. (1,394 sq. m.) per hangar, that are separated by less than 50 ft. (15.2 m.) from each other, must be provided with fire protection as called for by UFC 3-600-01 Section 6-16, “Aircraft Facilities”.

c. Any hangar within 100 ft. (30.5 m.) of a normally occupied structure (office, shop, lodging building, etc) must be provided with fire protection as called for by UFC 3-600-01 Section 6-16, “Aircraft Facilities”.

3-4.8.1 Fire Alarm System

The fire alarm notification system must be activated at each exit by either:

a. Manual pull stations

OR

b. Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

OR

c. Combined standalone sounder and strobe battery powered push button stations

3-4.9 Fuel Depots (Petroleum, Oil and Lubricants (POL) and Hazardous Material Storage Areas).

3-4.9.1 Fixed POL Storage

Fixed POL installations, including cut and cover type tanks, must comply with UFC 3-460-01.

3-4.9.2 Hazardous Materials and Hazardous Waste Storage

Hazardous materials and hazardous waste must be protected in accordance with UFC 3-600-01.

3-4.9.3 Flammable Liquid Storage

Flammable liquid storage tanks must be located as follows:

a. Above-ground tanks containing liquids with flash points less than 100 degrees F (38 degrees C) (gasoline, most solvents) must be separated from adjacent tanks or important buildings by 100 ft. (30.5 m.) or one tank diameter, whichever is greater.

b. Above-ground tanks containing liquids with flash points over 100 degrees F (38 degrees C) (typical diesel fuel and fuel oil) and more than 50,000 gallons (189,270 liters) must be separated from important buildings by 100 ft. (30.5 m.).

c. Above-ground tanks containing liquids with flash points over 100 degrees F (38 degrees C) and less than 50,000 gallons (189,270 liters) must be separated from important buildings by a minimum of 60 ft. (18.3 m.).

d. Underground storage tanks and bladders must be separated from adjacent underground tanks or important buildings by a minimum of 25 ft. (7.6 m.). Each underground bladder or tank must be provided an independent berm sized for containment of the largest tank’s volume.

e. All flammable liquid tanks must be provided with fire response vehicle access within one tank diameter of the tank on at least one side.

3-4.10 Mixed-use Occupancies and Co-locating of Occupancies.

Residential occupancies with accommodations for more than 10 persons must be located in separate buildings from dining, offices, and recreational occupancies. Dining, offices, and recreational occupancies may be co-located in a single building.

Conference rooms, lunch rooms, gymnasiums, or other assembly spaces located within a business or other occupancy may have an occupant load of up to 49 persons in a single space without the facility being considered a mixed-use occupancy. Occupant loads shall be calculated using NFPA 101 Chapter 7, Means of Egress.

Comply with NFPA 101 Chapter 6, Classification of Occupancy and Hazard of Contents, requirements for occupancy classifications and egress related to mixed-use occupancies and with IBC Chapter 5, General building Heights and Areas, for all other requirements related to mixed-use occupancies.

3-4.11 Medical Facilities.

Medical facilities are those that house inpatients. Refer to the applicable Service Medical Group for guidance in constructing medical facilities. These facilities will require a fire sprinkler system.

3-4.12 Sprinkler System Design Criteria.

3-4.12.1 Non-Residential Buildings

For the purposes of non-residential military facilities in the temporary or semi-permanent construction level, NFPA 13 serves as the sprinkler standard for sprinkler systems. In situations where it may not be possible to construct systems meeting the requirements of NFPA 13 related to water storage volume, the number of design sprinklers from NFPA 13R and an amended water supply duration may be used in lieu of the NFPA 13 requirements for non-storage buildings or non-hazardous occupancies.

NFPA 13R requires that all (or 4 at most if more than 4 exist in compartment) sprinklers in the hydraulically most remote compartment must be able to operate at the required density for 30 minutes. For the purposes of this document, the water supply must be required to supply sprinklers for 20 minutes, with a maximum supply volume of 2,000 gallons (7,571 liters) of water (based on 4 sprinklers operating at 25 gpm for 20 minutes).

For non-residential buildings, all other aspects of sprinkler installation, including scope of sprinkler system coverage and installation standard must be per NFPA 13.

3-4.12.2 Non-Residential Buildings

For the purposes of non-residential military facilities in the temporary or semi-permanent construction level, NFPA 13 serves as the sprinkler standard for sprinkler systems. In situations where it may not be possible to construct systems meeting the requirements of NFPA 13 related to water storage volume, the number of design sprinklers from NFPA 13R and an amended water supply duration may be used in lieu of the NFPA 13 requirements for non-storage buildings or non-hazardous occupancies.

NFPA 13R requires that all (or 4 at most if more than 4 exist in compartment) sprinklers in the hydraulically most remote compartment must be able to operate at the required density for 30 minutes. For the purposes of this document, the water supply must be required to supply sprinklers for 20 minutes, with a maximum supply volume of 2,000 gallons (7,571 liters) of water (based on 4 sprinklers operating at 25 gpm for 20 minutes).

For non-residential buildings, all other aspects of sprinkler installation, including scope of sprinkler system coverage and installation standard must be per NFPA 13.

3-4.12.3 Residential Buildings.

For residential buildings requiring sprinkler protection, sprinkler systems must be designed per NFPA 13R and this section, or NFPA 13D as applicable.

3-4.13 Design Documentation

- Drawing / Narrative Basis of Design (can be combined)

- A fire protection summary is required for all designs. Provide a summary discussing the following minimum fire protection provisions:
- Building code analysis summary drawing (i.e., type of construction, height and area limitations, and building separation or exposure protection),
- Classification of occupancy, mixed use requirements, any hazardous areas,
- Requirements for fire and smoke barriers, fire rated walls,
- Life safety plan showing locations of fire rated walls, egress paths, travel distances, and emergency response vehicle access,
- Fire protection plan (include type of system and location of equipment), and water supply information (if system is required),
- Fire alarm system (and mass notification system if integrated into the fire alarm) plan showing type of system and location of equipment, indicating reporting method to a central station/base location (if system is required),
- Interior finish ratings required and provided
- Coordination with security and antiterrorism requirements.

3-5 PLUMBING AND MECHANICAL SYSTEMS.

Provide interior spaces intended for occupancy with ventilation by natural or mechanical means in accordance with the International Mechanical Code (IMC), Chapter 4, “Ventilation”.

Recommend interior spaces intended for occupancy be provided with active or passive air-conditioning systems capable of maintaining the spaces at an ASHRAE effective maximum temperature of 93 degrees Fahrenheit (33.9 deg. C), and effective minimum temperature of 60 degrees Fahrenheit (15.5 deg. C).

3-5.1 Requirements for Specific Systems.

The requirements listed below in the remainder of this section are additional life safety and habitability requirements that must be incorporated if these features are included in order to meet the functional requirements as defined by the COCOM.

3-5.2 Engineering Weather Data.

Follow UFC 3-400-02, Design: Engineering Weather Data.

3-5.3 HVAC Systems and Controls.

Follow IMC Chapter titled “General Regulations”.

3-5.4 Exhaust Systems.

Follow IMC Chapter 5, Exhaust Systems.

3-5.5 Noise.

Noise levels shall not exceed the permissible exposures of 29 CFR 1910.95, Table G-16.

3-5.6 Plumbing - Introduction and Administration.

Follow UFC 3-420-01, *Plumbing Systems*, Section titled “Purpose and Scope,” through Section titled “Primary Voluntary Consensus Standard Reference,” and Section titled “Conflicts in Criteria.”

Requirements in UFC 3-420-01, Section titled “Energy Efficiency in Water Conservation” and Section titled “Reliability” do not apply; however, consideration must be given to resource conservation where and when practical. See paragraph 1-11 of this UFC, “Resource Conservation.” Follow UFC 3-420-01, Section titled “Piping Arrangement.” Piping is not required to be concealed or painted.

Follow UFC 3-420-01, Appendix A: IPC Chapter 1 “Administration” Supplements, Item A, Delete Chapter 1 in its entirety.

Follow UFC 3-420-01, Appendix A: IPC Chapter 2 “Definitions” Supplements.

3-5.7 Plumbing - General Regulations.

Follow the International Plumbing Code (IPC), Chapter 3, General Regulations, with the following exceptions:

- Section Titled, “Protection Against Contact”: does not apply
- Section Titled, “Protection Against Physical Damage”: does not apply
- Section Titled, “Equipment Efficiencies”: does not apply
- Section Titled.1, “Condensate Disposal”: does not apply with the exception of the last sentence that does apply (i.e., “Condensate cannot discharge into a street, alley, or other areas so as to cause a nuisance”).
- Section Titled, “Drain Pipe Materials and Sizes”: does not apply; instead refer to IPC Table 314.2.2, Condensate Drain Sizing, for condensate drain sizing.
- Section Titled, “Auxiliary and Secondary Drain Systems”: does not apply
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 3 ”General Regulations” Supplements, Item F, Section 305.6 Freezing, with the exception of the third, fourth, and fifth sentences regarding piping freeze protection that do not apply.

- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 3 ”General Regulations” Supplements, Item G, Section 305.6.1 Sewer Depth, with the following revision: Revise to state: “Replace with the following: ‘Building sewers must be installed not less than 6 inches (150 mm) below the frost line.’”
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 3 ”General Regulations” Supplements, Item H, Section 312.4 Drainage and Vent Final Test, with the following revision: Revise to state “Add after the last sentence: ‘A peppermint test may be accepted as a final test for the drainage and vent systems, provided the contractor submits a testing procedure for approval.’”

3-5.8 Plumbing Fixtures.

Follow the International Plumbing Code, Chapter 4, Fixtures, Faucets, and Fixture Fittings, with the following exceptions:

- Section Titled, “Minimum Plumbing Facilities”: does not apply. Instead provide a minimum of one water closet and one showerhead for every 20 occupants and a maximum of one water closet and one showerhead for every 10 occupants.
- Section Titled, “Accessible Plumbing Facilities”: does not apply except for special use facilities, such as medical, where more stringent standards may apply.
- Section Titled, “Setting”: does not apply
- Section Titled.1, “Floor Flanges”: does not apply
- Section Titled.3, “Securing Wall-hung Water Closet Bowls”: does not apply
- Section Titled, “Water-tight Joints”: does not apply
- Section Titled, “Plumbing in Mental Health Centers”: does not apply
- Section Titled.1, “Connection of Overflows”: does not apply
- Section Titled, “Slip Joint Connections”: does not apply
- Section Titled, “Design and Installation of Plumbing Fixtures”: does not apply
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 4 "Fixtures, Faucets, and Fixture Fittings” Supplements, Item A, Section 401.2 Prohibited fixtures and connections, Item J, Add ”Section 411.3 Design guidance for emergency shower and eyewash stations”, Item K, Add ”Section 412.5 Required locations and construction“, and Item L, Add ”Section 412.6 Floor drains for emergency shower and eyewash stations”.

3-5.9 Water Heaters.

Follow the International Plumbing Code, Chapter 5, Water Heaters, with the following exceptions:

- Section 501.2, “Water Heater as a Space Heater”: does not apply
- Section 502.3, “Water Heaters Installed in Attics”: does not apply
- Section 503, “Connections”: does not apply
- Section 505, “Insulation”: does not apply
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 5 ”Water Heaters” Supplements, Item H, Add “Section 506 Sizing Hot Water Systems, 506.1 Sizing Calculations” with the following revision: Revise to state: “Design in accordance with American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) Handbook – *HVAC Applications*, Chapter 49 ‘Service Water Heating’; and in accordance with ASHRAE Standard 90.1, *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*. Size hot water system and set service water heater (SWH) storage temperature set point for not less than 140°F (60°C) to limit the potential for growth of Legionella pneumophila. Provide a hot water and cold water blending, tempering valve immediately downstream of the SWH storage tank to provide anti-scalding protection. Provide a balanced-pressure-type tempering valve. Set the blending valve to deliver 110°F (43°C) water to the fixtures except where higher temperatures are required by specialized equipment”.

3-5.10 Water Supply and Distribution.

Follow the International Plumbing Code Chapter 6, Water Supply and Distribution, with the following exceptions:

- Section 604.10, “Gridded and Parallel Water Distribution Systems”: does not apply
- Section 604.11, “Individual Pressure Balancing In-line Valves for Individual Fixture Fittings”: does not apply
- Section 608.8.3, “Size”: does not apply
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 6 ”Water Supply and Distribution” Supplements, Item B, Add ”Section 602.2.1 Non-potable water exception”, Item J, Add ”Section 607.1.1 Legionella Pneumophila (Legionnaire’s Disease)”, Item M, Section 608.1 “General”, and Item N, Section 611.2 “Reverse osmosis systems”.

3-5.11 Sanitary Drainage.

- Follow International Plumbing Code, Chapter 7, “Sanitary Drainage”.

- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 7, “Sanitary Drainage Supplements”, Item B, Section 712.3.2 “Sump Pit”, and Item D, Section 712.3.6 “Controls”.

3-5.12 Indirect/ Special Waste.

Follow International Plumbing Code, Chapter 8, “Indirect/Special Waste”.

3-5.13 Vents.

Follow International Plumbing Code, Chapter 9, “Vents”.

3-5.14 Traps, Interceptors, and Separators.

Follow International Plumbing Code, Chapter 10, “Traps, Interceptors, and Separators”, with the following exceptions:

- Section 1002.4, “Trap Seals”: applies with the exception of the second sentence that does not apply (i.e. “Where a trap seal is subject to loss by evaporation, a trap seal primer valve must be installed”).
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 10, “Interceptors and Separators Supplements”; Item A, Section 1002.4, “Trap Seals”.

3-5.15 Storm Drainage.

Follow International Plumbing Code, Chapter 11, “Storm Drainage”.

Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 11 “Storm Drainage” Supplements, Item B, Section 1104.2, “Combining Storm with Sanitary Drainage”, and Item C, Add ”Section 1104.4 Insulation of rainwater conductors”.

3-5.16 Special Piping and Storage Systems.

Follow UFC 4-510-01, *Design: Medical Military Facilities*, Section titled “Medical Gas Systems” for medical gas and vacuum systems.

3-5.17 Gray Water Recycling Systems.

Follow International Plumbing Code, Appendix C, “Gray Water Recycling Systems”, Sections C101 and C102.

3-5.18 Emergency Shower and Eyewash Stations.

Follow UFC 3-420-01, Appendix D, “Design Guidance for Emergency Shower and Eyewash Stations”.

3-5.19 Structural Safety.

Follow International Plumbing Code, Appendix F, “Structural Safety”.

3-5.20 Compressed Air Systems.

Follow Compressed Air and Gas Institute’s *Compressed Air and Gas Handbook* and ASME Boiler and Pressure Vessel Codes.

3-5.21 Fuel Oil Piping and Storage.

Follow requirements in IMC Chapter 13 for fuel storage and piping supporting building systems.

3-5.22 Boilers, Water Heaters, and Pressure Vessels.

Follow requirements in IMC Chapter 10 for facilities that are provided with boilers or water heaters, and pressure vessels.

3-5.23 Refrigeration.

Follow requirements in IMC Chapter 11 for facilities that are provided with refrigerant systems.

3-5.24 Design Documentation

Drawings:

- Natural ventilation - Floor plans showing the layout of the ventilation system, dimensions of openings and associated equipment, and the means of controlling the system.
- Mechanical ventilation - Floor plans showing the layout of the ventilation system, equipment schedules and details, schematic diagrams, and control sequences and diagrams.

Calculations based on facility function and local climatic conditions:

- Natural ventilation – Calculations showing ventilation opening areas.
- Mechanical ventilation – Calculations showing required ventilation air quantities based on facility occupancy.
- For any specific systems as defined in Section 3-4.1.1, Requirements for Specific Systems, provide Mechanical System documentation in accordance with UFC-3-400-10N, Chapter 3-4, “Calculations”, and Chapter 3-5, “Drawings”, and Plumbing System documentation per UFC 3-420-01, Chapter 1-10.2, “Calculations”, and Chapter 1-11, “Drawings”.

3-6 ELECTRICAL SYSTEMS.

3-6.1 Hazardous Material and Waste.

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 2-1.1, “Hazardous Materials and Waste, and Controlled Materials”.

3-6.2 Arc Flash Analysis.

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 3-2.2, “Electrical Calculations Overview”, with the exception of the list of required calculations as outlined at the end of the referenced section. The only required calculations are short circuit, arc flash and lightning protection analyses.

Comply with the requirements of UFC 3-501-01, Section 3-2.6, “Arc Flash Analysis”.

Comply with the requirements of UFC 3-501-01, Section 2-1.12, “Arc Flash Warning Labels”.

3-6.3 Short Circuit Analysis.

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 3-2.2, “Electrical Calculations Overview”, with the exception of the list of required calculations as outlined at the end of the referenced section. The only required calculations are short circuit, arc flash and lightning protection analyses.

Comply with the requirements of UFC 3-501-01, Section 3-2.4, “Short Circuit Analysis”.

3-6.4 Lightning Protection.

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 3-2.2, “Electrical Calculations Overview”, with the exception of the list of required calculations as outlined at the end of the referenced section. The only required calculations are short circuit, arc flash and lightning protection analyses.

Comply with the requirements of UFC 3-501-01, Section 3-2.15, “Lightning Protection Calculations”.

Comply with the requirements of UFC 3-520-01, *Interior Electrical Systems*, Section 3-14, “Lightning Protection Systems”.

3-6.5 Service Entrance and Distribution Equipment.

Comply with the requirements of UFC 3-520-01, *Interior Electrical Systems*, Section 3-2, “Service Entrance and Distribution Equipment”, third paragraph. First, second and fourth paragraphs are not applicable.

3-6.6 Circuit Lockout Requirements.

Comply with the requirements of UFC 3-520-01, *Interior Electrical Systems*, Section 3-2.9, “Circuit Lockout Requirements”.

3-6.7 Raceway and Wiring.

Comply with the latest edition of NFPA 70, *National Electrical Code*, Chapter 2, “Wiring and Protection”; Chapter 3, “Wiring Methods and Materials”; and Chapter 4, “Equipment for General Use”.

3-6.8 Emergency and Exit Lighting.

Comply with the requirements of UFC 3-530-01, *Interior and Exterior Lighting Systems and Controls, Appendix B Best Practices: Interior, “Emergency and Exit Lighting”.*

3-6.9 General Electrical Requirements.

Comply with the requirements of UFC 3-550-01, *Exterior Electrical Power Distribution*, Section 3-2, “General Electrical Requirements”.

3-6.10 Configuration for Pad-mounted Distribution Transformers, Switchgears, and Sectionalizing Termination Cabinets.

Use dead-front construction for pad-mounted distribution transformers, switchgears, and sectionalizing termination cabinets unless not available within system parameters.

In rare cases when “live-front construction” is required due to equipment ratings (available system fault current values), obtain approval from the authority having jurisdiction.

3-6.11 Distribution System Grounding.

Comply with the requirements of UFC 3-520-01, *Interior Electrical Systems*, Section 3-12, “Grounding, Bonding, and Static Protection”.

Comply with UFC 3-550-01, *Exterior Electrical Power Distribution*, Section 3-14, “Distribution System Grounding”.

3-6.12 Fire Protection System for Oil-filled Equipment.

Comply with the requirements of UFC 3-550-01, *Exterior Electrical Power Distribution*, Section 3-19, “Fire Protection Considerations”.

3-6.13 Underground Structures (Manholes and Handholes).

Where required, power and communication systems must be in separate manholes.

3-6.14 Emergency and Standby Power Systems.

Comply with the requirements of International Building Code (IBC) latest edition, Chapter 27, Electrical, Section 2702, with the exception of the following subsections: 2702.2.8, Semiconductor Fabrication Facilities; 2702.2.9, Membrane Structures; 2702.2.14, Covered Mall Buildings; and 2402.2.18, Airport Traffic Control Towers.

Comply with the requirements of UFC 3-520-01 *Interior Electrical Systems*, Section 3-8, “Emergency Generators”.

3-6.15 Design Documentation.

Provide as a minimum:

- Drawings

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 3-3, “Drawing Requirements”, and the following subsections:

- Section 3-3.2, “Site Plans”
- Section 3-3.9, “Lightning Protection Plans”
- Section 3-3.11, “Power One-line/Riser Diagrams”
- Section 3-3.18, “Grounding Diagram”
- Calculations

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, for the following calculations:

- Section 3-2.4, “Short Circuit Analysis”
- Section 3-2.6, “Arc Flash Analyses”
- Section 3-2.15, “Lightning Protection Calculations”

3-7 TELECOMMUNICATIONS SYSTEMS.

3-7.1 Grounding and Bonding.

Follow UFC 3-580-01, Telecommunications Interior Infrastructure Planning and Design, Section 2-9, “Grounding, Bonding and Static Protection”.

Follow UFC 3-580-01, Appendix A, Item 19: TIA-J-STD-607-B, Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises.

Follow UFC 3-580-01, Appendix A, Item 23: MIL-STD-188-124B, Grounding, Bonding And Shielding for Common Long Haul/Tactical Communication Systems Including Ground Based Communications- Electronics Facilities and Equipments.

Follow UFC 3-580-01, Appendix A, Item 24: MIL-HDBK-419A, Grounding, Bonding, and Shielding For Electronic Equipments and Facilities.

3-7.2 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

CHAPTER 4 SEMI-PERMANENT FACILITY CONSTRUCTION LEVEL

4-1 APPLICABILITY.

Buildings and facilities designed and constructed to serve a life expectancy of less than 10 years (120 months). With maintenance and upkeep of critical building systems, the life expectancy of a facility can be extended to 25 years (300 months). See JP 3-34.

4-2 CIVIL.

The requirements for site water treatment, storage and distribution, and waste disposal may be included in Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA) and as required by the Military Command having jurisdiction over the operation. The information below is a listing of some, but not necessarily all of those requirements. It is the responsibility of the service component engineer staff to determine which criteria are to be utilized for the operation.

4-2.1 Potable Water Supply Source Selection and Testing.

Use TB MED 577, *Sanitary Control and Surveillance of Field Water Supplies*, *Chapter* 5 “Water Source Selection and Basic Testing for Potability”, Chapter 6 “Advanced Water Surveillance and Testing”, Chapter 7 “Evaluation of Field Tests and Analytical Results (Health Guidelines)” for water supply source selection and testing. Use UFC 3-230-03A, *Water Supply*, Chapter 5, “Groundwater Supplies” for construction of wells for groundwater supplies.

4-2.2 Potable Water Treatment and Disinfection.

All drinking water facilities and systems must be designed and operated to ensure protection of personnel health and safety. The environmental annex (i.e., Annex L) of the applicable CCMD OPLAN/OPORD must be reviewed and updated as required to ensure appropriate force health protection standards for drinking water are included. Additional criteria may be applied in accordance with COCOM guidance, any applicable DoD policies, or international agreements. Facilities must also comply with TB MED 577, Chapter 9 Water Treatment and Disinfection, for potable water treatment and disinfection.

4-2.3 Gray Water Collection and Disposal.

Use Army FM 4-20.07, Chapter 2, Section I, “Gray Water Collection and Disposal”; Army FM 4-20.07, Chapter 3, Section II, “Gray Water Collection Subsystem”; AFH 10-222, Volume 4, Section 2.8, “Wastewater”; and AFH 10-222, Volume 4, Section 3.4.1, “Gray Water”.

4-2.4 Black Water Collection and Disposal.

Use Army FM 4-20.07, Chapter 2, Section I, “Black Water Disposal”; AFH 10-222, Volume 4, Section 2.8, “Wastewater”; and AFH 10-222, Volume 4, Section 3.4.2, “Black Water”.

4-2.5 Semi-Permanent Wastewater Treatment System.

If a wastewater treatment system is to be constructed to support facilities, use UFC 3-240-04A, *Wastewater Collection*, for wastewater collection, and use UFC 3-240-09FA, *Domestic Wastewater Treatment*, for wastewater treatment.

4-2.6 Stormwater.

Locate facilities and equipment away from areas subject to stormwater runoff and flooding.

4-2.7 Design Documentation.

Drawings: Site plan showing location of water source supply, sanitary sewer facilities, solid waste disposal areas, and all other facilities critical to life safety and health.

Calculations: Showing compliance with potable water testing requirements contained in referenced standards.

4-3 STRUCTURAL SYSTEMS.

4-3.1 Structural Design.

Structural Design must be in accordance with the International Building Code (IBC), Chapters 16, 17, 18, 19, 20, 21, 22, and 23 as modified by the Unified Facilities Criteria 3-301-01 *Structural Engineering*.

4-3.1.1 1604.3 Serviceability [Supplement].

Frame drift discussed in UFC 3-301-01 Section 2-1.2.1 need not be limited to prevent damage to non-structural elements provided any damage sustained does not create unsafe conditions for personnel in or around the structure.

4-3.1.2 1604.3.1 Deflections [Replacement].

Modify UFC 3-301-01 Sections 2-1.2.2 and 2-1.2.3 as follows: Deflections of structural members may exceed the limitations of IBC Sections 1604.3.2 through 1604.3.5, Table 1604.3, and Table 2-1 of UFC 3-301-01 provided: (1) The increased deflection does not cause excessive rotations in connections at ends of members that could result in connection failure or, (2) The increased deflection does not create an unsafe condition where finishes or other non-structural items could become dislodged and fall on personnel. Under no circumstances are member deflections to exceed L/120 where L is the member span in inches. Members supporting mission critical equipment sensitive to excessive member deflection or vibration must be designed to meet equipment requirements.

4-3.1.3 1607 Live Loads [Supplement].

It is not permissible to design structures for live loads less than those shown in UFC 3-301-01 Table D-1 or IBC Table 1607.1

Additionally, use the following minimum design loads:

- Reference UFC 3-301-01 Table D-1 with no live load reduction, or Floor minimum 100 psf for 1st floor loads (490 kg/m^2) more stringent than table G-1, minimum 50 psf for 2nd floor loads (245 kg/m^2)
- Roof Live Load as required by the facility location but not less than 20 psf (98 kg/m^2)
- Snow Load as required by the facility location but not less than 50 psf (245 kg/m^2)
- Dead Load shall be computed from material weights and partitions, safes, equipment, etc.

Live Load reductions are not permissible.

4-3.1.4 1609 Wind Loads [Supplement].

Site Specific:

- Values in UFC 1-301-01 section 1609.1.1

Unrestricted:

- Basic wind speed (3-sec gust) 110 mph (177km/hr)
- Exposure category C
- Importance factor I_w = 1.0

4-3.1.5 1613 Earthquake Loads [Supplement].

\3\ /3/

Site Specific:

- Within the United States use IBC Section 1613 **\3** 49 **/3/**
- Outside the United States use IBC Section 1613

Unrestricted:

- Within the United States use IBC Section 1613

- Outside the United States use IBC Section 1613

With a minimum of:

- For Risk category I, II, III or IV structures,
- Short period acceleration S_s = 0.55g
- One second acceleration S_1 = 0.13g
- Site class (assumed) D
- Importance factor I_e = 1.0

4-3.1.6 Structural Test and Special Inspections [Revision].

Delete IBC Chapter 17 Structural Tests and Special Inspections. The DOR must delineate all testing and inspection requirements in the construction drawings or specifications to ensure performance of the structural system. The DOR is responsible to provide an appropriate design in which the testing and inspection requirements specified in IBC Sections 1713, 1714, and 1715 can be met based on field capability and resources. Testing and inspections should include, but not be limited to, the following:

1. All Materials: Inspection of suitable sub-surface conditions. Visual inspection of member sizes, locations, spacing, and configuration. Visual inspection of splice/cold joint locations, connections, and adequate bearing.
2. Wood structures: In addition to the inspections for All Materials also perform visual inspection of connector (e.g. nails, screws, bolts) sizes, spacing and locations. Visual inspection of size and location of plate connections. Visual inspection of all straps, hold downs, and connection hardware. Visual inspection of overlapping lengths at splices. Visual inspection of member material grades. Visual inspection of sheathing thickness, sheathing material grades, shear wall locations, and cross bracing.
3. Masonry: In addition to the inspections for All Materials also perform visual inspection of grout placement. Visual inspection of reinforcing steel sizes, locations, clearances, configuration, embedment, and splice lengths. Grout cylinder compression tests, CMU compression tests, and verification of mortar and grout proportions.
4. Steel: In addition to the inspections for All Materials also perform visual inspection of deck profiles, diaphragm sizes and locations, and diaphragm connections. Visual inspection of completed welds. Visual inspection of connector (e.g. bolts, screws) number and patterns, and connector sizes. Inspection confirming proper tightening of the nuts. Visual inspection of cross bracing.

5. Concrete: In addition to the inspections for All Materials also perform visual inspection of formwork. Visual inspection of reinforcing steel sizes, locations, clearances, configuration, embedment, and splice lengths. Concrete anchors and embed sizes and locations. Concrete cylinder compression test, and water/cement ratio measurement.

4-3.1.7 1803.1 Geotechnical Investigations, General [Supplement].

Add exception: The DOR or qualified DoD personnel must accept simplified geotechnical investigations in lieu of the full requirements of sections 1803.3 through for one-story, simple span structures without basements that bear on shallow foundations and meet the following requirements:

1. For Occupancy Category I, II, or III structures, Ss does not exceed 0.55 and S1 does not exceed 0.13.
2. For Occupancy Category IV structures, Ss does not exceed 0.32 and S1 does not exceed 0.08.

In the absence of a Geotechnical Report, the DOR must design foundations for presumptive bearing capacities per IBC Section 1806.

4-3.1.8 1803.6 Reporting [Supplement].

The DOR must stipulate the required items, if any, to be included in a written report of the geotechnical investigations, which need not include any or all of IBC Section 1803.6, items 1 through 10.

4-3.1.9 1808.6.1 Foundations [Supplement].

Modify second sentence to read, “Deflection and racking of the supported structure must be limited to that which will not compromise the strength or serviceability of the structure.”

4-3.1.10 1809.5 Frost Protection [Supplement].

Add exception: One-story, simple span structures that bear on shallow foundations need not be protected.

4-3.1.11 1904 Durability Requirements [Delete].

Delete IBC Section 1904.

4-3.1.12 1907.7.6 Corrosive Environments [Delete].

Delete UFC 3-301-01 Section 2-4.2.1 and IBC Section 1907.7.6.

4-3.1.13 2203.2 Protection [Delete].

Delete IBC Section 2203.2.

4-3.1.14 2204.2 Bolting [Delete].

Delete UFC 3-301-01 Section 2-6.1.1.

4-3.1.15 2205.1 General [Supplement].

Delete UFC 3-301-01 Section 2-6.2.1. Members supporting mission critical equipment sensitive to excessive vibration must be designed to meet equipment requirements.

4-3.1.16 2205.4 Steel Structures in Corrosive Environments [Supplement].

Delete UFC 3-301-01 Section 2-6.2.2 except for steel sections with elements thinner than 3/8”.

4-3.1.17 2210.8 Floor Vibrations [Supplement].

Delete UFC 3-301-01 Section 2-6.4.3. Members supporting mission critical equipment sensitive to excessive vibration must be designed to meet equipment requirements.

4-3.1.18 2304.11 Protection Against Decay and Termites [Delete].

Delete section except in regions with a known significant risk of destructive insect infestations.

4-3.1.19 Semi-Permanent Construction Level Requirements.

Structural Design must be in accordance with the International Building Code (IBC), Chapters 16, 17, 18, 19, 20, 21, 22, and 23, and UFC 3-301-01 *Structural Engineering*.

4-3.1.20 Structural Test and Special Inspections [Revision].

Comply with testing and inspection requirements in Section 3-2.1.7 of this document.

4-3.2 Design Documentation.

Provide as a minimum:

- Drawings:
  - General Notes
  - Inspection Requirements
  - Foundation Plans
  - Framing Plans, all levels
  - Roof framing plans

  - Details
  - Schedules as required for footings, columns, beams, shear walls)

- Calculations:
  - Basis of Design: summary of applicable codes, live loading, snow loading, wind and seismic loading, dead load assumptions, gravity design, design of floor and roof framing members – beams, slabs, joist, decks, composite slabs, etc.
  - Column and bearing wall design
  - Foundation design
  - Lateral design: design of diaphragms and collectors, distribution of loads to lateral forces resisting elements (frames, walls), design of shear walls, moment frames, and braced frames, design of foundations at lateral force resisting elements, design of hold downs, straps, etc.
  - Design for AT/FP: confirm setbacks, wall construction types, and progressive collapse mitigation design requirements, check window designs, jambs and sills for AT/FP window loading requirements.
  - Load combinations used
  - Materials used with properties and section properties
  - Connection design and details – bolted and welded
  - Wind load analysis applied to structure
  - Seismic load analysis
  - Serviceability check (deflections and overturning)
  - Wall panel design (building envelop) and connection to superstructure
  - Stated structure life-span
  - Erection plan(s)

4-4 FIRE PROTECTION.

The overarching requirement is for Life Safety.

Property Protection is a consideration only if specifically required by the facility owning entity.

The intent of this document is to provide buildings that are limited in size (overall building height and floor area) so as to not require installed active fire protection or fire alarm systems, except where explicitly required by the criteria of an allowable occupancy in this UFC.

Any installed fire alarm system shall be a local alarm only and shall not require visual appliances (strobes), unless specifically required by the facility owning entity.

An acceptable alternate local alarm system:

a. Consisting of an alarm initiating device at each exit by either:

    i. Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

    OR

b. Combined standalone sounder and strobe battery powered push button stations with interconnection capability.

4-4.1 General requirements.

Use of Spray Plastic Foam Insulation (SPFI) is not allowed, except for commercially procured insulated metal roof panels. **\2** Use of pre-insulated panels (with any surface – metal, wood, plastic or other) containing foam insulation is not allowed. **/2/**

4-4.1.1 Mission Critical Facilities.

For mission critical facilities, see Figure E-1 in Appendix E for a decision tree with guidance on protection of assets for these facilities.

4-4.1.2 Antiterrorism Separation Distance.

Refer to UFC 4-010-01 for antiterrorism/force protection requirements related to space separation compliance.

For all buildings, provide access to at least one side of any building for the largest emergency response vehicle serving the site.

4-4.1.3 Unenclosed Vertical Openings.

Unenclosed vertical openings are generally not permitted. Vertical openings include but are not limited to atriums, stairways; hoist ways for elevators, dumbwaiters, or inclined and vertical conveyors (escalators); shafts used for light, ventilation or building services.

Mezzanines shall comply with requirements for mezzanines herein and in IBC Chapter 5, General Building Heights and Areas, and are not treated as vertical openings.

All vertical openings shall be enclosed or protected with shafts constructed as fire barriers as called for by the IBC Chapter 7, Fire and Smoke Protection Features, or NFPA 101 Chapters 7, Means of Egress, and 8, Features of Fire Protection, for the fire resistance rating of the barrier.

Any planned unenclosed vertical opening needs to be approved by the AHJ.

4-4.2 Construction Level Requirements and Space Separation Requirements per Occupancy.

Classifications of buildings within this section are based on occupancy. As defined by NFPA 101, Chapter 3, Definitions, the occupancy is the purpose for which a building or other structure, or part thereof, is used or intended to be used. The occupant load of these areas is calculated per NFPA 101, Chapter 7, Means of Egress.

4-4.2.1 Fire Separation Distance.

This document provides requirements for allowable fire separations between structures by occupancy classification.

4-4.2.2 Area Limits.

Area limits stated within this UFC are for a stand-alone building as defined in the IBC Chapter 5, General Building Heights and Areas. If larger building areas than stated herein are needed to meet the needs of users, then the following guidance is provided to facilitate the construction of buildings with larger areas, in order of preference:

1. Provide fire separation distance between separate structures in accordance with IBC Chapter 6, Types of Construction, requirements for fire separation between buildings.
2. Provide pedestrian walkways between buildings individually compliant with IBC Chapter 31, Special Construction, fire separation requirements to provide separate buildings interconnected with enclosed, conditioned walkways.
3. Provide fire rated exterior walls or fire walls between buildings in accordance with IBC Chapter 6, Types of Construction, requirements.

4. Provide buildings of an area or height to require fixed fire protection systems in accordance with IBC Chapter 5, General Building Heights and Areas requirements, and provide these fixed protection systems.

4-4.3 Assembly Occupancy

Assembly occupancy is an occupancy used for a gathering of 50 or more persons for deliberation, worship, entertainment, eating, drinking, amusement, awaiting transportation or similar uses; or used as a special amusement building, regardless of occupant load. Assembly occupancies include but are not limited to: dining facilities, clubs, chapels, conference rooms, and morale welfare, and fitness centers for general personnel use.

4-4.3.1 Building Construction.

Buildings must be constructed in accordance with one of the following options (a or b):

a. Buildings must be limited to one story high.

    i. Buildings constructed of combustible construction must be limited to 6,000 sq. ft. (557 sq. m.) in area.

    ii. Buildings constructed of non-combustible or fire-resistive construction must be limited to 9,500 sq. ft. (883 sq. m.) in area.

b. Buildings must be provided with a sprinkler system designed in accordance with the fire sprinkler requirements of this document. Buildings provided with this protection must be constructed in accordance with IBC Chapter 5, General Building Heights and Areas, limits on building areas. Building height must be limited to 2 stories.

4-4.3.2 Building Separation.

Buildings must be separated from other buildings by one of the following options (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings. The clear space may be used for vehicle roadways or pedestrian walkways, but not for parking, storage or vegetation other than lawns.

b. If fire separation distances as noted in Option (a) cannot be provided due to site constraints, one of the following must be provided:

    i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, requirements.

ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other similar type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Adjacent buildings must be separated by at least twice the height of the taller building.

4-4.3.3 Egress Requirements.

Comply with NFPA 101, Chapters 7, Means of Egress, and 12, New Assembly Occupancies, for egress, except as follows:

a. For buildings without sprinkler protection in accordance with this document, provide exits 100% above the number required by NFPA 101, Chapters 7, Means of Egress, and 12, New Assembly Occupancies. Exits must be evenly distributed along at least three sides of the building.

b. Provide local fire alarm notification throughout the space for evacuation in the event of an emergency. The fire alarm notification system must be activated by manual stations at each exit. The fire alarm notification system may be integrated with the mass notification system for the building. Fire alarm systems must comply with NFPA 72 requirements.

4-4.3.4 Kitchen Requirements.

Provide an exhaust hood with a listed kitchen hood fire protection system for any commercial-type cooking operation.

Provide one-hour rated fire barrier separation between any cooking/serving operations and the seating area(s).

4-4.4 Business Occupancy.

Business occupancy is an occupancy used for the transaction of business other than mercantile. Business occupancies include the following: general offices and administrative facilities, outpatient clinics, doctors' offices, detention facilities, and fitness centers that are located within an office, solely for office personnel use (no public or common use).

4-4.4.1 Building Construction.

Buildings must be constructed in accordance with one of the following options (a or b):

a. Buildings constructed of combustible construction must be limited to 9,000 sq. ft. (836 sq. m.) per floor, and 3 stories above grade.

   i. Buildings constructed of non-combustible or fire-resistive construction must be limited to 23,000 sq. ft. (2,137 sq. m.) per floor, and 3 stories above grade.

b. Buildings must be provided with a sprinkler system designed in accordance with the fire sprinkler requirements of this document. Buildings provided with this protection must be constructed in accordance with 2009 IBC Chapter 5, General Building Heights and Areas, limits on floor areas. Building height must be limited to 3 stories.

4-4.4.2 Building Separation.

Buildings must be separated from other buildings by one of the following (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings within the same contingency compound. A clear space of 100 ft. (30.5 m) must be provided between the building and other buildings not associated with the contingency compound. Clear space must not be used for vehicle parking, storage, or vegetation other than lawns.

b. If fire separation distances as noted in Option (a) cannot be provided, one of the following must be provided:

   i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, requirements.

   ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other similar type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Buildings must be separated by at least twice the height of the taller building.

Comply with NFPA 101, Chapters 7 and 38, for egress except that all exits, including grade level exit doors, exit stairs, and fire-rated exit passageways must discharge directly to the exterior to public ways.

4-4.4.3 Fire Alarm System.

Provide local fire alarm notification throughout the space where any of the following conditions occur:

a. Levels of the building located on other than grade level exceed 5,000 sq. ft. (465 sq. m.) per floor.

b. The total area of all floors exceeds 30,000 sq. ft. (2,787 sq. m.).

The notification system must be activated at each exit by either:

a. Manual pull stations

   OR

b. Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

   OR

c. Combined standalone sounder and strobe battery powered push button stations.

The fire alarm notification system may be integrated with the mass notification system for the building. Fire alarm systems must comply with the installation requirements of NFPA 72.

4-4.4.4 Detention Facilities.

Detention Facilities are classified as Business Occupancy with special population requirements. Detention facilities are those buildings and structures where persons are under restraint or where security is closely supervised and are not capable of self-preservation because the conditions of confinement are not under their control (i.e. they require assistance by the facility's staff to reach safety in an emergency situation). For occupancy classification purposes the population refers only to the number of persons being secured or restrained. The number of guests or staff is not counted.

4-4.4.4.1 Detention Facilities Allowable Population.

The allowable population of a detention facility, building or structure is no more than five (5) persons who are under restraint or security.

4-4.4.4.2 Detention Facilities Fire Separation Distance.

Buildings must be separated from other buildings by one of the following (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings within the same contingency compound. A clear space of 100 ft. (30.5 m) must be provided between the building and other buildings not associated with the contingency compound. Clear space must not be used for vehicle parking, storage, or vegetation other than lawns.

b. If fire separation distances as noted in Option (a) cannot be provided, one of the following must be provided:

   i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC

Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, requirements.

ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other similar type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Buildings must be separated by at least twice the height of the taller building.

4-4.5 Industrial Occupancy.

A factory-industrial occupancy is an occupancy in which products are manufactured or in which processing, assembling, mixing, packaging, finishing, decorating, or repair operations are conducted. This occupancy includes factories, laundries, power plants, maintenance shops, and pumping stations.

4-4.5.1 Building Construction.

Buildings must be constructed in accordance with one of the following options (a or b):

a. Buildings constructed of combustible construction must be limited to 8,500 sq. ft (790 sq. m.) and one story above grade.

    i. Buildings constructed of non-combustible or fire-resistive construction must be limited to 15,500 sq. ft. (1,440 sq. m.) per floor and two stories above grade.

b. Buildings must be provided with a sprinkler system designed in accordance with NFPA 13. Buildings provided with this protection must be constructed in accordance with IBC Chapter 5, General Building Heights and Areas, requirements for floor areas and heights.

4-4.5.2 Building Separation.

Buildings must be provided fire separation from other buildings by one of the following (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings. Clear space must not be used for vehicle parking, storage, or vegetation other than lawns.

b. If fire separation distance as noted in Option (a) cannot be provided, one of the following must be provided:

    i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC requirements.

ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other approved type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Fire separation distance between these buildings must be at least twice the height of the taller building.

4-4.5.3 Egress Requirements.

Comply with NFPA 101, Chapters 7, Means of Egress, and 40, Industrial Occupancies, for egress.

4-4.5.4 Mezzanines.

Mezzanines within industrial buildings cannot be used for normally occupied spaces (such as offices). Mezzanines must be limited to storage rooms and/or mechanical/electrical rooms only.

4-4.5.5 Fire Alarm and Mass Notification Systems.

Provide local fire alarm notification throughout the space where **1**\ any of the following conditions occur:

a. Levels of the building located on other than grade level exceed 5,000 sq. ft. (465 sq. m.) per floor.

b. The total area of all floors exceeds 30,000 sq. ft. (2,787 sq. m.).

The notification system must be activated at each exit by either:

a. Manual pull stations

OR

b. Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

OR

c. Combined standalone sounder and strobe battery powered push button stations.

The fire alarm notification system may be integrated with the mass notification system for the building. Fire alarm systems must comply with the installation requirements of NFPA 72. /**1**/

4-4.5.6 Hazardous Areas.

Hazardous areas such as flammable painting operations, combustible dust producing operations, areas with combustible hydraulic fluid systems over 100 gallons (379 liters), or other industrial operations with significant flammable liquid or gas storage and/or use must be protected by one of the following (a or b):

a. Provided protection in accordance with NFPA 13, 30, and 101 requirements.

b. These areas must be located in buildings with a minimum 100 ft (30.5 m) fire separation distance from adjacent buildings.

4-4.6 Residential Occupancy.

The residential occupancy is defined as an occupancy that provides sleeping accommodations for purposes other than health care or detention and correctional. Residential occupancies include one- and two-family dwellings, dormitories, barracks, billeting, Bachelor Enlisted Quarters and Bachelor Officer’s Quarters, apartment buildings, relocatable buildings and converted shipping containers.

4-4.6.1 Building Construction.

Buildings must be constructed in accordance with one of the following requirements (a or b):

a. Buildings constructed of combustible construction must be limited to 7,000 sq. ft. (650 sq. m.) per floor, and 2 stories in height.

    i. Buildings constructed of non-combustible construction must be limited to 15,000 sq. ft. (1,394 sq. m.) per floor, and 4 stories in height.

b. Buildings must be provided with a sprinkler system designed in accordance with NFPA 13R and the fire sprinkler requirements of this document. Buildings provided with this protection must be constructed in accordance with IBC Chapter 5, General Building Heights and Areas, requirements for floor areas. Building heights must be limited to 4 stories.

4-4.6.2 Building Separation.

Buildings must be separated from other buildings by one of the following (a or b):

a. A fire separation distance of 30 ft. (9.1 m) must be provided between the building and other buildings. Clear space must not be used for vehicle parking, storage, or vegetation other than lawns.

b. If fire separation distances as noted in Option (a) cannot be provided due to site constraints, one of the following must be provided (i, ii or iii):

i. Each exterior wall of the building that faces an exposing building must be rated at one hour with opening protectives in accordance with IBC Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, requirements.

ii. Each exterior wall of the building that faces an exposing building must be provided with a full height barrier (earth-filled bastions, pre-cast concrete barrier, sandbag revetment, or other similar type) without openings. The barrier must be at least as high as the eave level of the tallest structure involved. Fire separation distance must be at least twice the height of the taller building.

iii. The residential building must be provided with sprinkler protection by a system designed in accordance with NFPA 13R and the fire sprinkler requirements of this document.

4-4.6.3 Fire/Smoke Alarms.

Multiple station type smoke alarms must be provided throughout each room of the living unit in accordance with NFPA 72 residential fire alarm system requirements. Actuation of any smoke alarm must cause all smoke alarms within the living unit to generate an audible signal.

A manual alarm system must be provided throughout each building, with notification appliances provided in each living unit in accordance with NFPA 72 for residential type occupancies.

The notification system must be activated at each exit by either:

a. Manual pull stations

OR

b. Push-button stations with tamper resistant covers with battery powered alarm controlling a separate strobe.

OR

c. Combined standalone sounder and strobe battery powered push button stations

4-4.6.4 Range-Top Extinguishing Systems.

For all living units with residential range-top cooking units, an approved residential range-top extinguishing system must be provided. Actuation of the residential range-top extinguishing system must cause a general building alarm, and automatically shut off all sources of fuel and electrical power to the cooking unit.

4-4.6.5 Egress Requirements.

Comply with NFPA 101, Chapters 7, Means of Egress, and 28, New Hotels and Dormitories, for egress, except as modified below:

Means of egress from sleeping rooms must be provided in accordance with one of the following (a or b):

a. A secondary means of escape must be provided, consisting of a door or window readily operable from inside with no special tools or knowledge. The window must be sized at a minimum of 5.7 sq. ft, (0.53 sq. m.) with a width of at least 20 inches (508 mm) and an open height of at least 24 inches (610 mm). The secondary means of escape must be located on a different exterior wall than the main entrance door to the sleeping room.

b. For sleeping rooms where it is not practical to provide a secondary means of escape as noted in (a), the following must be provided (i and ii):

    i. Walls between sleeping rooms must be rated at a minimum of 30 minutes.

    ii. Sprinkler protection must be provided throughout the building installed in accordance with NFPA 13R or NFPA 13D requirements.

4-4.7 \4\ Storage.

Storage occupancy is an occupancy used primarily for the storage or sheltering of goods, merchandise, products, or vehicles. Storage occupancies include barns, cold storage, freight terminals, parking structures, truck and marine terminals, and warehouses. See section 4-4.9 of this document for requirements of fuel and hazardous materials storage areas.

4-4.7.1 Building Construction.

Buildings must be constructed in accordance with one of the following requirements (a, b, or c):

a. Buildings of combustible construction must be limited to 9,000 sq. ft. (836 sq. m.) in area and one story. Storage heights must be limited to 12 ft. (3.66 m) maximum.

b. Buildings of noncombustible or fire resistive construction must be limited to 17,500 sq. ft. (1,626 m.) and one story. Storage heights must be limited to 12 ft. (3.66 m) maximum.

c. Sized based on IBC Chapter 5, General Building Heights and Areas, and provided with sprinkler protection in accordance with UFC 3-600-01 and NFPA 13 requirements.

4-4.7.2 Building Separation.

Storage buildings must be provided with fire separation distance from surrounding buildings by one of the following options (a or b):

a. Fire separation distance of at least 60 feet (18.3 m) from any adjacent building must be provided.

b. Exterior walls must be rated at two hours or more, in accordance with IBC Chapters 6, Types of Construction, and 7, Fire and Smoke Protection Features, with 1-1/2 hour opening protectives provided for all openings on building sides where fire separation is less than 60 feet (18.3 m).

4-4.7.3 Egress Requirements.

Comply with NFPA 101, Chapters 7, Means of Egress, and 42, Storage Occupancies, for egress.

4-4.7.4 Mezzanines.

Mezzanines cannot be used for occupied spaces (such as offices). Any mezzanines can only be used for storage or mechanical/electrical equipment. **/4/**

4-4.8 Aircraft Hangars.

The requirements of UFC 4-211-01 do not apply, unless specifically required by the facility owning entity.

Aircraft hangars must be protected as follows:

a. Single hangars over 15,000 sq. ft. (1,394 sq. m.) must be provided with fire protection as called for by UFC 3-600-01 Section 6-16, “Aircraft Facilities”.

b. Multiple hangars less than 15,000 sq. ft. (1,394 sq. m.) per hangar, that are separated by less than 50 ft. (15.2 m.) from each other, must be provided with fire protection as called for by UFC 3-600-01 Section 6-16, “Aircraft Facilities”.

c. Any hangar within 100 ft. (30.5 m.) of a normally occupied structure (office, shop, lodging building, etc) must be provided with fire protection as called for by UFC 3-600-01 Section 6-16, “Aircraft Facilities”.

4-4.9 Fuel Depots (Petroleum, Oil and Lubricants (POL) and Hazardous Material Storage Areas).

4-4.9.1 Fixed POL Storage.

Fixed POL installations, including cut and cover type tanks, must comply with UFC 3-460-01.

4-4.9.2 Hazardous Materials and Hazardous Waste Storage.

Hazardous materials and hazardous waste must be protected in accordance with UFC 3-600-01.

4-4.9.3 Flammable Liquid Storage.

Flammable liquid storage tanks must be located as follows:

a. Above-ground tanks containing liquids with flash points less than 100 degrees F (38 degrees C) (gasoline, most solvents) must be separated from adjacent tanks or important buildings by 100 ft. (30.5 m.) or one tank diameter, whichever is greater.

b. Above-ground tanks containing liquids with flash points over 100 degrees F (38 degrees C) (typical diesel fuel and fuel oil) and more than 50,000 gallons (189,270 liters) must be separated from important buildings by 100 ft. (30.5 m.).

c. Above-ground tanks containing liquids with flash points over 100 degrees F (38 degrees C) and less than 50,000 gallons (189,270 liters) must be separated from important buildings by a minimum of 60 ft. (18.3 m.).

d. Underground storage tanks and bladders must be separated from adjacent underground tanks or important buildings by a minimum of 25 ft. (7.6 m.). Each underground bladder or tank must be provided an independent berm sized for containment of the largest tank’s volume.

e. All flammable liquid tanks must be provided with fire response vehicle access within one tank diameter of the tank on at least one side.

4-4.10 Mixed-use Occupancies and Co-locating of Occupancies.

Residential occupancies with accommodations for more than 10 persons must be located in separate buildings from dining, offices, and recreational occupancies. Dining, offices, and recreational occupancies may be co-located in a single building.

Conference rooms, lunch rooms, gymnasiums, or other assembly spaces located within a business or other occupancy may have an occupant load of up to 49 persons in a single space without the facility being considered a mixed-use occupancy. Occupant loads shall be calculated using NFPA 101 Chapter 7, Means of Egress.

Comply with NFPA 101 Chapter 6, Classification of Occupancy and Hazard of Contents, requirements for occupancy classifications and egress related to mixed-use occupancies and with IBC Chapter 5, General building Heights and Areas, for all other requirements related to mixed-use occupancies.

4-4.11 Medical Facilities.

Medical facilities are those that house inpatients. Refer to the applicable Service Medical Group for guidance in constructing medical facilities.

4-4.12 Sprinkler System Design Criteria.

4-4.12.1 Non-Residential Buildings.

For the purposes of non-residential military facilities in the temporary or semi-permanent construction level, NFPA 13 serves as the sprinkler standard for sprinkler systems. In situations where it may not be possible to construct systems meeting the requirements of NFPA 13 related to water storage volume, the number of design sprinklers from NFPA 13R and an amended water supply duration may be used in lieu of the NFPA 13 requirements for non-storage buildings or non-hazardous occupancies.

NFPA 13R requires that all (or 4 at most if more than 4 exist in compartment) sprinklers in the hydraulically most remote compartment must be able to operate at the required density for 30 minutes. For the purposes of this document, the water supply must be required to supply sprinklers for 20 minutes, with a maximum supply volume of 2,000 gallons (7,571 liters) of water (based on 4 sprinklers operating at 25 gpm for 20 minutes).

For non-residential buildings, all other aspects of sprinkler installation, including scope of sprinkler system coverage and installation standard must be per NFPA 13.

4-4.12.2 Storage Buildings, Factory-Industrial and Hazardous Areas.

Storage buildings, factory-industrial, and hazardous areas, if sprinklered, must be protected by systems designed per NFPA 13, including supply duration and flow volume requirements.

4-4.12.3 Residential Buildings.

For residential buildings requiring sprinkler protection, sprinkler systems must be designed per NFPA 13R and this section, or NFPA 13D as applicable.

4-4.13 Design Documentation.

- Drawing / Narrative Basis of Design (can be combined)
- A fire protection summary is required for all designs. Provide a summary discussing the following minimum fire protection provisions, based on UFC 1-200-01, UFC 1-201-01 and UFC 3- 600-01:
- Building code analysis summary drawing (i.e., type of construction, height and area limitations, and building separation or exposure protection),

- Classification of occupancy, mixed use requirements, any hazardous areas,
- Requirements for fire and smoke barriers, fire rated walls,
- Life safety plan showing locations of fire rated walls, egress paths, travel distances, and emergency response vehicle access,
- Fire protection plan (include type of system and location of equipment), and water supply information (if system is required),
- Fire alarm system (and mass notification system if integrated into the fire alarm) plan showing type of system and location of equipment, indicating reporting method to a central station/base location (if system is required),
- Interior finish ratings required and provided
- Coordination with security and antiterrorism requirements.

4-5 PLUMBING AND MECHANICAL SYSTEMS.

Provide interior spaces intended for occupancy with ventilation by natural or mechanical means in accordance with the International Mechanical Code (IMC), Chapter 4, “Ventilation”.

Recommend interior spaces intended for occupancy be provided with active or passive air-conditioning systems capable of maintaining the spaces at an ASHRAE effective maximum temperature of 93 degrees Fahrenheit (33.9 deg. C), and effective minimum temperature of 60 degrees Fahrenheit (15.5 deg. C).

4-5.1 Requirements for Specific Systems.

The requirements listed below in the remainder of this section are additional life safety and habitability requirements that must be incorporated if these features are included in order to meet the functional requirements as defined by the COCOM.

4-5.2 Engineering Weather Data.

Follow UFC 3-400-02, Design: Engineering Weather Data.

4-5.3 HVAC Systems and Controls.

Follow IMC Chapter titled “General Regulations*”.*

4-5.4 Exhaust Systems.

Follow IMC Chapter 5, Exhaust Systems.

4-5.5 Noise.

Noise levels shall not exceed the permissible exposures of 29 CFR 1910.95, Table G-16.

4-5.6 Plumbing - Introduction and Administration.

Follow UFC 3-420-01, *Plumbing Systems*, Section titled “Purpose and Scope,” through Section titled “Primary Voluntary Consensus Standard Reference,” and Section titled “Conflicts in Criteria.”

Requirements in UFC 3-420-01, Section titled “Energy Efficiency in Water Conservation” and Section titled “Reliability” do not apply; however, consideration must be given to resource conservation where and when practical. See paragraph 1-11 of this UFC, “Resource Conservation.” Follow UFC 3-420-01, Section titled “Piping Arrangement.” Piping is not required to be concealed or painted.

Follow UFC 3-420-01, Appendix A: IPC Chapter 1 “Administration” Supplements, Item A, Delete Chapter 1 in its entirety.

Follow UFC 3-420-01, Appendix A: IPC Chapter 2 “Definitions” Supplements.

4-5.7 Plumbing - General Regulations.

Follow the International Plumbing Code (IPC), Chapter 3, General Regulations, with the following exceptions:

- Section 310.5, “Urinal Partitions”: does not apply
- Section 313, “Equipment Efficiencies”: does not apply
- Section 314.2.1, “Condensate Disposal”: does not apply with the exception of the last sentence that does apply (i.e., “Condensate cannot discharge into a street, alley, or other areas so as to cause a nuisance”).
- Section 314.2.2, “Drain Pipe Materials and Sizes”: does not apply; instead refer to IPC Table 314.2.2, Condensate Drain Sizing, for condensate drain sizing.
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 3 ”General Regulations” Supplements, Item F, Section 305.6 Freezing, with the exception of the third, fourth, and fifth sentences regarding piping freeze protection that do not apply.
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 3 ”General Regulations” Supplements, Item G, Section 305.6.1 Sewer Depth, with the following revision: Revise to state: “Replace with the following: ‘Building sewers must be installed not less than 6 inches (150 mm) below the frost line.’”

- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 3 ”General Regulations” Supplements, Item H, Section 312.4 Drainage and Vent Final Test, with the following revision: Revise to state “Add after the last sentence: ‘A peppermint test may be accepted as a final test for the drainage and vent systems, provided the contractor submits a testing procedure for approval.’”

4-5.8 Plumbing Fixtures.

Follow the International Plumbing Code, Chapter 4, Fixtures, Faucets, and Fixture Fittings, with the following exceptions:

- Section 402, “Minimum Plumbing Facilities”: does not apply. Instead provide a minimum of one water closet and one showerhead for every 20 occupants and a maximum of one water closet and one showerhead for every 10 occupants.
- Section 404, “Accessible Plumbing Facilities”: does not apply except for special use facilities, such as medical, where more stringent standards may apply.
- Section 405.3, “Setting”: does not apply
- Section 405.4.1, “Floor Flanges”: does not apply
- Section 405.4.3, “Securing Wall-hung Water Closet Bowls”: does not apply
- Section 405.5, “Water-tight Joints”: does not apply
- Section 405.6, “Plumbing in Mental Health Centers”: does not apply
- Section 405.7.1, “Connection of Overflows”: does not apply
- Section 405.8, “Slip Joint Connections”: does not apply
- Section 405.9, “Design and Installation of Plumbing Fixtures”: does not apply
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 4 ”Fixtures, Faucets, and Fixture Fittings” Supplements, Item A, Section 401.2 Prohibited fixtures and connections, Item J, Add ”Section 411.3 Design guidance for emergency shower and eyewash stations”, Item K, Add ”Section 412.5 Required locations and construction“, and Item L, Add ”Section 412.6 Floor drains for emergency shower and eyewash stations”.
- Follow UFC 3-420-01, Plumbing Systems, Appendix A: IPC Chapter 4, “Fixtures, Faucets, and Fixture Fittings” Supplements, Items D or E, and F.

4-5.9 Water Heaters.

Follow the International Plumbing Code, Chapter 5, Water Heaters, with the following exceptions:

- Section 501.2, “Water Heater as a Space Heater”: does not apply
- Section 502.3, “Water Heaters Installed in Attics”: does not apply
- Section 503, “Connections”: does not apply
- Section 505, “Insulation”: does not apply
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 5 ”Water Heaters” Supplements, Item H, Add “Section 506 Sizing Hot Water Systems, 506.1 Sizing Calculations” with the following revision: Revise to state: “Design in accordance with American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) Handbook – *HVAC Applications*, Chapter 49 ‘Service Water Heating’; and in accordance with ASHRAE Standard 90.1, *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*. Size hot water system and set service water heater (SWH) storage temperature set point for not less than 140°F (60°C) to limit the potential for growth of Legionella pneumophila. Provide a hot water and cold water blending, tempering valve immediately downstream of the SWH storage tank to provide anti-scalding protection. Provide a balanced-pressure-type tempering valve. Set the blending valve to deliver 110°F (43°C) water to the fixtures except where higher temperatures are required by specialized equipment”.

4-5.10 Water Supply and Distribution.

Follow the International Plumbing Code Chapter 6, Water Supply and Distribution, with the following exceptions:

- Section 604.10, “Gridded and Parallel Water Distribution Systems”: does not apply
- Section 604.11, “Individual Pressure Balancing In-line Valves for Individual Fixture Fittings”: does not apply
- Section 608.8.3, “Size”: does not apply
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 6 ”Water Supply and Distribution” Supplements, Item B, Add ”Section 602.2.1 Non-potable water exception”, Item J, Add ”Section 607.1.1 Legionella Pneumophila (Legionnaire’s Disease)”, Item M, Section 608.1 “General”, and Item N, Section 611.2 “Reverse osmosis systems”.

4-5.11 Sanitary Drainage.

Follow International Plumbing Code, Chapter 7, “Sanitary Drainage”.

Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 7, “Sanitary Drainage Supplements”, Item B, Section 712.3.2 “Sump Pit”, and Item D, Section 712.3.6 “Controls”.

4-5.12 Indirect/ Special Waste.

Follow International Plumbing Code, Chapter 8, “Indirect/Special Waste”.

4-5.13 Vents.

Follow International Plumbing Code, Chapter 9, “Vents”.

4-5.14 Traps, Interceptors, and Separators.

Follow International Plumbing Code, Chapter 10, “Traps, Interceptors, and Separators”, with the following exceptions:

- Section 1002.4, “Trap Seals”: applies with the exception of the second sentence that does not apply (i.e. “Where a trap seal is subject to loss by evaporation, a trap seal primer valve must be installed”).
- Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 10, “Interceptors and Separators Supplements”; Item A, Section 1002.4, “Trap Seals”.

4-5.15 Storm Drainage.

Follow International Plumbing Code, Chapter 11, “Storm Drainage”.

Follow UFC 3-420-01, *Plumbing Systems*, Appendix A: IPC Chapter 11 “Storm Drainage” Supplements, Item B, Section 1104.2, “Combining Storm with Sanitary Drainage”, and Item C, Add ”Section 1104.4 Insulation of rainwater conductors”.

4-5.16 Special Piping and Storage Systems.

Follow UFC 4-510-01, *Design: Medical Military Facilities*, Section titled “Medical Gas Systems” for medical gas and vacuum systems.

4-5.17 Gray Water Recycling Systems.

Follow International Plumbing Code, Appendix C, “Gray Water Recycling Systems”, Sections C101 and C102.

4-5.18 Emergency Shower and Eyewash Stations.

Follow UFC 3-420-01, Appendix D, “Design Guidance for Emergency Shower and Eyewash Stations”.

4-5.19 Structural Safety.

Follow International Plumbing Code, Appendix F, “Structural Safety”.

4-5.20 Compressed Air Systems.

Follow Compressed Air and Gas Institute's *Compressed Air and Gas Handbook* and ASME Boiler and Pressure Vessel Codes.

4-5.21 Fuel Oil Piping and Storage.

Follow requirements in IMC Chapter 13 for fuel storage and piping supporting building systems.

4-5.22 Boilers, Water Heaters, and Pressure Vessels.

Follow requirements in IMC Chapter 10 for facilities that are provided with boilers or water heaters, and pressure vessels.

4-5.23 Refrigeration.

Follow requirements in IMC Chapter 11 for facilities that are provided with refrigerant systems.

4-5.24 Duct Systems.

Follow IMC Chapter 6, Duct Systems.

4-5.25 Hydronic Systems.

Follow IMC Chapter 12, Hydronic Piping.

4-5.26 Design Documentation

Provide as a minimum:

1. Drawings:

   a. Natural ventilation - Floor plans showing the layout of the ventilation system, dimensions of openings and associated equipment, and the means of controlling the system.

   b. Mechanical ventilation - Floor plans showing the layout of the ventilation system, equipment schedules and details, schematic diagrams, and control sequences and diagrams.

   c. Calculations based on facility function and local climatic conditions:

   d. Natural ventilation – Calculations showing ventilation opening areas.

   e. Mechanical ventilation – Calculations showing required ventilation air quantities based on facility occupancy.

f. For any specific systems as defined in Section 3-4.1.1, Requirements for Specific Systems, provide Mechanical System documentation in accordance with UFC-3-400-10N, Chapter 3-4, "Calculations", and Chapter 3-5, "Drawings", and Plumbing System documentation per UFC 3-420-01, Chapter 1-10.2, "Calculations", and Chapter 1-11, "Drawings".

4-6 ELECTRICAL SYSTEMS.

4-6.1 Hazardous Material and Waste.

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 2-1.1, "Hazardous Materials and Waste, and Controlled Materials".

4-6.2 Arc Flash Analysis.

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 3-2.2, "Electrical Calculations Overview", with the exception of the list of required calculations as outlined at the end of the referenced section. The only required calculations are short circuit, arc flash and lightning protection analyses.

Comply with the requirements of UFC 3-501-01, Section 3-2.6, "Arc Flash Analysis".

Comply with the requirements of UFC 3-501-01, Section 2-1.12, "Arc Flash Warning Labels".

4-6.3 Short Circuit Analysis.

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 3-2.2, "Electrical Calculations Overview", with the exception of the list of required calculations as outlined at the end of the referenced section. The only required calculations are short circuit, arc flash and lightning protection analyses.

Comply with the requirements of UFC 3-501-01, Section 3-2.4, "Short Circuit Analysis".

4-6.4 Lightning Protection.

Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 3-2.2, "Electrical Calculations Overview", with the exception of the list of required calculations as outlined at the end of the referenced section. The only required calculations are short circuit, arc flash and lightning protection analyses.

Comply with the requirements of UFC 3-501-01, Section 3-2.15, "Lightning Protection Calculations".

Comply with the requirements of UFC 3-520-01, *Interior Electrical Systems*, Section 3-14, "Lightning Protection Systems".

4-6.5 Service Entrance and Distribution Equipment.

Comply with the requirements of UFC 3-520-01, *Interior Electrical Systems*, Section 3-2, “Service Entrance and Distribution Equipment”, third paragraph. First, second and fourth paragraphs are not applicable.

4-6.6 Circuit Lockout Requirements.

Comply with the requirements of UFC 3-520-01, *Interior Electrical Systems*, Section 3-2.9, “Circuit Lockout Requirements”.

4-6.7 Raceway and Wiring.

Comply with the latest edition of NFPA 70, *National Electrical Code*, Chapter 2, “Wiring and Protection”; Chapter 3, “Wiring Methods and Materials”; and Chapter 4, “Equipment for General Use”.

4-6.8 Emergency and Exit Lighting.

Comply with the requirements of UFC 3-530-01, *Design: Interior and Exterior Lighting and Controls*, Section 5-6, “Emergency and Exit Lighting”.

4-6.9 General Electrical Requirements.

Comply with the requirements of UFC 3-550-01, *Exterior Electrical Power Distribution*, Section 3-2, “General Electrical Requirements”.

4-6.10 Configuration for Pad-mounted Distribution Transformers, Switchgears, and Sectionalizing Termination Cabinets.

Use dead-front construction for pad-mounted distribution transformers, switchgears, and sectionalizing termination cabinets unless not available within system parameters.

In rare cases when “live-front construction” is required due to equipment ratings (available system fault current values), obtain approval from the authority having jurisdiction.

4-6.11 Distribution System Grounding.

Comply with the requirements of UFC 3-520-01, *Interior Electrical Systems*, Section 3-12, “Grounding, Bonding, and Static Protection”.

Comply with UFC 3-550-01, *Exterior Electrical Power Distribution*, Section 3-14, “Distribution System Grounding”.

4-6.12 Fire Protection System for Oil-filled Equipment.

Comply with the requirements of UFC 3-550-01, *Exterior Electrical Power Distribution*, Section 3-19, “Fire Protection Considerations”.

4-6.13 Underground Structures (Manholes and Handholes).

Where required, power and communication systems must be in separate manholes.

4-6.14 Emergency and Standby Power Systems.

Comply with the requirements of International Building Code (IBC) latest edition, Chapter 27, Electrical, Section 2702, with the exception of the following subsections: 2702.2.8, Semiconductor Fabrication Facilities; 2702.2.9, Membrane Structures; 2702.2.14, Covered Mall Buildings; and 2402.2.18, Airport Traffic Control Towers.

Comply with the requirements of UFC 3-520-01 *Interior Electrical Systems*, Section 3-8, "Emergency Generators".

4-6.15 Underground Distribution General Criteria – Cable Identification in Manholes.

Tag all underground cables in all accessible locations such as in manholes, transformers, switches and switchgear. Install a detectable locator tape above all buried underground circuits.

4-6.16 Design Documentation

As a Minimum Provide:

- Drawings:
  - Comply with the requirements of UFC 3-501-01, *Electrical Engineering*,
  - Section 3-3, "Drawing Requirements", and the following subsections:
  - Section 3-3.1, "Legends and Abbreviations"
  - Section 3-3.2.2, "Transformer Details"
  - Section 3-3.2.3, "Underground Distribution"
  - Section 3-3.4, "Lighting Plans and Details"
  - Section 3-3.5, "Power Plans"
  - Section 3-3.12, "Telecommunications Riser Diagram"
  - Section 3-3.13, "Intercommunication/Paging Riser Diagram"
  - Section 3-3.14, "Fire Alarm Riser Diagram"
  - Section 3-3.16, "Schedules and Elevations"

Calculations:

- Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, for the following calculations:
  - Section 3-2.4, “Short Circuit Analysis”
  - Section 3-2.6, “Arc Flash Analyses”
  - Section 3-2.15, “Lightning Protection Calculations”

4-7 TELECOMMUNICATIONS SYSTEMS.

4-7.1 Grounding and Bonding.

Follow UFC 3-580-01, Telecommunications Interior Infrastructure Planning and Design, Section 2-9, “Grounding, Bonding and Static Protection”.

Follow UFC 3-580-01, Appendix A, Item 19: TIA-J-STD-607-B, Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises.

Follow UFC 3-580-01, Appendix A, Item 23: MIL-STD-188-124B, Grounding, Bonding And Shielding for Common Long Haul/Tactical Communication Systems Including Ground Based Communications- Electronics Facilities and Equipments.

Follow UFC 3-580-01, Appendix A, Item 24: MIL-HDBK-419A, Grounding, Bonding, and Shielding For Electronic Equipments and Facilities.

4-7.2 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

This Page Intentionally Left Blank

APPENDIX A CONSTRUCTION LEVEL CHECKLISTS

A-1 INITIAL CONSTRUCTION LEVEL CHECKLIST.

CIVIL				
	Are facilities and equipment located away from areas subject to stormwater runoff and flooding?	YES	NO	Comment
	Are low lying, tidal, and tributary areas avoided?			
	Were adjacent facilities or functional areas considered for stormwater runoff control?			
	Is water flow controlled with surface drainage and trenches?			
	Were available surface laid / shallow buried culverts utilized?			
STRUCTURAL				
	Were manufacturers’ instructions for Government-approved systems for assembly of pre-packaged shelters in theater followed?	YES	NO	Comment
ELECTRICAL				
	Were manufacturers’ instructions for installation of Government-approved pre-packaged electrical equipment in theater followed?	YES	NO	Comment
Complete the following only if pre-packaged systems are not available:				
	In compliance with the requirements of UFC 3-550-01, *Exterior Electrical Power Distribution*, Section 3-2, “General Electrical Requirements”.	YES	NO	Comment
	In compliance with the requirements of UFC 3-520-01, Interior Electrical Systems, Section 3-12, “Grounding, Bonding, and Static Protection”.			
	In compliance with UFC 3-550-01, Exterior Electrical Power			

	Distribution, Section 3-14, “Distribution System Grounding”.			
Grounding.	Are all electrical systems grounded in accordance with manufacturer recommendations?			
Power Cable Installation.	Were cables surface laid or protected from vehicular and foot traffic?			
Circuit Lockout Requirements.	Were manufacturers’ instructions for installation of Government-approved pre-packaged electrical equipment in theater followed?			
	Are non-government pre-packaged circuit breakers, disconnect switches, and other devices that are electrical energy isolating lockable or protected from unauthorized access?			
PLUMBING AND MECHANICAL				
Water Treatment, Storage, and Distribution.	Does design and operation of all potable water (drinking water) facilities and systems to ensure protection of health and safety meet requirements in COCOM or coalition guidance or international agreements?	YES	NO	Comment
	Are Army, Navy, Marine Corps systems in compliance with the respective chapters from ATP 4-44/MCRP 3-17.7Q Water Support Operations and NTRP 4-04.2.13/FM 3-34.469/AFMAN 32-1072, Water-Well Drilling Operations?			
Water Treatment	Are Air Force systems in compliance with the respective chapters from AF TTP 3-32.33 V1?			
Waste Water.	Are waste water facilities and systems designed and operated to ensure protection of health and safety in compliance with requirements in international			

	agreements, COCOM or coalition guidance?			
Heating, Ventilating and Air-Conditioning (HVAC).	Were ventilation and environmental control systems installed in accordance with manufacturers' instructions and service technical manuals for pre-packaged heating, ventilating, and air-conditioning (HVAC) systems?			
FIRE PROTECTION				
	Is Spray Plastic Foam Insulation (SPFI) used?	YES	NO	Comment
	Is exposed Urethane foam or other exposed plastic insulations on walls or ceilings used?			
Allowable Area / Population.	Are more than 200 persons shall be located within a billeting structure group?			
Structure Separation.	Where this document uses the term structure group, this is defined as a cluster of independent structures, including tents, trailers, containerized housing units, or similar construction. Separation of structures within structure groups consisting of fabric structures, containers, trailers, or similar structures must comply with the following:			
	Are UFC 4-010-01 requirements for antiterrorism/force protection requirements related to space separation met?			
	Is the minimum separation between individual structures within a row of a billeting structure group consisting of fabric structures of 12 ft (3.7 m) met?			
	Is the minimum separation between rows of structures within a billeting			

	structure group of 30 ft (9.1 m) met?			
	Is the minimum separation between billeting structure groups and other structures of 100 ft (30.5 m) met?			
	Is the minimum separation between billeting structure groups of 59 ft (18 m) met?			
	Use of Revetments.			
	Are the requirements of UFC 4-010-01 met for the use of revetments?			
Fire Safety Analysis for Constrained Sites	If site constraints do not permit compliance with the above space separation requirements, has a fire-safety analysis been done performed or reviewed by the Unit Safety Officer and approved by the first O-6 level officer in the chain of command.			
Interior Finishes / Fabric Coverings	Are fabric coverings for tents or membrane structures in accordance with NFPA 701 requirements?			
	Do other structures comply with NFPA 101 requirements? (Compliance with NFPA 101 can be achieved using painted or unpainted finishes of concrete masonry units, gypsum wallboard, sheet metal, or 3/8-inch (9.5 mm) plywood. Fabric covering or textile coverings must be fire retardant as established by the manufacturer through testing in accordance with NFPA requirements.)			
Fire Extinguishers.	Are all facilities provided with listed portable fire extinguishers consistent with the occupancy of the facility? (If traditional listed/approved extinguishers are not available, the			

	use of extinguishers with equivalent rating from EU, Asian, or other countries is permitted.)			
TELECOMMUNICATIONS				
	Are Army requirements in FM 4-20.07, paragraphs 2-79 and 4-25 met?	YES	NO	Comment
	Are Air Force requirements in AFH 10-222, Volume 1, Table 2.8, and Attachment 6 met?			
	Were Navy/Marine Corps assembly instructions for installation of pre-packaged equipment in theater followed?			
	If pre-packaged systems are not available and when fabricating a grounding system from components:			
	Was UFC 3-580-01, *Telecommunications Interior Infrastructure Planning and Design*, Section 2-7, “Grounding” followed?			
	Was UFC 3-580-01, Appendix A, Item 19: TIA-J-STD-607-B, Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises followed?.			
	Was UFC 3-580-01, Appendix A, Item 23: MIL-STD-188-124B, *Grounding, Bonding And Shielding for Common Long Haul/Tactical Communication Systems Including Ground Based Communications-Electronics Facilities and Equipments* followed?			
	Was UFC 3-580-01, Appendix A, Item 24: MIL-HDBK-419A, *Grounding, Bonding, and Shielding For Electronic Equipments and Facilities* followed?			

CYBERSECURITY				
	Are all control systems (including systems separate from an energy management control system) planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.	YES	NO	Comment

A-2 TEMPORARY CONSTRUCTION LEVEL CHECKLIST.

CIVIL				
Drawings	Site plan showing location of water source supply, sanitary sewer facilities, solid waste disposal areas, and all other facilities critical to life safety and health.	YES	NO	Comment
Calculations	Showing compliance with potable water testing requirements contained in referenced standards.			
STRUCTURAL				
Drawings		YES	NO	Comment
	General Notes			
	Inspection Requirements			
	Foundation Plans			
	Framing Plans, all levels			
	Roof Framing Plans			
	Details			
	Schedules as required (footings, columns, beams, shear walls)			
Calculations				
	Basis of Design; summary of applicable codes, live loading, snow loading, wind and seismic loads, and dead load assumptions Gravity design; design of floor and roof			

	framing members - beams, slabs, joists, decks, composite slabs, etc.			
	Column and bearing wall design			
	Foundation design			
	Lateral design; design of diaphragms and collectors, distribution of loads to lateral forces resisting elements (frames, walls), design of shear walls, moment frames, and braced frames, design of foundations at lateral force resisting elements, design of hold downs, straps, etc.			
	Design for AT/FP; confirm setbacks, wall construction types, and progressive collapse mitigation design requirements, check window designs, jambs and sills for AT/FP window loading requirements			
	Load combinations used			
	Materials used with properties and section properties.			
	Connection design and details – bolted and welded			
	Wind load analysis applied to structure			
	Seismic load analysis			
	Serviceability check (deflections and overturning)			
	Wall panel design (building envelope) and connection to superstructure			
	Stated structure life-span			
	Erection plan(s)			
ELECTRICAL				
Drawings		YES	NO	Comment
	Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 3-3, “Drawing Requirements”, and the following subsections:			

	Section 3-3.2, "Site Plans"			
	Section 3-3.9, "Lightning Protection Plans"			
	Section 3-3.11, "Power One-line/Riser Diagrams"			
	Section 3-3.18, "Grounding Diagram"			
Calculations		YES	NO	Comment
	Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, for the following calculations:			
	Section 3-2.4, "Short Circuit Analysis"			
	Section 3-2.6, "Arc Flash Analyses"			
	Section 3-2.15, "Lightning Protection Calculations"			
PLUMBING AND MECHANICAL				
Drawings		YES	NO	Comment
	Natural ventilation - Floor plans showing the layout of the ventilation system, dimensions of openings and associated equipment, and the means of controlling the system.			
	Mechanical ventilation - Floor plans showing the layout of the ventilation system, equipment schedules and details, schematic diagrams, and control sequences and diagrams.			
	Specific Systems, provide Mechanical System documentation in accordance with UFC-3-400-10N, Chapter 3-5, "Drawings"			
	Specific Systems, provide Mechanical System documentation in accordance with UFC-3-400-10N, Chapter 1-11, "Drawings".			
Calculations based on facility function and local climatic conditions				
	Natural ventilation – Calculations showing ventilation opening areas.			

	Mechanical ventilation – Calculations showing required ventilation air quantities based on facility occupancy.			
	Specific Systems, provide Mechanical System documentation in accordance with UFC-3-400-10N, Chapter 3-4, "Calculations"			
	Specific Systems, provide Plumbing System documentation per UFC 3-420-01, Chapter 1-10.2, "Calculations"			
FIRE PROTECTION				
Drawing / Narrative Basis of Design (can be combined)		YES	NO	Comment
	A fire protection summary is required for all designs. Provide a summary discussing the following minimum fire protection provisions, based on UFC 1-200-01, UFC 1-201-01 and UFC 3-600-01:			
	Building code analysis summary drawing (i.e., type of construction, height and area limitations, and building separation or exposure protection).			
	Classification of occupancy, mixed use requirements, any hazardous areas.			
	Requirements for fire and smoke barriers, fire rated walls.			
	Life safety plan showing locations of fire rated walls, egress paths, travel distances, and emergency response vehicle access.			
	Fire protection plan (include type of system and location of equipment), and water supply information (if system is required).			
	Fire alarm system (and mass notification system if integrated into			

	the fire alarm) plan showing type of system and location of equipment, indicating reporting method to a central station/base location (if system is required),			
	Interior finish ratings required and provided.			
	Coordination with security and antiterrorism requirements.			
TELECOMMUNICATIONS				
	Follow UFC 3-580-01, Telecommunications Interior Infrastructure Planning and Design, Section 2-9, “Grounding, Bonding and Static Protection”.	YES	NO	Comment
	Follow UFC 3-580-01, Appendix A, Item 19: TIA-J-STD-607-B, Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises.			
	Follow UFC 3-580-01, Appendix A, Item 23: MIL-STD-188-124B, Grounding, Bonding And Shielding for Common Long Haul/Tactical Communication Systems Including Ground Based Communications-Electronics Facilities and Equipments.			
	Follow UFC 3-580-01, Appendix A, Item 24: MIL-HDBK-419A, Grounding, Bonding, and Shielding For Electronic Equipments and Facilities.			
CYBERSECURITY				
	All control systems (including systems separate from an energy management control system) planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.	YES	NO	Comment

A-3 SEMI-PERMANENT CONSTRUCTION LEVEL CHECKLIST.

CIVIL				
Drawings	Site plan showing location of water source supply, sanitary sewer facilities, solid waste disposal areas, and all other facilities critical to life safety and health.	YES	NO	Comment
Calculations	Showing compliance with potable water testing requirements contained in referenced standards.			
STRUCTURAL				
Drawings		YES	NO	Comment
	General Notes			
	Inspection Requirements			
	Foundation Plans			
	Framing Plans, all levels			
	Roof Framing Plans			
	Details			
	Schedules as required (footings, columns, beams, shear walls)			
Calculations				
	Basis of Design; summary of applicable codes, live loading, snow loading, wind and seismic loads, and dead load assumptions Gravity design; design of floor and roof framing members - beams, slabs, joists, decks, composite slabs, etc.			
	Column and bearing wall design			
	Foundation design			
	Lateral design; design of diaphragms and collectors, distribution of loads to lateral forces resisting elements (frames, walls), design of shear walls, moment frames, and braced frames, design of foundations at lateral force			

	resisting elements, design of hold downs, straps, etc.			
	Design for AT/FP; confirm setbacks, wall construction types, and progressive collapse mitigation design requirements, check window designs, jambs and sills for AT/FP window loading requirements			
	Load combinations used			
	Materials used with properties and section properties.			
	Connection design and details – bolted and welded			
	Wind load analysis applied to structure			
	Seismic load analysis			
	Serviceability check (deflections and overturning)			
	Wall panel design (building envelope) and connection to superstructure			
	Stated structure life-span			
	Erection plan(s)			
ELECTRICAL				
Drawings		YES	NO	Comment
	Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, Section 3-3, “Drawing Requirements”, and the following subsections:			
	Section 3-3.1, “Legends and Abbreviations.			
	Section 3-3.2.2, “Transformer Details.			
	Section 3-3.2.3, “Underground Distribution”.			
	Section 3-3.4, “Lighting Plans and Details”.			
	Section 3-3.5, “Power Plans”.			
	Section 3-3.12, “Telecommunications Riser Diagram”.			

	Section 3-3.13, "Intercommunication/Paging Riser Diagram".			
	Section 3-3.14, "Fire Alarm Riser Diagram".			
	Section 3-3.16, "Schedules and Elevations".			
Calculations		YES	NO	Comment
	Comply with the requirements of UFC 3-501-01, *Electrical Engineering*, for the following calculations:			
	Section 3-2.4, "Short Circuit Analysis"			
	Section 3-2.6, "Arc Flash Analyses"			
	Section 3-2.15, "Lightning Protection Calculations"			
PLUMBING AND MECHANICAL				
Drawings		YES	NO	Comment
	Natural ventilation - Floor plans showing the layout of the ventilation system, dimensions of openings and associated equipment, and the means of controlling the system.			
	Mechanical ventilation - Floor plans showing the layout of the ventilation system, equipment schedules and details, schematic diagrams, and control sequences and diagrams.			
	Specific Systems, provide Mechanical System documentation in accordance with UFC-3-400-10N, Chapter 3-5, "Drawings"			
	Specific Systems, provide Mechanical System documentation in accordance with UFC-3-400-10N, Chapter 1-11, "Drawings".			
Calculations based on facility function and local climatic conditions				
	Natural ventilation – Calculations showing ventilation opening areas.			

	Mechanical ventilation – Calculations showing required ventilation air quantities based on facility occupancy.			
	Specific Systems, provide Mechanical System documentation in accordance with UFC-3-400-10N, Chapter 3-4, “Calculations”			
	Specific Systems, provide Plumbing System documentation per UFC 3-420-01, Chapter 1-10.2, “Calculations”			
FIRE PROTECTION				
Drawing / Narrative Basis of Design (can be combined)		YES	NO	Comment
	A fire protection summary is required for all designs. Provide a summary discussing the following minimum fire protection provisions, based on UFC 1-200-01, UFC 1-201-01 and UFC 3-600-01:			
	Building code analysis summary drawing (i.e., type of construction, height and area limitations, and building separation or exposure protection).			
	Classification of occupancy, mixed use requirements, any hazardous areas.			
	Requirements for fire and smoke barriers, fire rated walls.			
	Life safety plan showing locations of fire rated walls, egress paths, travel distances, and emergency response vehicle access.			
	Fire protection plan (include type of system and location of equipment), and water supply information (if system is required).			
	Fire alarm system (and mass notification system if integrated into the fire alarm) plan showing type of system and location of equipment, indicating reporting method to a central			

	station/base location (if system is required),			
	Interior finish ratings required and provided.			
	Coordination with security and antiterrorism requirements.			
TELECOMMUNICATIONS				
	Follow UFC 3-580-01, Telecommunications Interior Infrastructure Planning and Design, Section 2-9, “Grounding, Bonding and Static Protection”.	YES	NO	Comment
	Follow UFC 3-580-01, Appendix A, Item 19: TIA-J-STD-607-B, Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises.			
	Follow UFC 3-580-01, Appendix A, Item 23: MIL-STD-188-124B, Grounding, Bonding And Shielding for Common Long Haul/Tactical Communication Systems Including Ground Based Communications-Electronics Facilities and Equipments.			
	Follow UFC 3-580-01, Appendix A, Item 24: MIL-HDBK-419A, Grounding, Bonding, and Shielding For Electronic Equipments and Facilities.			
CYBERSECURITY				
	All control systems (including systems separate from an energy management control system) planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.	YES	NO	Comment

This Page Intentionally Left Blank

APPENDIX B GLOSSARY

B-1 ACRONYMS.

AFCEE	Air Force Center for Engineering and the Environment
BIA	Bilateral Infrastructure Agreement
DoD	Department of Defense
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
NAVFAC	Naval Facilities Engineering Command
SOFA	Status of Forces Agreements
UFC	Unified Facilities Criteria
U.S.	United States

This Page Intentionally Left Blank

APPENDIX C REFERENCES

ARMY PUBLISHING DIRECTORATE

Army Techniques Publications

ATP 4-44, *WATER SUPPORT OPERATIONS*

Field Manuals

FM 4-20.07

Technical Manuals

TM 3-34.56, *WASTE MANAGEMENT FOR DEPLOYED FORCES*

TM 3-34.70, *PLUMBING, PIPE FITTING, AND SEWERAGE*

Engineer Manuals

EM 385-1-1, *Safety and Health Requirements*

NATIONAL FIRE PROTECTION ASSOCIATION

NFPA 10, *Standard for Portable Fire Extinguishers*

NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies*

NFPA 101, *Life Safety Code*

NFPA 701, *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 1-200-01, *DoD Building Code*

UFC 1-201-02, *Assessment of Existing Facilities for Use in Military Operations*

UFC 3-301-01, *Structural Engineering*

UFC 3-310-04, *Seismic Design of Buildings*

UFC 3-420-01, *Plumbing Systems*

UFC 3-550-01 *Exterior Electrical Power Distribution*

UFC 3-580-01, *Telecommunications Interior Infrastructure Planning and Design*

UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

JOINT PUBLICATIONS

Department of Defense Dictionary of Military and Associated Terms

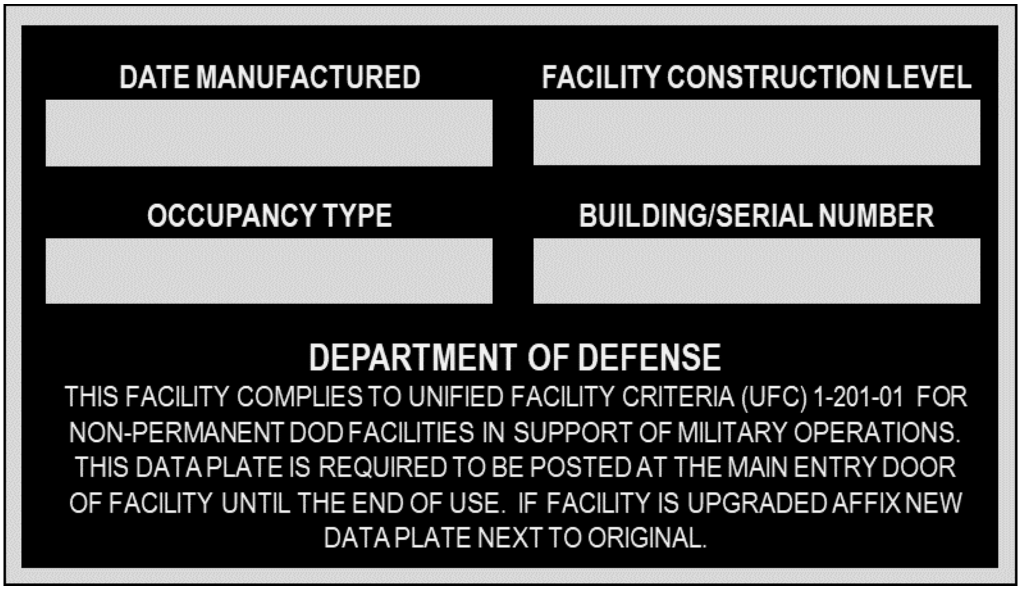
JP 1, *Doctrine for the Armed Forces of the United States*

JP 3-0, *Joint Operations*

JP 3-34, *Joint Engineer Operations*

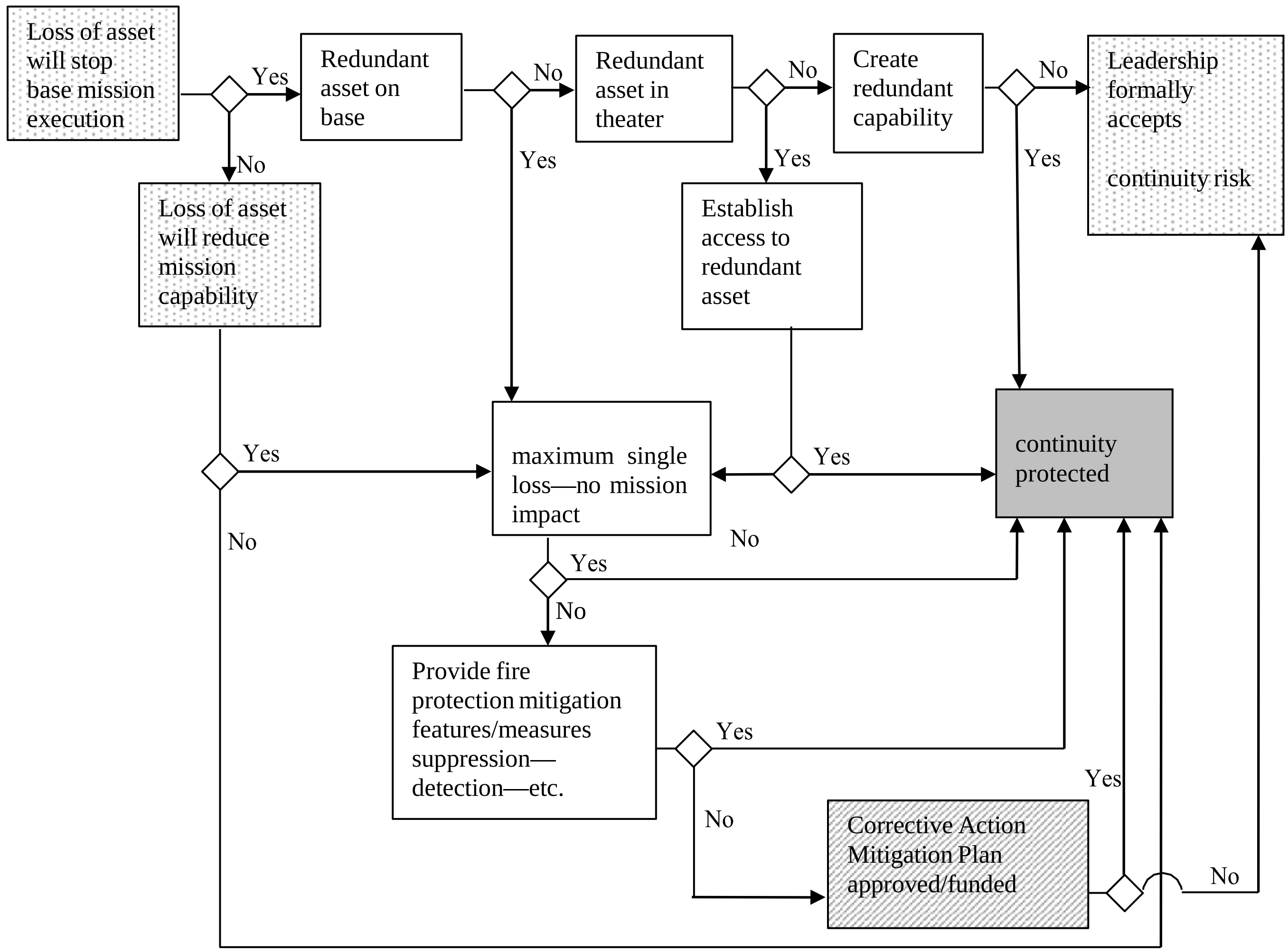
JP 4-0, *Joint Logistics*

APPENDIX D DATA PLATE EXAMPLE



This Page Intentionally Left Blank

APPENDIX E MISSION CRITICAL FACILITIES DECISION TREE



UFC 1-201-02
1 June 2014

UNIFIED FACILITIES CRITERIA (UFC)

ASSESSMENT OF EXISTING FACILITIES FOR USE IN MILITARY OPERATIONS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

ASSESSMENT OF EXISTING FACILITIES FOR USE IN MILITARY OPERATIONS

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Refer to UFC 1-200-01, *General Building Requirements*, for implementation of new issuances on projects.

AUTHORIZED BY:

JAMES C. DALTON, P.E. Chief, Engineering and Construction U.S. Army Corps of Engineers	JOSEPH E. GOTT, P.E. Chief Engineer Naval Facilities Engineering Command
JOE SCIABICA, SES Director Air Force Civil Engineer Center	MICHAEL McANDREW Director, Facilities Investment and Management Office of the Deputy Under Secretary of Defense (Installations and Environment)

UNIFIED FACILITIES CRITERIA (UFC)
NEW DOCUMENT SUMMARY SHEET

Document: UFC 1-201-02, Assessment of Existing Facilities for Use in Military Operations

Superseding: None.

Description: This UFC provides assessment guidelines for evaluating existing facilities for the potential use in military operations. Options are also included for mitigation of common building deficiencies.

Reasons for Document: This UFC was developed to accomplish the following:

- Provide contingency personnel with procedures to assess an existing facility to determine if the building achieves the minimum Life Safety and Habitability requirements to allow for occupancy in support of military operations.
- Provides options for mitigating the risks inherent with common building deficiencies

Impact: The following will result from the publication of this UFC:

- There is currently no UFC for evaluating existing facilities for use in military operations. This UFC establishes assessment protocols for evaluating existing facilities to ensure protection of life safety and health of personnel occupying these facilities.

Non-Unification Issues: None.

TABLE OF CONTENTS

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE.

This UFC provides procedures for assessing life safety and habitability aspects of existing facilities for potential occupancy by the Department of Defense (DoD) personnel in support of military operations.

1-2 APPLICABILITY.

This UFC applies to all DoD components involved in the expedient assessment of existing buildings in support of military operations primarily outside of the United States and its territories and possessions. Joint Publication JP 3-0, *Joint Operations*, provides typical examples of military operations where use of this UFC is appropriate. Requirements for preliminary evaluations do not apply when forces occupying the facility are engaged in actual combat operations.

1-3 SCOPE OF DOCUMENT.

The technical requirements in this UFC establish procedures for expedient assessment of existing facilities to ensure the minimum standards for safety and health of personnel consistent with the requirements of military operations in the following topics:

- Fire protection (includes Life Safety)
- Structural integrity
- Electrical systems
- Plumbing and Mechanical systems
- Telecommunications networks
- Other Hazards

1-4 ADDITIONAL DESIGN CRITERIA.

The Appendices provide references to related documents.

1-5 CRITERIA FOR NEW FACILITIES AND ALTERATIONS.

Refer to UFC 1-201-01, *Non-Permanent DoD Facilities in Support of Military Operations*, for life safety and habitability-related design requirements for new construction of non-permanent facilities for use by the Department of Defense (DoD) in support of military operations. Also follow the requirements in UFC 1-201-01 for additions and alterations to existing facilities.

1-6 AUTHORITY HAVING JURISDICTION.

The terms "Building Official" and "Authority Having Jurisdiction" (AHJ) as used in the codes and standards referenced in this UFC mean the Service office of responsibility, i.e., U.S. Army, HQ USACE/CECW-CE; U.S. Navy, NAVFACENGCOM HQ Code CHE; U.S. Marine Corps, HQMC Code LFF-1; and U.S. Air Force, HQ AFCEC/CL. The Service's Chief Engineer can delegate to their Technical Representative the enforcement of the codes and standards.

1-7 REACHBACK SUPPORT.

When deficiencies found require technical expertise for assessment or corrective measures, resources are available through Reachback capabilities within each branch of Service. See Appendix B for Service Reachback Contacts.

1-8 ENVIRONMENTAL ISSUES.

This UFC minimally addresses visual identification of potential environmental and health hazards. See the Initial Interior Walk-Thru portion of the Preliminary Evaluation as itemized in the checklist in Appendix D for the limited Environmental items being assessed in these Evaluations.

If such hazards or contaminants are observed or suspected during inspections, vacate the building and notify the Officer-in-Charge.

1-9 ANTITERRORISM/FORCE PROTECTION.

Force protection requirements are not covered by this document; however, when assessing any existing facility for use in military operations they should be integrated into facility planning when the operational environment requires it. DoD minimum antiterrorism standards for expeditionary and temporary structures are covered in Appendix D of UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*, and geographic Combatant Command supplemental Operational Orders. The *Joint Forward Operations Base (JFOB) Protection Handbook*, GTA 90-01-011, provides force protection planning and protective construction concepts for military operations facilities.

1-10 EXPLOSIVES SAFETY.

Explosives safety requirements are not covered by this document. When assessing any existing facility for use in military operations, exposure to the potential accidental explosive effects of U.S., host nation or multi-national Ammunition and Explosives (AE) in the surrounding area must be taken into consideration. Assessment of all facilities potentially falling within any explosive safety arcs should be performed in close coordination with knowledgeable explosives safety professionals. Explosive safety arcs around, but not limited to, AE storage, handling, maintenance, manufacturing, and disposal must be taken into consideration.

1-11 SPECIAL-USE FACILITY.

When the facility being assessed is proposed for special usage (e.g., hazardous material/hazardous waste storage, medical facility) additional criteria must be considered, and evaluation must be performed by specialists in that field.

CHAPTER 2 ASSESSMENT PROCESS

2-1 EVALUATION LEVELS.

The three levels of evaluation for facility occupancy are “Preliminary Evaluation”, “Detailed Evaluation” and “Engineering Evaluation”, further defined and described in the following sub-sections and chapters of this UFC. The items assessed are limited to requirements that affect life safety and health of occupants. Successful completion of an evaluation and mitigation of any deficiencies provides a level of safety to building occupants as described for the given evaluation level, for the duration defined for the given evaluation level. If the use of the building changes or the building systems are impacted by an adverse event (high winds, earthquakes or other battle damage), previous evaluations are no longer valid. In this situation, re-evaluate the building to re-establish the desired level of safety.

The Preliminary and Detailed Evaluations assess different items, and both evaluations are necessary to insure building safety and habitability. If time and skilled evaluators are available for the initial assessment, the Preliminary and Detailed Evaluations should be performed concurrently. Appendices D and E of this UFC contain checklists of specific items to be assessed during the evaluations. See Table 2-1 for a comparison of the evaluation level required and the inspector qualifications, based on the desired duration of building occupancy.

Copies of completed evaluation paperwork are to be maintained within the facility itself. In addition, copies of the Detailed and Engineering Evaluations are to be forwarded in accordance with operational requirements of the command’s Engineer Support Plan.

Table 2-1 Evaluation Level Comparison

	Preliminary	Detailed	Engineering
UFC chapter	Chapter 3 & Appendix D	Chapter 4 & Appendix E	Chapter 5
Purpose	Minimal level of safety for expedient, limited-use occupancy	Moderate level of safety for broader-use occupancy	Full compliance with all safety requirements for DoD Semi-Permanent facilities
Evaluators	Non-technical	Technical knowledge	Professional engineers
Focus	Extreme hazards posing imminent danger, less electrical and mechanical systems	Near-term risks to safety and health, including electrical and mechanical systems	Long-term risks from all building systems and functions
Valid period	90 days	5 years	10 years (extendable to 25 years)

2-2 PAST BUILDING USAGE.

Prior usage of the building being evaluated is important in identifying potential hazards that could exist. For instance, a building with a prior use as an industrial facility could likely have chemical contamination or other hazards that may classify the building as unsafe for occupancy.

Attempt to obtain documentation that would indicate past building usage or detailed design and construction documents (as-built drawings). Interviewing local residents as to prior building usage is also a valuable source of data.

CHAPTER 3 PRELIMINARY EVALUATIONS

3-1 PURPOSE.

The Preliminary Evaluation is a limited assessment to identify extreme hazards that pose an imminent risk to life safety or health, and to provide limited safety for immediate but limited-use occupancy. It is a tool for an Officer-in-Charge to identify buildings or portions of buildings that are safe to occupy for short periods of time. The evaluation is intended to be completed expeditiously with limited resources. Most buildings can be evaluated in 1-2 hours by field personnel, typically non-commissioned officers (NCO's).

The evaluation focuses on identification of structural damage, identification of hazardous materials, and verification of emergency egress pathways. The procedure includes mitigations for common deficiencies. It does not assess electrical or mechanical systems due their technical complexity. These systems are considered unsafe to operate pending completion of a Detailed Evaluation.

Due to the minimal scope of the Preliminary Evaluation and the limited experience of the evaluators, significant risks may exist even with a successful evaluation. Some of the risk, noted below, will increase with the duration of occupancy. For this reason, the preliminary evaluation is valid for a period of only 90 days which can be extend to 180 days with a second preliminary evaluation, to confirm that the condition of the building has not changed or that appropriate mitigations are in place. Performing successive Preliminary Evaluations to extend the occupancy beyond 180 days without performing a Detailed Evaluation is risky due to the potential for unknown or undiscovered hazards. The Detailed Evaluation is intended to better assess risks associated with longer term occupancy periods.

- Structural collapse from moderate or extreme environmental events, existing condition defects or overload.
- Fire or poisoning from combustible or hazardous materials
- Entrapment during fire due to lack of egress pathways.
- Electrical shock, severe burns or electrocution from improperly installed, damaged material, equipment or inadequate grounding system

3-2 GENERAL PERSONAL SAFETY.

Primary concern should be the evaluator's own personal safety. The following are basic parameters to ensure safety when conducting occupancy assessments:

1. Always wear standard issue personal protective equipment (PPE).
2. Work in teams of at least 2 people or have means of communication to response personnel
3. Be alert for falling objects or tripping hazards

3-3 EQUIPMENT FOR PRELIMINARY EVALUATIONS OF ALL SYSTEMS.

The following equipment is needed to assess all buildings and systems:

- Tape Measure
- Flashlight
- Camera
- Screwdriver

3-4 PRELIMINARY EVALUATION PROCESS.

A Preliminary Evaluation is performed utilizing the checklist in Appendix D of this document. The checklist is arranged in the order in which the evaluation should take place. In order to ensure personal safety, the inspector initially assesses the building and site for basic hazards from the exterior by traversing the perimeter of the facility prior to entering the building for interior assessments. The building can be entered only if the exterior visual assessment deems the building as safe. The Evaluation then proceeds with an initial interior walk-thru to expeditiously assess issues that may prevent occupancy. After completion of the exterior assessment and initial interior walk-thru, the building systems are evaluated by discipline to identify hazards that threaten life safety or health. If de-energized prior to assessment, building mechanical and electrical systems should not be turned on during preliminary evaluations to assess for short-term occupancy.

CHAPTER 4 DETAILED EVALUATIONS

4-1 PURPOSE.

The Detailed Evaluation identifies hazards that pose near-term risks to life safety and health, and provides minimal safety and habitability for longer occupancy periods than the Preliminary Evaluation. It also reduces risks to occupants by providing a broader assessment of buildings including electrical mechanical systems compared to the Preliminary Evaluation. The procedure includes mitigations for common deficiencies and focuses on:

- Identification of damaged, deteriorated or overloaded structures or elements
- Fire Protection
    - Occupancy based egress
    - Occupancy or building separation (via distance or physical separation)
    - Automatic fire sprinklers
    - Fire detection and notification
- Electrical system configuration, material and equipment installation and grounding
- Water distribution and sanitary systems

The Detailed Evaluation does not address all safety and habitability requirements that are specified in UFC 1-201-01 which are addressed in an Engineering Assessment. Occupancy limits or restrictions are intended to improve safety for higher risk occupancies (billeting, assembly and cooking operations).

Due to its limited scope, the detailed evaluation is valid for a period of five (5) years. Risks from building occupancy or failure to adequately mitigate deficiencies include:

- Structural collapse from extreme environmental events or from continuing deterioration of structural elements
- Fire
- Entrapment during fire due to lack of egress pathways
- Electrical shock, severe burns or electrocution from improperly installed, damaged material, equipment or inadequate grounding system
- Contamination or illness from water supply or sanitary systems

The Detailed Evaluation may take a full day, and could require longer for larger buildings. This evaluation must be performed by a trade-specific team with knowledge of building construction and building systems, such as technically-qualified Senior NCO's or Junior Officers.

4-2 FIELD EQUIPMENT.

The following equipment is needed to conduct a Detailed Evaluation.

4-2.1 Equipment for Detailed Evaluation of Structural Systems.

The following equipment is typically used to assess building structural systems:

- Ruler: Used to measure deflection, displacement, leaning, section loss, crack size, or separation.
- String: Used to measure member deflection or displacement.
- Plumb Bob: Used to measure leaning or out-of-plumb members.
- Level: Used to measure floor slope, settlement, and member deflection or displacement.
- Hammer: Used to locate delaminated or unsound portions of concrete or fully grouted masonry members.
- Knife: Used to probe wood members to identify decay or insect damage.
- Binoculars: Used to visually identify damage or deficiencies in portions of the structure that are inaccessible or at a distance.

4-2.2 Equipment for Detailed Evaluation of Fire Protection Systems.

The following equipment is typically used to assess building fire protection systems, active and passive:

- Step Ladder: Access Ceilings
- Camera
- Tape Measure
- Hand tools
- Flash light

4-2.3 Equipment for Detailed Evaluation of Plumbing and Mechanical Systems.

The following equipment is typically used to assess building plumbing and mechanical systems:

- Portable Water Temperature Sensor (in piping)
- Portable Water Test Kit (for collecting and testing water samples)
- Portable Air Temperature Sensor

4-2.4 Equipment for Detailed Evaluation of Electrical Systems.

The following equipment is typically used to assess building electrical systems:

- Voltage/Amp Meter
- Receptacle Tester
- Wrench
- Screwdriver

4-3 STRUCTURAL SYSTEMS.

This section includes assessment and risk mitigation of common deficiencies found with regard to structural systems in existing facilities. The structural deficiencies and conditions listed in this section are numerous, but not intended to be all inclusive. Judgment must be exercised by assessors for deficiencies observed that are not listed. All structural system evaluations outlined in this section are performed by visual inspections, field surveys, and on-site measurement and testing.

4-3.1 Field Surveys and On-Site Testing.

Perform visual inspection, measurement, and testing of building and structural components to assess the structural framing system, primary gravity and lateral force resisting systems, materials, and potential structural deficiencies identified in the section entitled, “Acceptance Criteria”. Begin with a survey of the exterior of the building on all sides looking to identify overall deficiencies listed in the section entitled, “Overall Structural Damage”. If no deficiencies are found, perform a survey of the interior of the structure looking to identify deficiencies to individual framing components as indicated in the section entitled, “Damage to Structural Framing Components”.

As necessary, perform on-site measurement and testing of structural components and materials including, but not limited to, the following:

- General Displacements: Measure the following typical displacements as follows:
    - Leaning or out-of-plumb structural members using a plumb bob and tape measure/ruler; floor slope or settlement using a level and tape measure/ruler; crack widths using a tape measure or crack width ruler; and member deflections or displacements using a string with a line level and tape measure/ruler.
    - Structural Steel: Measure section loss due to corrosion using calipers or ruler.
    - Masonry or Concrete: Tap on concrete or fully grouted masonry with hammer to locate delaminated or unsound portions of members. Measure section loss in any exposed corroding reinforcing steel.

Identify and measure the widths and extents of all significant cracks (typically 1/8 inches (3 mm) or wider).

- o Wood: Probe wood members with a screwdriver or knife to identify decay or insect damage. Measure section loss with a ruler.

Visual inspection, tests, and measurements must be executed as thoroughly and carefully as required to detect the presence and extent of any of the conditions outlined in the following the section entitled, “Acceptance Criteria”.

4-3.2 Acceptance Criteria.

Perform inspection of building to identify the existence of any of the conditions listed below. If any of the following conditions are identified, see the section entitled “Mitigation Measures”.

4-3.2.1 Overall Structural Damage.

Perform inspection of the exterior of the building to determine the existence of any of the following conditions:

- Collapse or partial collapse.
- Building or individual story leaning more than 4 inches (100 mm) total or more than H/200 (where H= height of building or story height in inches).
- Base of building pulled apart with cracks or separations exceeding ¼ inch (6 mm), or differentially settled, with fractured foundations, broken anchor bolts, or displaced soils. Building shifted off foundation.
- Building in zone of suspected major soil slope movement, sinkholes, or severe erosion.
- Building in danger of being impacted by sliding or falling landslide debris from upslope.
- Significant exterior wall cracks or out of plane wall offsets at cracks.
- Significant blast or fire damage.
- Any loose or damaged finishes, parapets, canopies, built up ice or snow on roofs, or other items that could fall on occupants, especially at entrances.

4-3.2.2 Damage to Structural Framing Components.

Perform inspection of the interior of the building to determine the existence of any of the following conditions:

- Leaning: Columns, piers, or bearing walls (including foundation walls) substantially out of plumb as measured by a horizontal offset exceeding 4 inches (100 mm) total or more than H/200 where H is the height of the vertical member being measured (column, building story, etc.) in inches.

- Buckling: Columns, piers, diagonal bracing, or bearing walls (including foundation walls) that are buckled or bowed.
- Damage to horizontal framing members: Roof or floor framing exhibiting cracks, spalls, splits, or other damage, sloping or sagging in excess of L/180 at any point along the span where L = span length in inches, or separation from walls or other supports.
- Damage to vertical framing members: Any cracking with vertical or horizontal displacements in columns, walls, piers, pilasters, diagonal bracings, or corbels.
- Connections: Visible damage of floor-to-wall, roof-to-wall, beam-to-beam, beam-to-column, column-to-floor, or diagonal bracing connections; steel framing, missing bolts or rivets, cracks or breaks in welds, bolts, or connection plates and angles; wood framing, split members at joints or gaps between ends of connected members; concrete and masonry framing, significant cracks at joints between members and/or exposed reinforcing steel at connections.
- Bracing: Broken, bent or damaged bracing members or elements and their connections in horizontal and vertical planes.
- Connection to foundation: Damaged connections between superstructure and foundation that would allow uplift of structure or movement off foundation during wind or seismic event.
- Fire: Evidence of fire resulting in significant reduction in member depth or width in wood framing, twisting or warping of steel framing, or spalling of concrete or masonry and damage to reinforcing steel.
- Deterioration of structural elements from exposure to weather or contact with earth: Rotting or insect infestation in wood framing; corroded structural steel members; corroded reinforcing steel and concrete spalling and cracking in concrete structures; freeze-thaw splitting and cracking damage in structural masonry or concrete. Effective loss of member width/depth or weakening of any structural element due to deterioration.
- Falling hazards: Any loose or damaged structural framing, non-structural finishes, ductwork, equipment, or architectural elements that could fall on building occupants.

4-3.3 Mitigation Measures.

Should any of the conditions from the section entitled, “Acceptance Criteria” be observed, the building is unsafe to occupy until mitigation measures outlined below for specific conditions have been implemented, or Reachback has been engaged and specified mitigation has been completed.

For single story structures, cordon off damaged portions of structures with areas of localized damage or collapse totaling less than 25% of the overall building footprint.

Damaged or partially collapsed multi-story buildings or structures with damage to more than 10% of the overall building footprint are unsafe to occupy; consult Reachback.

Remove any non-structural debris and loose finishes that are considered a falling hazard. Engage professional engineering personnel to determine appropriate repair measures or to evaluate the potential for removal of damaged or loose structural elements that could pose a falling hazard. To prevent overloading of the structure, locate storage and/or heavy equipment on ground supported floor slabs.

4-4 FIRE PROTECTION

This section includes survey methods and lists of common deficiencies found with regard to fire protection in existing facilities. The information herein is limited to fire protection requirements that affect life safety of occupants, without consideration for mission continuity. Survey the building by conducting a walk-through of each room. Complete the checklist for Detailed Evaluations that is included in Appendix E.

This document provides guidance related to fire separation of buildings for preventing fire spread between buildings. For requirements for space separation between buildings related to anti-terrorism/force protection, refer to UFC 4-010-01. It is not the intent of this document to supersede UFC 4-010-01.

For definitions of terms used in this section, see Appendix C.

Reachback assistance is required for any modification or additions to any fire protection systems.

4-4.1 Fire Protection Detailed Evaluations.

These requirements are not for use in engineering evaluations.

4-4.1.1 Building Separation.

Perform the following assessments:

- Determine the building separation from any nearby buildings as defined in Appendix C-1.
- If the building is less than 30 ft. (9.1 m.) from adjacent buildings, the following criteria must be met:

Table 4-1 Separation Requirements

Separation Distance "X"	Exterior Wall Construction of Building to be Occupied	
	Factory Industrial, Business or Storage Occupancies	**Billeting, Institutional or Assembly Occupancies**
X < 10 ft. (X < 3.1 m.)	Contiguous Exterior wall with No Openings	Contiguous Exterior wall with: 1) Noncombustible Exterior Facing, 2) No Openings or Protected Openings
10 ≤ X < 30 ft. (3.1 m. ≤ X < 9.1 m.)	Contiguous Exterior wall with No Openings, or Protected Openings	Contiguous Exterior Wall with No Openings, or Protected Openings
X ≥ 30 ft. (X ≥ 9.1 m.)	No restrictions	No restrictions

4-4.1.2 Building Height.

Perform the following assessments on the building:

- Determine the number of stories of the building as defined in Appendix C-1.
- Determine the construction type of the building, combustible or non-combustible, as defined in Appendix C-1.
- Determine the existence of vertical openings as defined in Appendix C-1.

Building requirements or restrictions based on Building Height are as follows:

- Buildings of non-combustible construction, or of any construction with a functional automatic sprinkler system throughout, and with no vertical openings connecting more than 2 stories, can be safely occupied up to 3 floors above grade.
- Buildings of combustible construction, without an automatic sprinkler system, or with unprotected vertical openings between more than 2 floors, can be safely occupied up to 2 floors above grade.
- Building basement levels can be safely occupied by occupancies other than billeting, institutional or assembly.
- Sub-basement levels as defined in Appendix C-1 cannot be safely occupied.

4-4.1.3 Occupancy.

Determine the following:

- Confirm the planned occupancy (ies) as defined in Appendix C-3.

Building requirements based on Occupancy type are as follows:

- Dining, medical (non-inpatient), administrative, and/or recreational facilities may be collocated in a single structure.
- Where mixed occupancies as defined in Appendix C-3 exist, the most restrictive life safety requirements (including allowable travel distances, building separation requirements, fire protection requirements, and fire alarm requirements herein) for the occupancies involved are applied.

4-4.1.4 Means of Egress.

Perform the following assessments and calculations regarding Means of Egress:

- Survey all building areas to be occupied and determine the following:
  a. Number of exits (as defined in Appendix C-2) per floor,
  b. Width of exit doors as defined in the Exit Capacity definition in Appendix C-2,
  c. Internal width of exit stairs as defined in the Exit Capacity discussion in Appendix C-2,
  d. Longest travel distance per floor as defined in Appendix C-2,
  e. Length of any dead end corridors as defined in Appendix C-2,
  f. Existence of any large areas (over 2000 sq. ft. (186 sq. m.)) with only one door or path leading to an exit.
  g. Measure the area(s) to be used as assembly spaces.
  h. Confirm if any assembly occupancies are provided with only one door or exit path leading to an exit from the assembly space.
- Confirm one of the following:
  - o Each exit remains unlocked in the direction of egress when the area is occupied, OR:
  - o Any locked doors in an exit path are under the control of the occupants of the room/space, and are provided with panic hardware as defined in Appendix C-2.
- Confirm that exits are not blocked or obstructed by materials, so that access to exits is available.
- Confirm that enclosed exit stairs are not used to store materials.

- Calculate occupant loads based on the parameters given in Appendix C-3. Measure overall areas of spaces to be occupied.
- Calculate the exit capacity as defined in Appendix C-2 based on the number of exits for a space.
- Compare the calculated exit capacity to the calculated occupant load. It is unsafe to occupy the space if the occupant load is higher than the exit capacity.
- Compare the measured travel distance to the travel distance limits for the occupancy involved from the definitions section in Appendix C-2.

4-4.1.5 Automatic Sprinkler Systems and Fire Suppression Systems.

Automatic sprinkler system is required for billeting occupancy and a fire suppression system is required for kitchen grills/hoods.

Perform the following assessments on the automatic sprinkler systems (if provided):

- Identify any existing sprinkler, standpipe, hose stations, or other fire suppression system in the building.
- A qualified person should confirm that existing water supplies (fire pump, water storage tanks, or public water system) are in service. Fire pumps should be operated by decreasing the sprinkler system pressure or flowing water in the system to determine if the fire pump starts automatically on pressure drop.
- Qualified persons include persons trained specifically within the trades of building engineering or maintenance, or active fire protection systems maintenance or installation. Contact Reachback for assistance before conducting any testing of these systems.

4-4.1.6 Fire Alarm Systems.

Fire alarm systems are required for the following:

a. A building with billeting occupancy (smoke detection is strongly recommended to be included)

b. A building with assembly occupancy.

c. A building with institutional occupancy.

d. A building with business occupancy over 5,000 sq. ft. (465 sq. m.) in a basement, second or third floors.

Perform the following assessments on the fire alarm systems (if provided):

- If building has existing fire alarm notification systems, a person, specifically trained in building engineering or maintenance, or trained in fire alarm system installation or maintenance, should determine if the notification systems are functional by operating the system. Confirm that notification appliances produce audible levels of sound in all areas of the building, or record what portions of the building have fire alarm notification appliances. If speakers are provided, confirm that the language used in the announcement is understood by the planned occupants.

- If a fire detection system is present, determine the extent of the system's coverage.

Fire alarm systems provided for the purpose of compliance with this document may be battery operated multiple station type smoke alarm systems, interconnected either by wires or wireless type.

4-4.1.7 Hazardous Areas.

Perform the following assessments:

- Identify hazardous areas and equipment as defined in Appendix C-1.
- Existence of hazardous areas or equipment without fixed separation by walls or space separation is not safe, see the section entitled, "Hazardous Areas" for mitigation.

4-4.1.8 Interior Finish.

Perform the following assessments of the building's interior finishes:

- Determine the interior finish in occupied areas through observations.
- Gypsum wallboard (or sheetrock), unpainted or painted metal, 3/8 inch (9.5 mm) painted or unpainted plywood, concrete block or other stone materials provide acceptable interior finish. Combustible fabrics or textiles, and rigid or sprayed-on plastic foam insulations are not acceptable as interior finishes for occupied areas.

4-4.1.9 Vertical Openings.

Perform the following assessments:

- Identify any vertical openings as defined in Appendix C-1 that exist within occupied floors.
- Vertical openings connecting more than 2 stories is not safe.

4-4.2 Mitigation Measures.

4-4.2.1 Building Separation.

For single story structures, if the fire separation criteria are not met, a mitigating measure to provide protected openings can be provided with HESCO or other similar barriers, free-standing pre-cast concrete type barriers, or sandbag revetments between buildings. If these barriers are at least as tall as the eave of the taller of the two buildings to be separated, separation between the building under consideration can be considered adequate. For taller buildings, it is also acceptable to cover existing glazed openings in exterior walls from the interior side with plywood, metal or gypsum board, or to locate sandbags along the interior side of the wall opening. Open doorways can be protected by providing solid core wood or metal doors with no glazed openings and an automatic closer. Open louvers can be provided with an extended metal cover. If this issue cannot be addressed through these field mitigation measures, obtain Reachback assistance to identify additional options.

4-4.2.2 Building Height.

Limiting occupancy to lower levels and to a single basement promotes more timely and safe relocation of persons. If it is possible to reliably limit occupancy of higher floors through administrative procedures, then it would not be necessary to physically block access to higher floors.

If building height issues cannot be resolved with field modifications given herein, if it is desired to occupy levels higher or lower than those stated herein, or if repairs to vertical openings are planned, use Reachback for technical assistance.

4-4.2.3 Occupancy.

It may be possible to mitigate existing occupancy deficiencies by providing passive or active fire protection systems.

Reachback for technical assistance is necessary for technical solutions to mixed occupancy issues that cannot be addressed by the mitigation measures presented herein.

4-4.2.4 Means of Egress.

If there are not a sufficient number of exits, the exits do not provide sufficient exit capacity, or actual travel distances exceed the travel distance limits provided herein, an exit (or exits as needed) can be added by providing an exterior exit in an exterior wall if practical. If on an upper level floor, an exit door to a fire escape can be built if practical, with Reachback assistance. Fire escapes must be constructed of noncombustible materials and supported by surrounding grade if practical (rather than hung from the building). If security or other constraints do not permit installation of a fixed external fire escape ladder, provide a portable fire escape ladder in each room near an above grade window. Newly provided second exits or escape ladders should be separated by as much distance as practical from the other existing exit within a space. Contact Reachback assistance before beginning any new construction work or modifying existing construction.

Exit paths from spaces must be provided only through spaces of less hazardous occupancies that are under control of the persons egressing, and not subject to locking. For example, an exit path from one office through another office that is not subject to locking is acceptable. An egress path from an office through a storage room subject to locking, or through a boiler room is not acceptable. A second option for exiting should be provided in this situation, or the office area should not be occupied. It is not safe for Assembly occupancies to be located in areas with only one exit path, and should be relocated if it is not possible to provide a second exit path from the space.

One option for compliance is to only occupy the portion of a space within the allowable travel distance for the occupancy. If functioning sprinkler systems are provided for the occupied areas, contact Reachback if additional travel distance and dead end allowances are needed.

4-4.2.5 Automatic Sprinkler Systems.

For a billeting occupancy, the lack of automatic sprinkler systems in a building is a deficiency. For buildings with planned occupancy for billeting limit the total area of billeting occupancy to less than 7,000 sq. ft. (650 sq. m.) per level, and provide **one** of the following four options to mitigate this deficiency(a or b or c or d):

a. A fire watch covering all areas of the building.

b. Direct exits from each living unit, or from each open area to the exterior.

c. Solid, contiguous, full height stud or Concrete masonry unit type (CMU) wall partitions subdividing each living unit, and functioning battery operated smoke alarms within each living unit. Smoke alarms must be either wired multiple station, or wireless multiple station type.

d. Limit the number of beds to less than 10 within an occupied building.

For open bays planned for billeting occupancy greater than 7000, sq. ft. (650 sq. m.), contact Reachback support for assistance. Occupancy load, egress and ceiling height must be evaluated in order to determine appropriate mitigating fire protection system, active and/or passive requirements.

For occupancies other than billeting, building automatic sprinkler systems can be mitigating factors for certain other deficiencies. The lack of an automatic sprinkler systems throughout the occupancy or building is not a deficiency for occupancies other than Billeting.

4-4.2.6 Fire Alarm Systems.

Fire alarm systems (notification) are required in certain occupancies as noted in the section entitled, “Fire Alarm Systems” located in Fire Protection Detailed Evaluation paragraphs.

The existence of a complete, functional sprinkler system in all areas of a building, with water flow alarms is sufficient mitigation for a fire detection and alarm system or fire alarm notification system.

A 24 hour fire watch is a mitigating factor for the lack of a fire notification system. A person on duty having a portable horn or sounding device to notify all occupants in case of a fire event is a mitigating factor for an automatic alarm system. If the building is not occupied 24 hours a day, the fire watch is only necessary while the building is occupied.

New equipment installation or repairs beyond simple corrections need to be conducted under the guidance of Reachback assistance. If fire alarm systems are not provided and are needed, or if it is desired to provide a fire alarm system as a mitigating factor or any other reason, contact Reachback support for assistance.

4-4.2.7 Hazardous Areas.

Hazardous areas or hazardous equipment without fixed separation by walls is a deficiency. For hazardous equipment, as defined in Appendix C-1, this issue can be resolved by the existence of, or by providing a fixed suppression system (wet or dry chemical system typically), or providing a separating wall around the equipment area. Space separation of at least 25 ft. (7.6 m) from occupied buildings is also mitigation for unprotected hazardous equipment.

Existing or planned hazardous areas need segregation and/or fire protection (as discussed herein) if these areas are to remain in service within a building. Relocation of hazardous areas outside the building in a separated area is the preferred option, if possible. It is acceptable to remove hazardous equipment from service by administrative controls if it can be confirmed that the system will remain unused.

The preferred method of mitigating hazardous material or waste storage is removal of the storage to a location outside and separated from occupied buildings by at least 50 ft. (15.2 m). Any detailed evaluations of ventilation or containment systems, or improvements for these systems needs to be through Reachback assistance.

Installation of new construction enclosure walls, automatic sprinkler system, fire suppression systems, repairs or modifications of existing hazardous equipment to reduce its hazard, needs to be conducted with Reachback for technical assistance. It needs to be confirmed that a new hazard (inadequate ventilation, etc.) is not created by enclosing a hazardous operation.

4-4.2.8 Interior Finish.

In order to provide a thermal/fire barrier, exposed combustible insulation (polystyrene, polyurethane, paper or similar types of insulation), or combustible finishes (cork, plastic or fiberglass panels, cloth or similar finishes) can be covered with ½ inch (12.7 mm) layer of gypsum wallboard, 3/8 inch (9.5 mm) plywood, 22 gage corrugated steel, or removed, if possible. Exposed foam-in-place insulation is considered a highly combustible material; unless specific documentation is provided to the contrary. Combustible decorations must be removed from occupied areas.

4-4.2.9 Vertical Openings.

Vertical openings connecting more than 2 stories is not safe. The measures given in the section entitled, "Building Height" to only occupy two floors above grade level provides sufficient mitigation of a vertical opening issue. If it is desired to occupy levels more than two stories above grade, and a vertical opening exists within the planned space that is more than 2 stories, use Reachback assistance to see if the facility, considered in its entirety, can be occupied as planned.

One field measure that can be taken to resolve a vertical opening issue in buildings higher than two stories is enclosing the open shaft (for example, enclosing one level of a 3-story opening to create a 2-story vertical opening) with gypsum wall board. It should be confirmed that enclosing a shaft used for supplying air will allow the shaft to provide mechanical ventilation, and that this modification may not cause structural issues. Any construction modifications should be completed under the guidance of Reachback assistance.

4-5 PLUMBING AND MECHANICAL SYSTEMS.

This section includes assessment and risk mitigation of common deficiencies found with regard to plumbing and mechanical systems in existing facilities. A checklist for use during assessments for Detailed Evaluations is included in Appendix E.

All plumbing and mechanical system evaluations outlined in this section are performed by visual inspection and tests. Refer to TM 3-34.70/MCRP 3-17.7E, *Plumbing, Pipe Fitting, and Sewerage*, for assistance in these Plumbing and Mechanical inspections.

4-5.1 Features Evaluated.

The following features are to be evaluated by visual inspection and tests.

4-5.1.1 Domestic Water System.

Perform the following assessments on the domestic water system:

- Take samples and test domestic water to verify water is safe to use and safe to drink.
- Visually inspect facility water storage tank (when located on roof or inside the facility) and all exposed domestic water piping and examine condition of ceilings, walls, and floors for signs of domestic water piping leaks.
- Determine if cross connections exist in piping systems.
- Determine and record location of domestic water service and main shutoff valve.

4-5.1.2 Domestic Water Heating Equipment.

Perform the following assessments on the domestic water heating equipment:

- Examine domestic water heating systems to determine if the systems have the following safety features.
  - Anti-siphon device, such as a cold water drip tube or a vacuum relief valve installed in the cold water supply line
  - Electrical disconnect or fuel supply shut off valve
  - Self-closing pressure relief and temperature valve
  - Pressure relief valve discharge pipe
- Determine if water is being heated and equipment is functioning properly, and if the hot water equipment consists of pressurized or non-pressurized tanks.

4-5.1.3 Sanitary Drainage and Vent System.

Perform the following assessments on the sanitary drainage and vent system:

- Visually inspect all exposed sanitary drainage and vent piping and examine condition of ceilings, walls, and floors for signs of sanitary system piping leaks.
- Examine fixture piping to ensure traps are present.
- Examine vents through roof to ensure they are free from blockages.

4-5.1.4 Roof and Overflow Drainage Systems.

Perform the following assessments on the roof and overflow drainage systems:

- Visually inspect all exposed roof drainage and overflow drainage piping and examine condition of ceilings, walls, and floors for signs of roof drainage and overflow drainage system piping leaks.
- Visually inspect all roof drains to ensure they are free from blockages.

4-5.1.5 HVAC Distribution System.

Perform the following assessments on the HVAC system:

- Before visual inspection and tests are conducted on the HVAC system, obtain local climatic conditions and validate required indoor environmental conditions for various occupancies and functions proposed for the facility.
- Inspect all HVAC equipment and perform functional testing to determine if safe and operational.
- Measure and record HVAC system air and water temperatures where possible.

- Inspect system filters and replace as necessary.

4-5.1.6 HVAC Piping Systems.

Perform the following assessments on the HVAC piping system:

- Visually inspect all exposed piping and ceiling areas to determine if pipes are leaking.
- For piping associated with HVAC systems, measure and record water system temperatures where possible.

4-5.2 Mitigation Measures.

4-5.2.1 Domestic Water System.

If water tests show that domestic water is not safe, shut off or disable water supply and post signs that state “Do Not Use Water”. If water tests show that water is safe but not potable, post signs that state “Do Not Drink Water”.

If pipes are found to be leaking, trace leaks back to their source and determine feasibility of repairs. If leaks are repairable, then shut off water, repair leaks, and re-fill domestic water system. If it is not feasible to repair the leaks, determine if severity of leaks necessitates a new piping system or if leaks can be tolerated without negative impact on the mission.

Determine if domestic water system has any direct connections to the building drainage system that would indicate a cross connection. If cross connections exist, record locations and piping arrangement and submit for Reachback support.

4-5.2.2 Domestic Water Heating Equipment.

Determine power or fuel source for domestic water heating equipment and ensure all connections to domestic water heating equipment are securely made.

Determine if necessary safety devices are installed on the domestic water heating equipment. Install any devices that are missing or not operating properly. The following safety devices are required:

- Vacuum relief valve on cold water piping located above water heater or tank for down-feed hot water systems or bottom-fed domestic water heaters.
- Means for disconnecting an electric water heater from its power source or a shutoff valve for piped fuel sources
- Temperature relief valve, pressure relief valve, or combination temperature and pressure relief valve.

Determine temperature of hot water storage and delivery systems. If the systems are not set at the temperatures listed below, change equipment settings to obtain the desired storage and distribution temperatures. Install a thermostatic mixing valve with the following set points to regulate water heater outlet temperatures if not already installed and operational.

- Hot water storage systems - 140°F (60°C)
- Hot water delivery systems - maximum temperature 120°F (49°C)

4-5.2.3 Sanitary Drainage System.

If pipes are found to be leaking, trace leaks back to their source and determine feasibility of repairs. If leaks are repairable, repair leaks on sanitary system. If it is not feasible to repair the leaks, determine which fixtures are upstream of leaks and decommission fixtures or post signs that state “Do Not Use Fixtures”.

Run water through fixture drains to ensure that all fixture traps have a trap seal.

Remove any blockages from vents through roof.

4-5.2.4 Roof and Overflow Drainage System.

If pipes are found to be leaking, trace leaks back to their source and determine feasibility of repairs. If leaks are repairable, repair leaks on roof drainage and overflow drainage system. If it is not feasible to repair the leaks, determine which roof drains or overflow drains are upstream of the leaks and determine if severity of leaks necessitates another means of roof drainage such as scuppers or if leaks can be tolerated without negative impact on the mission.

Remove any blockages from roof drains and overflow drains.

4-5.2.5 HVAC System.

If system operation is found to be faulty or potentially hazardous, system must be disabled by disconnecting power to the system.

4-5.2.6 HVAC Piping System.

If pipe leaks are found, the system should be traced and shut off if possible using existing shutoff valves.

4-6 ELECTRICAL SYSTEMS.

This section includes assessment and risk mitigation of common deficiencies found with regard to electrical systems in existing facilities. A checklist for use during assessments for Detailed Evaluations is included in Appendix E.

Electrical systems are inherently dangerous and all survey work requires a trained electrician. All equipment found to be de-energized must remain de-energized until a Detailed Evaluation can be performed. Proper personal protective equipment (PPE) must be used when testing or inspecting energized equipment.

Evaluate facilities against NFPA 70, *National Electrical Code (NEC)*, requirements for 60 hertz (Hz) systems and BS 7671, *Requirements for Electrical Installations*, requirements for 50 Hz systems.

4-6.1 Electrical Detailed Evaluations.

The Detailed Evaluation checklist included in Appendix E contains a sample Panel Schedule. This schedule format can be used to gather much of the electrical system data as outlined in this section and the accompanying checklist.

4-6.1.1 Short Circuit Ratings.

Using proper Personal Protective Equipment (PPE), collect the following information and provide to Reachback resources:

- Obtain volts, amps, number of phases and AIC rating for each panel.
- Obtain electrical equipment nameplate data such as horsepower, voltage, phase, and ampere for each feeder, panel, motor, transformer and major equipment item.
- Obtain feeder types, sizes, lengths, and quantity of feeders in each run, and the type of raceway in which each feeder is installed.

Reachback to perform the following after obtaining data above:

- Conduct infinite bus theory to estimate utility fault current if utility's data is unavailable.
- Perform short circuit calculations utilizing industry-recognized software in compliance with the IEEE Standard 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis*, recommended practices.
- Compare the results of calculations with actual equipment ratings.
- Create an up to date one-line diagram showing existing electrical system, refer to sample one-line diagram in Appendix E.
- Determine if electrical equipment has an AIC rating higher than the available fault current. The equipment must include, but is not limited to switchgear, switchboards, panelboards, busways, and safety switches.

4-6.1.2 Distribution System Grounding and Bonding.

Perform the following assessments and calculations:

- Inspect and test the facility's grounding system per NFPA 70 (60 Hz) or BS 7671 (50 Hz) and NFPA 780, *Standard for the Installation of Lightning Protection Systems*, for buildings with lightning protection, in addition to the following:

- Ensure there are no loose connections. Utilize infrared camera if available to look for hot spots when the system is energized.
- Ensure the system neutral is bonded to equipment grounding system at the service entrance including the connection to the grounding electrode for 60 Hz systems. Many 50 Hz systems, such as TN-S only require bonding at the source, i.e. transformer. This complies with BS 7671.
- Ensure ground rods are installed; if possible verify that the measured ground resistivity is 25 ohms or less at the service entrance for 60 Hz systems or at the source for 50 Hz systems.
- Check for electrical continuity between any metallic cold water pipes and the main grounding bus bar.
- Ensure separately derived systems (such as transformers, generators, battery/inverter systems, photovoltaic systems) are properly grounded.
- Record all grounding conductor sizes.
- Ensure grounding systems within the facility are bonded together at ground level or below.
- Ensure all access control fencing surrounding electrical equipment (generators, transformers, and switching stations) is properly grounded and bonded.
- Ensure facility has surge protection installed on all entering or exiting metallic electrical conductors, intrusion detection, communication antenna, and instrumentation lines. Surge protection is a requirement for all facilities with lightning protection systems installed.
- Test grounding system by using the 3 point fall-of-potential method.

4-6.1.3 Branch Circuit and Feeder Ratings.

Perform the following assessments and calculations:

- Determine the conductor sizes by either the conductors’ manufacturer marking or actual field measurements.
- Record conductor size and size of the over current protection device.
- Check for signs of damage, burning, or corrosion.
- Note if the conductors are copper or aluminum.
- Note the insulation type.
- Determine that the combination of the circuits’ conductors and circuit breakers/fuses are in compliance with the NFPA 70 (60 Hz) or BS 7671 (50 Hz) requirements for the loads being served.

4-6.1.4 Lightning Protection System.

Inspect the facility's lightning protection system per NFPA 780 in addition to the following:

- Check for loose connections.
- Check for missing conductors or components.
- Inspect system components for any signs of corrosion.
- Ensure all down conductors, roof conductors, and ground terminals are intact.
- Ensure conductors and system components are securely fastened to mounting surfaces.
- Ensure lightning protection system is bonded to the distribution grounding system.

Where a lightning protection system is not found, have a risk assessment performed per NFPA 780 via Reachback resources.

4-6.1.5 Raceways.

Perform the following assessments of the electrical raceways:

- Confirm the raceways are of the following approved types: Galvanized Rigid Steel (GRS) Conduit, Intermediate Metal Conduit (IMC), Electrical Metallic Tubing (EMT), Flexible Metallic Conduit (FMC), Polyvinyl Chloride (PVC), Liquid tight Flexible Metal Conduit and Surface Metal Raceways.
- Inspect for mechanical damage or missing raceway section or component.
- Inspect the raceway system for signs of corrosion
- Assess as to whether the raceway system is installed as defined per Uses Permitted by NFPA 70 (60 Hz) or BS 7671 (50 Hz).

4-6.1.6 Emergency and Exit Lighting.

Perform the following assessments of the emergency and exit lighting:

- Test batteries in all the egress and exit lighting fixtures. Battery must keep the fixture on for 90 minutes.
- Note the location of all exit signs. A minimum of one exit sign must be visible at every point along the path of egress. Verify exit lights at all exterior doors.
- Exit light placements are in compliance with the requirements of NFPA 101, *Life Safety Code*, and *International Building Code (IBC)*.

4-6.1.7 Transformers.

Perform the following assessments:

- Note the location of all transformers, transformer sizes, type, voltage, and nameplate information.
- Determine if the transformer is installed in accordance with NFPA 70 (60 Hz) or BS 7671 (50 Hz).

4-6.1.8 Receptacles.

Perform the following assessments of the grounded and GFCI protected receptacles:

- Note the location of all receptacles.
- Identify those receptacles that require GFCI protection and ensure protection functions are provided as required.
- Receptacles must be protected per NFPA 70 (60 Hz) or BS 7671 (50 Hz).

4-6.1.9 Foreign Voltages and Frequencies.

Obtain nameplate electrical data of the equipment and components and assure compatibility of the of the facility's electrical system voltage and frequency with the referenced electrical equipment and components which include but are not limited to HVAC equipment, transformers, fluorescent and HID lamps, motors, and circuit breakers. Refer to UFC 3-510-01, *Foreign Voltages and Frequencies Guide,* Appendix C, Derating Factors.

4-6.1.10 Circuit Lockout Requirements.

Review operational procedures for the military unit to occupy the facility to determine if they contain appropriate coverage of circuit lockout procedures.

4-6.2 Mitigation Measures.

4-6.2.1 Short Circuit Rating.

If electrical equipment's short circuit rating is not higher than the available fault current, do not energize electrical system (or de-energize if energized) and obtain guidance from Reachback resources.

4-6.2.2 Distribution System Grounding & Bonding.

Perform the following mitigation actions based on deficiencies found:

- Tighten all loose connections.
- Bond grounded (neutral) system to grounding system where required.
- Replace all grounding conductors that do not meet the NFPA 70 (60 Hz) or BS 7671 (50 Hz) requirements.

- Install ground rods.
- Repair or replace grounding and bonding system's conductors and components to meet the NFPA 70 (60 Hz) or BS 7671 (50 Hz) requirements and UFC 3-550-01*, Exterior Electrical Power Distribution*.

4-6.2.3 Branch Circuit and Feeder Rating.

Perform the following mitigation actions based on deficiencies found:

- Replace conductors and breakers/fuses as necessary to comply with the NFPA 70 (60 Hz) or BS 7671 (50 Hz) requirements for branch and feeder circuit sizing.

4-6.2.4 Lightning Protection System.

Perform the following mitigation actions based on deficiencies found:

- Tighten all loose connections.
- Provide missing conductors and components matching existing conditions.
- Replace all parts showing any sign of corrosion.
- Provide conductors for any missing down conductors and roof conductors.
- Securely fasten loose conductors and system components to mounting surfaces.
- Bond the lightning protection system to the distribution grounding system.
- Where a lightning protection system is not found and is needed, based on Reachback guidance, install a lightning protection system or abandon the building.

4-6.2.5 Raceway.

Perform the following mitigation actions based on deficiencies found:

- Replace any raceways that are not within the approved types noted above.
- Replace all damaged or missing raceway sections and components.
- Replace all corroded raceway system components.
- Exposed wiring must have sufficient mechanical protection.
- Correct raceway deficiencies to comply with NFPA 70 (60 Hz) or BS 7671 (50 Hz) requirements.

4-6.2.6 Emergency and Exit Lighting.

Perform the following mitigation actions based on deficiencies found:

- Replace defective egress and exit lighting fixture batteries.

- Provide additional exit signs such that an exit sign is always visible along the path of egress.
- Provide additional egress lighting fixtures to meet NFPA 101.
- Provide additional exit lights where necessary to comply with the requirements of NFPA 101 and IBC.

4-6.2.7 Transformers.

Perform the following mitigation actions based on deficiencies found:

- If transformers, located inside the facility, are not installed in compliance with NFPA 70 (60 Hz) or BS 7671 (50 Hz), contact Reachback for appropriate mitigation.
- Be aware of health hazards when replacing aged electrical equipment. Dry type equipment may contain asbestos. Liquid cooled components may contain oils with PCB's. Take all correct safety protections including specialized PPE when handling this equipment. Assume all equipment manufactured before 1970 to contain potentially hazardous or carcinogenic materials. Ensure proper disposal of replaced equipment is followed.

4-6.2.8 Grounded and GFCI Receptacle Test.

Perform the following mitigation actions based on deficiencies found:

- Where no grounding conductor is found, the receptacle must be GFCI protected.
- Where receptacles are located within 6 feet (2.0 m) of a water source, the receptacle must be GFCI protected. For facilities constructed in accordance with BS 7671 or similar codes, verify that GFCI protection for the entire circuit is located at the distribution board.
- GFCI protected receptacles that fail to trip must be replaced with similar.

4-6.2.9 Circuit Lockout Requirement.

If the circuit lock-out procedures are insufficient, or do not exist, then develop and utilize procedures in accordance with UFC 3-520-01*, Interior Electrical Systems*.

4-7 TELECOMMUNICATION SYSTEMS.

This section includes assessment and risk mitigation of common deficiencies found with regard to telecommunications systems in existing facilities. A checklist for use during assessments for Detailed Evaluations is included in Appendix E.

4-7.1 Telecommunications Detailed Evaluations.

4-7.1.1 Distribution System Grounding and Bonding.

Perform assessments and calculations per the section entitled, “Distribution System Grounding and Bonding”.

4-7.2 Mitigation Measures.

4-7.2.1 Distribution System Grounding & Bonding.

Perform mitigation actions based on deficiencies found per the section entitled “Distribution System Grounding and Bonding”.

CHAPTER 5 ENGINEERING EVALUATIONS

The Engineering Evaluation is a verification of compliance with minimum life safety and habitability requirements at the Semi-Permanent Construction Level specified in UFC 1-201-01. Facilities deemed to conform are safe to occupy for a period of up to 10 years. With maintenance and upkeep of critical building systems, this period can extend to 25 years. This evaluation requires extensive time and detailed information on the building, and must be performed by Professional Engineers with building design experience.

This Page Intentionally Left Blank

APPENDIX A REFERENCES

DEPARTMENT OF THE ARMY

TM 3-34.70/MCRP 3-17.7E, *Plumbing, Pipe Fitting, and Sewerage, http://armypubs.army.mil/doctrine/Active_TM.html*

DEPARTMENT OF DEFENSE

GTA 90-01-011, *Joint Forward Operations Base (JFOB) Protection Handbook,* https://rdl.train.army.mil/catalog/catalog/search.html

Joint Publication 3-0, *Joint Operations,* http://www.fas.org/irp/doddir/dod/jp3_0.pdf

DEPARTMENT OF DEFENSE, UNIFIED FACILITIES CRITERIA

http://dod.wbdg.org/

UFC 1-201-01, *Non-Permanent DoD Facilities in Support of Military Operations*

UFC 3-510-01, *Foreign Voltages and Frequencies Guide*

UFC 3-520-01, *Interior Electrical Systems*

UFC 3-550-01, *Exterior Electrical Power Distribution*

UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

http://www.ieee.org

IEEE Std 399, *IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis*

INSTITUTION OF ENGINEERING AND TECHOLOGY

http://electrical.theiet.org/

BS 7671, *Requirements of Electrical Installations*

INTERNATIONAL CODE COUNCIL

http://www.iccsafe.org/Pages/default.aspx

International Building Code (IBC)

NATIONAL FIRE PROTECTION ASSOCIATION

http://www.nfpa.org

NFPA 70, *National Electrical Code (NEC)*

NFPA 101, *Life Safety Code*

NFPA 780, *Standard for the Installation of Lightning Protection Systems*

APPENDIX B OTHER RESOURCES

The following documents can be utilized as informational resources.

DEPARTMENT OF THE AIR FORCE

http://www.e-publishing.af.mil/

AFH 10-222, Volume 3, *Civil Engineer Guide to Expeditionary Force Protection*

AFH 10-222, Volume 5, *Guide to Contingency Electrical Power System Installation*

AFH 10-222, Volume 6, *Guide to Bare Base Facility Erection*

AFH 10-222, Volume 22, *Camp Planning for Displaced Persons*

AFPAM 10-219 Volume 6, *Planning and Design of Expeditionary Airbases*

AFPAM 91-216, *U.S. Air Force Safety Deployment and Contingency Pamphlet*

ETL 09-3, *Chemical Dust Control for Contingency Roads, Base Camps, Helipads, and Airfields*

ETL 10-6, *External Foam Insulation of Temporary Structures*

ETL 10-7, *Connection Methods for Standby Generators – 600 Volts or Less*

DEPARTMENT OF THE ARMY

http://www.wbdg.org/ccb/browse_org.php?o=31

Army Handbook, *Environmental Baseline Survey and Occupational and Environmental Health Site Assessment Handbook: Contingency Operations (Overseas)*

SERVICE REACHBACK CONTACTS:

Army:

USACE Reachback Operations Center (UROC);
Email: UROC@usace.army.mil or UROC@usace.army.smil.mil;
NIPR website: https://uroc.usace.army.mil;
SIPR website: http://uroc.usace.army.smil.mil

Navy/Marine Corps:

NAVFAC PAC (PACOM AOR)
Cary Watanabe, Deputy CEBLM
cary.watanabe@navy.mil
808-472-1177

NAVFAC LANT (All other AORs)
NFCEL_CE_Reachback@navy.mil
757-322-8302

Air Force:

AFCEC Reachback Center
Email: AFCEC.RBC@tyndall.af.mil
Phone: DSN 312.523.6995, Comm 850.283.6995

APPENDIX C TECHNICAL FIRE PROTECTION DEFINITIONS AND GLOSSARY

C-1 GENERAL DEFINITIONS.

Above-grade Floor: A level in a building with all exits that are above grade, such that it's necessary to use interior stairs to exit.

Basement: A level in a building with all exits that are below grade, such that it is necessary to use interior stairs to exit. Exception: An otherwise below grade area with a "walk-out" exit, and otherwise complying with other egress requirements can be considered to be located "at grade."

Building Area: The area of the building, per floor, determined based on plans or measurements, inside the exterior walls. For buildings with areas per floor that are not equal, the effective area is the largest floor area.

Building Separation: The horizontal separation distance between the building under consideration and neighboring buildings on all sides. For multiple buildings on the same compound, assume an imaginary line halfway between buildings. The distance from building under consideration to adjacent existing buildings, or from the building under consideration to the imaginary line, whichever is shorter, is the fire separation distance.

Combustible Construction: A building with a wooden frame or floor structure is combustible. The frame of a building consists of columns, beams and/or joists. Combustible framing may not always be apparent without observing un-covered framing. Uncovered framing can often be seen in mechanical/electrical rooms or penthouses. Buildings of mixed construction types (combustible frame and noncombustible frames) are treated as combustible. If it is not possible to determine the construction type, assume it is combustible.

Combustible Storage: Combustible storage consists of paper, plastic, wooden, or cardboard materials. Metal objects, glass, and inorganic minerals (sand, salt) are non-combustible. Mixtures of combustible and non-combustible materials are combustible.

Fire Alarm Systems: These consist of speakers, horns or bells, and/or strobes or flashing lights that are operated by the fire alarm control panel in the event that an alarm condition exists.

Fire Detection Systems: Typically these systems consist of smoke or heat detectors in corridors, in elevator lobbies, or throughout all spaces. Manual pull stations are typically located near exit stairs and exterior exits. These fire detectors are connected by wires to the fire alarm system that is operated by one or more fire alarm control panel(s).

Fire Protection System, Active: Consists of any system such as automatic fire sprinkler system, manual hose station system, fixed automatic extinguishing systems (i.e., Carbon Dioxide, chemical extinguishing systems, or clean agent suppression system), fire alarm system, or fire detection system.

Fire Protection System, Passive: Consists of any system such as fire wall, fire door, firestopping, spray-applied fireproofing, etc.

Fire Suppression System: Automatic wet or dry chemical extinguishing system, clean agent fire extinguishing system, or carbon dioxide extinguishing system.

Flammable Gases: Gases such as propane or natural gas.

Flammable Liquids: Liquids such as gasoline, fuel oil, jet fuel, or paint thinner. Water based latex paint is non-flammable.

Fuel-fired Equipment: Building support equipment such as furnaces, boilers, or hot water heaters.

Hazardous Areas / Hazardous Equipment: For purposes of these evaluations, hazardous areas include, but are not limited to, the following:

a. An area with flammable liquid storage or use, or flammable gas storage.

b. A battery storage area with batteries sized over 10 cubic feet (0.283 cubic m.) in total volume.

c. An area with fuel-fired equipment (boiler, incinerator, gas water heater or similar equipement).

d. A kitchen grill or fryer within a building.

e. Oil-filled transformers.

f. Areas with over 1,000 sq. ft. (92.9 sq. m.) of stored combustible materials.

g. An area with combustible storage areas with combustible materials stacked over 12 ft. (3.7 m) high above the floor.

h. An area used for hazardous waste material storage (flammable, corrosive or noxious chemicals).

HESCO Barrier: Metal chain link assemblies assembled into rectangular enclosures, filled with gravel or sand.

Kitchen Grill: Heated appliance surface used for cooking.

Kitchen Hood: Liquid tight duct assembly typically located above a kitchen grill for carrying grease-laden vapors and cooking fumes away from the cooking surface.

Living Unit: In a billeting occupancy, the occupied area consisting of at least a sleeping room. This may also include a kitchen area, bathroom or living room assessable only to the bedroom.

Mezzanine: An intermediate floor located between the floor and ceiling of any building story.

Non-combustible Construction: Buildings constructed of metal joists, beams, and columns, or concrete beams, columns and/or floor slabs.

Officer in Charge: The officer identified by the safety program, risk management process, charged with identifying, assessing, and controlling risks arising from operational factors and making decisions that balance risk cost with mission benefits.

The JFC reduces the chance of mishap by conducting risk assessments, assigning a safety officer and staff, implementing a safety program. To assist in risk management, commanders and their staffs may develop or institute a risk management process tailored to their particular mission or operational area. (Refer to JP 3-0, Joint Operations Chapter III, paragraph 2.k)

Protected Opening: A wall opening within a fire-resistive wall such as a window, door or louver that has been provided with a protective cover that maintains the fire-resistivity of the wall assembly.

Shaft: An enclosed floor opening between two or more stories. Typically these are enclosed with construction typical of walls.

Smoke Alarms, Single or Multiple Station: A device that incorporates the smoke detector and the alarm sounding device in one unit operated from either a battery or building power. They can function independently (Single Station), or can be interconnected (Multiple Station) such that when one goes into alarm, all smoke alarm sounding devices activate.

Standpipe System: Standpipes are typically located within or near exit stairways, and have hose connection valves for large (usually 2½ inch (65 mm) diameter) use by fire responders. Small hose stations (usually 1½ inch (40 mm) diameter) are typically for occupant use, and have smaller diameter hose.

Story: The portion of the building between a floor and the next floor above, or between the floor and the roof. A mezzanine is not a story; it is part of the story below. A mechanical penthouse does not count as a story unless there are occupied spaces such as offices in the penthouse.

Sub-basement: A level in a building more than one level below grade. Exception: See exception in basement definition for certain walk-out basements. A space located one level beneath a walk-out basement meeting the exception given under “Basement” in this section is not a sub-basement.

Vertical Openings: Openings in the floor of a building such as atriums, open stairs, air shafts or pipe chases that are not enclosed by wall assemblies. Multiple vertical openings that are not separated horizontally by a wall are considered one vertical opening (e.g., a vertical opening connecting Levels 1 and 2, and a separate vertical opening connecting Levels 2 and 3, without a contiguous wall between them, are considered one vertical opening connecting Levels 1 through 3).

C-2 EGRESS DEFINITIONS.

Corridor: A pathway through a building enclosed by full height (floor to ceiling) walls that leads to an exit.

Dead end corridor: A section of corridor that does not lead to an exit stair or an exterior exit door. For example, for a building with 2 interior exit stairs and a corridor connecting these 2 stairs, any extension length of the corridor "outboard" of the 2 exit stairs is a dead end corridor length. The maximum dead end corridor limit for all occupancies of this document is 25 feet (7.6 m). If functioning sprinkler systems are provided for the occupied areas, contact Reachback if longer dead end allowance is needed.

Egress: The path of travel for persons from occupied areas through rooms or exits to reach areas outside of a building.

Exit: A door in the exterior wall of the building accessing the outdoors, a stairway interior to the building that is enclosed by walls and leads to the outdoors, or a stairway located on the exterior of the building, leading to the outdoors.

Exit Capacity: The calculated number of persons a given exit component (stair or exit door) can accommodate for determining the maximum allowable occupant load. Door width is the width of the opening through the door. Stair width is the width of a flight of stairs. If the stairs vary in width, measure the stairs at the narrowest point.

Exit Capacity			
Clear Width		Occupants per	
in	(mm)	Door	Stair
24	(610)	100	65
28	(710)	120	75
30	(762)	130	80
32	(812)	135	85
34	(863)	145	90
36	(915)	155	100
40	(1,015)	170	110
44	(1,117)	185	120

If the egress path consists of a door and a stair, the occupant load is limited by the smaller of the two exit capacities. For example, if the door is 34 inches (863 mm) wide (exit capacity of 145) and the stair is 44 inches (1117 mm) wide (exit capacity of 120), the stair is the limiting factor for determining the Exit Capacity.

Where there are two or more exits from a room or floor, the maximum allowable occupant load is determine by adding the exit capacities for each exit from that room or floor. For example, if there are two doors from the ground floor leading directly to the exterior, one door is 28 inches (710 mm) (exit capacity of 120) and the other 32 inches (812 mm) (exit capacity of 135); the total maximum occupant load for the ground floor is 255.

Means of Escape: A way out of the building other than by the use of enclosed exit stairs, exterior stairs, or exterior doors. For purposes of this document, two methods are allowed, subject to detailed evaluations:

a. Means of escape consisting of an operable window sized at no less than 6 sq. ft. (0.56 sq. m.) and with the bottom of the window located no more than 4 ft. (1.2 m.) above the floor. The window needs to open into an area having access to a yard or street area for rescue. If below grade, the window needs to open into a window well sized to allow personnel access, and if the window is more than 1 story above grade, the window needs to open above a platform or ladder allowing access to grade.

b. Fire escape ladders: An exterior ladder, usually metal, mounted on the side of a multi-story building that is accessed through a window or a door, and provides access to grade level.

Panic Hardware: A door latching assembly that typically includes a bar across part of the width, or across the entire width of the door; pushing on the bar in the direction of egress automatically opens the lock (if provided) and retracts the latch, opening the door.

Travel Distance Limit (Maximum Allowable): The distance a person needs to travel from the point that is most remote on a given floor to the nearest exit. Travel distance is measured along normal walking paths, taking a direct route. Allowable travel distance limits for occupants are established for occupancies as follows:

- Billeting: 175 ft. (53.3 m.)
- Assembly: 200 ft. (61.0 m.)
- Institutional: 150 ft. (45.7 m.)
- Business: 200 ft. (61.0 m.)
- Factory/Industrial: 200 ft. (61.0 m.)
- Storage: 200 ft. (61.0 m.)

The travel distance limits presented herein are based on unsprinklered buildings. If functioning sprinkler systems are provided for the occupied areas, contact Reachback if additional travel distance is needed.

C-3 OCCUPANCY DEFINITIONS.

Occupancy: For purposes of this document, occupancy consists of one or more of the following building uses:

a. Billeting (sleeping areas with more than 10 beds)

b. Institutional (hospital, confinement) areas over 1,000 sq. ft. (92.9 sq. m.)

c. Assembly (gathering places, cafeterias, etc.) exceeding 500 sq. ft. (46.5 sq. m.)

d. Business (offices) exceeding 1,000 sq. ft. (92.9 sq. m.)

e. Factory-Industrial (shops, mechanical spaces) areas over 1,000 sq. ft. (92.9 sq. m.)

f. Storage (including hangars and parking garages) areas over 1,000 sq. ft. (92.9 sq. m.)

Spaces of a lesser size than noted above are considered a part of the overall occupancy. If no occupancy as defined above exists, use the area of the largest use that exists.

Mixed Occupancies: Where more than one occupancy exists, base the requirements for life safety described herein on the most restrictive occupancy present. In the list of occupancies above, Billeting is the most restrictive, and Storage is the least restrictive, and the occupancies between are in descending order of restrictiveness with regard to life safety.

Occupied Spaces: spaces that are normally used by personnel other than building maintenance persons. Occupied spaces do not include unmanned storage rooms, lookout towers or guard positions, mechanical/electrical equipment rooms, or computer server rooms.

Occupant Load: The total number of people on a given floor. This number is calculated based on the number of chairs, desks, beds, or other suitable number. To calculate occupant loads for the given occupancies use the following:

a. Billeting: Use the maximum number of beds to be used.

b. Institutional: Use the maximum number of beds or maximum number of persons in detention.

c. Assembly: Number of seats if seats are provided. If seats are not provided, use 7 sq. ft. (0.65 sq. m.) per person through the area of Assembly use, deducting area for access/circulation paths that are maintained in the space.

d. Business: Use number of desks.

e. Factory/Industrial: Use 300 sq. ft. (27.9 sq. m.) per person, using the overall area of the occupancy.

f. Storage: Use 300 sq. ft. (27.9 sq. m.) per person, using the overall area of the occupancy.

C-4 GLOSSARY: ABBREVIATIONS AND ACRONYMS

A

AE	Ammunition and Explosives
AFCEC	Air Force Civil Engineer Center
AFH	Air Force Handbook
AFPAM	Air Force Pamphlet
AHJ	Authority Having Jurisdiction

B

BIA	Bilateral Infrastructure Agreement

C

C	Degrees Celsius

D

DoD	Department of Defense

E

EMT	Electrical Metallic Tubing
ETL	Engineering Technical Letter

F

F	Degrees Fahrenheit
Ft	feet
FMC	Flexible Metallic Conduit

G

GFCI	Ground Fault Circuit Interrupt
GRS	Galvanized Rigid Steel

H

H	Height
HID	High Intensity Discharge
HN	Host Nation
HNFA	Host Nation Funded Construction Agreements
HQMC	Headquarters, Marine Corps
HQUSACE	Headquarters, United States Army Corps of Engineers
HVAC	Heating, ventilation, and air conditioning

I

IBC	International Building Code
IEEE	Institute of Electrical and Electronics Engineers
IMT	Intermediate Metal Conduit
In	inch(es)

J

JFC	Joint Forces Commander
JFOB	Joint Forward Operations Base
JP	Joint Publication

L

L	length

M

m	meter
MIL-STD	Military Standard
mm	millimeter

N

NAVFAC	Naval Facilities Engineering Command
NAVFACENGCOM	Naval Facilities Engineering Command
NCO	Non-commissioned Officer
NEC	National Electrical Code
NFPA	National Fire Protection Association

P

PCB	polychlorinated biphenyl
PPE	Personal Protective Equipment
PVC	Polyvinyl chloride

S

SOFA	Status of Forces Agreement
Sq. ft.	square feet
Sq. m.	square meter

T

TM	Technical Manual

U

UFC	Unified Facilities Criteria
U.S.	United States
USACE	United States Army Corps of Engineers

V

VA	Volt-ampere
Vol	Volume

W

W	width

This Page Intentionally Left Blank

APPENDIX D PRELIMINARY EVALUATION CHECKLIST

This Preliminary Evaluation checklist can be printed and used to assess existing facilities being considered for occupancy up to 90 days.

Preliminary Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ____________________

LOCATION: ____________ **BLDG NO.:** ____________

INSPECTOR: ____________ **DATE/TIME:** ____________

General Personal Safety:
Basic parameters to ensure safety when conducting occupancy assessments:

- Always wear standard issue personal protective equipment (PPE).
- Work in teams of at least 2 or have means of communication to response personnel
- Be alert for falling objects or tripping hazards

Equipment:
See Chapter 3 of the UFC for a list of equipment typically used for these evaluations.

Evaluation Process:
Complete the checklist in the order it is arranged. Initially assess the building from the exterior. Then perform an initial interior walk-thru to expeditiously assess issues that may prevent occupancy. Finally, assess interior discipline-specific issues.

PRELIMINARY EVALUATION SUMMARY

Complete summaries below and outline results of the evaluation regarding the following:

- Any conditions discovered that restrict/prevent occupancy
- Any required or recommended mitigations to allow safe occupancy
- Any conditions requiring “Reachback” assistance

Entries must be signed by each inspector and the Officer in Charge If resources are available, Preliminary and Detailed Evaluations should be performed together.

Discipline/System	Inspection Summary
Structural Systems	Inspector Signature:
Fire Protection	Inspector Signature:
Electrical/ Telecom	Inspector Signature:
Mechanical/ Plumbing	Inspector Signature:

INSPECTION RECOMMENDATION

PRELIMINARY EVALUATION	
Building can be occupied as-is for 90 days (no deficiencies found)	
Building can be occupied for 90 days following mitigations summarized above	
Prior to initial occupancy “Reachback” is required as outlined above	
Building occupancy can be extended for an additional 90-day period	

Officer-in-Charge Signature:____________________

Preliminary Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ____________________
LOCATION: ____________________ **BLDG NO.:** ____________________
INSPECTOR: ____________________ **DATE/TIME:** ____________________

PRELIMINARY EVALUATION

Note: The Preliminary Evaluation is a limited assessment to identify extreme hazards that pose an imminent risk to life safety or health, and to provide limited safety for immediate but limited-use occupancy. Due to the minimal scope of the preliminary evaluation, significant risks may exist even with a successful evaluation. Valid for 90 days. For extended occupancy, Primary and Detailed Evaluations can be performed concurrently

BUILDING CHARACTERISTICS

Proposed Building Usage	
Number of Stories	
Building Height	
Footprint Area (square feet)	
Past Building Usage	
Type of Construction	
Year Constructed	
GPS Coordinates	

HISTORY OF BUILDING/FACILITY DATA

Note: the following valuable information can be obtained from Host Nation or local residents

Building documentation (as-builts) available?	
When was building last occupied?	
Who lived/worked in building?	
Are prior occupants still in area?	
What activities were performed in the building?	

BUILDING SKETCH

Preliminary Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

CONDITION ASSESSED	CONDITION FOUND?	INSPECTOR: SUGGESTED ACTION
Exterior Assessment		
Collapse or partial collapse of building		Do not enter
Building noticeably leaning		Do not enter
Building shifted off foundation		Do not enter
Numerous cracks more than 1/8 in. wide in exterior walls		Do not enter
Building has significant blast or fire damage		Do not enter
Items that could fall on personnel - Loose pieces of building walls - Broken or loose parapets - Built up snow or ice on roof - Damaged low roof over entrance		Remove loose items or block access to areas under loose items.
Downed power lines		De-energize power systems
Damaged or displaced gas lines		Shut off gas, or vacate area
Signs of previous industrial operations or hazardous material/waste release. Signs of hazardous material/waste releases include: - Open or damaged containers - Observed spills or releases - Detection of odors or physical reactions (e.g., dizziness, nausea, eye/skin irritation) - Broken or ruptured piping		Do not enter, report in accordance with reporting requirements
Partial control of site by DoD		Do not occupy unless control allows safe occupancy
Initial Walk-Thru		
Partial control of building by DoD		Do not occupy unless security controls allow safe occupancy
Existence of unexploded ordnance, explosives, or chemicals		Evacuate and report in accordance with reporting requirements
Rodent, insect or animal infestations		Do not occupy
Waste, sewage or standing water in bldg.		Do not occupy
Signs of excessive mold		Do not occupy
Exposed/disturbed insulation		Do not occupy unless determined not to be hazardous
Isolated collapse of building structure		Evacuate collapsed area
Open flames		Evacuate
Evidence of gas leaks		Evacuate
Inspect roof for loose equipment and falling hazards		Mitigate hazard
Structural Interior Issues		
Walls or columns visibly leaning, bent, cracked, or broken		Do not occupy
Floor or roof structural members sagging, cracked, broken, or separated from their supports		Do not occupy or if problem areas are localized, block access to damaged areas.
Structural members significantly deteriorated – rust, rot, or infested by termites		Do not occupy or if problem areas are localized, block access to damaged areas.
Structural members badly burned or twisted/sagging from fire		Do not occupy or if problem areas are localized, block access to damaged areas.

Preliminary Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

CONDITION ASSESSED	CONDITION FOUND?	SUGGESTED ACTION
Items that could fall on personnel - Loose pieces of walls, ceilings, or finishes - Loose ductwork or overhead equipment - Other miscellaneous non-structural items		Remove loose items or block access to areas under loose items.
Fire Protection Issues		
Building occupied at levels more than 2 stories above grade Building occupied in a sub-basement (more than one story below grade). (Occupancy includes use of the space for other than mechanical/electrical rooms, lookout/security rooms, or storage rooms)		Locate occupied spaces of building only 2 stories above grade. Do not occupy sub-basements. Conduct detailed evaluation to determine if allowable to occupy higher stories.
Areas inside buildings occupied by fueled airplanes or vehicles		Mitigation measures (complete one of the following prior to and during occupancy): 1) Remove airplanes, vehicles from building, 2) Remove fuel from this equipment, store fuel outside building
Hazardous Areas or equipment that is not enclosed by walls on all sides (cut-off rooms). - An area with flammable liquid use or storage, fuel storage, or flammable gas storage - Battery storage with batteries sized over 10 cu. ft. (0.283 m^3) in volume (total size) - An area with fuel-fired equipment (boilers, air handlers, hot water heaters) - An area with Oil-filled transformers - Areas with over 1,000 sq. ft. (92.9 sq. m) of stored combustible materials (paper, plastic, or wooden materials) - An area with combustible storage stacked over 12 ft. (3.66 m) high above the floor -An area with hazardous waste storage (flammable, corrosive or noxious chemicals)		Prior to occupancy: 1) Remove flammable liquids use and storage from premise, 2) Remove hazardous equipment from service, 3) For storage areas, remove storage, or provide a minimum 50 ft. (15.2 m) of space separation between occupied space and storage and a 24 hour fire watch, 4) Remove hazardous waste from building prior to occupancy.

Preliminary Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

CONDITION ASSESSED	CONDITION FOUND?	SUGGESTED ACTION
Deficient Egress Issues exist, including: - Number of exits from any building story is less than two (exits are doors to the exterior, an exterior stairway, or an interior stairway enclosed by walls) - Dead-bolt type locks on egress doors from occupied spaces - Paths to exits from occupied spaces through storage areas with no other exit path available - Paths to exits from occupied areas through hazardous areas with no other exit path available - Paths to exits are blocked by storage. - Exit stairs are used for storage.		Prior to occupancy: 1) Do not occupy a story with less than 2 exits. 2) Remove dead bolt type locks from egress doors. 3) Remove storage or hazardous process from building. 4) Remove hazardous process from service. 5) Provide additional exit option avoiding storage area or hazardous area. 6) Remove storage from exit paths.
Exposed plastic foam insulation or corkboard on walls or ceilings in occupied spaces		Remove insulation or corkboard prior to occupancy
Mechanical and Plumbing Issues		
Sanitary piping and venting is not properly configured and traps are not sealed		Occupy, but do not use systems and apply warning signs
Roof drainage and overflow drainage piping show evidence of leakage		Occupy, but perform any readily achievable drainage system repairs prior to occupancy
Roof drains show evidence of blockages		Occupy , but remove any roof drain blockages prior to occupancy
Fuel-fired heating system is in operation		Occupy, but de-energize heating system until Detailed Evaluation is completed
Hazardous or chemical storage areas do not have appropriate containment, ventilation and safety features		Occupy, but do not store chemicals in these areas
*Electrical and Telecommunications Systems		
Is existing electrical system de-energized		Do not energize electrical system until Detailed Evaluation is completed
Is existing electrical power system energized and was facility recently occupied		Do not de-energize and do not use electrical power system until proven safe through completion of a Detailed Evaluation
Survey the building and look for any exposed conductors.		Occupy, close off any rooms with exposed wiring and provide a warning sign. Where exposed wiring is found in areas that cannot be closed off, de-energize the systems per info below.
*Note: De-energized existing electrical systems cannot be energized until a Detailed Evaluation is conducted. Energized existing electrical systems cannot be used until a Detailed Evaluation is conducted.		

Additional Notes on Preliminary Evaluation Issues and Mitigation Actions:

APPENDIX E DETAILED EVALUATION CHECKLIST

This checklist can be printed and used to assess existing facilities being considered for extended occupancy up to 5 years. The checklist covers Detailed Evaluations and correlates to the technical content within Chapter 4 of this UFC.

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

DETAILED EVALUATION SUMMARY

Complete the summaries below and outline the results of the building evaluation regarding the following conditions:

- Any conditions discovered that restrict/prevent occupancy
- Any required or recommended mitigations to allow safe occupancy
- Any conditions requiring "Reachback" assistance

Entries must be signed by each inspector and the Officer-in-Charge.

Discipline/System	Inspection Summary
Structural Systems	Inspector Signature:
Fire Protection	Inspector Signature:
Electrical/ Telecom	Inspector Signature:
Mechanical/ Plumbing	Inspector Signature:

INSPECTION RECOMMENDATION

DETAILED EVALUATION	
Building can be occupied as-is for 5 years (no deficiencies found)	
Building can be occupied for 5 years following mitigations summarized above	
Prior to extended occupancy "Reachback" is required as outlined above	

Officer-in-Charge Signature:______________________________

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

DETAILED EVALUATION

Note: The Detailed Evaluation identifies hazards that pose near-term risks to life safety and health, and provides minimal safety and habitability for longer-term occupancy (5 years) than the preliminary evaluation. The Detailed Evaluation does not address all safety and habitability requirements that are specified in UFC 1-201-01 and addressed in an Engineering Assessment. For items answered as “Yes”, see section number reference in UFC for mitigation options.

BUILDING CHARACTERISTICS

Proposed Building Usage	
Number of Stories	
Building Height	
Footprint Area (square feet)	
Past Building Usage	
Type of Construction	
Year Constructed	
GPS Coordinates	

BUILDING SKETCH

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

STRUCTURAL SYSTEMS INSPECTOR:

CONDITION ASSESSED	CONDITION FOUND?	MITIGATION SECTION #	SUGGESTED MITIGATION
Overall Structural Damage			
Collapse or partial collapse		4-3.3	
Building or story leaning more than 4 in. (100 mm) or H/200 (H=bldg or story height in inches)		4-3.3	
Foundation damage or building shifted off foundation		4-3.3	
Building in zone of suspected slope instability, sinkholes, or erosion		4-3.3	
Building below region of potential landslide		4-3.3	
Significant exterior wall cracks or offsets		4-3.3	
Significant blast or fire damage		4-3.3	
Items that could fall on personnel - Loose pieces of parapets and facades - Built up snow or ice on roof - Damaged or poorly attached entrance canopies		4-3.3	
Damage to Structural Framing Components			
Leaning: Columns, piers, or bearing walls more than 4 in. (100 mm) or H/200 (H=bldg or story height in inches)		4-3.3	
Buckling: Columns, piers, diagonal bracing, or bearing walls		4-3.3	
Damage to horizontal framing members: Cracking with vertical or horizontal displacement in any horizontal framing member.		4-3.3	
Roof or floor framing sloping or sagging in excess of L/180, or separation from walls or other supports		4-3.3	
Damage to vertical framing members: Cracking with vertical or horizontal Displacement in any vertical framing member.		4-3.3	
Connections: Visible damage to connections		4-3.3	
Bracing: Broken, bent, or damaged bracing members		4-3.3	
Connection to foundation: Damaged connections between structural members and foundations.		4-3.3	
Fire: Section loss, twisting, warping, or spalling in structural members from fire		4-3.3	

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ____________________ **BLDG NO.:** ____________________
INSPECTOR: ____________________ **DATE/TIME:** ____________________

STRUCTURAL SYSTEMS INSPECTOR:

CONDITION ASSESSED	CONDITION FOUND?	MITIGATION SECTION #	SUGGESTED MITIGATION
Deterioration: Rotting or insect infested wood, corroded steel, spalled concrete, freeze-thaw damaged masonry or concrete.		4-3.3	
Falling Hazards: Any loose or damaged structural framing, finishes, equipment, or other items that could fall on occupants		4-3.3	

<u>Additional Notes on Structural Systems and Mitigation Actions:</u>

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ____________________
LOCATION: ____________ **BLDG NO.:** ____________
INSPECTOR: ____________ **DATE/TIME:** ____________

DETAILED EVALUATION (continued)

FIRE PROTECTION ISSUES — INSPECTOR:

CONDITION ASSESSED	CONDITION FOUND?	MITIGATION SECTION #	SUGGESTED MITIGATION
Conditions Requiring Field Mitigation or Reachback			
Building separation not adequate.		4-4.2.1	Seal up openings in exterior walls.
Planned occupancy of floors more than 3 stories above grade.		4-4.2.2	Occupy building only to a maximum of 3 stories above grade. Contact Reachback for assistance.
Planned occupancy of floors more than 2 stories above grade in building with any of the following: a. Combustible construction. b. No automatic sprinkler system c. Vertical openings connecting more than 2 stories.		4-4.2.2	Occupy building only to a maximum of 2 stories above grade. Contact Reachback for assistance.
Planned occupancy of basement levels by billeting, institutional or assembly occupancies.		4-4.1.2	Occupy basement levels by occupancies other than billeting, institutional or assembly.
Planned occupancy of sub-basement levels.		4-4.1.2	Do not occupy sub-basement levels.
Travel distance to exits exceeds allowable maximum distance.		4-4.2.4	Do not occupy remote space, occupy space by an occupancy with longer allowable travel distance, provide an additional exit option, or provide means of escape.
Dead end corridors longer than 25 ft. (7.6 m).		4-4.2.4	Provide additional exit path, means of escape, or do not occupy area with dead end corridor.
Less than 2 exits on each occupied level.		4-4.2.4	Provide additional remote exit or remote means of escape. Do not occupy floor with less than 2 exits.
Suite over 2,000 sq. ft. (186 sq m) with single exit path.		4-4.2.4	Provide additional remote exit path, remote means of escape, or do not occupy this area.
Assembly occupancy with less than 2 exit paths available from space.		4-4.2.4	Provide additional remote exit path or relocate assembly occupancy
Exit capacity is insufficient for any occupied area.		4-4.2.4	Provide additional exits, means of escape, or only allow what the exit capacity allows.
Exits blocked, obstructed, or enclosed stairs contain storage.		4-4.2.4	Remove obstructions or storage
Exit doors are locked, or not under control of occupants.		4-4.2.4	Remove locks or do not occupy area not controlling egress.
Exit paths routed from occupied areas through hazardous areas or areas of storage.		4-4.2.4	Provide exiting so it is not routed through hazardous areas or storage.

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

FIRE PROTECTION ISSUES INSPECTOR:

CONDITION ASSESSED	CONDITION FOUND?	MITIGATION SECTION #	SUGGESTED MITIGATION
Billeting occupancy without an automatic sprinkler system.		4-4.2.5	Area < 7,000 sq. ft. (650 sq. m.): Provide fire watch, direct exits to the exterior, subdividing walls separating this billeting area from other areas of the building including other billeting areas, and smoke alarms in billeting units; or limit occupancy to less than 10 beds. Area > 7,000 sq. ft. (650 sq. m.): Contact Reachback
Billeting occupancy with no installed fire evacuation alarm system.		4-4.2.6	Provide fire watch.
Kitchen grill/fryer with no hood.		4-4.2.5	Remove kitchen grill from service, or provide fixed wall around kitchen area.
Kitchen hood with no fixed fire suppression system		4-4.2.5	Provide fixed wall around kitchen area.
Assembly occupancy with partial, or no fire alarm system in building.		4-4.2.6	Provide manual notification and a fire watch when occupied.
Institutional occupancy with partial, or no fire alarm system in building.		4-4.2.6	Provide manual notification and a fire watch.
Business occupancy over 5,000 sq. ft. (465 sq m) in basement, second or third floors with partial, or no fire alarm system in building.		4-4.2.6	Provide manual notification and a fire watch when occupied.
Hazardous areas or hazardous equipment are not segregated from other occupancies by fixed walls.		4-4.2.7	Remove hazardous equipment from service, relocate equipment or materials, or provide fire suppression system (kitchen hood system) or automatic sprinkler system.
Hazardous or chemical storage areas are not provided with containment or ventilation.		4-4.2.7	Remove hazardous material storage.
Interior finishes consists of exposed combustible (plastic, foam) insulations, cork board, fabric assemblies, or combustible decorations.		4-4.2.8	Remove combustible finishes or cover with noncombustible fire barrier. Remove combustible decorations.
Vertical openings connecting more than 2 stories.		4-4.2.9, 4.4.2.2	Provide gypsum wallboard around one level to limit floor opening to 2 stories. See building height restrictions also.

Additional Notes on Fire Protection Issues and Mitigation Actions:

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ____________________

LOCATION: ____________ **BLDG NO.:** ____________

INSPECTOR: ____________ **DATE/TIME:** ____________

Partial Definition List:

Building Separation: The horizontal separation distance between the building under consideration and neighboring buildings on all sides. For multiple buildings on the same compound, assume an imaginary line halfway between buildings. The distance from building under consideration to adjacent existing buildings, or from the building under consideration to the imaginary line, whichever is shorter, is the fire separation distance.

Dead end corridor: A section of corridor that does not lead to an exit stair or an exterior exit door. For example, for a building with 2 interior exit stairs and a corridor connecting these 2 stairs, any extension length of the corridor "outboard" of the 2 exit stairs is a dead end corridor length. The maximum dead end corridor limit for all occupancies of this document is 25 feet (7.6 m).

Egress: The path of travel for persons from occupied areas through rooms or exits to reach areas outside of a building.

Exit: A door in the exterior wall of the building accessing the outdoors, a stairway interior to the building that is enclosed by walls and leads to the outdoors, or a stairway located on the exterior of the building, leading to the outdoors.

Exit Capacity: The calculated number of persons a given exit component (stair or exit door) can accommodate for determining the maximum allowable occupant load. Door width is the width of the opening through the door. Stair width is the width of a flight of stairs. If the stairs vary in width, measure at its narrowest point. Stairs are assumed to have inconsistent rise and run; however the run should not be less than 6 inches (127 mm).

Exit Capacity			
Clear Width		Occupants per	
in	(mm)	Door	Stair
24	(610)	100	65
28	(710)	120	75
30	(762)	130	80
32	(812)	135	85
34	(863)	145	90
36	(915)	155	100
40	(1,015)	170	110
44	(1,117)	185	120

If the egress path consists of a door and a stair, the occupant load is limited by the smaller of the two exit capacities. For example, if the door is 34 inches wide (exit capacity of 145) and the stair is 44 inches wide (exit capacity of 120), the stair is the limiting factor for determining the Exit Capacity.

Where there are two or more exits from a room or floor, the maximum allowable occupant load is determine by adding the exit capacities for each exit from that room or floor.

An Occupant Load greater than the Exit Capacity is unsafe.

Occupied Spaces: Spaces that are normally used by personnel other than building maintenance persons. Occupied spaces do not include unmanned storage rooms, lookout towers, guard positions, mechanical/electrical equipment rooms, or computer server rooms.

Occupancy: For purposes of this document, occupancy consists of one or more of the following building uses:

a) Billeting (sleeping areas with more than 10 beds)
b) Institutional (hospital, confinement) areas over 1,000 sq. ft. (92.9 sq. m.)
c) Assembly (gathering places, cafeterias, etc.) exceeding 500 sq. ft. (46.5 sq. m.)
d) Business (offices) exceeding 1,000 sq. ft. (92.9 sq. m.)
e) Factory-Industrial (shops, mechanical spaces) areas over 1,000 sq. ft. (92.9 sq. m.)
f) Storage (including hangars and parking garages) areas over 1,000 sq. ft. (92.9 sq. m.)

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ____________ **BLDG NO.:** ____________
INSPECTOR: ____________ **DATE/TIME:** ____________

Spaces of a lesser size than noted above are considered a part of the overall occupancy. If no occupancy as defined above exists, use the area of the largest use that exists.

Occupant Load: The total number of people on a given floor. This number is calculated based on the number of chairs, desks, beds, or other suitable number. To calculate occupant loads for the given occupancies use the following:

a) Billeting: Use the maximum number of beds to be used.
b) Institutional: Use the maximum number of beds or maximum number of persons in detention.
c) Assembly: Number of seats if seats are provided. If seats are not provided, use 7 sq. ft. (0.65 sq. m.) per person through the area of Assembly use, deducting area for access/circulation paths that are maintained in the space.
d) Business: Use number of desks.
e) Factory/Industrial: Use 300 sq. ft. (27.9 sq. m.) per person, using the overall area of the occupancy.
f) Storage: Use 300 sq. ft. (27.9 sq. m.) per person, using the overall area of the occupancy.

An Occupant Load greater than the Exit Capacity is unsafe.

Travel Distance Limit (Maximum Allowable): The distance a person needs to travel from the point that is most remote on a given floor to the nearest exit. Travel distance is measured along normal walking paths, taking a direct route. Allowable travel distance limits for occupants are established for occupancies as follows:

a) Billeting: 175 ft. (53.3 m.)
b) Assembly: 200 ft. (61.0 m.)
c) Institutional: 150 ft. (45.7 m.)
d) Business: 200 ft. (61.0 m.)
e) Factory/Industrial: 200 ft. (61.0 m.)
f) Storage: 200 ft. (61.0 m.)

Vertical Openings: Openings in the floor of a building such as atriums, open stairs, air shafts or pipe chases that are not enclosed by wall assemblies. Multiple vertical openings that are not separated horizontally by a wall are considered one vertical opening (e.g., a vertical opening connecting Levels 1 and 2, and a separate vertical opening connecting Levels 2 and 3, without a contiguous wall between them, are considered one vertical opening connecting Levels 1 through 3).

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

DETAILED EVALUATION (continued)

PLUMBING AND MECHANICAL SYSTEM ISSUES INSPECTOR:

CONDITION ASSESSED	CONDITION FOUND?	MITIGATION SECTION #	SUGGESTED MITIGATION
Visual Inspection and Tests			
Domestic water unsafe based on testing?		4-5.2.1	
Any evidence of plumbing systems leaking?		4-5.2.1	
Any domestic water system cross connections?		4-5.2.1	
HVAC system does not function properly, is unsafe or not operational?		4-5.2.5	
Exposed or above-ceiling HVAC pipes leaking?		4-5.2.6	
Visual Inspection and Field Surveys			
Hot water systems are not configured properly or do not have appropriate safety equipment?		4-5.2.2	
Hot water equipment does not function properly or has inappropriate temperature settings?		4-5.2.2	
Sanitary piping and venting is not configured properly and/or not all traps are sealed?		4-5.2.3	
Vents through roof show signs of blockage?		4-5.2.3	
Roof and overflow drainage systems are obstructed by debris or not configured properly?		4-5.2.4	
Fuel system components are inappropriate or unsafe to operate?		4-5.2.2	

Additional Notes on Plumbing and Mechanical System Issues and Mitigation Actions:

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

DETAILED EVALUATION (continued)

ELECTRICAL SYSTEM ISSUES INSPECTOR:

CONDITION ASSESSED	CONDITION FOUND?	MITIGATION SECTION #	SUGGESTED MITIGATION
Field Measurements and Calculations			
Equipment short circuit ratings are less than minimum requirements?		4-6.2.1	
Distribution System Grounding does not meet NFPA 70 (60 Hz) or BS 7671 (50 Hz) and UFC 3-550-01?		4-6.2.2	
Branch circuit conductors, conduit and breakers' sizes do not comply with NFPA 70(60 Hz) or BS 7671 (50 Hz)?		4-6.2.3	
Feeder circuit conductors, conduit and/or breakers' sizes do not comply with NFPA 70 (60 Hz) or BS 7671 (50 Hz)?		4-6.2.3	
Visual Inspection and Field Surveys			
Lightning Protection System is not installed per NFPA 780.		4-6.2.4	
Raceway applications do not comply with NFPA 70? (60 Hz) or BS 7671 (50 Hz)		4-6.2.5	
Branch and Feeder conductors; installations do not comply with NFPA 70? (60 Hz) or BS 7671 (50 Hz)		4-6.2.3	
Emergency and Exit Lighting equipment and placements do not comply with NFPA 101 and IBC?		4-6.2.6	
Transformers' application and installation do not comply with NFPA 70(60 Hz) or BS 7671 (50 Hz)?		4-6.2.7	
Grounding type and GFCI receptacles do not comply with NFPA 70(60 Hz) or BS 7671 (50 Hz)?		4-6.2.8	
Procedural Reviews			
Military unit does not have appropriate circuit lock-out procedures?		4-6.2.9	

Additional Notes on Electrical System Issues and Mitigation Actions:

Detailed Evaluation Checklist for Building Occupancy

BUILDING DESCRIPTION: ______________________
LOCATION: ______________ **BLDG NO.:** ______________
INSPECTOR: ______________ **DATE/TIME:** ______________

DETAILED EVALUATION (continued)

TELECOMMUNICATIONS ISSUES INSPECTOR:

CONDITION ASSESSED	CONDITION FOUND?	MITIGATION SECTION #	SUGGESTED MITIGATION
Distribution System Grounding does not meet NFPA 70 (60 Hz) or BS 7671 (50 Hz) and UFC 3-550-01?		4-6.2.2	

Additional Notes on Telecommunications System Issues and Mitigation Actions:

ADDITIONAL NOTES AND ACTION ITEMS

NOTES	ACTIONS

Sample – Electrical Panel Schedule

PANEL 2U2C2

PANEL LOCATION: RM 123
MAIN BREAKER / MLO: '150A MCB
VOLTAGE: 208 V/Y120, 3PH, 4 WIRE

MAIN BUS RATING 225A
WITH 200% NEUTRAL
MINIMUM INTERRUPTING CAPACITY (RMS SYM AMPS) 22,000

CIRCUIT	CONNECTED LOAD (KVA)			*	CKT BRKR			CKT BRKR			*	CONNECTED LOAD (KVA)			CIRCUIT
DESCRIPTION	A	B	C		TRIP	P	NO	NO	P	TRIP		A	B	C	DESCRIPTION
RECEPTACLES - RM 22	1.60	------	------		20	1	1	2	1	20		1.60	------	------	RECEPTACLES - RM 22 CUP - 07
RECEPTACLES - RM 22	------	1.60	------		20	1	3	4	1	20		------	1.60	------	RECEPTACLES - RM 22 CUP - 07
RECEPTACLES - RM 22	------	------	1.60		20	1	5	6	1	20		------	------	1.60	RECEPTACLES - RM 22 CUP - 07
RECEPTACLES - RM 22	1.60	------	------		20	1	7	8	1	20		1.60	------	------	RECEPTACLES - RM 22 CUP - 08
RECEPTACLES - RM 22 CUP-06	------	1.60	------		20	1	9	10	1	20		------	1.60	------	RECEPTACLES - RM 22 CUP - 08
RECEPTACLES - RM 22 CUP-06	------	------	1.60		20	1	11	12	1	20		------	------	1.60	RECEPTACLES - RM 22 CUP - 08
RECEPTACLES - RM 22 CUP-06	1.60	------	------		20	1	13	14	1	20		1.60	------	------	RECEPTACLES - RM 22
RECEPTACLES - RM 22 CUP-18	------	1.60	------		20	1	15	16	1	20		------	1.60	------	RECEPTACLES - RM 22
RECEPTACLES - RM 22 CUP-18	------	------	1.60		20	1	17	18	1	20		------	------	1.60	RECEPTACLES - RM 22
RECEPTACLES - RM 22	1.60	------	------		20	1	19	20	1	20		1.60	------	------	RECEPTACLES - RM 22
RECEPTACLES - RM 22	------	1.60	------		20	1	21	22	1	20		------	1.60	------	RECEPTACLES - RM 22
RECEPTACLES - RM 22	------	------	1.60		20	1	23	24	1	20		------	------	1.60	RECEPTACLES - RM 22
RECEPTACLES - RM 22	1.60	------	------		20	1	25	26	1	20		1.60	------	------	RECEPTACLES - RM 22
RECEPTACLES - RM 22	------	1.60	------		20	1	27	28	1	20		------	1.60	------	RECEPTACLES - RM 22
RECEPTACLES - RM 22	------	------	1.00		20	1	29	30	1	20		------	------	1.60	RECEPTACLES - RM 22
LAB EQUIPMENT E1	1.60	------	------		60	2	31	32	1	20		1.60	------	------	RECEPTACLES - RM 22
	------	1.60	------				33	34	2	20		------	1.00	------	RECEPT. EQUIP. RM. 22
RECEPTACLES - RM 22	------	------	1.00		20	1	35	36				------	------	1.00	
CUP-07-RM 22	1.00	------	------		20	2	37	38	3	30			------	------	TVSS
NEMA 6-20R	------	1.00	------				39	40				------		------	
SPACE	------	------					41	42				------	------		
LEFT SUB-TOTAL	10.60	10.60	8.40												
RIGHT SUB-TOTAL	9.60	9.00	9.00												
PER PHASE TOTAL	20.20	19.60	17.40												
PANEL TOTAL			57.20												

TOTAL PANEL LOAD		
	CONNECTED	DEMAND
KVA	57.2	35
AMPS	158.8	97

* **NOTES:** (G = GF, L = LOCKABLE, S = SHUNT TRIP)
CONDITION: PANEL LOCKS ARE DAMAGED.

Blank – Electrical Panel Schedule

PANEL ____________

PANEL LOCATION: ____________________ MAIN BUS RATING ________
MAIN BREAKER / MLO: ____________________
VOLTAGE: ____________________ MINIMUM INTERRUPTING CAPACITY (RMS SYM AMPS) ________

CIRCUIT	CONNECTED LOAD (KVA)			*	CKT BRKR			CKT BRKR			*	CONNECTED LOAD (KVA)			CIRCUIT
DESCRIPTION	A	B	C		TRIP	P	NO	NO	P	TRIP		A	B	C	DESCRIPTION
		------	------				1	2					------	------	
	------		------				3	4				------		------	
	------	------					5	6				------	------		
		------	------				7	8					------	------	
	------		------				9	10				------		------	
	------	------					11	12				------	------		
		------	------				13	14					------	------	
	------		------				15	16				------		------	
	------	------					17	18				------	------		
		------	------				19	20					------	------	
	------		------				21	22				------		------	
	------	------					23	24				------	------		
		------	------				25	26					------	------	
	------		------				27	28				------		------	
	------	------					29	30				------	------		
		------	------				31	32					------	------	
	------		------				33	34				------		------	
	------	------					35	36				------	------		
		------	------				37	38					------	------	
	------		------				39	40				------		------	
	------	------					41	42				------	------		

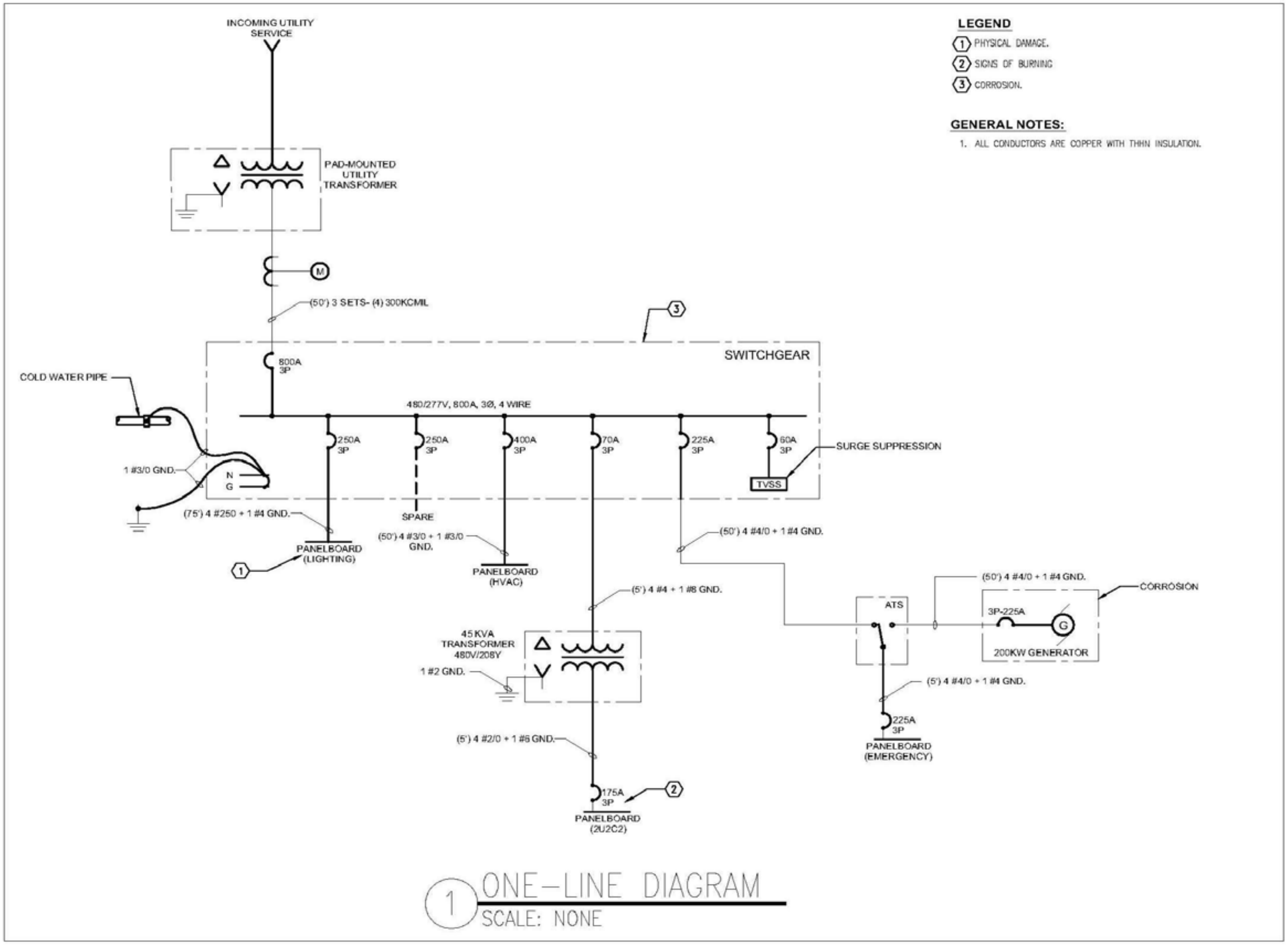
	A	B	C
LEFT SUB-TOTAL			
RIGHT SUB-TOTAL			
PER PHASE TOTAL			
PANEL TOTAL			

TOTAL PANEL LOAD		
	CONNECTED	DEMAND
KVA		
AMPS		

* **NOTES:** (G = GF, L = LOCKABLE, S = SHUNT TRIP)

CONDITION: ____________

Sample – Electrical One-Line Diagram



UFC 1-300-01
17 December 2021
Change 1, 6 May 2025

UNIFIED FACILITIES CRITERIA (UFC)

CRITERIA FORMAT STANDARD

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

CRITERIA FORMAT STANDARD

Indicate the Military Department Preparing Activity responsible for the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	6 May 2025	General updates (links, clerical); 1-3 Applicability; 1-6 limit of changes; 2-1 referencing UFGS in UFC; 3-3.10.2 commentary formatting; 3-3.12 reference publication exceptions

This UFC supersedes UFC 1-300-01, dated 18 July 2018.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website https://www.wbdg.org/dod/ufc.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

PETE G. PEREZ, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Systems Command

NANCY J. BALKUS, P.E., SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW, SES
Deputy Assistant Secretary of Defense
(Construction)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

FIGURES

TABLES

This Page Intentionally Left Blank

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This document provides a unified approach to the appearance, formatting and content of Unified Facilities Criteria (UFC) and Facilities Criteria (FC) documents. UFC and FC are used to provide technical information to plan, design, construct, operate, and maintain DoD facilities. FCs are criteria documents that are not unified with all Military Departments.

In accordance with the authority in MIL-STD-3007, UFC are prepared by DoD committees called Discipline Working Group (DWG) and are published by the Military Departments under the authority of the Engineering Senior Executive Panel (ESEP).

1-2 REISSUES AND CANCELS.

This UFC reissues and cancels UFC 1-300-01, 18 July 2018.

1-3 APPLICABILITY.

This document applies to the preparation of UFC and FC documents prescribed by MIL-STD 3007. **\1** This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, with no exceptions. **/1/**

1-4 VARIATIONS IN FORMAT.

The format prescribed herein is intended to provide uniformity.

Variations in format must be approved by the Coordinating Panel (CP). The DWG will forward the request to vary from the prescribed format to the CP for approval early in the development process.

1-5 PUBLICATION.

Criteria documents are published in electronic media only. The Memorandum of Agreement for the Whole Building Design Guide establishes the Whole Building Design Guide (WBDG) (https://www.wbdg.org) as the sole distribution method for internet access.

Exception: Controlled Unclassified Information CUI documents will not be maintained on the WBDG. **\1** Instructions on how to obtain the document will be posted on the WBDG. **/1/** CUI documents must be marked, handled and distributed in accordance with DODI 5200.48.

1-5.1 Assigning Publication Numbers.

The DWG responsible for the criteria document will recommend the most appropriate numerical series based on APPENDIX A (for example: UFC 4-010-XX). Series 4 numbering is based on the DoD hierarchical scheme of real property types, functions and Category Groups found in DoDI 4165.03. Ensure proposed number does not duplicate or conflict with publication numbers of other planned, published, or archived criteria. Prior to initial review submittal, the DWG will forward the proposed number recommendation to the CP for approval.

1-5.2 Document Size.

Criteria documents are distributed in electronic format. Therefore; at the discretion of the DWG, documents exceeding 20 Mb in size may be separated into volumes. For criteria separated into volumes, list the issuance title, followed by a colon and the volume-specific title.[1] Each volume will be a separate document with individual tables of content, chapters, appendices and paragraph numbers specific to that volume.

1-5.3 Publication Date.

The DWG coordinates the publication date with the National Institute of Building Sciences (NIBS) after ESEP approval.

1-6 DOCUMENT UPDATES.

Updates to an existing document may be a change or a revision. The responsible DWG will determine whether the update will be a change or a revision.

1-6.1 Changes.

\1 A change amends no more than 40 percent of an existing issuance and has the full authority of the issuance. The 40 percent is based on either a single update or the cumulative total of multiple updates. Changes may include the addition of entire chapters or appendices.

- The number of changes is limited to the number of years in the designated document refresh rate, after which the document must be revised.
- Exception: UFC 3-701-01 may exceed the maximum number of changes established by its refresh rate due to the bi-annual update of the data tables. However, UFC 3-701-01 must undergo a revision in accordance with its refresh rate. **/1/**
- Changes are published upon DWG approval.

1-6.2 Identifying Changes.

Mark the start of changed text with the number of the change enclosed with backslash virgule symbols (**\X**) and the end of changed text with forward slash virgule symbols (**/X/**) in bold type. Provide a **\1** space both before and after the change **/1/** mark for

[1] DoD Issuances Standards

readability. Respectively, the letter "X" represents the number of the change, see Figure 1-1. Simple typographic or grammar changes do not need to be marked.

Figure 1-1 Example Marking Changes

> **CHAPTER 2 PRELIMINARY DESIGN DATA**
>
> **2-1 GENERAL.**
>
> **\1** The need for subsurface drainage and frost protection must be identified during the design stage to enable incorporation of appropriate features into the pavement design. **/1/** Verification of design assumptions is important to obtain reliable designs. If during construction any of the site conditions were found different than those assumed in the design, the design may have to be modified. Some site-related factors affect the need for frost protection and the need for subsurface drainage. In this section, investigation of those site factors is discussed.

1-6.3 Revisions.

If more than **\1** 40 **/1/** percent of an issuance requires change, when the number of changes **\1** will exceed the number of years in the designated document refresh rate **/1/**, or if there are significant program or project cost implications (for example, updating to new versions of industry standards) the issuance must be a revision. Revisions are approved by the DWG, CP and ESEP. The Preparing Activity will forward the completed criteria document to the CP when the revision has been approved by the DWG and is ready for ESEP approval and signature.

- **\1** Exception: UFC 3-701-01 may exceed the maximum number of changes established by its refresh rate due to the bi-annual update of the data tables. However, UFC 3-701-01 must undergo a revision in accordance with its refresh rate. **/1/**

- Revisions are published upon ESEP approval.

1-6.3.1 Formatting Revision.

Update to current UFC Template, remove previous recorded changes from the title page, delete previous change markings, and provide a new publication date.

1-7 ELECTRONIC FORMAT.

Criteria documents will be created and modified using the current UFC Template. The UFC Template can be found on the Whole Building Design Guide at: https://www.wbdg.org/dod/ufc. Published documents are distributed in Portable Document Format (PDF).

1-7.1 UFC Template.

The UFC Template includes customized styles for chapter headings, subparagraphs, figure titles, table titles, and general text with custom multilevel lists. The customized styles enable consistent formatting, PDF generation with bookmarks and the ability to generate Table of Contents, List of Figures, and a List of Tables.

- For new documents, use the current UFC Template.
- For revisions, update to the current UFC Template.
- For changes, updating to the current UFC Template is not required.

1-7.2 PDF.

Final criteria documents are published in PDF. The final PDF for publication must have bookmarks for the Table of Contents, Chapters, Appendices, Figures, Tables and level 1 and 2 paragraphs to allow prompt navigation through the PDF. Make the Table of Contents, Chapters and Appendices a level one bookmark. Make the level 1 paragraphs (for example, 4-2) a level two bookmark. Make paragraph level 2 (for example, 4-2.1), Tables and Figures a level three bookmark.

1-8 COPYRIGHT RELEASES.

For copyrighted materials, obtain written permission from the copyright holder. Identify the material properly in the UFC according to the requirements of the copyright holder.

1-9 REGISTERED TRADEMARKS.

Identify all registered trademarks by the appropriate symbol (® or ™).

1-10 GLOSSARY.

APPENDIX B contains acronyms, abbreviations, and terms.

1-11 REFERENCES.

APPENDIX C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies. Refer to UFC 1-200-01, for the applicable publication date for International Building Code®. **\1** Refer to UFC 1-200-02, for the applicable publication date for ASHRAE Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings. **/1/**

CHAPTER 2 STYLE AND FORMAT

2-1 INTRODUCTION.

The style and format **\1** are **/1/** designed to facilitate ease of preparation and use. The DWG is responsible for the format, technical content, and overall quality of its criteria document in accordance with the following guidelines:

- Provide documents that meet the format and content requirements in accordance with UFC 1-300-01.
- Provide technical information in a well-written, straightforward manner.
- Reference non-Government standards to the greatest extent possible and avoid repeating commercially available criteria.
- Clearly state unique government requirements and exceptions to non-Government standards and commercially available criteria. Each exception to the industry standards should be verifiable as to the functional need and to assure it promotes the lowest life cycle cost.
- Maximize functionality while addressing security, sustainability, energy, life safety, and health requirements. Using lessons learned and innovative technology, develop the criteria to promote lowest life-cycle cost, maximum environmental responsiveness, energy efficiency, quality of life, and productivity.
- Write criteria to the level of the experienced engineer and architect. Focus on performance criteria. Exclude textbook information, charts and figures, and other information that is available in non-Government standards, commercial and industry references. Documents are not intended to be training manuals or compilations of reference material.
- Exception: Operations and Maintenance criteria may be written in procedural language at the level of the experienced field personnel. Operations and Maintenance criteria may also include textbook information, charts, figures and other information readily needed for use in the document, refer to MIL-STD-38784A.
- **\1** Do not reference Unified Facilities Guide Specifications (UFGS) without qualifying how the reference is to be applied. In UFC, do not rely on UFGS to communicate requirements, and use them only to contextualize specific information and processes. **/1/**
- Generally, larger criteria documents that contain multiple topics may be broken into separate volumes to facilitate updating; see paragraph 1-5.2. However, document size and content must also address the following:
    - User/usage
    - Use in design and construction contracts

- Types of projects affected
- Other documents that reference or work with the criteria document
- Ease to maintain the criteria

2-2 WRITING STYLE.

Write in a direct, active voice with simple, concise sentences in the present tense. Use language appropriate for the user with the experience level required by the subject matter. Avoid ambiguous, indefinite terms such as "too short" or "relatively simple." Quantify whenever possible. Define what applies before using "applicable."

Avoid using the Latin abbreviations for “for example” (e.g.) and “that is” (i.e.) in text. Write out the lead-in to your example: “for example” or “such as.” The use of Latin abbreviations is acceptable within tables and figures. For additional guidance, see Federal Plain Language Guidelines or the Writing Style Guide and Preferred Usage for DoD Issuances.

2-2.1 Mood, Tense, and Voice.

Use the imperative mood (for example, install equipment). Use “must” instead of “shall” to prescribe mandatory requirements, actions and procedures. “Shall” imposes an obligation to act but may be confused with prediction of future action. “Must” imposes obligation and indicates a necessity to act.

In documents that are likely to become part of legal contracts, use imperative mood or “must” to impose a legal obligation. Use "will" to predict future action. Use "can" and "may" to permit choice and identify guidance. Use "should" to indicate desirable procedures that are advisory in nature. Don’t use “he” or “she” or “his” or “her” separately as generic (possessive) pronouns. Use “they” or “their” to avoid gender specificity. Often, rewriting a sentence eliminates the need for repetitive "he or she"; for example, "Information managers complete their training" rather than "the information manager completes his or her training."

2-2.2 Abbreviations, Acronyms, and Symbols.

Refer to the U.S. Government Printing Office, Style Manual for standard government abbreviations, acronyms and symbols. Refer to the Writing Style Guide and Preferred Usage for DoD Issuances for DoD abbreviations, acronyms. Refer to Joint Publication 1-02 for standard military acronyms and terms.

2-2.2.1 Abbreviations.

Use abbreviations consistently throughout a document. Spell out proper names on first use, and present the abbreviation immediately following in parentheses; use the abbreviation thereafter. Abbreviations for standard units of measure can be spelled out on the first use or included in the Glossary.

2-2.2.2 Acronyms.

Use established DoD and industry standard acronyms when the use will improve reader understanding of the text. Provide the complete term the first time it appears, followed by the acronym in parentheses. Then, use the acronym consistently throughout the remainder of the document. The acronyms “DoD,” “OSD,” and “U.S.” do not need to be established upon first use[2] . Acronyms other than DoD or industry standard must be used a minimum of three times in a document to be established; if the acronym is not used at least three times, spell out the term.

2-2.2.3 Symbols.

Symbols may be used in figures tables, and equations. Do not use symbols in the text; for example, use the word "feet" or the abbreviation “ft.”, not the symbol (‘). However, Greek symbols, the percent symbol (%) and the degree mark (°) are acceptable to use in the text.

2-2.3 Capitalization, Punctuation, Grammar, and Syntax.

Refer to U.S. Government Printing Office, Style Manual for rules on capitalization, punctuation, grammar, and syntax.

2-2.4 Metric System of Measurement.

Provide measurements in English inch-pound units with metric dimensions in parentheses[3] including tables and figures. Calculate metric dimensions to the same level of significance as the English inch-pound units. Refer to IEEE/ASTM SI 10 for metric practices such as methods of converting and rounding.

2-2.5 Forms.

Forms may be developed for specific data collection tasks required to use the criteria. To make **\1** printing **/1/** easier, each form should occupy a separate page.

2-3 FORMAT.

The format of criteria documents is standardized for uniformity. Use the format described in this UFC which is preset in the UFC Template.

2-3.1 Page Layout.

Use 8.5- by 11-inch (215 by 280 mm) page size. Foldout sheets should be avoided.

---

[2] *WRITING STYLE GUIDE AND PREFERRED USAGE FOR DOD ISSUANCES*
[3] SD-10, *Guide for Identification and Development of Metric Standards*

2-3.2 Margins.

Use 1-inch (25 mm) margins left, right and top, 0.75-inch (19 mm) margin on bottom. Position marginal copy (headers and page numbers) 0.5-inch (13 mm) from the top and bottom edge of the page. All text is left-aligned at the margin, including paragraph numbers, except as noted for headers, page numbers, chapter/appendix titles, figure, table, and equation titles.

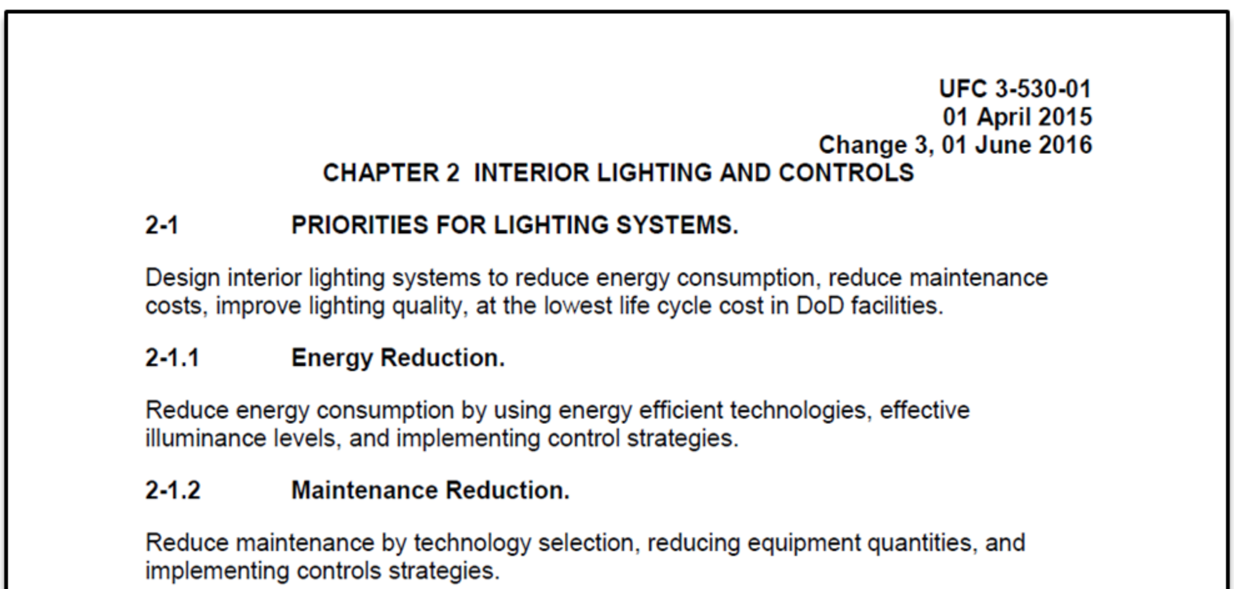
2-3.3 Font.

Use 12-point Arial unless otherwise indicated. Ensure color fonts appear legible when printed black and white.

2-3.4 Headers.

Each page, including the cover and the title page, will bear the criteria designation and publication number (short title) and the publication date as marginal copy, right-justified, one-half inch from the top of the page. The short title occupies the first line; the publication date appears directly beneath the short title. If the issuance is one volume in a multi-volume issuance, add “[comma] Volume #” after the issuance number (e.g., UFC 1-300-01, Volume 1). If the document is a Change, the change number and date will appear directly below the publication date. For an example, see Figure 2-1.

Figure 2-1 Example Header


UFC 3-530-01
01 April 2015
Change 3, 01 June 2016

CHAPTER 2 INTERIOR LIGHTING AND CONTROLS

2-1 PRIORITIES FOR LIGHTING SYSTEMS.

Design interior lighting systems to reduce energy consumption, reduce maintenance costs, improve lighting quality, at the lowest life cycle cost in DoD facilities.

2-1.1 Energy Reduction.

Reduce energy consumption by using energy efficient technologies, effective illuminance levels, and implementing control strategies.

2-1.2 Maintenance Reduction.

Reduce maintenance by technology selection, reducing equipment quantities, and implementing controls strategies.

2-3.5 Footers.

All pages starting with the Table of Contents (TOC) must have a footer consisting of the page number. Do not include Chapter or Appendix modifiers with page numbers. Center page numbers horizontally in the bottom of the footer (bottom marginal copy area) of each page.

2-3.5.1 Front Matter.

Page numbers will not appear on the cover, title page, and foreword. Beginning with the first page of the table of contents, number pages consecutively with lowercase roman numerals.

2-3.5.2 Main Text.

Beginning with the first page of main text and continuing through the last page of the document (including chapters and appendices), number pages consecutively with Arabic numerals. Do not include chapter numbers in the page numbers.

2-3.6 Paragraph Numbering.

Number all main text and appendix text paragraphs. Use the bold paragraph numbering preset in the UFC Template. Do not change the formatting of the paragraph numbering in the UFC Template. In main text, number paragraphs and subparagraphs consecutively from beginning to end, using a period to separate the numbers representing each breakdown. Where a document is divided into chapters, number each paragraph consecutively within the chapter, beginning each paragraph number with the applicable chapter number followed by a dash and then the paragraph number (for example, 2-1, 2-1.1). Where the document has appendices, number appendix and paragraphs consecutively within each appendix, beginning each paragraph with the letter designation of the appendix followed by a dash and then the paragraph number (for example, A-1, A-1.1). Limit subparagraphs to four numbers separated by periods (for example (2-1.1.1.1). Generally, if there is a subordinate paragraph there should be a minimum of two subordinate paragraphs.

2-3.7 Paragraph Titles.

Numbered subparagraphs must have a title. Titles of level 1 paragraphs must be bold uppercase. Titles of subparagraphs (level 2 and below) must be bold with initial capital letters only. Indent paragraph titles 1 inch (25mm) from left margin and end with a period. Place the paragraph text flush with the left margin on the line below the paragraph title. For consistency, follow this rule even for numbered and titled paragraphs that will not appear in the Table of Contents.

2-3.8 Paragraph Text.

Use no more than two paragraphs beneath any paragraph or subparagraph title. Place all lines flush with the left margin. Leave a maximum of 12 point of space between paragraphs. This may be reduced to a minimum of 6 point if it is necessary to adjust the content on an individual page.

2-3.9 Bullet Styles.

Choose a bullet style that is appropriate to the context of the material being presented. Use alphabetical or numerical bullets when listing must be followed in order and use symbol bullets when no order is required. Bullets should be used to list items or brief points. They should not substitute for paragraph headings. Bulleted lists exceeding one page should be re-organized under appropriate paragraph headings. Lettered or numbered steps may exceed one page in length, as required. Leave a maximum of 6 point of space between bullets and 12 point before the next paragraph. This may be reduced to a minimum of 6 point if it is necessary to adjust the content to fit on an individual page.

2-3.10 Tables.

Use a table to present information that is best communicated in tabular rather than paragraph form. All tables must be referenced in the text. Center tables and position each table after the paragraph which first references it. If this causes the table to break between two pages, the entire table may be placed on the next page. If tables are not able to fit on one page, table headers must be repeated at the top of the following pages. Number tables consecutively within each chapter or appendix, using the chapter number or appendix letter first, followed by a dash (for example: for Chapter 2, Tables 2-1, 2-2, 2-3), see Table 2-1 for an example. Column headings should be bold face type and consider 25% darker shading for column header background and 1-pt line for bottom border of column header row and the table outline, see Table 2-1 and 3-1. Font size may be reduced to a minimum 8-point to enhance the presentation of data within a table. Tables may be rotated to Landscape format if required.

Table 2-1 Example Table

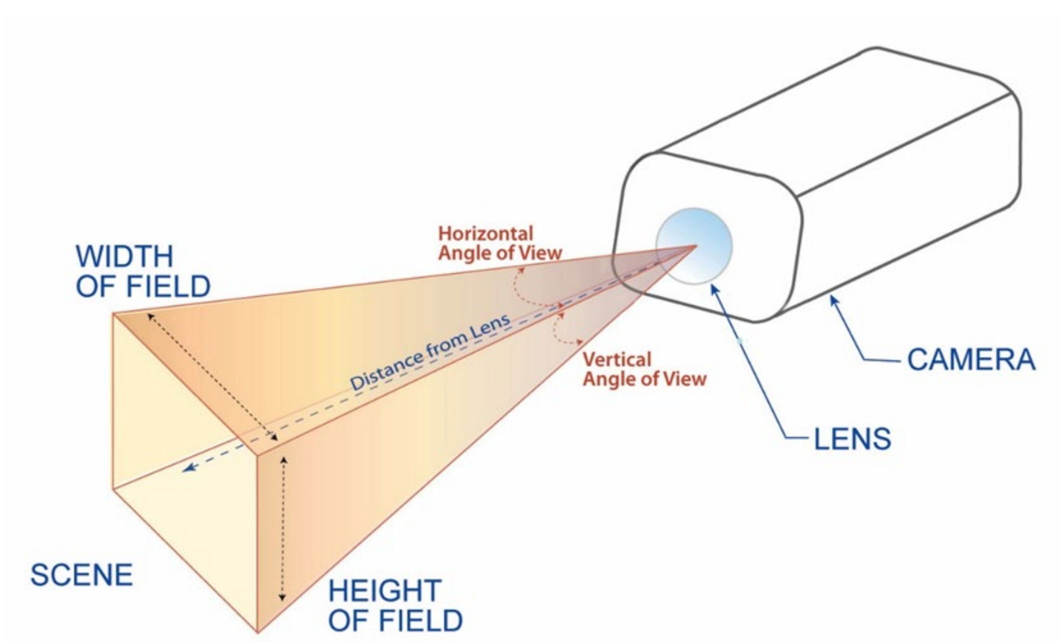
Control Strategy Name	**Control Strategy Description**
Manual On/Manual Off	The lights are manually turned on and manually turned off. This approach can only be used when other control strategies cannot be implemented due to operational requirements.
Photo sensor on/ photo sensor off	At sunset or shortly after, the lights automatically turn on. At sunrise or shortly before, the lights automatically turn off.
Photo sensor on/ timeclock off	At sunset or shortly after, the lights automatically turn on. At a preset time, the lights turn off.
Timeclock on/ timeclock off	At a preset time, the lights automatically turn on. At a preset time, the lights automatically turn off.

Timeclock on/ vacancy adjust/ timeclock off	At a preset time, the lights automatically turn on. Upon sensing vacancy, the lights switch or dim to 50% of full light output. At a preset time, the lights automatically turn off
Timeclock on/ conflict level adjust/ timeclock off	At a preset time, the lights automatically turn on. Upon sensing a reduction in conflict level (pedestrian or vehicular), the lights switch or dim to 50% of full light output.
\1\ /1/	**\1\ /1/**

2-3.11 Figures.

Use a figure to present information that is best communicated as an illustration. Figures must be referenced in the text. Figures may be color or black and white drawings or images. Ensure color figures appear legible when printed black and white. Center figures and position the figure after the paragraph which first references it. If the figure is too large for the remaining space on the page, allow text to fill the remainder of the page and place the figure at the top of the next page. If figures are so numerous they disrupt the flow of text, group them at the end of the chapter. If more than one chapter is affected, group all figures in an appendix. Embed (do not link) figures within the document file. Minimum font size for labels and callouts within figures is 8-point. Number figures similar to tables. Figures may be rotated to Landscape format if required. See Figure 2-2 for an example.

Figure 2-2 Example Figure



2-3.12 Equations.

Minimum font size for equations is 8-point. Leave a maximum of 24 point of space between equations and 12 point before the next paragraph. This may be reduced to a minimum of 6 point if it is necessary to adjust the content to fit on an individual page. In mathematical equations, use italic for all letter symbols, capitals, lowercase, small capitals, and superiors and inferiors (exponents and subscripts); use roman for figures, including superiors and inferiors.[4]

- If an equation or a mathematical expression needs to be divided, break before +, −, = or other mathematical symbol.
- A short equation in text should not be broken at the end of a line. Space out the line so that the equation will begin on the next line; or better, center the equation on a line by itself.
- An equation too long for one line is set flush left, the second half of the equation is set flush right, balance the two parts as nearly as possible.
- When there are two or more equations in a series, center the longest equation in the group and aligned the equal signs of the addition equations.

If equations do not immediately follow the associated text or if they are referenced in a different paragraph or equation, they must be numbered. Number equations similar to tables, see Equation 2-1 for an example.

Equation 2-1. Example Equation

$$T_S = D\left(\frac{vm^{0.5}\cos^{0.8}\theta}{1.125D^{1.5}\log_{10}BHN}\right)^{1.25}$$

Where:
v = impact velocity (m/s)
D = projectile diameter (mm)
T_S *= thickness of steel plate to prevent perforation (mm)*
θ = angle of obliquity (degrees)
m = mass of projectile (kg)
BHN = Brinnell Hardness Number

2-3.13 Warnings, Cautions, and Notes Headings.

For Operations and Maintenance documents, it may be necessary to include warnings, cautions, and notes headings in the text to highlight essential operating or maintenance procedure, practice, condition or statement, which, if not strictly observed could result in

[4] U.S. Government Printing Office, *Style Manual*

an injury, death or long-term health hazard. For guidance on warnings, cautions, and notes headings, refer to MIL-STD-38784A.

2-3.14 External References in Text.

Identify documents referenced in the text by publication number only. Add volume number when applicable. Document titles normally will not be cited in the text; locate full titles in the reference list. When references are issued without number identifiers, include their titles in the text in italics according to the examples in this UFC. If the reference is a web site, provide the name of the web site, followed by the uniform reference locator (URL) in parenthesis. For example, Whole Building Design Guide (https://www.wbdg.org/)

Do not use criteria to republish material available from another source. Information extracted from other publications for inclusion must not exceed one page in length. Present such extracted material in quotation marks, indented 0.5 inch (12.5 mm) from both right and left margins with 6-point space at the top and bottom, and provide appropriate references.

2-3.15 Internal References in Text (Cross-Reference).

Do not use vague terms such as 'previously discussed,' 'prior,' or 'in following paragraphs. Identify cross-references in the text by the number such as chapter number, paragraph number, figure number, table number, or equation number. An example would be, “See paragraph 3-2.5” or, “See Figure 3-2”.

2-3.16 Footnotes.

Use footnotes to give credit for a regulatory or functional authority requirement, legal citation, copyrighted, or quoted material. Identify the footnote with an Arabic superscript number. Number footnotes consecutively from 1 to 99 and then begin with 1 again. If the document is divided into chapters, number the first footnote in each chapter as "1." In supplemental sections, such as appendixes, footnotes begin with 1. Footnotes to tables are numbered independently from footnotes to text. Place footnotes at the bottom of the same page containing the referenced text, separating them from the main text by a hairline rule.

This Page Intentionally Left Blank

CHAPTER 3 ORGANIZATION AND CONTENT

3-1 ORGANIZATION.

Use the following outline:

- Front Matter
  - *Cover*
  - *Title page*
  - *Foreword*
  - *Table of Contents*
- Chapter 1 – Introduction
  - *Background*
  - *Purpose and Scope*
  - *Reissues and Cancels*
  - *Incorporates and Cancels*
  - *Applicability*
  - *Overarching Criteria or Regulatory Requirements*
  - *Regulatory or Functional Authorities*
  - *General Building Requirements*
  - *Cybersecurity*
  - *Glossary*
  - *References*
- Chapter 2 (and following chapters)
  - *Technical requirements*
- Appendix A – Best Practices and other content
- Appendix B – Glossary
- Appendix C – References

3-2 FRONT MATTER.

The front matter includes Cover Page, Title Page, Foreword, Summary Sheet, and Table of Contents. These pages are mandatory for each document including volumes. The latest version of the front matter is maintained in the UFC Template.

3-2.1 Cover Page.

The cover page will include criteria type, document title, DoD Symbol and distribution statement.

3-2.1.1 Criteria Type.

Criteria Type is either Unified Facilities Criteria (UFC) or Facilities Criteria (FC) center justified in bold uppercase.

3-2.1.2 Document Title.

Title will be the title of the criteria in bold uppercase and include modifier when applicable. The first line of the document title will contain only the description of the system, engineering discipline, or facility type. Provide a second line modifier to the title when the document is other than design criteria. Modifiers include but are not limited to, Planning, Design and Construction, Operations Manual, Maintenance Manual, or Inspection Procedures. If no modifier, it will be assumed that the document contains design requirements. If possible, the title should not exceed two lines. Do not use the same title for more than one issuance.

For issuances separated into volumes, list the issuance title, followed by a colon and the volume-specific title (Criteria Title: Volume-Specific Title)[5].

3-2.1.3 DoD Symbol.

DoD symbol will be centered on page, refer to UFC Template.

3-2.1.4 Distribution Statement.

Include distribution statement A or C in accordance with DoDI 5230.24, as follows:

- DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.
- DISTRIBUTION STATEMENT C. Distribution authorized to U.S. Government Agencies and their contractors (fill in reason) (date of determination). Other requests for this document will be referred to the preparing activity.

Most unclassified criteria documents will require Distribution Statement A. Criteria documents determined to be CUI, will require Distribution Statement C and be marked, handled and distributed in accordance with DoDI 5200.48. For these Distribution C documents, the reason will be for “administrative” or “operational” use, the date will be the date determination was established (not necessarily the publication date). Requests for these documents using the Freedom of Information Act (FOIA) will be coordinated with the preparing activity in accordance with DoDI 5230.24.

3-2.2 Title Page.

The title page has a standard copyright statement, a list of the participating Activities and the Record of Changes.

[5] DoD Issuances Standards

3-2.2.1 Participating Activities.

List the participating activities and identify the Preparing Activity parenthetically. See this UFC for an example.

3-2.2.2 Record of Changes.

Record of Changes is applicable when issuing a Change. List each change on the title page under the Record of Changes. Editorial and simple changes may be listed with a general statement such as, "Modified paragraphs 2-1.5, 2.2.3, 2-2.4, 2-4.1.1, 2-4.2.1, 2-8, 2-8.2, 2-8.3 and 3-2". Changes that add requirements, direction or content should be individually identified such as, "Adopts 2015 IBC" or "Added Appendix C Daylighting Best Practices". Simple typographic or grammar changes do not need to be listed. For Revisions, remove all previous changes from the title page, and delete all change markings in the text of the document.

3-2.3 Foreword.

The foreword is identical for all criteria documents and includes general information and the authorization signatures. Prior to publication, refer to the UFC Template for the latest version of the foreword to include current authorized signature authorities.

Exception: For FC, include the signatures of the applicable DoD Components and substitute FC for UFC as applicable.

3-2.4 Summary Sheet.

The original Summary Sheet including Impact and Unification Issues has been deleted from the Front Matter of new and revised UFCs. Provide a separate Impact and Unification issues form to justify service specific requirements and document criteria impacts. See UFC Template for additional information.

3-2.5 Table of Contents.

A Table of Contents (TOC) is mandatory for all criteria documents. As a minimum, the TOC should list Chapters and Appendices with titles and subparagraphs down to second level. Do not list the front matter in the TOC. TOC is generated based on the styles used in the document. Do not manually change the text in the TOC itself. Instead, adjust the appropriate content within the body of the document and update the TOC. The UFC Template will facilitate the automatic generation of the table of contents. If document is one volume in a multi-volume issuance, each volume must have a TOC and each TOC will only include the information for the individual volume.

3-2.5.1 Table of Figures and Tables.

Include a list of figures and tables when there are figures or tables included in the document or volume. If so, format these listings similarly to the rest of the table of contents under the separate headings of "Figures" or "Tables". Format the list of Figures and Tables using the UFC Template.

3-3 CHAPTER 1 CONTENT.

Chapter 1 provides an introduction to define its content, applicability, use and includes the overarching criteria or regulatory requirements. In general, Chapter 1 may contain the following sections:

- *Background*
- *Purpose and Scope*
- *Reissues and Cancels*
- *Incorporates and Cancels*
- *Applicability*
- *General Building Requirements*
- *Cybersecurity*
- *References*
- *Glossary*

3-3.1 "Background" Paragraph.

This paragraph is optional but included when it is important to inform the user why the criteria was created. Here is an example from UFC 1-200-02:

> "The Energy Policy Act of 2005, Energy and Independence Security Act of 2007, and Executive Order (EO) 13693 mandate Federal agencies to lead by example, promoting sustainable Federal buildings through environmentally-sound, economically-sound, and fiscally-sound design, construction, and operating decisions. The Federal requirements collectively are referred to as the "Guiding Principles" and are detailed in "Guiding Principles for Sustainable Federal Buildings and Associated Instructions", February 2016, which replaces "Guiding Principles for Federal High Performance and Sustainable Buildings", 2008. Consistent with UFC program requirements, this UFC integrates DoD requirements (DoDI 4170.11 and other DoD Policies) with High Performance and Sustainable Building (HPSB) Guiding Principles and industry standards for high performance and sustainable buildings."

3-3.2 "Purpose and Scope" Paragraph.

This paragraph is mandatory and at a minimum, this paragraph defines the purpose and scope of the criteria. Here is an example from UFC 3-530-01:

> "This UFC provides requirements for the design of interior and exterior lighting systems and controls based on the Illuminating Engineering Society of North America's (IES) Lighting Handbook Reference and Application, 10th Edition (hereafter called IES Lighting Handbook), Energy Policy Act of 2005, and current recommended practices. This UFC meets

the current IES standard of practice and addresses general lighting requirements for DoD facilities."

3-3.3 "Reissues and Cancels" Paragraph.

This paragraph is mandatory for document updates. List the UFC number, title, version, and publication date of the current online version this UFC is replacing. Do not include the current publication in the reference list. If the document is a new UFC, remove the entire paragraph.

3-3.4 "Incorporates and Cancels" Paragraph.

This paragraph is mandatory for UFCs incorporating and cancelling other documents. List the type, number, title, and publication date of the documents being incorporated and cancelled. If multiple documents are being incorporated and cancelled, list the documents alphabetically on subsequent lines. If the issuance is not incorporating and cancelling another document, remove the entire paragraph.

3-3.5 "Applicability" Paragraph.

This paragraph is mandatory and must define the applicability of the criteria. UFC 1-200-01 defines the applicability of the DoD Building Code and should be used as a baseline. To define applicability, include:

- Facility, building or system type
- Triggers or exceptions
- Service element(s) for non-unified facility criteria.

Here is an example from UFC 3-530-01:

"This UFC applies to interior or exterior lighting systems for construction, repair, and maintenance projects."

3-3.5.1 Facility, Building or System Type.

Facility, building or system type typically follows the title of the criteria. In some cases, it may be necessary to include modifiers such as temporary, semi-permanent, non-permanent facilities that support Military Operations or non-DoD Tenant Buildings on DoD Installations.

3-3.5.2 Triggers or Exceptions.

In some cases it may be required to include applicable triggers or exceptions in the applicability. Typical examples are:

- Effective date

- Location (example: CONUS, OCONUS, within or outside the United States and its territories)
- Occupancy (example: inhabited, primary gathering, billeting)
- Size (example: For buildings greater than 25,000 SF (2,322 m2)
- Replacement cost. Do not use Plant Replacement Value (PRV)
- Acquisition method (example: Military Construction, Public Private Venture, leases)

3-3.6 "Overarching Criteria or Regulatory Requirements" Paragraph.

Additional paragraphs may be included in Chapter 1 to reference overarching criteria, policy or regulatory requirements that are the basis for the requirements determination. Examples are:

- Public Law
- Executive Orders
- DoD Directives, Instructions, Manuals and Directive-Type Memorandums
- Applicable regulatory requirements

3-3.7 "Regulatory or Functional Authorities" Paragraph.

In some criteria documents, it may be necessary to include the regulatory or functional authority for reference, coordination and waiver and exemption coordination. These regulatory or functional authorities may be associated with a facility type or program. The information should include:

- Project or criteria coordination requirements
- Waiver and exemption approval authorities, if other than that defined in MIL-STD-3007.
- Program or regulatory authorities
- Overview of a criteria or policy that are linked together to include their hierarchy.

The following example is from the FC for Navy Child Development Centers:

"**1-7 REGULATORY AUTHORITIES.**

The program regulatory authorities are included below.

1-7.1 Military Authorities.

The comprehensive authorities having jurisdiction for CDCs are the following:

1-7.1.1 Navy.

The following authorities must approve the acquisition methodology, the design team composition, site selection, facility requirements, the DD Form 1391, concept development, and the final design-build request for proposal (RFP) or final design:

- Commander of Naval Installations Command (CNIC) N926 Child and Youth Programs, and N944 Fleet and Family Readiness, Integrity Drive, Millington, TN 38055-6560.
- NAVFAC FAC/FEC

Planners must contact N926 and N944 during planning development and prior to final signature of the DD Form 1391.

1-7.1.2 Marine Corps.

The following authorities must approve the acquisition methodology, the design team composition, site selection, facility requirements, the DD Form 1391, concept development, and the final DB RFP or final design:

- HQMC, Marine Corps Installations Command (GF-4)
- HQMC, Marine and Family Programs Division (MFY-3)
- HQMC, Semper Fit and Exchange Services Division (MRD)"

3-3.8 "General Building Requirements" Paragraph.

The General Building Requirements paragraph is mandatory for all design criteria documents. Refer to the UFC Template for the latest version of the standard paragraph. The current version contains the following:

> "Comply with UFC 1-200-01, DoD Building Code (General Building Requirements). UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFC and government criteria referenced therein."

3-3.9 "Cybersecurity" Paragraph.

The Cybersecurity paragraph is mandatory for all design criteria documents that include control systems. Refer to the UFC Template for the latest version of the standard paragraph. The current version contains the following:

> "All facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed,

acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy."

3-3.10 "Non-Government Standard Modification" Paragraph.

For criteria intended to amend, delete, replace or supplement a building code or a non-government standard, include a paragraph similar to the following:

"1-4 2015 IBC and ASCE/SEI 7-10 Modifications.

UFC 1-200-01 uses and supplements 2015 IBC as the building code for DoD. Chapter 2 of this UFC further modifies the IBC for structural-specific design requirements and is organized by the chapter of IBC that each section modifies. Chapter 3 of this UFC further modifies ASCE/SEI 7-10 for structural-specific design requirements and is organized by the chapter of ASCE/SEI 7 that each section modifies. The 2015 IBC and ASCE/SEI 7-10 section modifications are one of four actions, according to the following legend:

[Addition] – Add new section, including new section number, not shown in 2015 IBC or ASCE/SEI 7-10.

[Deletion] – Delete referenced 2015 IBC or ASCE/SEI 7-10 section.

[Replacement] – Delete referenced 2015 IBC or ASCE/SEI 7-10 section or noted portion and replace it with the narrative shown.

[Supplement] – Add narrative shown as a supplement to the narrative shown in the referenced section of 2015 IBC or ASCE/SEI 7-10."

The section modifiers are identified at the end of the paragraph title. Use the level one and two paragraphs to identify the primary code sections. The third level paragraphs may be the code paragraphs. Here is an example:

"2-4 CHAPTER 19 – CONCRETE.

2-4.1 Section 1901 – GENERAL.

1901.7 - Construction Joints [Addition]

Provide construction, contraction, and expansion joints in structures in accordance with ACI 224.3R and ACI 318, Section 26.5.6.

1901.8 – Tension Ties [Addition]

Where reinforcement is used as a tension tie, splices must be made with a full mechanical or full welded splice per ACI 318 Section 25.4.

1901.9 – Drying Shrinkage [Addition]

Concrete drying shrinkage must be determined for the approved concrete mixture per ASTM C157/C157M as modified by ACI 364.3R and must not exceed 0.05."

3-3.10.1 Tables, Figures and Equations from Non-Government Standards.

Tables, Figures and Equations that are taken from or modified from a non-government standard may use the designation from the Non-Government Standard. The Tables and Figures from the non-government standard do not have to be listed in the Table of Figures or Table of Tables.

3-3.10.2 Commentary.

Limited commentary is allowed when modifying non-government standard to explain or provide the rationale for the standard modification. Commentary should be brief and to the point. Provide a commentary paragraph in chapter 1 and precede commentary with a "[C]" and highlight the narrative with 25% gray. The following example is from UFC 3-301-01.

"**1-7 COMMENTARY.**

Limited commentary has been added to the chapters. Section designations for such commentary are preceded by a "[C]" and the commentary narrative is **\1** shaded.

[C] 1613.1 – Scope [Supplement]

Although Chapter 14 of ASCE 7-16 is not adopted by the 2021 IBC, occasional references to ASCE 7-16 Chapter 14 sections are made in this UFC." **/1/**

3-3.11 "Glossary" Paragraph.

A Glossary is mandatory for all criteria documents using acronyms other than "DoD," "OSD," or "U.S.". The Glossary is always in the second to last appendix. When referring to the Glossary in text, always capitalize "Glossary." List the acronyms, abbreviations and terms that are cited in the text to include the appendices. If the definition of a term has a source, provide citation. Refer to the UFC Template for the latest version of the standard paragraph. The current version contains the following:

"Appendix X contains a list of acronyms, abbreviations, and definitions".

3-3.12 "References" Paragraph.

A reference list is mandatory for all criteria documents that refer to other documents or sources. The reference list is always in the last Appendix. List all publications cited in the text, including appendices in the reference list[6]. Do not include references that are not referenced in the text. Refer to the UFC Template for the latest version of the standard paragraph. The current version contains the following:

> "Appendix X contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies. **\1** Refer to UFC 1-200-01, for the applicable publication date for International Building Code®. Refer to UFC 1-200-02, for the applicable publication date for ASHRAE Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings." **/1/**

In some cases it may be warranted to include additional sources of information about the criteria subject. See 3-7.6 for information on supplemental resources.

3-4 TECHNICAL CHAPTERS.

The technical chapters provide the technical requirements for the criteria starting with Chapter 2. Additional chapters may be added depending on the organization of the subject matter. For example, if discipline-specific criteria include interior and exterior systems, a separate chapter may be provided for each system. Include the unique government requirements and any modifications to non-government standards or existing criteria in the technical chapters. Minimize and streamline content by:

- Including only the technical requirements
- Utilizing performance criteria to the greatest extent possible
- Referencing non-government standards to the greatest **\1** extent **/1/** possible
- Referencing other criteria documents to the greatest **\1** extent **/1/** possible
  - Do not include content from UFC 1-200-01
  - Do not include content contained in the core UFC
- Locating supporting information, best practices and guidance in the Best Practices or other appendices

3-4.1 Exceptions.

An exception is something that is excluded from a criteria requirement and is identified within the criteria. Exceptions can be described in the requirement or listed after the requirements. Follow the methodology in the International Building Code (IBC) to identify exceptions. Example from the IBC:

[6] DoD Issuances Standards

- "Stages greater than 1,000 square feet in area (93 m2) shall be equipped with a Class III wet standpipe system with 1-1/2-inch and 2-1/2-inch (38 mm and 64 mm) hose connections on each side of the stage."
- "Exception: Where the building or area is equipped throughout with an automatic sprinkler system, a 1-1/2- inch (38 mm) hose connection shall be installed in accordance with NFPA 13 or in accordance with NFPA 14 for Class II or III standpipes."

3-4.2 Facility Systems Safety.

Safety is an important component of maintaining and operating DoD facilities and must be incorporated in criteria development and the design process. Incorporating facility system safety in criteria and ultimately the design process will provide the greatest opportunity to reduce risk at the lowest life cycle cost. Therefore, criteria must incorporate concepts from ANSI/ASSE Z590.3, which provides guidance for a life-cycle assessment and a design model that balances environmental and occupational safety and health goals over the life span of a facility.

3-4.3 Multi-Disciplinary and Facility-Specific Design Criteria.

Multi-disciplinary and facility-specific design criteria must convey a wide variety of information. Organize the information in the following order.

- Sustainability and Energy-High Performance and Sustainable Building Requirements (Only if information is needed above what is covered in UFC 1-200-01)
- Physical Security and Antiterrorism (Only if information is needed above what is covered in UFC 1-200-01)
- Architecture
- Interior Design
- Civil Engineering
- Landscape Architecture
- Geotechnical Engineering
- Structural Engineering
- Mechanical Engineering
- Electrical Engineering
- Fire Protection

3-4.3.1 Functional Data Sheets.

A Functional Data Sheet (FDS) is a table intended to provide design criteria for a specific room or space. FDSs are not required if the minimum design criteria is provided in UFC 1-200-01, the applicable core criteria documents or the contents of the technical chapters of the facilities type criteria. The criteria in the FDS should be performance based when possible. For example, do not indicate that an interior wall must be concrete masonry unit (CMU) because CMU may not be standard construction in regions outside the U.S. Instead, describe the desired performance. An example for an interior CMU wall could be "durable wall assembly that is resistant to physical damage, moisture, insects and fire". If required, the FDSs are provided in a separate chapter. See Figure 3-1 for an example of a blank FDS. The FDS generally follows the Uniformat II/Work Breakdown Structure (WBS). The Interior Construction/Built-In Equipment category includes anything physically attached or plumbed to the building such as counters, cabinets, casework, toilet accessories, window shades or blinds, and recessed projection screens. The Furnishings and Equipment category includes loose or moveable items that have no permanent connection to the structure of a building or utilities such as desks, chairs, and shelving.

The Functional Data Sheets are intended to provide the minimum requirements for the respective rooms and spaces for the designer, planner, or RFP preparer. These minimum requirements apply in addition to the requirements of the criteria document and the referenced documents. Blank spaces found in the Functional Data Sheets indicate building components or systems should follow standard guidance per UFC 1-200-01.

Figure 3-1 Example Functional Data Sheet

Description/Usage	
Ceiling Height	
Windows	
Doors	
Interior Construction / Built-in Equipment	
Finishes	Walls
	Floor
	Base
	Ceiling
Plumbing	
HVAC	
Fire Protection and Life Safety	
Power	
Lighting	
Telecommunications	Telephone
	Data
	CATV
Security	IDS
	ACS
	VIDEO
Acoustics	
Furnishings and Equipment	
Special Requirements	
Adjacencies / Location within Facility	
	For Use during project execution by appropriate Service
Occupancy	Staff
	Other
Min. net Ft^2 (m^2)	

3-5 "BEST PRACTICES" APPENDIX.

Best Practices; if required, begins with Appendix A. Do not include requirements in the Best Practices. Best Practices appendices are not intended to be a textbook or to repeat information from industry standards and other non-government references. The Best Practices appendix contains commentary and guidance which are not enforceable in contracts. The main purpose is to communicate proven facility solutions, systems, and lessons learned, but may not be the only solution to meet the requirement. In general, follow the associated formatting and content in the associated technical chapter. For example, if there were a technical chapter for interior systems and one for exterior systems, then the best practices should be separated into two appendices. Include the following at the beginning of the any Best Practices appendix,

"The Best Practices Appendix is considered to be guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned, but may not be the only solution to meet the requirement."

3-6 "GLOSSARY" APPENDIX.

The Glossary is always the second to last appendix[7]. It is broken up into two parts, Acronyms and Abbreviations and Definitions, as appropriate. Present acronyms as they appear within the UFC text; for example, ESEP, CUI, kPa, mm. If the Acronym or definition of a term has a source, provide citation. An example is included in UFC Template. Use the font, spacing, and alignment provided in the template.

3-7 "REFERENCES" APPENDIX.

The reference list is always the last appendix[7]. Use the Appendix to list references in alphabetical order. Generally, include a standard designation, title, and publisher. Specific information for different reference types, and the order to present this information, is provided in the paragraphs below.

If the appendix is several pages, consider breaking the references into categories. For example, a document may use the categories "Government" and "Non-government"; or it may categorize the references by military agencies: "Air Force," "Army," and "Navy" or Standards organization. Choose categories that break the references into manageable lists that are logical for the user. An example is included in UFC Template. Use the font, spacing, and alignment provided in the template.

3-7.1 Publisher Information.

Provide the user with the necessary publisher information to obtain the reference. For the purposes of this UFC, "publisher" is defined as the entity with control and authority over distribution. In cases where more than one entity wields such control and authority, list the lead or authoring entity as publisher. If the reference can only be obtained from a single source, include the address, telephone number, or web site. If

[7] DoD Issuances Standards

this information is not listed, it will be assumed that the reference may be obtained through the web search or the normal means of obtaining any book or magazine.

3-7.2 Government Standards.

List government standards (UFC, Military, or Federal Standards, or other government standards or specifications) using the appropriate standard designation (UFC 1-200-01, MIL-STD-3007), followed by the title in italics and web site, if applicable.

3-7.3 Non-government Standards.

List non-government standards (for example, ASTM Standards, ASME Standards) in alphabetical order using the appropriate standard designation (ASTM A 38) followed by the title in italics and web site, if applicable.

3-7.4 Books and Periodicals.

If the reference is a book or a complete journal, list these documents in alphabetical order by title in italics, author name, publisher and web site, if applicable.

If the reference is a distinct portion of a book or journal (an article or a chapter,) list in alphabetical order by title in quotation, followed by the title in italics, the author's name, publisher, and web site, if applicable.

3-7.5 Web Sites.

If the reference is a web site, list in alphabetical order by the name of the web site in all upper case, followed by the uniform reference locator (URL).

3-7.6 Supplemental Resources.

It may be warranted to include additional sources of information about the criteria subject, such as web sites or journals that publish new findings about a subject on a regular basis. In such cases, include these resources in a separate appendix titled "Supplemental Resources," and list in the same manner as for References. Limit supplemental resources to a single page.

3-8 “INDEX” APPENDIX.

An index is not required and is not to be included. Indexes are difficult to develop and maintain, and electronic format allows for simple searches to locate occurrences of words and phrases.

APPENDIX A NUMBERING OF UNIFIED FACILITIES CRITERIA

A-1 UFC SERIES 1 - POLICY, PROCEDURES, AND GUIDANCE.

- 1-100 Series - General
- 1-200 Series - Policy
- 1-300 Series - Procedures and Guidance
- 1-400 Series - Reserved
- 1-500 Series - Reserved
- 1-600 Series - Reserved
- 1-700 Series - Reserved
- 1-800 Series - Reserved
- 1-900 Series – Miscellaneous

A-2 UFC SERIES 2 - MASTER PLANNING.

- 2-100 Series - Comprehensive Master Planning
- 2-200 Series - Land Use Planning
- 2-300 Series - Utility System Planning
- 2-400 Series - Transportation System Planning
- 2-500 Series - Spatial Data Systems
- 2-600 Series - Installation Design Guides
- 2-700 Series - Outdoor Recreation Planning
- 2-800 Series - Planning in the Noise Environment
- 2-900 Series - Reserved

A-3 UFC SERIES 3 - DISCIPLINE-SPECIFIC CRITERIA.

A-3.1 3-100 Series - Architecture and Interior Design.

- 3-101 General
- 3-110 Architectural Design
- 3-120 Interior Design
- 3-130 Arctic and Subarctic Construction
- 3-140 Reserved
- 3-150 Reserved

- 3-160 Reserved
- 3-170 Reserved
- 3-180 Reserved
- 3-190 Miscellaneous

A-3.2 3-200 Series - Civil / Geotechnical / Landscape Architecture.

- 3-201 General
- 3-210 Site Planning and Design
- 3-220 Geotechnical
- 3-230 Water
- 3-240 Sanitary
- 3-250 Vehicle Roadway Design
- 3-260 Airfield Pavements
- 3-270 O&M for Airfield Pavements
- 3-280 Environmental Remediation
- 3-290 Miscellaneous

A-3.3 3-300 Series - Structural and Seismic Design.

- 3-301 General
- 3-310 Structural Design Criteria
- 3-320 Structural Design Guidance
- 3-330 Structural Design Commentary
- 3-340 Hardened Structures – Conventional Weapons Effects
- 3-350 Hardened Structures – Nuclear Weapons Effects
- 3-360 Reserved
- 3-370 Reserved
- 3-380 Reserved
- 3-390 Miscellaneous

A-3.4 3-400 Series - Mechanical.

- 3-401 General
- 3-410 HVAC

- 3-420 Plumbing Systems
- 3-430 Central Plants and Energy Distribution Systems
- 3-440 Renewable Energy Systems
- 3-450 Acoustics and Vibration Control
- 3-460 Fuel Storage and Distribution Systems
- 3-470 Energy Monitoring and Control Systems
- 3-480 Reserved
- 3-490 Miscellaneous

A-3.5 3-500 Series - Electrical.

- 3-501 General
- 3-510 Foreign Voltages
- 3-520 Interior Electrical Systems
- 3-530 Lighting Design and Controls
- 3-535 Airfield Lighting Systems
- 3-540 Electric Power Generation
- 3-550 Electric Power Supply and Distribution
- 3-555 400Hz Power Systems
- 3-560 Electrical Safety
- 3-570 O&M: Cathodic Protection
- 3-575 Lightning Protection
- 3-580 Telecommunications
- 3-590 Miscellaneous

A-3.6 3-600 Series - Fire Protection.

- 3-601 General
- 3-610 Reserved
- 3-620 Reserved
- 3-630 Reserved
- 3-640 Reserved
- 3-650 Reserved
- 3-660 Reserved

- 3-670 Reserved
- 3-680 Reserved
- 3-690 Miscellaneous

A-3.7 3-700 Series - Cost Engineering.

- 3-701 Pricing Guides
- 3-710 Code 3 Design with Parametric Estimating
- 3-720 Economic Analysis Guides
- 3-730 Programming and Budget Cost Estimating
- 3-740 Construction Cost Estimating
- 3-750 Reserved
- 3-760 Reserved
- 3-770 Reserved
- 3-780 Reserved
- 3-790 Miscellaneous

A-3.8 3-800 Series - Environmental.

- 3-801 General

A-3.9 3-900 Series - Reserved.

A-4 UFC SERIES 4 - MULTI-DISCIPLINARY & FACILITY-SPECIFIC DESIGN.

Series 4 numbering is based on the DoD hierarchical scheme of real property types, functions and Category Groups found in DoDI 4165.03.

A-4.1 4-000 - General.

- 4-010 Multi-Disciplinary Requirements
- 4-020 Security Engineering
- 4-021 Electrical Engineering
- 4-022 Civil Engineering
- 4-023 Structural Engineering
- 4-024 Chemical, Biological, Radiological, Nuclear (CBRN)
- 4-025 Waterfront

- 4-026 Threats
- 4-027 Expeditionary/Contingency
- 4-030 Sustainable Development

A-4.2 4-100 Series - Operational and Training Facilities.

- 4-120 Liquid Fuel Dispensing Facilities
- 4-121 Aircraft Dispensing
- 4-130 Communications, Navigational Aids and Airfield Lighting
- 4-133 Navigation and Traffic Aids - Buildings
- 4-134 Navigation and Traffic Aids - Other than Buildings
- 4-140 Land Operational Facilities
- 4-141 Operational - Buildings
- 4-150 Waterfront Operational Facilities
- 4-152 Wharfs
- 4-159 Other Waterfront Operational
- 4-160 Harbor and Coastal Operational
- 4-170 Training Facilities
- 4-171 Training Buildings
- 4-179 Training Facilities - Other Than Buildings

A-4.2.1 4-200 Series - Maintenance and Production Facilities.

- 4-210 Maintenance
- 4-211 Maintenance – Aircraft
- 4-212 Maintenance – Guided Missiles
- 4-213 Maintenance - Ships, Spares
- 4-214 Maintenance - Tank, Automotive
- 4-215 Maintenance – Weapons, Spares
- 4-216 Maintenance - Ammunition, Explosives, Toxins
- 4-218 Maintenance - Facilities for Miscellaneous Procured Items and Equipment
- 4-220 Production
- 4-229 Production - DoD Maintenance, Repair, and Operation of Installations

A-4.3 4-300 Series - Research, Development, Test, and Evaluation Facilities.

- 4-310 Science Laboratories
- 4-390 Other Than Buildings

A-4.4 4-400 Series - Supply Facilities.

- 4-420 Ammunition Storage
- 4-440 Storage - Covered
- 4-442 Storage - Covered - Installation and Organizational
- 4-450 Storage - Open
- 4-451 Storage - Open - Depot

A-4.5 4-500 Series - Hospital and Medical Facilities.

- 4-510 Medical Center / Hospital

A-4.6 4-600 Series - Administrative Facilities.

- 4-610 Administrative Buildings

A-4.7 4-700 Series - Housing and Community Facilities.

- 4-710 Family Housing
  - 4-711 Family Housing - Dwellings
- 4-720 Unaccompanied Personnel Housing
  - 4-721 Unaccompanied Personnel Housing - Enlisted Personnel
  - 4-722 Unaccompanied Personnel Housing - Mess Facilities
  - 4-724 Unaccompanied Personnel housing - Officers' Quarters
- 4-730 Community Facilities - Personnel Support and Service
- 4-740 Community Facilities - Morale, Welfare and Recreation - Interior
- 4-750 Community Facilities - Morale, Welfare and Recreation - Exterior
- 4-760 Museums and Memorials

A-5 4-800 SERIES - UTILITIES AND GROUND IMPROVEMENTS.

- 4-820 Heat and Refrigeration (Air Conditioning)
- 4-826 Refrigeration (Air Conditioning) - Source
- 4-830 Sewage and Waste
- 4-832 Sewage and Industrial Waste - Collection
- 4-860 Railroad Tracks

A-5.1 4-900 Series – Real Estate.

- 4-910 Land
- 4-911 Land Purchase, Condemnation, Donation or Transfer
- 4-920 Other Rights

A-6 UFC SERIES 5 - SOFTWARE AND TOOLS.

- 5-000 - Software and Tools.

This Page Intentionally Left Blank

APPENDIX B GLOSSARY

B-1 ACRONYMS.

AFCEC	Air Force Civil Engineer Center
BIA	Bilateral Infrastructure Agreement
CMU	Concrete Mason Unit
CONUS	Continental United States
CP	Coordinating Panel
CUI	Controlled Unclassified Information
DWG	Discipline Working Group
ESEP	Engineering Senior Executive Panel
FC	Facilities Criteria
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
IBC	International Building Code
NAVFAC	Naval Facilities Engineering Systems Command
OCONUS	Outside the continental United States
PDF	Portable Document Format
PRV	Plant Replacement Value
SOFA	Status of Forces Agreements
TOC	Table of Contents
USACE	U.S. Army Corps of Engineers
UFC	Unified Facilities Criteria
URL	Uniform Reference Locator
WBDG	Whole Building Design Guide
WBS	Work Breakdown Structure

B-2 DEFINITION OF TERMS.

Continental United States: United States territory, including the adjacent territorial waters, located within North America between Canada and Mexico. Also called CONUS. (JP 1-02)

Coordinating Panel: A four-member panel composed of a senior representative of each Military Department and the Office of the Secretary of Defense (OSD) responsible for day-to-day administration and management of the UFC program under the direction of the ESEP. (MIL-STD-3007)

Discipline Working Group: Lead representative from each Military Department responsible for the unification and maintenance of criteria documents. (MIL-STD-3007)

Engineering Senior Executive Panel: A four-member panel composed of a Senior Executive Service (SES) representative from each Military Department and the OSD responsible for directing and resourcing the UFC program consistent with statutory requirements and DoD policy. (MIL-STD-3007)

Facilities Criteria: FC define functional requirements for specific types of facilities within a Military Department. (MIL-STD-3007)

Military Department: One of the departments within the Department of Defense created by the National Security Act of 1947, which are the Department of the Army, the Department of the Navy, and the Department of the Air Force. (JP 1-02)

Preparing activity (PA): Lead activity assigned responsibility for the management of the criteria document. (MIL-STD-3007)

Replacement Cost: Replacement costs include construction of standard foundations, all interior and exterior walls and doors, the roof, utilities out to the 5-foot line, all built-in plumbing and lighting fixtures, security and fire protection systems, electrical distribution, wall and floor coverings, heating and air conditioning systems, and elevators. Not included are project costs such as design, supporting facility costs, special foundations, equipment acquired with other funding sources (e.g. mission-funded range targets), contingency costs, and supervision, inspection, and overhead (SIOH). Also not included are items generally considered personal property such as computer systems, telephone instruments, and furniture. (UFC 3-701-01)

Technical Proponent: A representative from a participating organization responsible for developing or coordinating the project-level effort to update a criteria document. The technical proponent can be a DWG or FWG member or other member of a participating organization or technical agency. (MIL-STD-3007)

Technical Representative: Technical working-level representative from another participating organization for a particular document assigned to assist the technical proponent in the DoD component review, unification, and maintenance of a criteria document. (MIL-STD-3007)

APPENDIX C REFERENCES

GOVERNMENT

Federal Plain Language Guidelines
https://www.plainlanguage.gov/guidelines/

Principles of Clear Writing
https://www.archives.gov/federal-register/write/legal-docs/clear-writing.html

SD-10, *Guide for Identification and Development of Metric Standards*
https://www.nist.gov/system/files/documents/pml/wmd/metric/sd10final.pdf

U.S. Government Printing Office, *Style Manual*
https://www.govinfo.gov/collection/gpo-style-manual?path=/GPO/U.S./Government/Publishing/Office/Style/Manual%20

DEPARTMENT OF DEFENSE

https://www.esd.whs.mil/DD/

DoDI 5200.48, *Controlled Unclassified Information (CUI)*

DoDI 5230.24, *Distribution Statements on Technical Documents*

DoDI 4165.03, *DoD Real Property Categorization*

Joint Publication 1-02, *DoD Dictionary of Military and Associated Terms*
https://irp.fas.org/doddir/dod/jp1_02.pdf

Writing Style Guide and Preferred Usage for DoD Issuances
https://www.esd.whs.mil/DD/plainlanguage/

DoD Issuances Standards
https://www.esd.whs.mil/Portals/54/Documents/DD/iss_process/standards/DoD_Issuance_Style_Guide.pdf

MIL-STD-962, *Department of Defense Standard Practice Defense Standards Format and Content*
https://www.dsp.dla.mil/Policy-Guidance/Key-Policy-Documents/

MIL-STD-3007, *Department of Defense Standard Practice Standard Practice For Unified Facilities Criteria and Unified Facilities Guide Specifications*
https://www.wbdg.org/dod/fedmil/mil-std-3007

MIL-STD-38784A, *Department of Defense Standard Practice General Style and Format Requirements for Technical Manuals*
http://www.everyspec.com

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 1-200-01, *DoD Building Code*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 3-301-01, *Structural Engineering*

UFC 3-530-01, *Interior and Exterior Lighting Systems and Controls*

UFC 3-701-01, *DoD Facilities Pricing Guide*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

NON-GOVERNMENT

AMERICAN SOCIETY OF SAFETY PROFESSIONALS

ANSI/ASSE Z590.3, *Prevention Through Design Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes*

INTERNATIONAL CODE COUNCIL

IBC, *International Building Code*

IEEE STANDARDS ASSOCIATION / ASTM INTERNATIONAL

IEEE/ASTM SI 10, *American National Standard for Metric Practice*

UFC 1-300-02
1 April 2014
Change 3, 18 May 2021

UNIFIED FACILITIES CRITERIA (UFC)

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS) FORMAT STANDARD

UNIFIED FACILITIES CRITERIA (UFC)

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS) FORMAT STANDARD

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	4/1/2017	Addition of corrosion control requirements and Sustainability Reporting submittals. Clarified text paragraphs, notes to the designer, tailoring, and Operation and Maintenance Data and Manuals.
2	4/1/2019	Deleted paragraphs 1-4.4, 2-2.11 and 2-2.12.5. Editorial changes to paragraphs 2-1.3.1, 2-2.2, 2-2.12 and 2-3.4. Updated paragraph 2-2.12.3 to clarify submittal designations. Added paragraphs 2-2.10 and 2-2.12.3.3.
3	5/18/2021	Added requirements for referencing FAR clauses, listing items in the SUBMITTALS article, using unique submittal item names, avoiding gender-specific pronouns, and adding change date in section date tag.

This UFC supersedes UFC 1-300-02, dated 1 September 2004, with Changes 1-4.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force **\2** Civil Engineer Center (AFCEC) **/2/** are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Hard copies of UFC printed from electronic media should be checked against the current electronic version prior to use to ensure that they are current.

AUTHORIZED BY:

JAMES C. DALTON, P.E.
Chief, Engineering and Construction
U.S. Army Corps of Engineers

JOSEPH E. GOTT, P.E.
Chief Engineer
Naval Facilities Engineering Command

JOE SCIABICA, SES
Director
Air Force Civil Engineer Center

MICHAEL McANDREW
Director, Facilities Investment and Management
Office of the Deputy Under Secretary of Defense
(Installations and Environment)

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 1-300-02, *UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS) FORMAT STANDARD*

Superseding: UFC 1-300-02, dated 1 September 2004, with Changes 1-4

Description of Changes:

- This document is a complete update to UFC 1-300-02, establishing criteria and standards for development and preparation of UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS).

Reasons for Document:

- Further unify requirements for preparation of the UFGS.
- Comply with Construction Specifications Institute (CSI) MasterFormat®**\3** latest version.**/3/**
- Coordinate with enhancements to SpecsIntact software capabilities.

Impact:

- There are negligible cost impacts.

Unification Issues

- Submittal processes for Army, Navy, and Air Force are not unified. Thus, designations after the submittal items in the Submittal Article are different for the Army, Navy, and Air Force. The Army uses the Resident Management System (RMS) to automatically track and manage submittal items, while the Navy and Air Force do not. The methodology used in a project is dependent on who the construction agent is for the project, as defined in DoD Directive (DoDD) 4270.5. Design-Build (D-B) procedures are different for each DoD Component; thus, this UFC only addresses D-B as necessary for the Submittal Article. Requirements for each Component are provided in separate criteria.
- Processes for submittal of project specifications packages by each DoD Component are not unified due to differences among organizational, operational, and administrative structure and processes.

TABLE OF CONTENTS

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC provides guidance for the preparation of Unified Facilities Guide Specifications (UFGS). The Services under the auspices of the Tri-Service Engineering Senior Executive Panel (ESEP) publish the UFGS. A definition of the ESEP is contained in MIL-STD-3007. Tri-Service committees called Discipline Working Groups (DWG) prepare the UFGS. Publication of UFGS is only by electronic media available from the distribution sources indicated in the Foreword of this UFC. UFGS are not proprietary and are available at no cost to the user.

1-2 APPLICABILITY.

This UFC applies to all Tri-Service elements and Contractors preparing UFGS. Requirements referencing Army, Navy, or Air Force only are applicable where that DoD Component is the construction agent as defined in DoDD 4270.5, and responsible for the preparation of the construction contract drawings and specifications as the designated design and construction agent in executing Military Construction Program responsibilities.

1-3 REFERENCES.

References used in this UFC are:

- \1\ASTM SI-10, American National Standard for Use of the International System of Units (SI), http://www.astm.org
- ISO 9223, Corrosivity of Atmospheres – Classification, Determination, and Estimation, International Organization for Standardization (ISO), http://www.iso.org /1/
- DoD Directive 4270.5, Military Construction, 5 February 2005, http://www.dtic.mil/whs/directives/corres/pdf/427005p.pdf .
- \3\MIL-STD-3007, Department of Defense Standard Practice: Standard Practice for Unified Facilities Criteria and Unified Facilities Guide Specifications, Defense Standardization Program, https://assistca.dla.mil.
- MasterFormat® *: Master List of Numbers & Titles for the Construction Industry,* Construction Specifications Institute, https://www.csiresources.org/home/3/
- SectionFormat™/PageFormat™*, The Recommended Format for Construction Specifications Sections,* Construction Specifications Institute, https://www.csiresources.org/home
- The CSI Project Delivery Practice Guide, Construction Specifications Institute, https://www.csiresources.org/home
- The CSI Construction Specifications Practice Guide, Construction Specifications Institute, https://www.csiresources.org/home

- SpecsIntact QuickStart Guide Numeric, National Aeronautics and Space Administration (NASA), http://si.ksc.nasa.gov/PDF/LearningGuides/QSGuideNumeric.pdf

  \3\/3/

- FAR Clause 52.211-6 *Brand Name or Equal;* General Services Administration (GSA), https://www.acquisition.gov/far
- \1\FC 1-300-09N, NAVY and MARINE CORPS Design Procedures, Tri-Service Engineering Senior Executive Panel, https://wbdg.org/ffc/dod/ /1/
- UFGS 01 33 00, *Submittal Procedures*, Tri-Service Engineering Senior Executive Panel, https://wbdg.org/ffc/dod/
- \1\UFGS 01 33 29, *Sustainability Reporting*, Tri-Service Engineering Senior Executive Panel, https://wbdg.org/ffc/dod/
- UFGS 01 78 23, *Operation and Maintenance Data*, Tri-Service Engineering Senior Executive Panel, https://wbdg.org/ffc/dod/
- UFGS 01 78 24.00 10, *Operation and Maintenance Data Requirements*, Tri- Service Engineering Senior Executive Panel, https://wbdg.org/ffc/dod/
- UFGS 01 78 24.00 20, Facility Electronic Operation and Maintenance Support Information (eOMSI), Tri-Service Engineering Senior Executive Panel, https://wbdg.org/ffc/dod/ /1/

1-4 CONTENT AND FORMAT.

UFGS are for the purpose of translating design criteria into construction requirements that have been coordinated with industry, thereby providing requirements for specifiers to incorporate into construction Contracts. Each DWG is responsible for the technical content, format, and overall quality of their UFGS. This UFC establishes the general content and appearance of UFGS publications. The UFGS format is based on the Construction Specifications Institute (CSI) *SectionFormat*™ and is designed to be used with SpecsIntact software. An example layout of UFGS is included in Appendix A, and SpecsIntact software includes an electronic UFGS section template in the proper format for use in creating a new UFGS section.

1-4.1 Content Guidance.

Since UFGS are a basis for construction Contract documents, write the UFGS in a manner that will facilitate use on the job and **\1** avoid **/1/** misinterpretations **\1** that may lead **/1/** to legal complications. **\1\/1/** Reference non-Government standards to the greatest extent **\1** possible and **/1/** avoid repeating the requirements of commercially available criteria and standards. UFGS are broad in their applicability and non-geographical in technical content. In general, requirements or restrictions for specific localities should not be included in **\3**a master UFGS; instead, requirements or limitations for various climatic, environmental,**/3/** or operating conditions are appropriate.

\1 Provide bracketed or tailored options, and Notes to the Designer, in the UFGS sections when the selection of a material, component, or system for corrosion prevention, life cycle cost effectiveness, or durability depends on the location, application, conditions, or atmospheric and chemical environment. In the notes, provide direction on identifying and selecting those variables. Use International Organization for Standardization (ISO) 9223 and Environmental Severity Classification (ESC) factors, to help specify when to use materials, coatings, and other design elements in a given project location or atmospheric environment. Additionally, provide direction on what item to use based on other relative criteria such as soil corrosivity, ultraviolet exposure, solar radiation, biological, or other factors causing deterioration of a material or its properties because of a reaction of that material with its chemical environment. **/1/**

1-4.2 Editing UFGS for Projects.

\1\ /1/\3 The UFGS are master guide specifications that provide the minimum level of quality. Edit the specification sections for project requirements. Add, modify, and delete content as required for each project scope. Do not specify lesser quality requirements than are provided in the UFGS.**/3/**

\2\ /2/

This Page Intentionally Left Blank

CHAPTER 2 UFGS REQUIREMENTS

2-1 UFGS SECTION ORGANIZATION.

\1 This paragraph describes the organization of a UFGS section. **/1/**

2-1.1 Construction Specifications Institute (CSI).

CSI prescribes the use of three parts in each section, and further recommends that a consistent sequence of subject matter be maintained within each PART. These recommendations are included in Appendix A and must be followed to the extent practical in UFGS. Insert the text “Not used.” when a PART has no content.

2-1.2 Table of Contents (TOC).

\1 SpecsIntact has two options for printing the Table of Contents using the Process and Print/Publish function: 1) For the entire project or master, and 2) For the section. The project or master TOC is printed as a separate document. The section TOC is printed within the section when the “Combine Sections and Section TOC” is selected. **\1** For instructions, refer to the SpecsIntact QuickStart Guide, Process & Print/Publish Settings. **/1/**.

2-1.3 Attachments.

Section attachments (such as Appendices, Figures, Forms) can be listed in the section table of contents by the using the attachment tag, <ATT>, around the attachment title in the section text. Full instructions are provided in the *SpecsIntact QuickStart Guide*. **/1/**

2-1.3.1 Appendices.

Attaching appendices to a UFGS section is rarely necessary. Create a simple appendix at the end of a section in SpecsIntact when necessary for project specifications. **\2** An **/2/**exception **\2** is when there is **/2/** a complex appendix **\2**, which **/2/** may be a separate PDF file and manually inserted into the final electronic portable document format (PDF) file for the project specification.

2-1.3.2 Figures.

Do not include figures in UFGS sections. When a project requires a figure in the specification, attach PDF figures to the final electronic specification PDF file.

2-2 FORMAT.

\1 Use of SpecsIntact software and the UFGS database is mandatory. SpecsIntact includes a UFGS section template that complies with this UFC and can be used as a starting point for preparing new UFGS sections. **\3**Specifications must be in UFGS format, comply with this UFC, and be prepared in SpecsIntact.**/3/ /1/**

2-2.1 Electronic File Format.

\1 The section **/1/** template assures that page layout, banners, notes, text paragraphs, tables, fonts, page numbers, headers, and other basic elements of a UFGS are consistent within each UFGS document and within the UFGS system. SpecsIntact files are Extensible Markup Language (XML) format with the extension SEC. SpecsIntact will also publish UFGS in Adobe Acrobat (PDF extension) and Microsoft Word (DOC extension) formats. Download SpecsIntact from the SpecsIntact web site (http://specsintact.ksc.nasa.gov/Index.shtml), and download the PDF SpecsIntact QuickStart Guide, which provides instructions for its use.

The most current version of UFGS is available from the Whole Building Design Guide (WBDG) DoD web page (https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs). Individual sections are available in both PDF and SEC formats. The entire UFGS Master is available in SEC format in a zipped file with the extension ZIP.

2-2.2 Section Numbering.

Each UFGS carries an identifying document or section number and title in accordance with the CSI MasterFormat® **\2\ /2/** Update Numbers & Titles (**\2\ /2/** latest version). If a number listed in Masterformat® is used, then use its exact title as listed.

UFGS with the 5th level designator denote UFGS on the same subjects: "10" for Army, "20" for Navy, "30" for Air Force, and "40" for the National Aeronautics and Space Administration (NASA) (for example, 01 45 00.00 10). These 5th level designators facilitate management of specifications and provide identification within WBDG, the Internet, and the SpecsIntact systems.

2-2.3 Part and Subpart Numbering.

Number Parts and subparts (paragraph and subparagraphs) within the UFGS in accordance with the SpecsIntact numeric system described in *SpecsIntact QuickStart Guide Numeric*. Each Part and subpart down to the sixth level is numbered as shown in Table 2-1.

Table 2-1 Parts and Subpart Numbering

Parts and Subpart Numbering
PART 1 GENERAL (Part Level)
1.1 ARTICLE (1st Level)
1.1.1 Paragraph (2nd Level)
1.1.1.1 Subparagraph (3rd Level)
1.1.1.1.1 Subparagraph (4th Level)
1.1.1.1.1.1 Subparagraph (5th Level)
1.1.1.1.1.1.1 Subparagraph (6th Level)

2-2.4 Subpart Titles.

Each numbered subpart must have a title; uppercase for the first level (ARTICLE) and title case for the lower level subparts as shown above. **\1**

2-2.5 Text Paragraphs within Parts and Subparts.

Use no more than two untitled text paragraphs within a part or subpart.

2-2.6 Notes to the Designer.

\3Notes provide directions and criteria for the designer to choose options and alternatives available in the pertinent subpart, and to identify when tailoring options are present. **/3/**Provide notes between the subpart title and text paragraph to indicate when to use the paragraph, how to choose bracketed items, and to indicate what tailoring tags are in the text paragraph. Provide the note itself within tailoring tags if the note only applies if the tailoring option is selected; thus, the note will be deleted if the tailoring option is not selected. **/1/**

2-2.7 Units of Measure (English or Metric).

\1 For UFGS Masters, provide measurements in both English and Metric units, with Metric units first. The format is:"…text<MET> 50 mm</MET><ENG> 2 inches</ENG> text;" with no space between the text before the MET tag, a space before the measurement within the tags, and no space between tags. Provide conversions in accordance with ASTM SI 10 or industry practice or standard. Do not use parenthesis to show both English and Metric units.

For projects, select either English or Metric units when setting up the Job. **/1/**

2-2.8 Reference Publications.

All references in the UFGS section subparts are also listed in the section paragraph "REFERENCES." **\1** In the UFGS, the reference identifier (RID) for the reference must appear and be tagged in the reference paragraph and at all occurrences in the text using the SpecsIntact software. **/1/\1**

2-2.8.1 Standards Organizations.

/1/ Identify standards producing organizations cited in the paragraph with the acronym in the Unified Master Reference List (UMRL) or provide an appropriate acronym if the Data Base Manager has assigned none. If there are conflicting acronyms, use the acronym approved by the database manager. Where dual acronyms may be used to identify the standards-producing organization and an underwriting organization, such as American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE), use the issuing organization only, IEEE in this case. The RID must consist of the organization acronym and publication number as stated in the UMRL. **\1\\3**

2-2.8.2 Federal Acquisition Regulations (FAR) Clauses

Avoid referencing FAR clauses, as they are provided in the contract's procurement requirements. When referencing a clause cannot be avoided, use the FAR number followed by the title (in title case) in the text. Do not include the date of the FAR clause. Do not include the FAR clause in the REFERENCES paragraph. Verify FAR titles at Acquisition.gov.

Examples:

- FAR 52.243-4 Changes
- FAR 52.236-2 Differing Site Conditions**/3/**

2-2.8.3 Reference Dates and Titles.

/1/ Use the most current reference standard in the UFGS unless specific reason exists to cite an earlier version of the standard. The reference title must consist of the year of publication in parenthesis followed by the title as stated in the UMRL. **\1**Separate the date of a reference revision (R), change (C), or similar edition (for example, editions and errata), from the original date with a semi-colon (2009; R 2010; C 2011: errata 2012), and exactly as it appears in the UMRL **/1/**. Use the UMRL in conjunction with the SpecsIntact software to automatically update the standards referenced in the UFGS. Use industry reference standards to the maximum extent possible for products and their installation to reduce the written text in the body of the UFGS. **\1**

2-2.8.4 Quoting Reference Standards.

/1/ Do not quote or repeat portions of the referenced standard in the text of the guide specifications unless it is necessary to improve clarity and readability.

2-2.9 Cross References.

Avoid cross-referencing other specification sections and paragraphs in other sections or in the same section. When a section cross-reference is necessary, the format is Section <SRF>01 23 40</SRF> MISCELLANEOUS (where MISCELLANEOUS is the full Section title). When necessary to reference paragraphs within the same section, reference by paragraph title, not by paragraph number, for example, paragraph EQUIPMENT. Paragraphs automatically renumber after changes, but paragraph titles do not change.

2-2.10 \2\ Tailoring /2/.

\2 Tailoring options in the UFGS allow pre-editing of information such as materials, methods, DoD Service-specific, or regional requirements in the creation of the project specification. The tailoring option provides a higher level of editing that reduces editing time.

2-2.10.1 Service-Specific Tailoring.

Master UFGS writers must reconcile agency differences to the greatest extent possible to avoid the need for Service-specific paragraphs within a specification. In most cases when more than one Service-specific paragraph is required within a specification, incorporate Service-specific tailoring. In most cases:

- Do not use both tailoring and bracketed paragraphs for a particular DoD Service's requirements within one specification.
- Along with tailoring, provide a Note to the Designer to indicate what tailoring is in the text and the criteria for choosing the tailored option.
- For clarity in viewing a UFGS in a format other than SpecsIntact, provide tailored items as part of a complete sentence, rather than items within a sentence. Example: show as "<TAI OPT>Use galvanized steel. </TAI> <TAI OPT>Use stainless steel.</TAI>" Do not show as "Use <TAI OPT>galvanized </TAI><TAI>stainless </TAI>steel."

2-2.10.2 Design-Build or Design-Bid-Build Tailoring.

Some masters are developed to have tailoring options for design-build or design-bid-build contracts, as well as options for Service-specific requirements. Ensure that design-only requirements for design-build projects are captured in tailoring tags. Use these tailoring options to distinguish between Design-Build versus Design-Bid-Build requirements that are service-specific:

- Air Force Design-Build
- Air Force Design-Bid-Build

- Army Design-Build
- Army Design-Bid-Build
- NASA Design-Build
- NASA Design-Bid-Build
- Navy Design-Build
- Navy Design-Bid-Build **/2/**

\3Use the following where requirements apply to all Services:

- Design-Build
- Design-Bid-Build**/3/**

2-2.11 Brackets.

Use brackets for choices of two or more items, and for blank options requiring designer input. In addition, brackets may be used to identify text that may not be applicable to all projects, for example, regional requirements, agency requirements, or non-standard technical requirements. If the same bracketed choices are used more than one time in the UFGS section, consider tailoring. Consider using brackets or tailoring, but not both.

\1 Organize bracketed options in the order of the most commonly used item first (such as [galvanized steel] [stainless steel]). **/1/** Provide brackets around five blank underscored characters ([_____]) to indicate the designer is to provide wording. **\1** Unless the bracketed choices are known industry practices, provide a Note to the Designer to assist in the editing of the bracketed items or filling in the blank. Provide a space between bracketed items; an example follows: Provide [galvanized steel] [stainless steel] enclosure. **/1/**

\2\ /2/

2-2.12 Submittal Items.

\3Only submittal items are allowed in the SUBMITTALS article; do not include instructions or other explanatory text. Format submittals within the SUBMITTALS article as shown in Appendix A. Each submittal item must be within one set of submittal tags, for example, _{Item}, do not list multiple submittal items separated by commas within submittal tags, for example, _{Item 1, Item 2}. Commas are field separators in the submittal register data file and commas within submittal tags will cause problems when imported into the Resident Management System (RMS) or Excel spreadsheets. Double-space submittal items.**/3/**

2-2.12.1 Submittal Descriptions (SD).

Section 01 33 00 SUBMITTAL PROCEDURES contains general requirements for each submittal description number, for example, SD-01, SD-02. UFGS authors must compare the requirements of each submittal item in a technical section to the item descriptions provided in Section 01 33 00 Submittal Descriptions paragraph. **\1\/1/\3**

2-2.12.2 Submittal Naming Convention.

Use unique names for submittal items to define or differentiate. For example, if the submittal item, “Wall Louvers” is required under both SD-02 Shop Drawings and SD-04 Samples, use the unique submittal names, “Wall Louvers” under SD-02 and “Wall Louver Samples” under SD-04.

2-2.12.3 Submittal Items Tagged in the Section Subpart Text.

Each submittal item in the SUBMITTALS article must appear only once outside the SUBMITTALS article in the section subpart text. In cases where the submittal item is part of tailored or bracketed text, the submittal item may appear more than once in the section subpart text. Submittal items must appear, within the tags, exactly as written in the SUBMITTALS article and in the section subpart text with the exception of the case; submittal items are not case-sensitive. Provide a detailed description of the submittal item and its requirements in the section subpart text, and not in the SUBMITTALS article. Do not repeat information already provided in UFGS 01 33 00.

2-2.12.4 \2\ Submittal Classifications. /2/

\2\/3/

2-2.12.4.1 Government (G) Submittals.

When a "G" follows a submittal item, it indicates Government approval is required for that item. Only use a "G" in submittal tags for items deemed sufficiently critical, complex, or aesthetically significant to merit approval by the Government. For example:

<ITM>_{Fire Hydrants}; _{G<TAI OPT=ARMY>[, [_____]]</TAI>}</ITM>

2-2.12.4.2 Information Only Submittals.

Submittal items for information only or approved by the Contractor QC System, depending on terminology used by the agency, have no additional designation following the submittal item. For example:

<ITM>_{Fire Hydrants}</ITM>

2-2.12.4.3 Sustainability (S) Submittals.

Use an “S” following a submittal item to designate Sustainability submittals required by **\3**UFGS 01 33 00 and described in more detail in UFGS 01 33 29 when used. These submittals are compiled by the awarded Contractor into the electronic Sustainability eNotebook.**/3/** Provide these “S” submittal items under the appropriate submittal description (SD) in the SUBMITTALS article. Unlike a whole product submittal, these submittals are intended to only provide and highlight the information required to validate compliance with UFGS 01 33 29 Sustainability Reporting. When revising Masters:

- Ensure each product within a Master has been researched for industry minimum availability.
- Add the minimum compliance supported by industry as the default requirement.
- Ensure that the sustainability requirement is provided in the related subpart text.
- Ensure submittal tagging is added for each individual sustainable requirement per product. This ensures when Masters are edited, deleted products that have associated “S” submittals will also be deleted.

For example:

\3<LST>_{SD-03 Product Data}</LST>

<ITM>_{Recycled Content for Carpeting}; _S</ITM>

<LST>_{SD-07 Certificates}</LST>

<ITM>_{Indoor Air Quality for Rubber Cushion}; _S<ITM>

<ITM>_{Indoor Air Quality for Polyurethane-Foam Cushion}; _S<ITM> **/2//3/**

2-2.12.5 Submittal Item Reviewers.

2-2.12.5.1 Army.

For Army only, the brackets following a "G" on a submittal item indicate a specific Government reviewer and approval is required for that item. Navy, Air Force, and NASA do not typically use codes following the "G" in their projects. For submittals requiring Government approval on Army projects, a code of up to three characters within the submittal tags may follow the "G" designation to indicate the approving authority. Codes for Army projects using the Resident Management System (RMS) are “AE" for Architect-Engineer; "DO" for District Office (Engineering Division or other organization in the District Office); "AO" for Area Office; "RO" for Resident Office; and "PO" for Project Office.

2-2.12.5.2 Navy.

For Navy only, do not use the brackets following the “G.” For projects, edit UFGS 01 33 00 SUBMITTAL PROCEDURES, paragraph FORWARDING SUBMITTALS REQUIRING GOVERNMENT APPROVAL, to designate who approves Government Approved submittals.

2-2.12.6 Design-Build Submittals for Design after Award.

2-2.12.6.1 Army.

For Army only, when a "D" follows a submittal item, it indicates Designer of Record Approval (DA) is required for that item. When a "C" follows a submittal item, it indicates Government Conformance Review of Design (CR) is required for that item. When an "R" follows a submittal item, it indicates both a Designer of Record Approval and Government Conformance Review (DA/CR) is required for that item. When an "A" follows a submittal item, it indicates both a Designer of Record Approval and Government Approval (DA/GA) is required for that item.

2-2.12.6.2 Navy.

For Navy only, comply with **\1** FC 1-300-09N **/1/** and contract documents.

\2\ \1\ /2/

2-2.12.7 Operation and Maintenance Data.

2-2.12.7.1 Operation and Maintenance Data Packages.

Data packages are provided for a complete assembly, and specified in the technical sections. Use UFGS 01 78 23, Operations and Maintenance Data, paragraph SCHEDULE OF OPERATION AND MAINTENANCE DATA PACKAGES to choose which data package to specify. Create a submittal item for that package in the SUBMITTALS paragraph under SD-10 Operation and Maintenance Data. Annotate the data package type after the submittal item, and as shown in the example below. The data package required depends on the complexity of the system; package complexity increases from Data Package 1 to Data Package 5. Generally, technical specifications with complex equipment or systems that contain commissioned or energized moving parts (for example, Fire Protection, Mechanical, and Electrical systems), require a Data Package submittal. A detailed description of the contents of the data packages are described in UFGS 01 78 23, paragraph TYPES OF INFORMATION REQUIRED IN O&M DATA PACKAGES. If additional or detailed content is required in the data package, add that information into the section’s subpart text where the submittal item is specified. An example showing the submittal item in SD -10, and text describing additional or detailed content of the package within a subparagraph of the section, follows:

Example:**\3**

<SPT=1.3>1.3 <TTL>SUBMITTALS</TTL>

<LST>_{SD-10 Operation and Maintenance Data}</LST>

<ITM>_{Electrical Systems}, Data Package 5;
_G</ITM>

<ITM>_{Metering}, Data Package 5; _G</ITM>

</SPT=1.3>

Within the section text:

<SPT=1.5.1>1.5.1 <TTL>_{Electrical Systems}</TTL>

<TXT>Provide operation and maintenance manuals for electrical systems in accordance with Section <SRF>01 78 23<SRF/> OPERATION AND MAINTENANCE DATA that provide basic data relating to the design, operation, and maintenance of the electrical distribution system for the building. In addition to the requirements, include the following:<TXT>

<LST INDENT=-0.33>a. Single line diagram of the "as-built" building electrical system.</LST>

<LST INDENT=-0.33>b. Schematic diagram of electrical control system (other than HVAC, covered elsewhere).</LST>

<LST INDENT=-0.33>c. Manufacturers' operating and maintenance manuals on active electrical equipment.<\LST>

</SPT=1.5.1>**/3/**

2-2.12.7.2 Operation and Maintenance Manuals.

Operation and Maintenance (O&M) Data Packages, when required by the technical UFGS sections, are assembled into Operation and Maintenance (O&M) Manuals for the project. The requirements and format of the O&M Manuals are provided in UFGS 01 78 23. Additional O&M Manual requirements for the Army are provided in UFGS 01 78 24.00 10, and additional requirements for the Navy are provided in UFGS 01 78 24.00 20. **/1/**

2-3 WRITING STYLE.

Write in a direct, active voice with simple, concise sentences as much as possible. Avoid ambiguous, indefinite terms such as "too short" or "relatively simple." UFGS should supplement the dimensions, sizes, and relationships shown on the drawings with requirements for materials, installation, and other non-graphic requirements. Define what applies in lieu of using "applicable" or other indefinite wording. Do not use "and/or"; do not use the virgule (/) to substitute for "and" or "or." Do not use "etc."; use "e.g.," "for instance," or "such as." Do not use "as shown on the drawings" as this phrase is frequently overlooked by the project specification writer or editor; if used in the text and the item is not shown on the drawings, then the item is not specified.

2-3.1 Mood, Tense, and Voice.

Project specifications are directed to the construction Contractor. Do not use the term "the Contractor shall." The Contractor is responsible for performing the work as shown and specified; therefore, there is no reason to use the phrase. In general, use the imperative mood (such as, Install equipment) except when clarity requires the use of the indicative mood (such as, equipment must). Avoid the use of "shall" and "must;" if use cannot be avoided, use “must” instead of “shall” unless it changes the meaning of the sentence. The term “will” indicates Contract requirements performed by the Government. Specify execution of alternatives with guidance. Use “may” only when specifying discretionary Government options. Do not use the word “should” in the specification text for mandatory requirements as “should” implies a recommendation. “Should” may be in the Notes to indicate desirable procedures that are advisory in nature. Do not use the term "furnish" unless only delivery of material to the site is required. Use "provide" to mean "furnish and install." Do not use the word "per" but use "in accordance with" instead.

Speak only to the Contractor, not the subcontractor, supplier, or manufacturer. The Contractor cannot be directed through the manufacturer or supplier or vice versa. Stating "the manufacturer must provide," could be interpreted as simply informing the Contractor that a party other than the Contractor is responsible, comparable to "the Government will provide." Likewise, there is usually no reason to differentiate between actions expected of the "Contractor" and the Contractor's various suppliers, to attempt to do so borders closely on an assignment of work. Do not use the specification to instruct the Contracting Officer.

2-3.2 Abbreviations and Acronyms.

Use of abbreviations and acronyms must follow the practices within the discipline involved**\1\/1/**. At the first use, write out the term completely and follow with the abbreviation or acronym in parentheses. Use abbreviations for units such as psi, cfm, and kW, and be consistent in their use.

2-3.3 Units.

Spell out numbers under 10, except units of time and measurement, and use numerals for numbers 10 and above. Always present dimensions as numerals, but always spell out "one" and "zero" when used singly. Do not repeat a spelled-out number with a numeral in parentheses.

2-3.4 Terminology.

- **\2** Avoid the use of colloquial terms or jargon. For example, do not use "bulkhead" for wall, "deck" for floor, or "head" for toilet.
- Eliminate redundant and superfluous wording such as "conforming to," "all," and "type."
- **\1**Do not use **/1/**indefinite items such as "etc.," "any," and "and/or."
- **\1**Do not use **/1/**vague words and phrases or escape clauses such as “in this specification,” "as may be required," "as necessary," "an approved

type," "as approved/directed/determined by the Contracting Officer," "first class workmanship," "securely," "thoroughly," "suitable," "properly," "good working order," "neatly," "carefully," and "installed in a neat and workmanlike manner."

- Avoid the use of long, compound, or hyphenated words such as "hereinbefore" and "hereinafter." **/2/**

2-3.5 Symbols.

Because of potential problems, do not use the symbols **\1** shown in Table 2-2 **/1/** in the UFGS.**\3** Instead, replace the symbol with the corresponding terminology.**/3/**

Table 2-2 Symbols

Symbol	For
‘	foot
“	inch
#	pound
%	percent
°	degree
+	plus
-	minus
+/-	plus or minus
•	by
/	per
@	at

However, feet and inch symbols are acceptable when both are in a dimension (for example, 8’-8”) and in tables. Avoid or minimize the use of parentheses and quotation marks. **\1\/1/ \3\/3/**

2-3.6 Pronouns.

Avoid the use of pronouns "he," "his," "this," "they," "their," "who," "it," and "which." **\1** Use pronouns **/1/** sparingly if at all; it is usually better to repeat the noun. **\3**Use generic “they” and “their” in lieu of gender-specific pronouns if use cannot be avoided.**/3/**

2-3.7 Capitalization.

Capitalize "Contractor," "Contracting Officer," "Government," and “Contract**”** in specifications. Use the term "Contracting Officer" **\1**; do not use terms such as **/1/** “Officer in Charge of Construction,” “Contracting Officer Representative,” or “Government Representative.”

2-3.8 Brand Name Specifications.

Do not use brand name or restrictive requirements unless it is conclusively established that no substitute will serve the purpose. Use of brand name items is prohibited unless formal written approval is obtained from a Level One Contracting Officer. **\1 /1/\3**To preclude the product from being considered proprietary, follow agency FAR requirements on acceptable number of manufacturers or suppliers capable of providing the product. **/3/**If use of brand name is authorized, provide a cost estimate in relation to the total project cost **\1** to the Government, **/1/** specify the brand name item by manufacturer's name and catalog number, followed by the phrase: "notwithstanding any other provision of the Contract, no other product will be acceptable." This statement is necessary to override the Contract clause that permits substitution of any supposedly equal product unless such language is used.

Any specification section that contains brand name items must include a notice to that effect on the first page of the section. Place the following above the section number and title at the top of the first page of the section:

****

This Specification Contains Brand Name Products.

****

The use of brand name items has been the subject of many Contract claims. Project designers and specifiers must be aware of the restriction on the specification of brand name items and take special precautions to avoid their use unless formal written approval is obtained.

2-3.9 “Brand Name or Equal” Specifications.

Refer to Federal Acquisition Regulations (FAR) Clause 52.211-6 Brand Name or Equal. **\1** Do not **/1/** use “Brand Name or Equal,” **\1** unless approved by the Contracting Officer. If allowed to **/1/** specify an item as “brand name or equal,” provide salient characteristics of the brand name items **\1** in the UFGS, **/1/** to determine equality.

2-3.10 Warranty Clauses.

Ordinarily, do not include warranty clauses in the UFGS. A warranty clause is any provision that modifies terms of the normal 1-year warranty required by the Contract clause. There are two classes of exceptions. First, in rare instances, it is acceptable to extend the period of the warranty based on the judgment of the author, if the industry routinely provides such extended periods of warranty and the unusually complex nature of the product makes the provision cost effective on a life-cycle basis, or if UFGS suggest the extension. Second, it is possible to add terms to a warranty, but only in the rarest of circumstances and with written approval from an appropriate authority or when UFGS indicate such an extension has been reviewed and approved by a Level 1 Contracting Officer.

2-3.11 Contract Clauses.

Do not repeat the Contract clauses in UFGS. The Contract clauses in the Contract contain requirements which affect the general conduct of the work in the Contract. If these are randomly modified within the specifications, it may weaken or void the Contract clauses.

2-3.12 Specifying New Items.

From time-to-time, requests are made to consider the use of materials that are relatively new. While the Government encourages innovative solutions, manage risk appropriately. Take care in specifying items that have not gained widespread acceptance and use. Usually, service records of new materials do not exist. It is therefore necessary to base performance on laboratory tests. These tests:

- Must have been made under the conditions of actual use,
- Must have been conducted by a reputable, independent laboratory, and
- Must have factual documentation sufficient to support evaluation of the material.

Most manufacturers will furnish all requested information about a product and answer all reasonable questions. The manufacturer may also provide a suggested, competitive, generic type specification section that may be edited for the UFGS. Ensure the item specified is not a brand name.

2-4 TABLES AND FORMS.

Tables and forms developed with SpecsIntact may be included within the UFGS section. Otherwise, provide tables, figures, and forms that cannot be included in the UFGS section file on a web site for download, for example, **\3**UFGS Forms, Graphics, and Tables http://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs/forms-graphics-tables**/3/ /1/** Provide instructions to the designer in the UFGS notes to download and append to the end of section in the final electronic PDF file. Otherwise, provide the hyperlink uniform resource locator (URL) for the Contractor to download.

2-4.1 Formatted Tables.

Formatted tables in UFGS are restricted to the portrait format. The table text font will be the same as used for the section text. Notes may contain tables.

2-4.2 Forms, Hyperlinks and URLs.

Provide instructions in the notes to verify that all forms, hyperlinks and URLs in the UFGS are valid and current before publishing the project specifications.

2-5 MODIFICATIONS.

2-5.1 Clerical Repairs.

\1\/1/ A clerical repair consists of non-technical modifications to the specification section. The modifications are administrative in nature, such as typographical corrections, reference updates, spacing corrections, tagging corrections, CSI conformance, and formatting. Do not document clerical repairs in the section banner, Change List or Revision List.

2-5.2 Change.

A Change consists of technical modifications to a specific aspect or subject of the specification section. The modifications are often associated with resolution of a criteria change request (CCR). A Change only addresses the specific issue without a review of the entire specification section. Note the most recent Change **\3**number and Change date in the section banner and in the section date tag;**/3/** however, do not revise the section date. Provide the nature of the changes to the Database Managers to incorporate in the Change List. **\1**Use the following format in the section banner to indicate a change:

Example:

USACE / NAVFAC / AFCEC / NASA	**UFGS-08 34 73 (November 2009** **Change 2 – 08/16** --
Preparing Activity: NASA	**Superseding** **UFGS-08 34 73 (October 2006) /1/**

\3Add change number to the Section Date below the Section Title. For example, the following shows a revision date of November 2009 and a Change 2 date of August 2016:

<DTE>11/09, CHG2: 8/16</DTE>/3/

2-5.3 Revision.

A Revision is an updating of various requirements in a UFGS and republication of the UFGS with a revised date and a superseded section date. A Revision could also be a complete rewrite or refresh of the UFGS section. Provide the nature of the revisions to the Database Managers to incorporate in the Revision List.

2-5.4 Superseding Dates.

If there is a Revision to the section, change the date in the Section Header (Banner) to reflect the current release month and year. The previous section number/date will become the Superseding section number/date.

Example:

\3\USACE / NAVFAC / AFCEC / NASA/3/	**UFGS-08 34 73 (November 2009)**
	--
Preparing Activity: NASA	**Superseding UFGS-08 34 73 (October 2006)**

If a section number change has occurred, the previous section number / date will become the Superseding section number / date.

Example:

USACE / NAVFAC / AFCESA / NASA	**UFGS-08 34 73.00 40 (November 2009)**
	--
Preparing Activity: NASA	**Superseding UFGS 08 34 73 (August 2009)**

Change Section Date below the Section Title to the current Release Date.

Example:

<DTE>11/09</DTE>

2-6 UFGS APPROVAL.

Coordinate UFGS for approval in accordance with MIL-STD-3007. DWG technical representatives must review each UFGS. When appropriate, extend the opportunity for review to major commands, facility users, and private industry. Preparing activities must coordinate new and changed UFGS within their agency and with their counterparts in the other agencies. Upon completion, submit new and revised UFGS to the Technical Proponent for final review and approval. Changes to UFGS are subject to coordination and approval of the other agencies whenever the change affects the technical content of the UFGS. However, the Preparing Activity is always obligated to consider and resolve requests from other agencies for changes to UFGS.

APPENDIX A UFGS ORGANIZATION GUIDANCE

The following guidance is based on the paragraph titles and sequence recommended in the CSI SectionFormat™ Outline. This format has been adopted by the agencies supporting the SpecsIntact software. Use this arrangement to the extent applicable in the preparation of UFGS by eliminating paragraphs which do not apply and adding additional paragraphs, as necessary. It is important that UFGS authors understand that the paragraphs listed below are not mandatory. Use only those paragraphs that are applicable to the specified subject, and add any applicable requirements not listed. It is important to follow the sequence of information provided herein even when adjusting the paragraph titles to fit the specified subject matter.

Paragraph and subparagraph numbering to the third level must have titles and be completely numeric. Below the paragraph or subparagraph level, titles are optional, and list and item tags may be used with an alternating alpha-numeric designation. This format will not translate to the Alphanumeric format and will not automatically renumber. For example:

Table A-1 Examples of Numeric Format

Numeric without Tags	**Numeric with Tags (highlighted in red)**
PART 1 GENERAL (Part Level)	<PRT =1> <TTL>PART 1 GENERAL</TTL>
1.1 ARTICLE (1st Level)	**\1**<SPT =1.1>1.1 <TTL>ARTICLE</TTL>
1.1.1 Paragraph (2nd Level)	<SPT =1.1.1>1.1.1 <TTL>Paragraph</TTL>
1.1.1.1 Subparagraph (3rd Level)	<SPT =1.1.1.1>1.1.1.1 <TTL>Subparagraph</TTL>
a. Example	<LST INDENT=-0.33>a. Example</LST>
(1) Example	<ITM INDENT=-0.33>(1) Example</ITM>
(a) Example	<ITM>(a) Example</ITM>
1. Example	<ITM INDENT=0.33>1. Example</ITM>
\11.1.1.1.1 Subparagraph	<SPT =1.1.1.1.1>1.1.1.1.1 <TTL>Subparagraph</TTL>
1.1.1.1.1.1 Subparagraph	<SPT =1.1.1.1.1.1>1.1.1.1.1.1 <TTL>Subparagraph</TTL>
/1/(Do not use ITM progression beyond this level.)	</SPT =1.1.1.1.1.1></SPT =1.1.1.1.1>**/1/**</SPT =1.1.1.1></SPT =1.1.1></SPT =1.1>

Refer to the *SpecsIntact QuickStart Guide Numeric* for instructions for how to tag paragraphs using the SpecsIntact software.

PART 1 GENERAL

1.1 UNIT PRICES

Specify measurement and payment requirements for work subject to extreme variation in estimated quantity when unit price bidding is required. Do not use this paragraph for guide specifications covering building components or for other construction features when quantities can be reasonably calculated from information included in the Contract.

1.2 REFERENCES

List only the publications cited in the text of the guide specification in this paragraph by organization, designation, date, and title. Reference the publications in the text by basic designation (Reference Identifier (RID)) only.

1.3 DEFINITIONS

Only use this paragraph to define terms used in the specification section that are not defined by a commercial or Government standard and to provide a common interpretation of a term for Contractual purposes.

1.4 ADMINISTRATIVE REQUIREMENTS

Use this paragraph to categorize the requirements as related to the specific section when more than one of the subordinate titles is required. Omit this when only one of the subordinate titles is required and use the subordinate title as a primary paragraph title.

1.4.1 Pre-Installation Meetings

Specify requirements for meetings to coordinate the work or to sequence related work for sensitive and complex items in this paragraph.

1.4.2 Sequencing

Specify requirements for coordinating work done in sequence with, or at the same time as, work in another section. Specify the particular sequence of events here.

1.4.3 Scheduling

Specify requirements for coordinating work that requires unusual scheduling with work in other sections. Specify the particular schedule of events here.

1.5 SUBMITTALS

Limit Submittals to those necessary for adequate quality control. Organize submittal requirements using the following eleven classifications:

SD-01 Preconstruction Submittals

SD-02 Shop Drawings

SD-03 Product Data

SD-04 Samples

SD-05 Design Data

SD-06 Test Reports

SD-07 Certificates

SD-08 Manufacturer's Instructions

SD-09 Manufacturer's Field Reports

SD-10 Operation and Maintenance Data

SD-11 Closeout Submittals

1.5.1 Example: Submittal Item Format shown with Tags

<LST>_{SD-03 Product Data}</LST>

<ITM>_{Submittal Item}; _{G<TAI OPT=ARMY>[, [_____]] </TAI>}</ITM>

1.6 MAINTENANCE MATERIAL SUBMITTALS

Categorize maintenance materials requiring no action other than confirmation of receipt under an explanatory heading.

1.6.1 Spare Parts

\3Spare parts are generally not allowed. If allowed by the contracting agency, use this paragraph to specify extra stock materials and items provided for Government use. Identify the type and quantity here but include the actual characteristics of the materials in Part 2. If allowed by the contracting agency, include items that might be difficult to obtain because of color or pattern match, or spare parts needed to ensure continued operation of critical equipment. **/3/**Identify the items, state the quantities required, and indicate delivery to whom, when, and where.

1.7 QUALITY CONTROL

1.7.1 Regulatory Requirements

This paragraph includes obligations for compliance with specific code requirements for Contractor-designed items such as wood trusses, labeling such as Underwriters Laboratory, Inc., and requirements of public authorities such as state highway departments.

1.7.2 Qualifications

This paragraph includes statements of qualifications for Contractor designers, manufacturers, fabricators, welders, installers, and applicators of products and completed work.

1.8 DELIVERY, STORAGE, AND HANDLING

This paragraph includes the necessary requirements on packing and shipping, acceptance at site, and storage and protection.

1.9 PROJECT/SITE CONDITIONS

1.9.1 Environmental Requirements

This paragraph establishes any physical or environmental limitations or criteria. Such conditions might include temperature, weather, humidity, ventilation, and illumination required for proper installation or application.

1.9.2 Existing Conditions

This paragraph includes statements or references to documents where information may be found pertaining to such items as existing structures or geophysical reports.

1.10 WARRANTY

This paragraph describes special or extended (more than one year) warranty or bond covering the conformance and performance of the work of the section. A thorough understanding of warranties is necessary to develop this paragraph.

PART 2 PRODUCTS

2.1 SYSTEM DESCRIPTION

Describe performance or design requirements and tolerances of a complete system in this paragraph. Limit descriptions to composite and operational properties to the extent necessary to link multiple components of a system together, and to interface with other systems.

2.1.1 Design Requirements

Design requirements may include criteria for structural, thermal, acoustical, or other properties. State required tolerances here only as they apply to the performance of the complete system. Include tolerances of fabrication and installation in their respective paragraphs under Part 1.

2.1.2 Performance Requirements

Performance requirements may include criteria for structural, thermal, acoustical, or other properties. State required tolerances here only as they apply to the performance of the complete system. Include tolerances of fabrication and installation in their respective paragraphs under Part 2.

2.2 ASSEMBLY [OR] FABRICATION

This paragraph describes items that must be shop manufactured, fabricated, or assembled before delivery to the site.

2.2.1 Factory Assembly

This paragraph states factory assembly as a result.

2.2.2 Shop Fabrication

This paragraph states shop fabrication as a result, but may include statements of required methods, trial or permanent assembly of equipment and components away from the construction site.

2.2.3 Tolerances

Specify allowable variations from specified requirements here.

2.2.4 Finishes

Specify any shop or factory finishing requirements here.

2.3 MANUFACTURED UNITS

This paragraph provides statements describing a complete manufactured unit, usually a standard catalog item. Statements may include descriptive requirements for the materials, specific fabrication, finishes, and function. Use separate paragraphs for each different item when appropriate. The name used for the manufactured unit must be consistent throughout the guide specification.

2.4 EQUIPMENT

This paragraph provides statements describing the function, operation, and other specific requirements of equipment installed in the work. Use separate paragraphs for each different item when appropriate.

2.5 COMPONENTS

This paragraph provides statements describing the specific components of a system, manufactured unit, or type of equipment installed in the work. Use separate paragraphs for each different item when appropriate.

2.6 MATERIALS

Identify the material, system, assembly, or product furnished. Independently incorporate Materials specified here into the work under PART 3 EXECUTION. Consistently use the name for the material throughout the guide specification. Omit this paragraph when the materials can be included with the description of a particular manufactured unit, equipment, component, or accessory.

2.7 MIXES

This paragraph provides proportions and procedures for mixing materials. Mixing is the preparation of materials for use and considered to be part of the manufacturing process even when this work done onsite. This paragraph is required for products such as asphaltic concrete, Portland cement, concrete, mortar, and plaster.

2.8 ACCESSORIES

Provide requirements for subordinate or secondary items that aid and assist primary products specified above or are necessary for preparation or installation of those items. This paragraph should not include basic options available for manufactured units and equipment.

2.9 TESTS, INSPECTIONS, AND VERIFICATIONS

Specify tests, inspections, or verifications of products required at the source here, i.e., plant, mill, factory, or shop.

PART 3 EXECUTION

3.1 EXAMINATION

Specify the act of physically determining that conditions are acceptable to receive the primary products of the section. Specify requirements for verifying suitability of conditions for installation here. Specify requirements for verifying the absence of defects or errors that would cause defective installation or application of products, or cause latent defects in workmanship and function, here.

3.2 PREPARATION

This paragraph covers actions required to physically prepare the surface, area, or site to incorporate the primary products of the section.

3.2.1 Protection

This paragraph specifies requirements for protecting the surrounding areas and surfaces.

3.2.2 Surface Preparation

This paragraph describes preparatory work required prior to installation, application, or erection of primary products.

3.3 ERECTION

This paragraph covers actions required to accomplish a specified unit of work in the section, and may include requirements necessary for installation of products furnished under other sections. If products are to be installed according to manufacturer's instructions, then the manufacturer's instructions should be a required submittal as evidence of those requirements. Separate paragraphs for each different item, as appropriate, may be used. The names of the products or the type of work may be incorporated into the paragraph titles, in which case the wording should reflect the generic product or terminology used throughout the Contract documents.

3.4 INSTALLATION

This paragraph may be used when more appropriate than paragraph ERECTION.

3.5 APPLICATION

This paragraph may be used when more appropriate than paragraph ERECTION.

3.5.1 Special Techniques

This paragraph describes special procedures for incorporating products. These procedures may include spacing, patterns, or unique treatments. The wording of the paragraph title should reflect the subject matter.

3.5.2 Interface with Other Products

This paragraph provides descriptions specific to compatibility and transition to other materials. This may include incorporating accessories, anchorage, and any special separation or bonding.

3.5.3 Tolerances

This paragraph covers allowable variations in application thickness or from indicated locations.

3.6 FIELD QUALITY CONTROL

3.6.1 Tests

This paragraph defines the tests required for installed or completed work. These tests are different and separate from those required for materials and products prior to installation or application.

3.6.2 Inspection

This paragraph defines the inspections required for installed or completed work. These inspections are different and separate from those required for materials and products prior to installation or application.

3.6.3 Manufacturer Field Service

This paragraph covers specific requirements when manufacturers are to provide field quality control with onsite personnel for instruction or supervision of the installation or application of their products, or for startup or demonstration.

3.7 SYSTEM STARTUP

This paragraph lists actions applicable to the startup of operational systems and equipment.

3.8 ADJUSTING AND CLEANING

This paragraph provides final actions to prepare installed equipment or other completed work to properly function or perform.

3.9 CLOSEOUT ACTIVITIES

This paragraph covers requirements for demonstrating, instructing, and training owner's personnel on sequence of operations, general facility operation, and facility maintenance procedures.

3.9.1 Demonstration

This paragraph covers requirements of the installer or manufacturer to demonstrate the proper operation of equipment.

3.9.2 Training

This paragraph covers requirements of the installer or manufacturer to train the Owner's personnel in the operation and maintenance of equipment for ongoing facility management and maintenance.

3.10 PROTECTION

This paragraph includes provisions for protecting installed work prior to acceptance of the project. Protection of surrounding areas and surfaces during application or installation is included in paragraph PREPARATION. Include only statements unique to the particular section.

3.11 MAINTENANCE

This paragraph covers provisions for maintenance as applicable to critical systems, equipment, and Storm Water Pollution Protection Plan (SWPPP) landscaping. Service agreements, if not paid in advance, should be separate from the construction agreement to avoid delaying the final payment and holding the contract open for extended periods.

3.12 SCHEDULES

This paragraph includes schedules that indicate where to put what or provides other coordinating data. Schedules are sometimes placed here in the specification section rather than on the drawings. (Only the format for a schedule would normally be included in a UFGS.)

This Page Intentionally Left Blank

UFC 1-300-08
3 April 2023

UNIFIED FACILITIES CRITERIA (UFC)

CRITERIA FOR TRANSFER AND ACCEPTANCE OF DOD REAL PROPERTY

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UFC 1-300-08
3 April 2023

UNIFIED FACILITIES CRITERIA (UFC)

CRITERIA FOR TRANSFER AND ACCEPTANCE OF DOD REAL PROPERTY

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes UFC 1-300-08, dated April 2009.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website https://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

PETE G. PEREZ, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Systems Command

DAVID H. DENTINO, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW, SES
Deputy Assistant Secretary of Defense
(Construction)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

TABLES

This Page Intentionally Left Blank

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

DoD initially published processes, business rules, and data standards for real property accountability in the Real Property Inventory Requirements (RPIR) document in January 2005. The RPIR was developed by representatives of the Military Departments, Defense Agencies, and was facilitated by the Office of the Secretary of Defense. The RPIR document fully describes the Real Property Unique Identifier (RPUID) and its uses. RPUIDs are assigned by the Data Analytics Integration Support (DAIS) platform, which interfaces with the authoritative source system for each Service's real property inventory. These organizations also developed the Real Property Acceptance Requirements (RPAR) document, August 2006, which clarifies the role of the RPUID in the DD Form 1354 process.[1] All of these requirements have been integrated into DoD's Business Enterprise Architecture (BEA), the blueprint for DoD's business transformation.[2]

1-2 REISSUES AND CANCELS.

This UFC reissues UFC 1-300-08, dated 16 April 2009 (with Change 2). It incorporates guidance for use of DD Form 1354, Transfer and Acceptance of DoD Real Property, dated August 2022.

1-3 PURPOSE AND SCOPE.

This UFC provides for consistent guidance throughout DoD and provides a consolidated reference for:

- Identifying use of a draft, interim, and final version of the DD Form 1354.
- Describing how the DD Form 1354 is used as part of a real property business process.
- Defining the roles and responsibilities in the DD Form 1354 development process.

This UFC covers the entire process, beginning with the identification of the requirement for a DD Form 1354, continuing through updating an interim DD Form 1354, and concluding with steps taken to produce a final. At the time of publication of this UFC, the current version of DD Form 1354 was August 2022. Refer to the Washington Headquarters Service publishing site to ensure the most current version of DD Form 1354 is used.

https://www.esd.whs.mil/portals/54/documents/dd/forms/dd/dd1354.pdf

---

[1] RPIR and RPAR are available online at the OASD(EI&E) RPA library: https://www.acq.osd.mil/eie/bsi/bei_rpa.html.

[2] The BEA is available online at: https://bea.osd.mil/.

1-3.1 Methods of Acquisition.

Although there are other types of acquisition, this UFC establishes the process required for documenting the following:

- Acquisition by construction: Transfer and acceptance of accountability of a newly constructed real property asset from a construction agent to the receiving Service; also provides for the relief of the construction in progress (CIP) account.
- Capital improvement to existing facilities: Transfer and acceptance of accountability for an improvement to a real property asset from a construction agent to the receiving Service; also provides for the relief of the CIP account.
- Intra-DoD transfers: Transfer and acceptance of real property asset accountability between the Services or Washington Headquarters Services (WHS).
- Inventory adjustment: Provides documentation for an undocumented real property asset found on site; includes, but not limited to, “found on site,” category-code adjustments (conversions or diversions), and impairment adjustments (unit of measure quantity or value changes).

These acquisition types are most common. Others include, but are not limited to, gifts, donations, capital leases, seized/condemned, and forfeited, and may use the DD Form 1354 if there is not sufficient supporting documentation. Refer to DoDI 4165.71 and DoD 7000.14-R FMR Vol 4, Chapter 24, Table A4-1, for additional details on acceptable supporting documentation for various acquisition methods. The installation RPAO will work the higher headquarters point of contact for additional assistance.

1-3.2 GSA Form 1334.

Transfer of property from non-DoD Federal Agencies requires GSA Form 1334, Request for Transfer of Excess Real and Related Personal Property. A DD Form 1354 may still be required to ensure proper accountability and valuation of the asset. RPAO will work with their higher headquarters points of contact for additional assistance as required.

1-4 APPLICABILITY.

This UFC applies to Military Departments and WHS. It applies to all organizations having accountability for real property assets throughout the DoD and their respective DoD Construction Agent (DCA), such as U.S. Army Corps of Engineers (USACE), Naval Facilities Engineering Systems Command (NAVFAC), Air Force Civil Engineer Center (AFCEC), the United States Property and Fiscal Officers (USPFO) of the National Guard Bureau (NGB), and the Pentagon workforce. Host nation-funded construction on DoD-managed property will follow the same procedures outlined in paragraph 2-2.1 for acquisition by construction. DoD Construction Agents are responsible for completing the DD Form 1354 for construction funded by other project sponsors to include Defense agencies and DoD field activities.

1-5 GLOSSARY.

Appendix B contains acronyms, abbreviations, and terms.

1-6 REFERENCES.

Appendix C contains a list of references used in this document. The publication date of the code or standard is not included. Unless otherwise specified, the most recent edition of the referenced publication applies.

This Page Intentionally Left Blank

CHAPTER 2 PREPARING THE DD FORM 1354

2-1 WHAT IS DD FORM 1354?

DD Form 1354 is an instrument used by Military Services and WHS to document the acceptance and valuation of Real Property assets and the addition of the asset to the Accountable Property System of Record (APSR). This UFC covers the four most commonly used cases for changes to the APSR (new construction, capital improvements, transfer of real property assets between Services and WHS, and inventory adjustments). DD Form 1354 may be used for other acquisition types where appropriate documentation does not exist to accurately document the asset. (See Table 24-2, DoD 7000.14-R FMR, Vol. 4, Chapter 24, for examples of acceptable documentation.) DD Form 1354 is part of the life cycle of real property asset accountability business processes that crosses communities such as planning, programming, construction, contracting, financial management and real estate. It is used to document the cost of preparing an asset for use, which includes documenting demolition changes to the footprint for new construction.

2-2 ACQUISITION TYPES.

Acquisition is the process by which DoD acquires a legal interest in a real property asset and accepts the asset into the inventory of the DoD for the first time. A complete listing of all acquisition methods can be found in the Real Property Information Model (RPIM) at https://extranet.acq.osd.mil/ie/. Acquisition by construction and by lease are two common acquisition types.

- Acquisition by construction: Acceptance of a new real property facility (buildings, structures, or linear structures) into DoD inventory and accountability and valuation resulting in a new “footprint.”
- Acquisition by lease: Acceptance of a real property asset via a contract (leasehold agreement) that conveys a real property asset for a specified period of time for a specified consideration. A leasehold agreement must include the right of possession.

2-3 CAPITAL IMPROVEMENTS/ENHANCEMENTS TO EXISTING FACILITIES.

Capital improvements/enhancements for real property are often referred to as modifications, modernizations, upgrades, and improvements. A capital improvement is any improvement that increases the useful life, capacity, or size or modifies functionality of an existing asset, regardless of the source of funding or capitalization threshold. Improvements to real property assets must be capitalized when (1) the improvement increases the asset's useful life by two or more years or increases its capacity or size; and (2) the cost of the improvement equals or exceeds the capitalization threshold (see DoD 7000.14 FMR Volume 4, Chapter 24, paragraph 2.5 (240205)). Examples of capital improvements include:

- Increasing the useful life by two or more years: Major replacements, renovations, or reconstruction to restore facilities deteriorated through years of use.
- Increasing capacity: Changes in internal structural systems with the intent of increasing usable space. Example: raising the roof on a warehouse to increase cubic feet.
- Increasing size: An addition, expansion, or extension to the building (increasing footprint).
- Modifying functionality: Conversion of facility type (change of category code), as in changing an office to a warehouse; or upgrading architectural elements of a facility that are not failing (for example, upgrading a flat roof to a pitched roof or installing an elevator where none existed).

2-4 INTRA-DOD SERVICES TRANSFERS.

A transfer between Services is a real estate action which changes the accountability for DoD real property and installed equipment to or from one Military Department or WHS to another. In accordance with Section 2696 of Title 10, United States Code (U.S.C.), a transfer between DoD Components occurs in the real property asset's life cycle when there is a change in accountability of any type (physical, legal, or financial). DoD Components must manage real property by periodically reviewing their real property holdings, both land and facilities, to identify unneeded and underused property eligible for transfer. This transfer shifts accountability between DoD Components but does not culminate in an acquisition or disposal to overall DoD inventory and does not require compensation.

2-5 INVENTORY ADJUSTMENT (FOUND ON SITE)

This acquisition method is the discovery of a real property asset that is not currently included in the inventory or correction of inventory when key elements of the APSR are incorrect. Inventory adjustment is used to document assets missing the original acquisition documentation. Often these assets are considered "found on site." A "found on site" transaction provides documentation for a real property addition to the real property inventory as a result of a physical inventory discrepancy (the asset is not currently in the inventory). Inventory adjustment is also used for correcting discrepancies from the actual asset characteristics and the real property record (changes in size or category code, often because a previous renovation project was not accurately documented as described in paragraph 2-3).

2-6 VERSIONS OF DD FORM 1354.

The three versions of the DD Form 1354 are:

- Draft
- Interim
- Final

Different acquisition methods typically require a different version of the DD Form 1354. Table 2-1 summarizes appropriate uses for each version.

Table 2-1 Use of DD Form 1354 by Acquisition Type

Acquisition Type	Draft	Interim	Final
New Construction	X	X	X
Capital Improvement	X	X	X
Transfer Between Services			X
Inventory Adjustment			X

Roles and responsibilities for completing the various versions of the DD Form 1354 are found in Chapter 3. Instructions for completing the form are found in Chapter 4. Requirements for supporting documentation are found in Chapter 5.

2-6.1 Draft DD Form 1354.

2-6.1.1 Purpose.

The purpose of the draft DD Form 1354 is to capture the information obtained once funding has been authorized, to request the RPUID(s), and to forecast the changes to the real property inventory. It serves as the baseline between the DCA and the RPAO. The draft establishes the level of detail and the different components of a project and must be provided by the DCA in accordance with the Services' guidelines.

2-6.1.2 When to Use the Draft Version.

The draft version of DD Form 1354 is used as a working document for acquisition by construction and capital improvement to existing facilities acquisition methods. It is used to effectively capture information during the design or Request for Proposal (RFP) preparation stage. This information may be updated upon:

- changes in scope.
- changes in cost estimates.
- addition or deletion of RPUID.

2-6.1.3 Included Costs.

The draft may include expected project costs to be capitalized by RPUID and costs such as acquisition; planning and design (P&D) after funding and design approval; supervision, inspection and overhead (SIOH); and estimated acquisition and/or construction contract costs. Appendix A-2 provides a list of the costs typically included. This list is part of the Real Property Construction in Progress Requirements (CIPR) document, developed by representatives of the Military Departments, Defense Agencies, and OSAD(EI&E).[3]

2-6.1.4 Tenant Organizations.

Tenants on DoD installations, who are responsible for the acquisition of a new asset, must submit the elements included on the draft DD Form 1354 to the Installation Management Organization (IMO) Real Property Accountable Officer (RPAO) to facilitate assignment of appropriate facility numbers and RPUIDs.

2-6.2 Interim DD Form 1354.

2-6.2.1 Purpose.

The interim DD Form 1354 allows transfer of accountability from the DCA to the accountable Service or WHS on the placed-in-service date prior to determination of final costs, such as in contract closeout or claims settlement. The interim DD Form 1354 may be used for all acquisition methods or transaction types to include both the Acquisition by Construction and Capital Improvement to Existing Facilities.

2-6.2.2 When to Use the Interim Version.

An interim DD Form 1354, usually based on the latest draft DD Form 1354 iteration, is prepared at the placed-in-service date after substantial completion of construction in preparation for facility acceptance or building occupancy.

2-6.2.3 Included Costs.

The draft DD Form 1354 includes actual project costs to be capitalized as reflected in the CIP account by RPUID. It includes costs such as, but not limited to, P&D, SIOH, and construction contracts. The cost matrix illustrating the types of construction costs to be accumulated in the CIP account is available in the CIPR document. The interim DD Form 1354 includes the Unit of Measure Accountability (UMA) and the Unit of Measure Operational (UMO), where appropriate, quantities by category code(s) for each RPUID. These costs will support the valuation used for financial reporting.

2-6.2.4 Use of Multiple Interim Forms.

Multiple interim DD Forms 1354 may be required when a construction project contains multiple facilities with different turnover dates, or when a portion of a single large facility or a phase of a multi-phase construction project is placed into service. At this time, all cost information accumulated in the CIP account is transferred to the real property asset account. All additional project costs incurred following the placed-in-service date must be transferred from the CIP account to the real property asset account by RPUID and documented on the final DD Form 1354.

[3] CIPR is available online at the OASD(EI&E) library: https://www.acq.osd.mil/eie/bsi/bei_rpa.html.

2-6.2.5 Placed-in-Service Date.

The placed-in-service date will be established on an interim DD Form 1354 and is not to be updated with the final DD Form 1354. If there are multiple interim DD Forms 1354 for a single project, the final DD Form 1354 will include the placed-in-service date from the first interim DD Form 1354. The placed-in-service dates for subsequent interim DD Forms 1354 will be annotated on the final DD Form 1354 in block 28, **PROJECT REMARKS**.

2-6.2.6 Box 14 (Sustainability Code).

The sustainability code indicates project achievement of High Performance and Sustainable Building requirements as defined in UFC 1-200-02. See Paragraph 4-1.17 for instructions.

2-6.3 Final DD Form 1354.

2-6.3.1 Acquisition by Construction and Capital Improvement to Existing Facilities.

The final DD Form 1354 must be completed after the final costs for the project are known. The DCA furnishes the final DD Form 1354 to the accountable Service or WHS. There is only one final project DD Form 1354 even where there are multiple interim DD Forms 1354. The final DD Form 1354 establishes the final costs incurred for each facility in a project. All additional expenses incurred following the placed-in-service date on the interim DD Form 1354 must be transferred from the CIP account to the real property asset account in accordance with DoD 7000.14-R, Vol. 4, Chapter 24, paragraph 2.4.1.2.1. The final DD Form 1354 distributes unallocated costs across the assets as appropriate and marks financial closeout of the CIP account for the project. This process updates the final valuation cost of the assets.

2-6.3.2 Transfer Between Services and/or WHS.

The final DD Form 1354 (and associated supplemental information) lists all real property assets, and all data/information required as specified in RPAR, to complete the transfer from one Military Service or WHS to another. A carrying memorandum signed by the Deputy Assistant Secretaries of the losing and gaining Services is included with the DD Form 1354 for transfers of real property.

2-6.3.3 Inventory Adjustment.

Undocumented real property assets discovered on site should have a Final DD Form 1354 prepared, with all known information, to initiate the real property inventory record and asset information file which will eventually contain, at a minimum, audit supporting documentation. Due diligence must be performed to locate supporting documentation and document this information on the DD Form 1354. If supporting documentation is not located, an estimated acquisition date can be established, method of acquisition should be Inventory Adjustment (Found on Site), and date should be the date of like or similarly-aged assets on the installation. Additional methods of determining estimated placed-in-service dates are listed in Table A4-3, DoD 7000.14-4-R FMR, Chapter 24, Vol 4. Any other missing information must be determined and recorded. Any cost information must be substantiated in accordance with DoD 7000.14-4-R FMR, Chapter 24, Vol 4.

2-6.3.4 Acquisition by Lease.

Although not detailed in this UFC, the DD Form 1354 can be used for lease acquisitions if there is not sufficient supporting documentation (e.g., lease agreement). Requirements are similar to those for Transfer Between Services. RPAOs will work with their headquarters POC to ensure complete documentation requirements.

CHAPTER 3 ROLES AND RESPONSIBILITIES

3-1 ROLES.

The following offices/individuals have a role in the DD Form 1354 process:

- DoD Construction Agent (DCA) (NAVFAC, USACE, AFCEC)
- Project Sponsor (PS)
- Installation Management Office (IMO) (e.g., Directorate of Public Works/Facilities Management Office/Base Civil Engineer (DPW/FMO/BCE))
- IMO Real Property Accountable Officer (RPAO) or approved accepting official
- IMO Realty staff

The above are key participants in the transfer and acceptance process. In some instances, the same person may perform more than one role. Other participants, such as safety and fire inspectors, contracting officers, and construction contractors are not specifically addressed in this UFC, but they may also play a role in the transfer and acceptance process. Table 3-1 shows these roles for the acquisition methods discussed in Chapter 2.

3-1.2 DoD Construction Agent (DCA)

The DCA has primary responsibility for the DD 1354 process for construction and capital improvement acquisitions. The DCA does not have a role in transfers between services or inventory adjustments.

The DCA documents the design/scoping phase by applying the rules in DoD FMR 7000.14-R, Volume 4, Chapter 24, "Real Property," or Volume 11B, *Reimbursable Operations Policy - Working Capital Funds (WCF)*, as well as specific Service guidance. DCA actions in paragraphs 3-1.2.1 through 3-1.2.1.3 may be performed by the project manager, construction manager or field office, dependent on the management structure for the specific contract.

3-1.2.1 Management of DD Form(s) 1354.

3-1.2.1.1 Draft and Interim DD Form 1354 Preparation, Facility Inspection and Acceptance.

The DCA will initiate the draft DD Form 1354 when requesting an RPUID and facility number at the beginning of the construction project. The DCA will complete the Interim DD Form 1354s in collaboration with the PS and RPAO and ensure they are signed and furnished to the PS and RPAO. The DCA notifies the PS and RPAO when construction is substantially complete and schedules an inspection (sometimes referred to as the building occupancy inspection or the Red Zone inspection). The DCA, or representative, sets up an acceptance inspection with the contractor, the PS, and the RPAO or designated representative, to review the facility and inspect for quality workmanship prior to signing the interim DD Form 1354, and occupying the facility.

Once the DCA, PS, inspection engineers, RPAO and other approving parties attending the inspection have agreed the construction is acceptable, the DCA accepts the construction from a contractor on behalf of the government using contract procedures. This is the placed-in-service date recorded in block 7a. The DCA signs the interim DD Form 1354 and provides it and supporting documentation to the RPAO, or approved accepting official, for acceptance into the federal inventory. The DCA must include a copy of contractual deficiencies (“punchlist”) as an enclosure to the Interim DD Form 1354 and reference it in block 27. Government liability starts upon the placed-in-service date of the real property asset. Occupancy of new construction or improvements should not occur prior to the placed-in-service date.

3-1.2.1.2 Post-Acceptance Oversight.

After acceptance of the real property asset, the DCA operates in an oversight capacity to ensure contract deficiencies, if any, are corrected. If a phased project, additional interim DD Forms 1354 may need to be issued. Upon contract completion, the final DD Form 1354 is completed and signed. The DCA’s signature on the final DD Form 1354 indicates all the contract requirements have been met (all invoices have been paid, all claims resolved) and the contract files are ready to be retired. The DCA maintains any required supporting documents per DoD 7000.14-R FMR Vol 4 Chapter 24, Table 24-2.

3-1.2.1.3 Preparation of Final DD Form 1354 and Project Closeout.

The DCA will complete a final DD Form 1354 at the close-out of the project, updating any differences in costs from the interim DD Form 1354 and provide it, along with any additional supporting documentation, to the RPAO. The placed-in-service date does not change with the Final DD Form 1354.

3-1.3 Project Sponsor (PS).

The PS is the DoD Component that establishes the project requirements, priorities, program, and budget. DoD agencies and combatant commands are not authorized to hold real property assets; these assets are held in the real property inventory of the real property accountable Service for the site where the asset is located. DoD agencies and combatant commands must obtain approval from the Military Department that will hold the real property asset in their inventory before approval of the DD Form 1391.

The PS should participate in the acceptance walk-through of the facility, working with the DCA to identify any discrepancies between the contract documents and completed facility (for example, punch list items). The PS is not the accepting organization but is informed of the placed-in-service date (building occupancy) when the DCA accepts the facility from the contractor. The placed-in-service date is the date used to reconcile all costs incurred and accumulated in the CIP account. The PS provides all costs to the DCA, whether incurred by or provided to the DCA, for inclusion in the full cost of the asset prior to the DCA signing the final DD Form 1354 statement of completion (block 24). See DoD 7000.14-R FMR, Vol. 4 Chapter 24, 2.4.1.2.2.

3-1.4 Real Property Accountable Officer (RPAO) or Approved Accepting Official.

The RPAO has been delegated the responsibility by an appropriate authority to ensure individual real property assets are accepted into and accurately accounted for in the real property inventory. RPAO is responsible for custody, records maintenance, and safekeeping of records for all lands and facilities (building, structures, and linear structures) under their purview. The RPAO must ensure documentation is retained in accordance with applicable laws, regulations, and instructions. See Table 5-1.

3-1.4.1 Delivery of RPUID to DCA.

The RPAO or approved accepting official ensures at least one RPUID is provided to the DCA for the draft DD Form 1354, no later than the time both design and funding authorizations are received. All other necessary RPUIDs will be provided to the DCA for completion of acceptance documentation, including interim DD Forms 1354.

3-1.4.2 Recording Construction Project Assets into APSR.

For construction projects, the RPAO, or delegated representative, accepts and accurately records the real property assets into the APSR, as verified by the RPAO signing and dating the interim DD Form 1354 in block 25. The accepted-by date and the placed-in-service date represent different actions in the process and are not usually the same. A copy of the RPAO-signed DD Form 1354 will be provided to the DCA and PS, if required, upon signature. The RPAO must update the real property inventory as needed after receipt of the interim and final DD Form 1354s.

3-1.4.3 Real Property Transfers.

For transfers of real property, the losing MILDEP or WHS RPAO prepares the Transfer DD Form 1354.

3-1.4.4 Assets Found On-Site.

For assets found on site, the RPAO ensures the DD Form 1354 and appropriate supporting documentation are prepared and entered into the real property inventory.

3-1.5 Other Involved Personnel.

The Realty staff is responsible for all real property actions for their assigned properties from the beginning of the acquisition/disposal process through final acceptance/release. The RPAO will coordinate with the Realty staff to ensure real property transactions are appropriately prepared and executed, and the real property inventory is updated accurately.

The DPW/FMO/BCE directs master planning services, construction, and real property maintenance at the installation and its sites. The individuals performing these tasks within these organizations may be known as the Public Works Officer, Director of Public Works, or the Staff Civil Engineer.

Table 3-1 Roles per Acquisition Method

Acquisition Method	Role	Primary Actions
Construction and Capital Improvements	Project Sponsor (PS)	• Initiates, sponsors, and funds construction project. • Obtains at least one RPUID from the Installation Management Organization's RPAO at the start of the project. • Attends final inspection. • Acknowledges to DCA that asset meets PS requirements. • Receives copy of all DD Forms 1354. • Provides a copy of all auditable supporting documentation to RPAO for its respective portion of the project for which it has financial responsibility. • Ensures all capitalized project costs incurred by the PS and accumulated in the CIP account are provided to DCA for inclusion in the full cost of the asset.
	DCA or Public Works Officer/Engineer (responsibility usually based on construction threshold)	• Ensures at least one RPUID is initially assigned to the project. • Has primary responsibility for construction. • Ensures DD Form(s) 1354 is/are prepared and furnished to the RPAO and PS IAW Service directed timeline. • Notifies PS of substantial construction completion and schedules inspection. • Verifies acceptable contract performance and receives constructed facilities from contractor on behalf of the government establishing the placed-in-service date. • Ensures contract deficiencies, if any, are corrected. • Ensures contract is closed out and retains supporting documents.

Acquisition Method	Role	Primary Actions
	RPAO	• Ensures RPUID(s) for the project are provided to the DCA and/or PS upon request. • Signs the DD Form 1354 on behalf of the accountable organization to accept the RP into the APSR as of the placed-in-service Date IAW Service timeline. • Ensures data recorded is accurate, complete, and retained in accordance with applicable laws and regulations.
Transfer Between Services	Public Works Officer/ Base Civil Engineer	• Facilitates logistics of transfer.
	RPAO of losing installation	• Ensures all required forms, source materials, and transfer documents, along with supporting documentation, are accurately prepared and transmitted for appropriate signature in accordance with applicable laws and regulations. • Ensures all transfers are accurately recorded in the inventory.
	RPAO of gaining installation	• Ensures the forms, source materials, and transfer documents, along with supporting documentation received from the losing installation, are complete and used to accurately place the assets on the inventory and are retained in accordance with applicable laws and regulations. • Ensures all assets are accurately recorded in the inventory.
	Realty staff	• Supports RPAO.
Inventory Adjustment (Found on Site)	Public Works Officer/ Base Civil Engineer	• Assists in determining and substantiating the category code and acquisition cost.
	RPAO	• Ensures DD Form 1354 is prepared and supporting documentation is collected for real property assets found on site. • Ensures information recorded is accurate, complete, and retained in accordance with applicable laws and regulations. • Accepts the asset into the real property inventory.
	Realty staff	• Supports RPAO.

This Page Intentionally Left Blank

CHAPTER 4 COMPLETING DD FORM 1354

4-1 FORMAT AND INSTRUCTIONS.

This chapter focuses on completing the DD Form 1354 for a military construction (MilCon) project, which is one of the more common uses. In most cases, the data elements will be the same for other acquisition types and capital improvements. Detailed block-by-block instructions are provided with examples and a description of the source of the information for preparing the DD Form 1354. Associated RPIR or CIPR data elements are also included. Because this form is used for a variety of purposes, not all of the data blocks are required for each usage. When a block is not to be filled out, enter N/A for "not applicable." There should be no blank data fields except in block 23, **ITEM REMARKS**, where blanks are allowed.

Most of the information needed for MilCon projects on the DD Form 1354 is originally contained in the DD Form 1391, "FY __ Military Construction Project Data" and the project folder. During the construction process, some of the information may change. Table 4-1 shows a crosswalk from blocks in the enacted DD Form 1391 to the blocks in the DD Form 1354. The latest DD Form 1391 should be validated by the project designers prior to use in preparing a DD Form 1354. In the absence of a DD Form 1391, a work request often provides similar data needed to complete the DD Form 1354. Reference the latest version of the RPIM available on the OSD Real Property Accountability web site https://www.acq.osd.mil/eie/bsi/bei_rpa.html (right hand navigation bar, located under the Tools heading; Common Access Card required).

Table 4-1 Crosswalk from DD Form 1391 to DD Form 1354

DD Form 1391		DD Form 1354	
block Number	**block Name**	**block Number**	**block Name**
3	Installation and Location	6	Real Property Site Unique Identifier/ Site Name/Installation Code/ Installation Name
6	Category code	11	Category Code
7	Project number	3	Project/Job Number
9	Cost estimates		
	Item	9	Item No.
	U/m	15/17	Unit of Measure Accountability (UMA)/Unit of Measure Operational (UMO)
	Quantity	16/18	Total Quantity UM 1/Total Quantity UM 2
	Cost	19	Cost
10	Description of Proposed Construction	28	Project Remarks

A blank DD Form 1354 is provided as Appendix A. Note the reverse of the form provides a brief description for each block on the form.

Table 4-2 summarizes the narrative information in paragraphs 4-1.1 through 4-1.31. A single example is used for all the example entries to the DD Form 1354 data fields in the narrative portion of this chapter. The example is a Military Construction, Army (MCA) project to construct a new battalion headquarters and classroom, and associated structures and utilities. Although a data element may be a code in the system that is using the data element, it should not be displayed without meaningful text.

Table 4-2 RPIM Data Elements by DD Form 1354 Block

Block Number	Block Name	RPIM Data Element
	PAGE OF PAGES	N/A
1	FROM	Asset Construction Agent Code Address information
2	DATE PREPARED	N/A
3	PROJECT/JOB NUMBER	Project Number
4	SERIAL NUMBER (Optional)	N/A
5	TO	Installation Code Installation Name Installation Reporting Component Code
6	RPSUID/INSTCODE/INSTNAME	Real Property Site Unique Identifier Installation Code Installation Name Site Name
7	CONTRACT NUMBER(S)	Instrument Number Instrument Amendment Number Project/Work Order Number
7a.	RPA PLACED-IN-SERVICE DATE	RPA Placed-in-Service Date
8	TRANSACTION DETAILS	Acquisition Method Type Code
9	ITEM NO.	Asset Configuration Design Use CATCODE Code Land Acquisition Tract Identifier Asset Configuration Design Use Total Size Unit of Measure Code
10	FACILITY NO./RPUID	Facility Number Real Property Unique Identifier
11	CATCODE	Asset Configuration Design Use CATCODE Code
12	CATCODE DESCRIPTION	N/A

Block Number	Block Name	RPIM Data Element
13	CONS TYPE CODE	Construction Type Code
14	SUST CODE	Facility Sustainability Code
15	UMA	RPA Total Unit of Measure Code Asset Configuration Design Use Unit of Measure Code Site Land Total Area Unit of Measure Code
16	QUANTITY	RPA Total Unit of Measure Quantity Asset Configuration Design Use Size Quantity Site Land Total Area Quantity
17	UMO	N/A
18	QUANTITY	N/A
19	COST	Acquisition Original Asset Recorded Cost Amount Project Detail Fund Cost Amount Project Total Fund Cost Amount Acquisition Basic Cost Acquisition Cost to Government Amount Acquisition/Capital Improvement Cost Amount Facility Total Accumulated Depreciation Amount Facility Book Value
20	FUND SOURCE	Acquisition Fund Source Code Project Detail Fund Code
21	FUND ORG	Acquisition Organization Code Project Detail Organization Code
22	RPA INT TYPE CODE	RPA Interest Type Code
23	ITEM REMARKS	N/A
24	STATEMENT OF COMPLETION	N/A
25	ACCEPTED BY	N/A
26	PROPERTY VOUCHER NUMBER	N/A
27	CONSTRUCTION DEFICIENCIES	N/A
28	PROJECT REMARKS	N/A

4-1.1 PAGE OF PAGES.

Enter the page number and the total number of pages comprising each DD Form 1354 project or transaction. When two or more pages are required to describe the information required for blocks 1 through 23, complete blocks 24 through 26 only on the first or signature page. Signing officials should initial subsequent or unsigned pages.

4-1.2 1. FROM.

Enter the name of the construction or transfer agent accomplishing the new acquisition, construction, or capital improvement of existing facilities or initiating the transfer of existing real property.

Example:	U.S. Army Corps of Engineers Kansas City District Area Engineer
RPIM Data Element:	Asset Construction Agent Code Address information (address data elements are those in BEA)

4-1.3 2. DATE PREPARED.

Enter the date the DD Form 1354 is prepared. Use *YYYYMMDD* format for all dates. This is the date used to track different editions when revisions are necessary. The form is considered prepared when it is ready for signatures in blocks 24 and 25.

Example:	Use 20080715 for date: 15 JUL 2008
RPIM Data Element:	N/A

4-1.4 3. PROJECT/JOB NUMBER.

Enter the PS's project number. Specifically for new MilCon, use the project number assigned on a DD Form 1391. For transfers and inventory adjustments, this field is optional.

Example:	DD Form 1391 project number 20027
RPIM Data Element:	Project Number

4-1.5 4. SERIAL NUMBER – designed to be used for version control as needed.

This is an optional number that may be assigned to the DD Form 1354 for version control. Each version of the DD Form 1354 for the same project can have a new serial number.

Example:	2008-0001, 2008-0002, where 2008 is the fiscal year and the last four digits are the sequence number. Note: The Navy uses a serial number like W25G1Q04TU12345, where W25G1Q is the Unit Identification Code (UIC) of the organization in block 1, 04 is the fiscal year, TU is the standard document type, and 12345 is a 5-digit serial number.
RPIM Data Element:	N/A

4-1.6 5. TO.

Enter the name of the organization or agency to which the transfer will be made. Always include the installation code and name of the gaining installation. Installation codes are available from individual Service databases of installations or provided by the gaining installation RPAO.

Example:	Directorate of Public Works Fort Riley Installation Code 20605
RPIM Data Elements:	Installation Code Installation Name Installation Reporting Component Code

4-1.7 6. RPSUID/SITENAME/INSTCODE/INSTNAME.

Enter the Real Property Site Unique Identifier (RPSUID), site name, installation code, and installation name of the physical location for the real property asset being transferred/accepted.

Example:	5502 Hunter Army Airfield Installation Code 13395 Fort Stewart
RPIM Data Elements:	Real Property Site Unique Identifier Installation Code Installation Name Site Name

4-1.8 7. CONTRACT NUMBER(S).

Enter the construction contract number (multiple contract numbers, if applicable) in this block if any project work is performed under a contract. Include the delivery order number in addition to the contract number if the contract could authorize work under different delivery orders that are not related to the project described in the DD Form 1354. For internally executed projects, enter the Work Order Number(s). These are Service-specific number(s) related to the project. For transfers and inventory adjustment (found on site), the field is optional.

Example:	DACA31-98-D-0052.
RPIM Data Elements:	Instrument Number Instrument Amendment Number Project Number
or	
CIPR Data Element:	Work Order Number

4-1.9 7a. RPA PLACED-IN-SERVICE DATE.

This is the date the real property asset (or a portion of the asset) is available and accepted for use by DoD. Complete in accordance with paragraph 3-1.2.1.3 and DoD 7000.14-R FMR Vol. 4, Chapter 24, section 2.4.1.3. The Accepted By date (block 25c) and the placed-in-service date are not usually the same date; the placed-in-service date is typically prior to the signatures on the DD Form 1354. For new construction and capital improvements, the placed-in-service date is the date warranties begin and the government assumes liability for the asset from the contractor.

For transfers between Services, the placed-in-service date is the date the asset was originally constructed to capture the actual age of the facility or asset for depreciation calculations.

For inventory adjustments, the placed-in-service date is the date the asset was acquired or the date the adjustment was made which necessitates the DD Form 1354 (date the renovation or conversion was completed). If the date is unknown, estimate the date and document with an attestation memorandum outlining the process used to research the date and rational for establishing the estimated date. DoD 7000.14-R FMR Vol 4 Chapter 24, paragraph 4.6.5 contains order of precedence for establishing age of an asset, and assumed placed-in-service dates in Table A4-3.

4-1.10 8. TRANSACTION DETAILS.

This block is divided into three subparts:

- Subpart a identifies the type of acquisition for this project.

- Subpart b provides the reason the DD Form 1354 is being issued, in terms of an event. Check only one box.
- Subpart c identifies the version of this DD Form 1354 (draft, interim, or final). Check only one box.

4-1.10.1 8a. TYPE.

Insert an "X" in the appropriate box of Subpart a to indicate whether the transaction involves acceptance of new construction, transfer of existing facilities, capital improvements to existing facilities, or inventory adjustment (found on site). Select the acquisition type for the primary facility. If there are multiple acquisition types (for example, construction and capital improvement), select the acquisition type for the preponderance of the project.

4-1.10.1.1 ACQUISITION ________________.

Fill in the acquisition method. The acquisition method code for construction is CONS; reference the latest version of RPIM for all other acquisition methods.

4-1.10.1.2 TRANSFER BETWEEN SERVICES.

This denotes transfer of accountability for existing real property asset(s) and includes transfers between WHS and the Services.

4-1.10.1.3 CAPITAL IMPROVEMENT.

This denotes the real property asset size or capacity, useful life, or operating efficiency of an existing real property asset.

4-1.10.1.4 INVENTORY ADJUSTMENT.

This is the discovery of a real property asset not currently included in the real property inventory, or discovery of a change to the asset not accurately listed in the Real Property record.

RPIM Data Element: Project Type Code

4-1.10.2 8b. WHEN/EVENT.

Insert an "X" in the appropriate box of Subpart b to indicate when (in terms of an event) the DD Form 1354 is issued (transfer and acceptance occurs). Check only one box.

4-1.10.2.1 TOTAL ASSET PLACED-IN-SERVICE.

Check when the transfer or acceptance of the whole asset occurs.

RPIM Data Elements: RPA Placed-in-Service Date

Capital Improvement Placed-in-Service Date

4-1.10.2.2 PARTIAL ASSET PLACED-IN-SERVICE.

Check when the transfer or acceptance documented by this interim DD Form 1354 is for only a portion of the project or a phased turnover of one or more facilities in a multiple facilities project. When each phase is placed-in-service, it will have its own interim DD Form 1354.

RPIM Data Elements: RPA Placed-in-Service Date
Capital Improvement Placed-in-Service Date

4-1.10.3 8c. VERSION.

Use this to indicate whether the DD Form 1354 is a draft, interim, or final. Check only one box.

4-1.11 9. ITEM NO.

A key step in preparing a DD Form 1354 is identifying the various components or items of the project. Enter a separate line and item number for each new real property asset, facility addition, capital improvement, or deletion, including additions to, or deletions from, utility systems or other previously existing facility records. If there are more item numbers than will fit on a single page, attach the list of additional items as a separate document or spreadsheet (hard copy or electronic).

4-1.11.1 Multiple Use Assets.

If the real property asset has more than one use, identify each with the appropriate facility category code and unit of measure. List these multiple uses such that the multi-purpose facility has one item number and several different lines, one for each category code.

RPIM Data Elements: Asset Configuration Design Use CATCODE Code (may be more than one) – blocks 11 and 12

Asset Configuration Design Use Total Size Unit of Measure Code (may be more than one) – block 15 or 17, as appropriate

If land is purchased as part of the project, show it as a separate line item.

RPIM Data Element: Land Acquisition Tract Identifier (may be more than one) – block 23

4-1.11.2 Demolition.

There are two ways to account for the demolition portion of the project within the footprint of the new construction and to document the reduction of real property:

1. Attach an Authorization for Demolition form (Service-specific form) to the DD Form 1354 to document category codes and quantities of demolished real property. These should be listed separately from constructed/ transferred item numbers.
2. Indicate as additional DD Form 1354 item numbers all demolished real property facility numbers (block 10a.) and category codes (blocks 11 and 12) using negative numbers (shown in parentheses) for units of measure (block 16 or 18, as appropriate), and indicate N/A for costs in block 19.

Disposal cost within the footprint of the project is added into total construction cost of the new facility prompting the demolition. Capture demolition on the interim DD Form 1354 to allow for timely updates to the Real Property record.

4-1.11.3 IBE and EIP Lists.

Separate lists of installed building equipment (IBE) (real property) and equipment in place (EIP) (personal property) may be attached to the DD Form 1354 in accordance with Service guidance.

4-1.12 10a. FACILITY NO.

Enter the facility number assigned to each item number. The facility number is assigned in accordance with the installation's master numbering plan of the host installation and is unique within the installation. The installation RPAO provides the facility number(s) to the DCA early in the design phase for construction. For capital improvements and transfers between Services, the facility number is already available. For inventory adjustment (found-on-site) real property assets, the facility number is supplied by the RPAO or delegated representative.

RPIM Data Element: Facility Number

4-1.13 10b. RPUID.

Enter the RPUID assigned to each real property asset provided by the host installation. The RPUID is a unique non-intelligent code used to permanently identify a real property asset (land parcel, building, structure, or linear structure). The installation RPAO provides these numbers to the DCA after the funding and design authorizations have been received.

RPIM Data Element: Real Property Unique Identifier

4-1.14 11. CATCODE.

Record the appropriate accountable Service's design use category code for each facility use itemized. Category codes crossing Military Department host-tenant relationships must be within the same FAC. When a constructed facility has more than one design use, each use must be identified as a separate line under the same item number and captured at 100% of its measured area. Lesser gross square footage may be captured. Real property assets listed may be land parcels, buildings, linear structures (for example, utility distribution lines, roads, and streets), or structures, and must be classified in accordance with the Service implementation of DoDI 4165.03. Reference the Real Property Classification System (RPCS) to find the facility category code, category description, and the various units of measure associated with each facility category code. The RPCS is available on the OASD(EI&E) Real Property Accountability web site https://extranet.acq.osd.mil/ie/ (Common Access Card required). See also https://www.acq.osd.mil/eie/bsi/bei_rpa.html. Identification of items and their category codes and costs is essential for the interim and Final DD Form 1354.

RPIM Data Elements: Asset Configuration Design Use CATCODE Code

4-1.15 12. CATCODE DESCRIPTION.

Use the current version of RPCS to determine the correct facility category code title corresponding to the category code entered in block 11.

4-1.16 13. CONS TYPE CODE.

Indicate the type of construction: P = Permanent, S = Semi-permanent.

RPIM Data Element: Construction Type Code

4-1.17 14. SUST CODE.

This data element is required for all non-disposed buildings meeting the following:

- Greater than or equal to 10,000 gross square feet (GSF).
- Located in the United States and its territories.
- Legal interest of owned (G) or museum trust (M).

This data element is optional for:

- Owned or museum trust buildings greater than 5,000 GSF and less than 10,000 GSF.
- Leased or state government-owned buildings of any size.

Do not report this data element for:

- Non-building assets.
- Buildings located outside the United States and its territories.
- Buildings of 5,000 or less GSF.
- Buildings with the status of excess, surplus, or disposed.

Valid codes are in parentheses:

- **Yes (1)**: The building has been evaluated and qualifies as a sustainable Federal building as outlined in the E.O. 13834 Implementing Instructions[4]. If the project is a new building or new work in an existing building which is subject to the requirements; and the resulting building is projected to be 100% compliant when work is completed; and the High Performance and Sustainable Building or Third-Party Certification checklist for the building is attached to the DD Form 1354, mark box 14 as "1."
- **No (2)**: The building has been evaluated and does not qualify as a sustainable building Federal building as outlined in the E.O. 13834 Implementing Instructions[4].
- **Not Yet Evaluated (3)**: The building has not yet been evaluated.
- **Not Applicable (4)**: The building is excluded because it meets all of the following conditions:
  - o Unoccupied: The building is occupied 1 hour or less per person per day on average.
  - o Low/No Energy Use: Total energy consumption from all sources is less than 12.7 kBtu/GSF/year.
  - o Low/No Water Use: Water consumption is less than 2 gallons per day on average.

RPIM Data Element: Facility Sustainability Code

4-1.18 15. PRIMARY/UMA.

Enter the primary unit of measure for each design use category code for each item of real property. The Service implementation of DoDI 4165.03 identifies the primary/secondary unit of measure for each real property category code. Refer to the RPCS (current version) for the associated Unit of Measure Accountability for the category code (reference the 5-6 digit CC tab).

RPIM Data Elements: RPA Total Unit of Measure Code

[4] At the time of publication, EO 13834 had been rescinded by EO 14057; however, implementation guidance for EO 14057 had not been issued. Continue to use the implementation guidance for EO 13834 for determining sustainability eligibility (https://www.sustainability.gov/pdfs/eo13834_instructions.pdf).

Asset Configuration Design Use Unit of Measure Code
Site Land Total Area Unit of Measure Code

4-1.19 16. PRIMARY/QUANTITY.

Enter the total area quantity in the unit of measure specified in column 15 for each item of real property. For buildings, enter the gross area. For demolition, enter negative numbers in parentheses or attach an Authorization for Demolition.

For capital improvements increasing the size of the existing facility, the quantity entered here should be the quantity by which the capital improvement increased the size (area), not the total quantity (including the capital improvement) for the facility. For example, if there is an existing 10,000-square-foot facility to which a capital improvement adds 5,000 square feet, then 5,000 would be the quantity entered, not 15,000. If a capital improvement does not increase the size, enter N/A in this block.

RPIM Data Elements: RPA Total Unit of Measure Quantity
Asset Configuration Design Use Size Quantity
Site Land Total Area Quantity

4-1.20 17. SECONDARY/UMO.

Refer to the RPCS (current version) to determine if a Unit of Measure Operational is required. For category codes with a UMO, it is required. Note not all category codes have a UMO. For each item of real property, enter the appropriate unit of measure for capacity/other as applicable to the design use category code. The Service implementation of DoDI 4165.03 identifies the appropriate capacity/other unit of measure for each real property category code.

RPIM Data Element: N/A

4-1.21 18. SECONDARY/QUANTITY.

Enter the total quantity of capacity/other in the unit of measure specified in column 17 for each item of real property, if applicable. For demolition, enter negative numbers in parentheses or attach an Authorization for Demolition. For capital improvements increasing the capacity of the existing facility, the quantity entered here should be the quantity by which the capital improvement increased the capacity, not the total quantity (including the capital improvement) for the facility. If a capital improvement does not increase the capacity, enter N/A in this block.

RPIM Data Element: N/A

Note for blocks 15 through 18: Each Service category code reference stipulates an area (primary) or another unit of measure (secondary; for example, capacity), or both. If both units of measure are stipulated in the reference, then both are required on the DD Form 1354. If only one measure is required, place N/A in the other set of columns.

4-1.22 19. COST.

The DD Form 1354 identifies the cost of individual real property assets listed on the form. These costs are required as part of the Service's financial statements. The preparer must identify the total project cost and determine which elements are to be capitalized as real property, as well as costs assigned to each facility. All costs for a multi-purpose facility should be shown against the facility's predominant design use category code, and the cost column for the other categories of the multi-purpose facility should be annotated as N/A.

The DCA must provide distinct breakout costs for each different building, linear structure, and structure constructed as part of the project. For example, if the project consists of two buildings, parking, sidewalks, water supply branch lines, sewer branch lines, and exterior lighting, costs must be provided for all separate items in block 9. Each one of these seven items would be identified with a separate RPUID. No maintenance or repair work costs should be entered on the DD Form 1354.

CIPR Data Element:	Capital Improvement Recorded Cost
RPIM Data Element	Acquisition Original Asset Recorded Cost Amount

4-1.22.1 Demolition Costs.

If demolition is within the footprint of a new construction project, then demolition costs are considered site preparation costs and included as part of the new facility costs on the DD Form 1354. If demolition is not within the footprint of new construction, its cost is expensed and is not included on the DD Form 1354.

4-1.22.2 Preliminary and Final Costs.

Costs provided in a DD Form 1354 can be either preliminary or final. Costs on the interim DD Forms 1354 are preliminary costs entered in the APSR. Costs on a final DD Form 1354 are the final costs. The office preparing an interim DD Form 1354 must maintain a suspense file to ensure the accepting RPAO is furnished with an updated DD Form 1354 with the final l costs (total costs -- not the difference between the interim and final) entered upon financial closeout. Final costs are typically available several months, or if legal claims are involved, one or more years after physical completion and facility transfer. For real property assets found on post/site, or for other existing facilities with unknown original construction costs, an effort should be made to determine the actual costs. If the actual costs cannot be determined, then develop and thoroughly document an estimate of these costs. In these cases, the estimates will become the final costs.

4-1.22.3 Total Project Cost.

Record total project cost in **PROJECT REMARKS** (block 28), which includes:

- P&D, including project management costs.
- Construction contract supervision and administration (SIOH and post-award project management costs).
- Construction costs (including site preparation, which also includes demolition within the footprint of the existing facilities).

Report project-funded equipment costs in accordance with Service guidance. If applicable, include project-funded equipment costs as separate line items on the DD Form 1354 in Block 28. Project-funded equipment costs are recorded in block 28 for information, but are not recorded in the APSR. The DCA prorates P&D and SIOH costs among the real property assets comprising the project and includes the prorated P&D and SIOH costs in the real property asset costs in column 19 for each real property asset. Estimated costs may be used to prorate P&D and SIOH costs to the individual item number in column 9.

RPIM Data Elements: Project Detail Fund Cost Amount
Project Total Fund Cost Amount

4-1.22.4 Acquisition Costs.

The cost in column 19 is the sum of real estate transaction costs and the actual purchase or fee costs. Show these two components of real estate costs in **PROJECT REMARKS** (block 28).

RPIM Data Elements: Acquisition Original Asset Recorded Cost Amount
Acquisition Basic Cost

4-1.22.5 Transfer Costs.

The cost in column 19 is the sum of actual costs that were on the losing agency's facility records. This is the depreciated acquisition cost to government, also known as the facility book value.

RPIM Data Element: Acquisition/Capital Improvement Cost Amount
Facility Total Accumulated Depreciation Amount
Facility Book Value

4-1.22.6 Cost Methodology

For construction or capital improvements, the DCA can use the following step-by-step procedure for computing the costs in block 19:

1. Identify all assets, including facilities and infrastructure and their associated direct construction costs, on the DD Form 1354. Identify site preparation costs including footprint demolition, equipment (if project-funded), or other costs included with the costs directly attributable to those facilities. Identify costs associated with facilities that would increase existing supporting facility records, such as utility lines or pavements.
2. Allocate the P&D and SIOH costs (including project management costs) (indirect costs) among the facilities listed on the DD Form 1354. If P&D and SIOH costs are known for the entire project but are not known for individual facilities, prorate total P&D and SIOH costs among the different facilities. Prorate based on either individual area/size of the facility or individual facility construction working estimates. Annotate in **PROJECT REMARKS** the basis used to prorate or allocate P&D and SIOH costs to individual facilities.
3. Compute the individual facility and incremental consolidated facility costs by summing the actual direct and allocated indirect costs computed in steps one and two.
4. Check to ensure the sum of the individual facility direct costs equals the total project contract cost. List the total project cost and the individual total project cost contributions of construction, P&D, SIOH, EIP, and any non-capitalizing costs (for example, non-footprint demolition) in **PROJECT REMARKS**. If the sum of the individual facilities (RP and EIP) on the DD Form 1354 does not equal the project total, explain in **PROJECT REMARKS**.

4-1.23 20. FUND SOURCE.

When recording costs, the preparer must identify the types of funds obligated or lines of accounting for the funds. It is important for compliance with Chief Financial Officers to identify the fund source in this column for each real property asset or item. When there is more than one fund source for a single real property asset, show all fund sources. The construction authorization document usually identifies the fund source(s) or lines of accounting. Use space in **PROJECT REMARKS** for continuation of data that does not fit in column 20.

Example: MilCon or O&M

RPIM Data Elements: Acquisition Fund Source Code (may be more than one)
Project Detail Fund Code (may be more than one)

4-1.24 21. FUND ORG.

Identify the organization(s) responsible for funding the acquisition of this real property asset.

Example: ARMY

RPIM Data Element: Acquisition Organization Code (may be more than one)
Project Detail Organization Code

4-1.25 22. RPA INT TYPE CODE.

Document the government's interest or ownership in the real property asset. Interest reflects ownership from a legal perspective, not who has control of, or accountability for, the real property asset.

Example: DoD government owned

RPIM Data Element: RPA Interest Type Code

4-1.26 23. ITEM REMARKS.

Use this column to note any information or remarks about the specific item number from column 9. Explain any prorating of costs among various items, as well as any removals or demolitions. If more space is required for item remarks, use block 28. It is not necessary to duplicate in column 23 the project level remarks that appear in block 28. Also use space in **PROJECT REMARKS** for continuation of data that does not fit in column 23.

RPIM Data Element: N/A

4-1.27 24. STATEMENT OF COMPLETION.

This block is signed (either electronically or manually) by an individual responsible for and authorized to transfer accountability. Normally, the DCA signs (either electronically or manually) and dates block 24 for new construction and capital improvements once the asset(s) is/are substantially complete as part of the interim DD Form 1354 process. This signature evidences verification of construction details. The DCA will continue to monitor costs through completion of the asset(s) and will include the final costs as part of executing the final DD Form 1354.

The Installation Management Organization's RPAO signs (either electronically or manually) when transferring real property from one installation to another. Enter the date at the time of signature. To simultaneously transfer property responsibility and accountability for transfers, the date must be prior to, or the same as, the date of acceptance in block 25 on the DD Form 1354. Use the standard date format *YYYYMMDD*.

For inventory adjustments, the preparer (for example, the Real Property Specialist) of the final DD Form 1354 will sign in block 24.

RPIM Data Elements: N/A

4-1.28 25. ACCEPTED BY.

ACCEPTED BY is the final step and occurs when a portion of the project is completed for an interim DD Form 1354 or after the project is closed out for a final DD Form 1354. This block is signed (either electronically or manually) by the individual responsible for and authorized to accept accountability for the assets described in accordance with the Service directed timeline. In most cases, the RPAO signs (either electronically or manually) block 25. The properties accepted must have been inspected and determined to meet standards except for the deficiencies listed in block 27.

Enter the date at the time of signature. The date must be after, or the same as, the date of **STATEMENT OF COMPLETION** in block 24 on the DD Form 1354. **ACCEPTED BY** date is generally after the **RPA PLACED-IN-SERVICE DATE** (block 7a). This signature must occur in accordance with the Service directed timeline. Once the form is signed, electronically or manually, do not update unless it is re-signed by the transferring/accepting officials.

Barring mitigating circumstances (such as litigation or claims), complete final costs within the fiscal quarter of the **RPA PLACED-IN-SERVICE DATE** to facilitate financial closeout.

RPIM Data Element N/A

4-1.29 26. PROPERTY VOUCHER NUMBER.

The preparer should leave this field blank. The receiving installation RPAO fills in the property voucher number when the DD Form 1354 information is recorded in the installation real property voucher register in accordance with Service guidance.

RPIM Data Element N/A

4-1.30 27. CONSTRUCTION DEFICIENCIES.

Enter any significant construction deficiencies for the project. Do not list any perceived deficiencies in the scope or design of the project, as this transfer identifies only deficiencies in the awarded construction contract performance the Government needs completed before declaration of completion of the contracted work. If there are more entries than fit on a single page, attach the construction deficiencies as a separate document or spreadsheet or as an electronic file.

Example:	Restore all grassed areas disturbed by construction. Replace/repair iron rod fence that was damaged during construction.
RPIM Data Element:	N/A

4-1.31 28. PROJECT REMARKS.

Enter any project-related text that would help others understand the real property transaction identified on the DD Form 1354. Remarks pertaining to only one Item should be listed in column 23. block 28 may contain:

- Full description of capital improvements.
- Continuation of data that does not fit in blocks 1 through 8, and columns 20 through 23.
- List of attachments to DD Form 1354 (such as the Building Information Checklist).
- Total project cost and four individual components of total project cost.
- Contact information for DD Form 1354 preparer.

If there are more remarks than fit in block 28 on a single page, attach the additional remarks as a separate document or spreadsheet (hard copy or electronic).

CHAPTER 5 SUPPORTING DOCUMENTATION

5-1 ATTACHMENTS.

Typically, a DD Form 1354 does not stand alone. Tables 5-1 through 5-3 provide a list of the physical, legal, and financial supporting documentation that could be added by the preparer to ensure a complete DD Form 1354 for the types of acquisition methods discussed in this UFC. The preparer of the DD Form 1354 should supply the documentation necessary according to specific requirements of the project/transaction. Documentation must be included with the DD Form 1354 at signature; however, updates may occur until final documentation is provided. Once documentation is attached to the DD Form 1354, it is expected to remain with the DD Form 1354 for the required period of legal retention as determined by the National Archives and Records Administration and the DoD Records Management Program.

5-1.1 Acquisition by Construction and Capital Improvements to Existing Facilities.

Table 5-1 Construction/Capital Improvement Typical Physical, Legal, and Financial Supporting Documentation

Evidential Matter	Examples
Evidence of project approval	Such as, but not limited to: • Approved work order • Approved DD Form 1391 • Statute • Authorization memorandum
Evidence of obligation on behalf of the government	Such as, but not limited to: • For contracts and contract modifications, the following information is utilized: o Title/first page from contract o Contract statement of work or specifications o Contract Accounting Cite page o Dollar amount of contract o Location o Parties to the contract o Signature page [signature of all parties] o
Evidence of costs	Such as, but not limited to: • Approved invoices reflecting the amount submitted for payment • Evidence of in-house construction costs, including labor • Other costs (such as SIOH)

Evidential Matter	Examples
Evidence of project closeout	Such as, but not limited to: • Pictures before and after construction • Evidence of demolition, if applicable • Certified copies of pertinent real estate documents, such as deeds of acquisition, leases, or judgments from condemnation procedures • List of EIP with models, serial numbers, and warranty information • High Performance and Sustainable Building Checklist • Third Party Certification Checklist

5-1.2 Transfer Between Services and/or WHS.

Table 5-2 provides a list of the typical supporting documentation for this acquisition method. DoD Directive 4165.06 and DoD Instructions 4165.14 and 4165.70 provide further guidance for this acquisition method.

If the Service transferring assets has assets under construction or pending final acceptance at the time of transfer, this Service's assigned DCA will maintain responsibility for the construction project until final acceptance. The Service which is receiving the assets will conduct the final acceptance transaction to fully relieve the construction-in-progress account.

Table 5-2 Transfer Between Services Typical Physical, Legal, and Financial Supporting Documentation

Evidential Matter	Examples
Evidence of transfer	Such as, but not limited to: • List of assets • Memorandum between Deputy Assistant Secretaries of losing and gaining Services

5-1.3 Inventory Adjustment (Found on Site).

The ultimate goal for this acquisition method is to have as complete a file as for the other acquisition methods. Make all reasonable efforts to ascertain the original acquisition method and locate any information required to complete the file. In the absence of documentation to support the value of the asset, the Service must determine an acquisition date, valuation method and prepare an attestation memorandum as to how the valuation was determined. Table 5-3 provides a list of the typical supporting documentation for this acquisition method.

Table 5-3 Inventory Adjustment (Found on Site) Typical Physical, Legal, and Financial Supporting Documentation

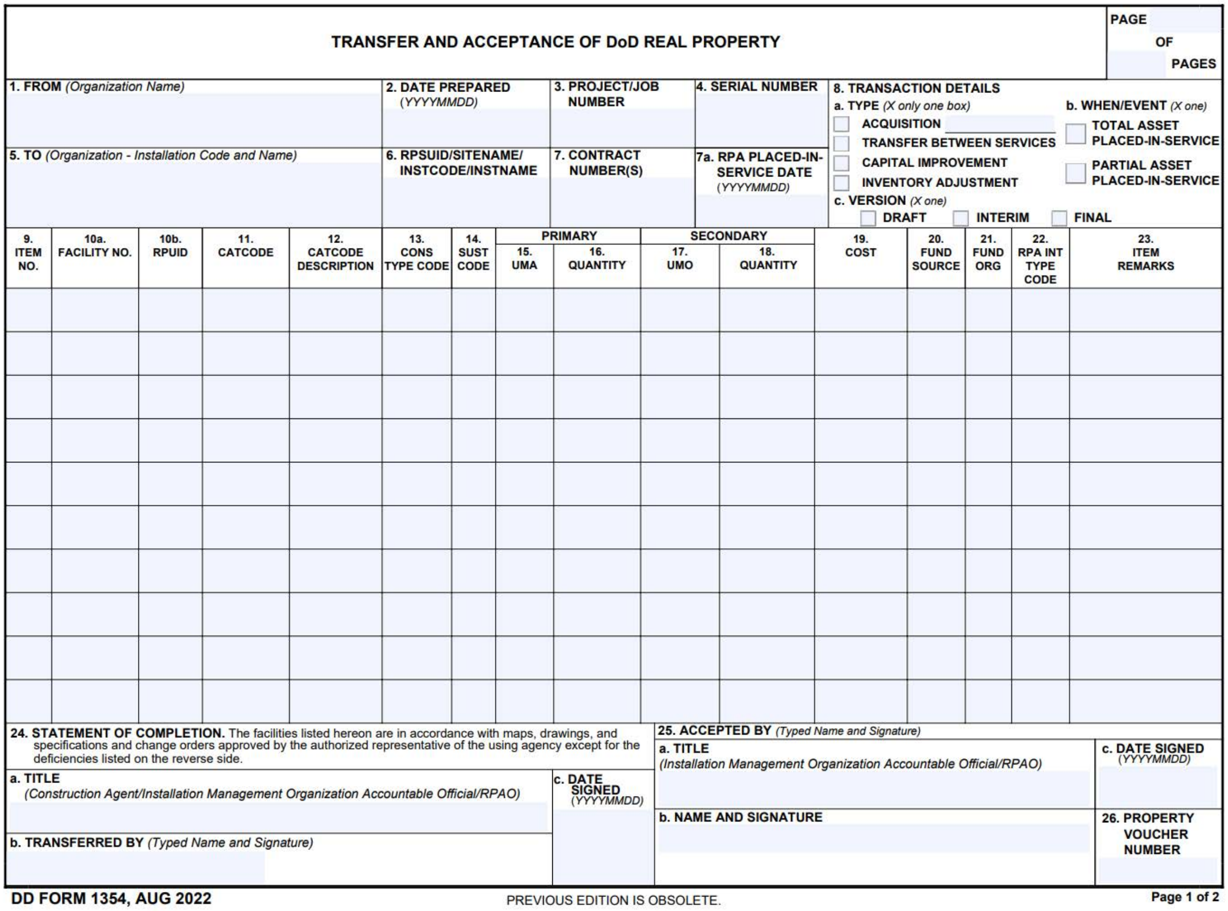
Evidential Matter	Examples
Evidence of obligation on behalf of the Government or legal interest	Dependent on probable method of acquisition. See RPIM for complete list of acquisition methods); refer to Tables 5-1 and 5-2 above.
Evidence of valuation	If evidence of actual acquisition cost cannot be determined, attestation memorandum identifying method used to determine alternative valuation

This Page Intentionally Left Blank

APPENDIX A BEST PRACTICES

A-1 DD FORM 1354.

The DD Form 1354, "Transfer and Acceptance of DoD Real Property," is available via the Washington Headquarters Service publishing site: https://www.esd.whs.mil/portals/54/documents/dd/forms/dd/dd1354.pdf.



TRANSFER AND ACCEPTANCE OF DoD REAL PROPERTY

PAGE OF PAGES

1. FROM *(Organization Name)*
2. DATE PREPARED *(YYYYMMDD)*
3. PROJECT/JOB NUMBER
4. SERIAL NUMBER
5. TO *(Organization - Installation Code and Name)*
6. RPSUID/SITENAME/ INSTCODE/INSTNAME
7. CONTRACT NUMBER(S)
7a. RPA PLACED-IN-SERVICE DATE *(YYYYMMDD)*
8. TRANSACTION DETAILS
a. TYPE *(X only one box)*: ACQUISITION; TRANSFER BETWEEN SERVICES; CAPITAL IMPROVEMENT; INVENTORY ADJUSTMENT
b. WHEN/EVENT *(X one)*: TOTAL ASSET PLACED-IN-SERVICE; PARTIAL ASSET PLACED-IN-SERVICE
c. VERSION *(X one)*: DRAFT; INTERIM; FINAL

9. ITEM NO.	10a. FACILITY NO.	10b. RPUID	11. CATCODE	12. CATCODE DESCRIPTION	13. CONS TYPE CODE	14. SUST CODE	PRIMARY 15. UMA	PRIMARY 16. QUANTITY	SECONDARY 17. UMO	SECONDARY 18. QUANTITY	19. COST	20. FUND SOURCE	21. FUND ORG	22. RPA INT TYPE CODE	23. ITEM REMARKS

24. STATEMENT OF COMPLETION. The facilities listed hereon are in accordance with maps, drawings, and specifications and change orders approved by the authorized representative of the using agency except for the deficiencies listed on the reverse side.
a. TITLE *(Construction Agent/Installation Management Organization Accountable Official/RPAO)*
b. TRANSFERRED BY *(Typed Name and Signature)*
c. DATE SIGNED *(YYYYMMDD)*

25. ACCEPTED BY *(Typed Name and Signature)*
a. TITLE *(Installation Management Organization Accountable Official/RPAO)*
b. NAME AND SIGNATURE
c. DATE SIGNED *(YYYYMMDD)*
26. PROPERTY VOUCHER NUMBER

DD FORM 1354, AUG 2022 PREVIOUS EDITION IS OBSOLETE. Page 1 of 2

27. CONSTRUCTION DEFICIENCIES *(Attach blank sheet for continuations)*	**28. PROJECT REMARKS** *(Attach blank sheet for continuations)*

INSTRUCTIONS

GENERAL. This form has been designed and issued for acceptance of real property or transfer between the DoD Components.

For detailed instructions on how to fill out this form, please refer to Unified Facilities Criteria 1-300-08.

Existing instructions issued by the DoD Components relative to the preparation of DD Form 1354 are applicable to this revised form to the extent that the various items and columns on the superseded forms have been retained. The DOD Components may promulgate additional instructions, as appropriate.

For detailed information on data inputs and codes, please refer to the latest version of the Real Property Information Model (RPIM) Report and use the RPIM Pick Lists for Block responses: https://extranet.acq.osd.mil/ie/

SPECIFIC DATA ITEMS.

1. From. Name of the DoD Component.

2. Date Prepared. Date of actual preparation. Enter all dates in YYYYMMDD format (Example: March 31, 2010 = 20100331).

3. Project/Job Number. Project number on a DD Form 1391 or Individual Job Order Number.

4. Serial Number. Sequential serial number assigned by the preparing organization (e.g.,Item 17. 2010-0001).

5. To. Name and address of the receiving installation, activity, and Service of the Real Property Accountable Officer (RPAO).

6. RPSUID/SITENAME/INSTCODE/INSTNAME. Site Unique Identifier and name or installation code and name where the constructed facility is located.

7. Contract Number(s). Contract number(s) for this project.

7a. RPA Placed-In-Service Date. The calendar date the asset is accepted for use by DoD.

8. Transaction Details.
a. Type of Transaction. X only one box.
For Acquisition Type, refer to the Acquisition Method Code pick list in RPIM.
b. When/Event. When or event causing preparation of DD Form 1354. X only one box.
c. Version. Draft, interim, or final DD Form 1354. X only one box.

9. Item Number. Use a separate item number for each facility, no item number for additional usages.

10a. Facility Number. An installation specific asset identification number.

10b. RPUID. A unique non-intelligent code to permanently identify an asset.

11. CATCODE. The real property Category Code (CATCODE) that classifies the designed use of the asset (original or current) and corresponds to the largest quantity of the asset that is utilized for a single purpose (RPA Predominant Design Use CATCODE).

12. CATCODE Description. The CATCODE name corresponding with Item 11.

13. Construction (CONS) Type Code. The code represents the Construction Type Code and valid values can be found in the RPIM pick list by the same name. Type of construction will be PERM for Permanent or SEMI for Semi-permanent.

14. Sustainability (SUST) Code. : This code is also known as the Facility Sustainability Code and valid values can be found in the RPIM pick list by the same name. It indicates whether a facility meets the Guiding Principles of Federal Leadership in High Performance and Sustainable Buildings for buildings greater than 10,000 sq. ft. The list of valid values is: 1, 2, 3, 4.

15. UMA. Enter the primary unit of measure accountability for each design use category code for each item of real property.

16.Quantity. Enter the total quantity in the unit of measure accountability specified for each item of real property.

17. UMO. Enter the appropriate unit of measure operational for capacity/configuration as applicable for the design use category code.

18. Quantity. Enter the total quantity of capacity/configuration in the unit of measure operational specified for each item of real property.

19. Cost. Enter the total project cost for each item of real property. UFC 1-300-08 contains additional guidance.

20. Fund Source. Identify the fund source in this column for each real property asset or item. UFC 1-300-08 contains additional guidance.

21. Funding Organization. Identify the organization(s) responsible for funding the acquisition of this real property asset.

22. RPA Interest Type Code. This code represents the RPA Interest Type Code and valid values can be found in the RPIM pick list by the same name. The code is used to identify the type of legal interest that DoD holds in a real property asset.

23. Item Remarks. Remarks pertaining only to the item number identified in Item 9; show cost sharing.

24. Statement of Completion. Typed name, signature, title, and date of signature by the responsible transferring individual or agent. In the case of a real property acceptance action this is signed by the DoD Construction Agent. In the case of a real property transfer this is signed by the Installation Management Organization.

25. Accepted By. Typed name, signature, title, and date of signature by the Installation Management Organization RPAO or accepting official.

26. Property Voucher Number. Next sequential number assigned by the RPAO in voucher register.

27. Construction Deficiencies. List construction deficiencies in project during contractor turnover inspection.

28. Project Remarks. Project level remarks and continuation of blocks.

DD FORM 1354, AUG 2022 PREVIOUS EDITION IS OBSOLETE. **Page 2 of 2**

A-2 PROJECT COST TYPES.

Cost Type	Description
Total labor cost	The total cost of government burdened labor directly associated with the construction project. Includes both military and civilian labor costs, in accordance with current published DoD Comptroller annual reimbursable rates.
Direct cost of materials and supplies	The purchase price, the cost of inspection, and loading assumed by the carrier.

Cost Type	Description
Cost of Supervision, Inspection, and Overhead (SIOH)	A fee applied to the cost of a construction contract to recover direct and indirect expenses for a project's construction management services. Examples may include, but are not limited to: administration of social programs, claims analysis, constructability review, contract/project administration, cost estimation, cost management, labor rates, materials testing, post construction activities, procurement of materials, equipment, project management, quality assurance, scheduling, and value engineering.
Cost of transportation	Amounts paid for transportation of workers, materials, and supplies in connection with the construction project.
Cost of handling and storage	Amount paid for packaging and storing the materials, supplies, and equipment used in the construction project.
Cost of injuries and damages	Costs resulting from injuries to people or damage to property incurred directly as a result of the construction project.
Cost of legal and recording fees	Legal fees incurred to bring the asset to its intended use (such as title or recording fees).
Cost of architecture and engineering studies	Amounts paid for engineering, architectural, and other outside services for designs, plans, surveys, and specifications. May include design reviews, environmental impact studies, and soil testing for the new construction projects.
Cost of site and asset preparation	Amounts paid to prepare the site for new construction, such as soil removal, grading, and infill. Includes amount paid to prepare the asset for its intended use, such as installation of utilities into an asset.
Cost of installed equipment	Fixed equipment and related installation costs required for a complete and usable asset.
Usage cost of government furnished equipment or material (GFE, GFM)	The usage cost of the government furnished equipment, material, and facilities used in construction work. Example: Use of a government owned grader for site preparation billed at the assigned hourly rate.
Cost of donated assets	The fair market value of real property and installed equipment donated to the government.

A-3 CONSTRUCTION-IN-PROGRESS COST TYPES.

Costs must be accumulated for constructed assets. Reference DoD 7000.14-R FMR, Vol. 4, Chapter 24, Annex 1 for more information.

Cost Type	Description
Cost of contract work	Amounts paid for work performed under contract, as well asany incentive fees paid to contractors to reward performance goals.
Direct cost of labor	The direct cost of labor and all associated fringe benefits inconnection with the construction project. Includes both military and civilian labor costs.
Direct cost of materials and supplies	The purchase price and the cost of inspection.
Cost of Supervision, Inspection, and Overhead (SIOH)	Support associated with the administration of contracts for facility projects. Support may include processing of contract award and payments, performing inspections, and other actions taken during project execution.
Cost of transportation	Amounts paid for transportation of workers, materials, and supplies in connection with the construction project.
Cost of handling and storage	Amount paid for packaging and storing the materials andsupplies and equipment used in the construction project.
Cost of legal and recording fees	Legal fees incurred to bring the asset to its intended use(such as title or recording fees).
Cost of architecture and engineering studies	Amounts paid for engineering, architectural, and other outside services for designs, plans, specifications, and surveys after funding and design authorization. May includedesign reviews, environmental impact studies, and soil testing for the new construction projects.
Cost of facility and site preparation	Amounts paid to prepare the site for new construction, such as soil removal and restoration. Includes amount paid to prepare the asset for its intended use, such as installation of utilities in a facility.
Cost of installed equipment	Fixed equipment and related installation costs required for activities in a facility.
Cost of government furnished property	An appropriate share of the cost of the government furnishedequipment and material used in construction work.
Cost of donated assets	The fair market value of equipment donated to the government, as authorized by a special legislation, inconnection with the construction project.

APPENDIX B GLOSSARY

B-1 ACRONYMS.

AFCEC	Air Force Civil Engineer Center
APSR	Accountable Property System of Record
BCE	Base Civil Engineer
BEA	Business Enterprise Architecture
BIA	Bilateral Infrastructure Agreement
CATCODE	Category Code
CC	Category Code
CCMD	Combatant Command
CCR	Criteria Change Request
CFOA	Chief Financial Officers Act
CIP	Construction in Progress
CIPR	Construction in Progress Requirements
CJCS	Chairman, Joint Chiefs of Staff
CWE	current working estimate
DAIS	Data Analytics and Integration Support Platform
DCA	DoD Construction Agent
DoD FMR	Department of Defense Financial Management Regulation
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DPW/FMO/BCE	Directorate of Public Works/Facilities Management Office/Base Civil Engineer
EIP	Equipment In Place
FAC	Facility Analysis Category
FacMgr or FACMGR	Facility Manager

FMR	Financial Management Regulation (DoD)
G	Government
GFE	Government Furnished Equipment
GFM	Government Furnished Material
GSA	General Services Administration
GSF	gross square feet
HNFA	Host Nation Funded Agreement
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HVAC	heating, ventilation, and air conditioning
IBE	Installed Building Equipment
IG	Inspector General
IMO	Installation Management Organization
JS	Joint Staff
kBtu	thousand British thermal units
MCA	Military Construction, Army
MilCon	Military Construction
N/A	not applicable
NAVFAC	Naval Facilities Engineering Command
NGB	National Guard Bureau
O&M	operations and maintenance
OASD(EI&E)	Office of the Assistant Secretary of Defense for Energy, Installations, and Environment
OSD	Office of The Secretary of Defense
P&D	Planning and Design
PCE	project cost estimate
POC	point of contact

PS	Project Sponsor
RFP	Request for Proposal
RPAO	Real Property Accountable Officer
RPAR	Real Property Acceptance Requirements
RPCS	Real Property Categorization System
RPI	Real Property Inventory
RPIM	Real Property Information Model
RPIR	Real Property Inventory Requirements
RPO	Real Property Office
RPSUID	Real Property Site Unique Identifier
RPUID	Real Property Unique Identifier
SF	square feet
SIOH	Supervision, Inspection, and Overhead
SOFA	Status of Forces Agreement
UIC	Unit Identification Code
UMA	Unit of Measure Accountability
UMO	Unit of Measure Operational
U.S.C.	United States Code
USACE	United States Army Corps of Engineers
USPFO	United States Property and Fiscal Officer
WCF	working capital fund
WHS	Washington Headquarters Services
WIP	work in progress

B-2 DEFINITION OF TERMS.

Administrative Accountability: The Service accountable for the real property does not use the real property for which it is accountable; another Service or agency controls the use of the property.

Accountable Property System of Record (APSR): The business system/application used to account for and maintain accountability of DoD government property.

Building: A roofed and floored facility enclosed by exterior walls and consisting of one or more levels suitable for single or multiple functions which protects human beings and their properties from direct harsh effects of weather such as rain, wind, and sun.

Capital Improvement: Includes any improvement that increases the useful life, efficiency, capacity, or size of an existing asset, or modifies the functionality or use of the asset, regardless of the source of funding or capitalization threshold.

Capital Improvement Placed-in-Service Date: The calendar date when an improvement to a real property facility is available for use by DoD; the date on which the leasehold improvement (capital improvement) is made to a leased facility. On this date, the government assumes liability and the warranties begin for the capital improvement to which they have received title. Also includes date of leaseholds.

Chief Financial Officers Act (CFOA): The federal law requiring government agencies to produce auditable financial statements and timely, accurate financial data. Includes accounting for costs spent on construction and capital improvements of government facilities.

Construction in Progress (CIP) Account: In the context of real property construction, the accumulations of costs of construction for or by the Project Sponsor since project inception. (See **Work-in-Progress**, this Appendix. Not to be confused with the Capital Investment Program, also referred to as CIP.

Current Working Estimate (CWE): The estimated cost of a new construction project. As the design process proceeds, the current working estimate will change, and only becomes fixed when a construction bid is accepted.

DoD Construction Agent (DCA): The DoD organization authorized pursuant to Section 2851 of Title 10, U.S.C., and DoD policy (DoDD 4270.05) to administer design and construction contracts for DoD facilities projects in accordance with applicable laws and regulations.

DoD Components: The Office of the Secretary of Defense (OSD); the Military Departments; the Chairman, Joint Chiefs of Staff (CJCS) and the Joint Staff (JS); the combatant commands (CCMD); the Office of the Inspector General (IG) of the DoD; the Defense agencies; DoD field activities; and all other organizational entities within DoD.

Equipment in Place (EIP): A special category of personal property (not real property). EIP consists of capital equipment and other nonexpendable equipment of a movable nature that has been fixed in place or attached to real property, but not as an integral part of the facility, and therefore may be severed or removed from a facility without severely damaging, destroying, or reducing the usefulness of the facility. EIP is personal property and does not include installed building equipment. It is accounted for on property book records (not real property records). EIP costs may be included as a funded construction cost.

Execution Authority: The individual authorized to sign the DD Form 1354. For new construction or alteration executed with MilCon funding, this is a senior representative of the DCA. Execution authority for conversion, diversion, alteration, minor construction, and inventory adjustments (found on site) may be the installation/ garrison/base commander. However, this authority is often delegated to the Director of Public Works/Facilities Manager/Base Civil Engineer (DPW/FacMgr/BCE). The actual execution authority is a Service-, or WHS-specific decision.

Facility: A building, structure, or linear structure that includes in the basic record for the facility such things as landscaping, HVAC equipment, utility connections, stairs, ramps, passageways, and other real property installed equipment that facilitates the use of and is inclusive/intrinsic to the facility itself.

Installation Management Organization (IMO): The Military Department (or WHS for the Pentagon Reservation) with custody and accountability for the physical infrastructure and real property of the military installation on which construction will occur. The IMO may authorize another DoD Component with physical control over an installation, or portion thereof, to perform roles and responsibilities of the IMO, provided it does so in writing and with specificity.

Installed Building Equipment (IBE): Synonymous with real property installed equipment.

Land: A portion of the earth's surface distinguishable by boundaries. The types of land assets in the RPI include everything from unimproved wilderness areas to central urban developments. Land must be inventoried by parcel, starting when the parcel was transferred into a custody and control of a Military Department or the WHS.

Land Parcel: A specific area of land with a perimeter delineated by a cadastral survey.

Linear Structure: A facility whose function requires it traverse land (such as a road, rail line, pipeline, fence, pavement). Includes distribution systems providing a common service or commodity to more than one building or structure.

Military Construction (MilCon): Per Title 10, U.S.C., Section 2801, includes any construction, development, conversion, or extension of any kind, carried out with respect to a military installation. A military construction project includes all military construction work necessary to produce a complete and usable facility or a complete and usable improvement to an existing facility.

Project Cost Estimate (PCE): The estimated costs for an entire project (up to the limit of funds received), to include planning and design, site preparation, construction, and overhead. The PCE may include costs that will not be capitalized, such as any work designated as repairs or design breakage. The DCA Project Manager uses the PCE to manage the project against funds available.

Placed-in-Service Date: Calendar date the real property asset is available for use by DoD and the government assumes liability, receives legal interest, and the warranties and depreciation begin.

Planning and Design (P&D): Costs associated with design of military construction projects. These costs are accounted for separately since Congress funds them as a separate line item for future MilCon projects. P&D is one of the four cost components (along with SIOH, construction, and equipment costs) reflected in **PROJECT REMARKS** (block 28) on DD Form 1354.

Project Sponsor (PS): The DoD Component that establishes project requirements, priorities, program, and budget. DoD agencies and combatant commands are not authorized to hold real property, and as such, these assets are under the jurisdiction of, and held in the real property inventory of the real property accountable Service for the site where the asset is located.

Real Property: Land and improvements to land (such as buildings, structures, and linear structures (see **Facility**, this Appendix)).

Real Property Installed Equipment (RPIE). An item of equipment that is affixed and built into a facility as an integral part of the facility. To qualify as RPIE, the equipment must be necessary to make the facility complete, and if removed, would destroy or severely reduce the designed usefulness and operation of the facility. RPIE costs are included as a funded initial construction or renovation cost. RPIE may be accounted for as a real property equipment asset record, but not as a separate facility record in the real property inventory. RPIE includes such items as control systems, heating, cooling, electrical, emergency lighting, and is synonymous with IBE.

Real Property Asset: An individual building, structure, linear structure, or land parcel.

Real Property Asset Placed-in-Service Date: Calendar date the real property asset is available for use by DoD. On this date, title for assets listed on the acceptance form is transferred, the government assumes liability, and the warranties begin for the asset to which DoD has received title.

Real Property Site Unique Identifier (RPSUID): A unique non-intelligent code used to permanently identify real property sites. A real property site is a specific geographic location that has individual land parcels and/or facilities assigned to it.

Real Property Unique Identifier (RPUID): As defined in the RPIR, the RPUID is a non-intelligent code used to permanently and uniquely identify a real property asset. Each real property asset in which the DoD has a legal interest must be assigned an RPUID.

Repair: A project to restore a real property facility, system, or component to such a condition allowing it to effectively be used for its designated functional purpose (source: 10 U.S.C. 2811).

Structure: A facility, other than a building or linear structure, which is constructed on or in the land.

Supervision, Inspection, and Overhead (SIOH): SIOH is a fee applied to the cost of a construction contract to recover direct and indirect expenses for a project's construction management services. Examples of SIOH may include but are not limited to administration of social programs; claims analysis; constructability review; contract/project administration; cost estimation; cost management; labor rates; materials testing; post construction activities; procurement of materials; equipment; project management; quality assurance; scheduling; and value engineering.

Work-in-Progress (WIP): In the context of real property construction, this represents the accumulation of costs by the DCA billed to the PS since project inception. Billed costs are recorded in the corresponding CIP account by the PS, but only costs that must be capitalized. (See **CIP**, this Appendix).

This Page Intentionally Left Blank

APPENDIX C REFERENCES

DEPARTMENT OF DEFENSE

DoD Financial Management Regulations

https://comptroller.defense.gov/fmr.aspx

DoD FMR 7000.14-R, Vol 4, Ch 24, “Real Property”

DoD FMR 7000.14-R, Volume 11B, *Reimbursable Operations Policy - Working Capital Funds (WCF)*

DoD Directives

https://www.esd.whs.mil/Directives/issuances/dodd/

DoDD 4165.06, *Real Property*

DoDD 4270.05, *Military Construction*

DoD Instructions

https://www.esd.whs.mil/Directives/issuances/dodi/

DoDI 4165.03, *DoD Real Property Categorization*

DoDI 4165.14, *DoD Real Property Inventory (RPI) and Forecasting*

DoDI 4165.70, *Real Property Management*

DoDI 4165.71, *Real Property Acquisition*

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE FOR ENERGY, INSTALLATIONS, AND ENVIROMENT

https://www.acq.osd.mil/eie/bsi/bei_rpa.html

Data Analytics & Integration Support (DAIS) Platform

https://extranet.acq.osd.mil/ie/

U.S. LAWS AND CODE OF FEDERAL REGULATIONS

https://www.govinfo.gov/

10 U.S.C. 2696, *Real property: transfer between armed forces and screening requirements for other Federal use*

10 U.S.C. 2801, *Military construction*

10 U.S.C. 2811, *Repair of facilities*

10 U.S.C. 2851, *Supervision of military construction projects*

Public Law 101-576, *Chief Financial Officers Act of 1990*

EXECUTIVE ORDERS

https://www.fedcenter.gov/programs/

EO 13834, "Efficient Federal Operations," 22 May 2018

EO 14057, "Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability," 8 December 2021

FC 1-300-09N
17 May 2024
Change 1, 17 April 2025

FACILITIES CRITERIA (FC)

NAVY AND MARINE CORPS DESIGN PROCEDURES

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

FACILITIES CRITERIA (FC)

NAVY AND MARINE CORPS DESIGN PROCEDURES

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	17 April 2025	Reorganization of Chapter 1 paragraphs; removed AFFF from Chapters 6 and 7; cost changes in Chapter 9; updated para 12-4 and 13-5; mods to B-3.3.1 b,c,d; addressed CCRs; added FRCS consideration for existing buildings; broken weblinks fixed; minor word changes throughout, in accordance with para 7-5.

This FC supersedes FC 1-300-09N, dated May 2014, with Change 6 dated July 2021.

This Page Intentionally Left Blank

FOREWORD

Facilities Criteria (FC) provide functional requirements (i.e., defined by users and operational needs of a particular facility type) for specific DoD Component(s), and are intended for use with unified technical requirements published in DoD Unified Facilities Criteria (UFC). FC are applicable only to the DoD Component(s) indicated in the title, and do not represent unified DoD requirements. Differences in functional requirements between DoD Components may exist due to differences in policies and operational needs.

All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the contracting team must ensure compliance with the most stringent of the FC, the SOFA, the HNFA, and the BIA, as applicable.

Because FC are coordinated with unified DoD technical requirements, they form an element of the DoD UFC system applicable to specific facility types. The UFC system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applicable to the Military Departments, Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) memorandum dated 29 May 2002. The UFC System also includes technical requirements and functional requirements for specific facility types, both published as UFC documents and FC documents.

FC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet site listed below.

FC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website https://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

S. Keith Hamilton, P.E.
Chief Engineer and Assistant Commander for Planning, Design and Construction n
Naval Facilities Engineering Systems Command (NAVFAC)

This Page Intentionally Left Blank

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 REISSUES AND CANCELS.

This FC reissues FC 1-300-09N, **\1** dated 1 May, 2014, with Change 6 dated 9 July 2021. **/1/**

1-2 PURPOSE AND SCOPE.

This FC provides policy and standards for planning, design, development, and revision of project documents, including drawings, specifications, and Requests for Proposal, for facilities under the cognizance of NAVFAC. This FC has been developed to ensure consistency and clarity of project documents that form the basis of contracts for planning, design, and construction of facilities. **\1** Use this FC for projects where NAVFAC is the construction agent, as defined in DoDD 4270.5, for preparation of construction contract drawings, specifications, and Request for Proposals for shore facilities, for both Design-Bid-Build (DBB) and Design-Build (DB) projects. The Design and Submittal procedures contained herein are pertinent to standards, software, and templates used, required, and unified within NAVFAC, and centered around the NAVFAC organization and operation. Procedures for NAVFAC may not work for USACE and Air Force operations due to organizational and operational differences. **/1/**

1-2.1 Organization of Document.

This document is organized into design policy, roles and responsibilities, design deliverables, and design phases. The design deliverables chapters contain general requirements that apply throughout the design process. For the disciplines, additional information is provided only if it is not already in another UFC; thus, a discipline paragraph may not be provided if the Core UFC already provides the requirements for that deliverable, or the level of completion of that deliverable. Core UFCs are defined and listed in UFC 1-200-01.

Detailed level of completion for each type of submittal, and for each discipline, only beyond what is specified in other UFCs, are included in each design phase.

This FC provides specific guidance on how and when to provide a project design deliverable for NAVFAC. This document is organized into design deliverables and design phases. Requirements for design deliverables, beyond or in more detail of what is already required by a Core UFC, are provided for NAVFAC-only. The requirements for when or to what extent these deliverables are provided are in the Phase chapters.

1-3 APPLICABILITY.

\1 This FC follows the same applicability as UFC 1-200-01, paragraph 1-3, with no exceptions. **/1/**.

1-4 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, *DoD Building Code* and UFC 1-200-02 *High Performance and Sustainable Building Requirements*. Use 1-200-02 in conjunction with UFC 1-200-01 and the UFC and government criteria referenced therein. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, physical security, cybersecurity, high performance and sustainability requirements, and safety. UFC 1-200-02 provides minimum unified requirements and coordinating guidance for planning, designing, constructing, renovating, and maintaining high performance and sustainable facilities that will enhance DOD mission capability by reducing total ownership costs. Use this FC in addition to UFC 1-200-01, UFC 1-200-02, and the UFC and government criteria referenced therein.

1-5 CYBERSECURITY.

Plan, design, acquire, execute, and maintain facility-related control systems (FRCS) (including systems separate from a utility monitoring and control system) in accordance with UFC 4-010-06, and when required by individual Service Implementation Policy.

1-6 EXCEPTIONS.

Austere Requirements may be invoked on a per-project basis, and only by formal letter from Commander, Naval Installations Command (CNIC). Austere requirement options are included in FC 4-721-10N, UFC 4-610-01, UFC 4-722-01, and UFC 4-740-02.

1-7 GLOSSARY.

APPENDIX D contains acronyms, abbreviations, and terms.

1-8 REFERENCES.

APPENDIX E contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 POLICY

2-1 CRITERIA.

Design Naval shore facilities in accordance with Navy and Department of Defense (DoD) Criteria. DoD Design Criteria are available from the Whole Building Design Guide (WBDG) (https://www.wbdg.org/dod). Design criteria include general criteria, as well as specific criteria on particular elements of the work (such as Geotechnical Engineering) and facility types (such as Bachelor Quarters). Design requirements are typically in the form of Unified Facilities Criteria (UFC). The contract will reference the specific requirements applicable to a particular project. Deviations from criteria must be approved by the NAVFAC Chief Engineer and in accordance with MIL-STD-3007.

2-2 METRIC POLICY.

Comply with MIL-STD-3007 for the use of SI in projects and criteria documents. NAVFAC policy is to use the metric system of measurement (International System of Units, SI) in planning and design criteria, Unified Facilities Guide Specifications (UFGS), and construction contract documents for MCON/MILCON, BRACON, and family housing, regardless of contracting method. See exception under paragraph 2-2.2 General Policy.

2-2.1 SI Definitions.

Hard Metric measurement: The actual size, capacity, or other measurement characteristic of a product is changed to a rational metric value. This measurement is used in the manufacturing process.

Soft Metric measurement: A simple arithmetical change from inch/pound to SI units, using a conversion factor, so that actual measurable characteristics remain virtually unchanged, or at least within the former tolerance limits.

Example: 4 foot by 8 foot panel is hard converted to 1200 mm by 2400 mm, or soft converted to 1219.2 by 2438.4 mm.[1].

2-2.2 General Policy.

In accordance with Public Law 94-168, design and construction of new or renovated facilities must use the metric system of measurement, unless its use is impractical or is likely to cause significant inefficiencies or loss of markets to United States firms. Specify hard metric products unless such products are unavailable or uneconomical. Do not use dual units on drawings on any type of project. The design agent project manager is responsible for making the determination on whether or not to use the metric system of measurement on a project-by-project basis. Decisions to not use the metric system must be justifiable and documented in permanent project files. Comply

[1] Definitions and example extracted from Fishman, Bernard L./Loshak, Lionel/Strelka, Charles S. Metric Architectural Drawing. Canada: John Wiley and Sons, Inc., 1981, p. 11.

with Facilities Engineering Systems Command (FEC) process for determination of exception for the metric system.

2-3 OWNERSHIP OF PROJECT DOCUMENTS AND DATA.

The clauses set forth in DFARS 252.227-7023, DFARS 227.71, and DFARS 227.72 apply to project documents and data.

2-4 OPERATION SECURITY (OPSEC).

The OPSEC process provides a means of screening information prior to public release in order to prevent aggregation with other information, ultimately revealing DoD intentions or capabilities. Publicly released documents such as field investigations, reports, studies, Basis of Design, calculations, drawings, specifications, or DB Request for Proposals (RFP) must not reveal sensitive or critical information.

2-4.1 OPSEC Review.

Include an OPSEC review by the requesting activity as part of the normal review process; prior to public release to identify information that may require protection. Where applicable, modify details and identifying information in order to eliminate information the requiring activity has identified as sensitive or critical. When CUI cannot be redacted from documents, mark and handle documented in accordance with DoDI 5200.48.

2-4.2 Mission Information.

DoD installations support units and missions that may be considered sensitive, critical or even classified. In addition, every DoD command performs a core, unclassified mission. Although unclassified, individual tasks required for a command to accomplish its mission may contain information that when pieced together with other information, reveal sensitive, critical, or even classified information.

2-4.3 Information Compilation.

The compilation of information that is individually unclassified may be classified as a result of the compilation. Classification requires a classification decision by an Original Classification Authority (OCA). NAVFAC is not an OCA.

2-4.4 Sensitive or Critical Information.

Sensitive or critical information is unclassified or controlled unclassified information (CUI) concerning the DoD activities, intentions, capabilities, limitations, or vulnerabilities. **\1** SECNAVINST 3070.2A **/1/** contains a critical information list. In addition, the following is provided to help avoid the disclosure of sensitive or critical information that must not be included in publicly releasable materials.

- Do not identify a command if their mission or portion of their mission is considered critical or classified.
- Do not identify a command's mission or the mission supported by a facility if the mission is considered critical or classified.
- Do not identify the capabilities or vulnerabilities of physical security or antiterrorism protective measures.
- Do not identify the location of a Sensitive Compartmented Information Facility (SCIF).
- Do not identify location of a Special Access Program Facility (SAPF).
- Do not identify Defense Critical Infrastructure.
- Do not identify the location of Communications Security (COMSEC) Equipment.
- Do not identify Take Charge and Move Out (TACAMO) systems or mission.
- Do not identify Nuclear Command, Control and Communications (NC3) systems or mission.
- Do not identify Military Strategic and Tactical Relay (MILSTAR) systems or mission.
- Do not identify Advanced Extremely High Frequency (AEHF) systems or mission.
- Do not identify purpose or frequency range of antennas or communication systems.
- Do not identify Low Frequency (LF) or Very Low Frequency (VLF) transmission systems, missions, or specific location or site of the LF or VLF system.

Sensitive area locations such as SCIF and SAPF, may be labeled as "Controlled Area" and may be shown on public releasable documents with the approval from the requesting activity's Site Security Manager or Officer.

2-5 REGISTRATION.

Develop stateside project documents under the direction of a Registered Architect or a Professional Engineer currently licensed in accordance with FAR 52.236-25. Develop foreign project documents under the direction of a Registered Architect or a Professional Engineer currently licensed by a United States state, commonwealth, or territory, the District of Columbia, or as permitted otherwise by the contract.

Each drawing must only be signed, sealed, and dated by the Registered Architect or the Professional Engineer who is registered to practice in the particular field involved for work depicted on that drawing, serves as the Designer of Record (DOR) for that work, and complies with requirements of FAR 52.236-25. Sign Record Documents in accordance with Chapter 12.

2-5.1 Certification.

Where special certifications are required for the design, certify in accordance with the contract and local requirements.

2-6 PROHIBITION OF POSTING CONTROLLED UNCLASSIFIED INFORMATION DESIGN DELIVERABLES ON UNSECURED SERVERS.

Design deliverables may contain Controlled Unclassified Information (CUI) or Department of Defense Unclassified Controlled Nuclear Information (DoD UCNI). The release of this information into the public domain may compromise an installation or facility's Antiterrorism (AT) or physical security protective measures. Examples include the design analysis where the design basis threat (DBT) is an explosive weight and the location of a SCIF or SAPF. Protect deliverables, such as drawings, specifications, calculations, cost estimates, and other design related information, that contain CUI, in accordance with DODI 5200.48.

2-7 DESIGN DELIVERABLES FOR NAVAL CONSTRUCTION FORCES - MARINE LOGISTICS GROUPS AND NAVY CONSTRUCTION BATTALIONS (SEABEES).

Due to the nature of the work performed by the Marine Logistics Groups and the Seabees, the design deliverables for their use must be tailored for expedient construction. Deployed battalions may be in remote locations under austere conditions. Researching materials and transmitting submittals can be difficult, if not impossible. Specify materials and performance requirements on the drawings to the most practical extent. Specify materials available on the Federal schedule supply lists, the battalion's supply schedules, or by product name (Contracting to include brand name or equal FAR clause in the solicitation). Avoid referencing codes or standards where possible, as reference materials may be difficult for the Battalion to obtain in the field.

2-8 OVERSEAS LOCATIONS TRANSLATIONS.

Prepare construction drawings in dual language at a majority of the overseas locations. Unless the contract scope indicates otherwise, translation of specifications is not required. Where dual language is required, the Host Nation A&E must accurately translate required documents such that they are clear and comprehendible to the local construction community. The Host Nation A&E may also be contracted to translate Government furnished studies, surveys, geotechnical reports, product specifications, host country requirements or other technical documents prepared in a foreign language and serve as an interpreter when meeting with local officials and contractors. Include translations with the Pre-Final (100%) submittal, and through project completion.

CHAPTER 3 ROLES AND RESPONSIBILITIES

3-1 DESIGNER OF RECORD (DOR).

3-1.1 Coordination with Command, Major Claimant, Region, and Activity.

Engage in and provide liaison with the Activity, and appropriate Activity personnel, in accordance with the contract, and during early design-development or RFP development.

The DOR is responsible for architectural and engineering aspects of the project to ensure reasonable facility cost appropriate for the functions performed through design and RFP development.

3-1.2 Coordination with Other Government Organizations.

Coordinate design input and reviews with other Government organizations described in this chapter in paragraph 3-2 Other Government Organizations and in accordance with the contract.

3-1.3 Document Review and Checking System.

The Document Review and Checking System (DrChecks) facilitates the formal review of complex project documents. DrChecks automatically tracks, collates, and measures technical discussions. Project documents can be uploaded into the project folders for download and review. Provide design reviews in DrChecks in accordance with the Contract. Contact the Government Design Manager to obtain registration information. DrChecks can be accessed at ProjNet.org (https://www.projnet.org).

3-1.4 Response to Review Comments.

Respond to comments in DrChecks or in accordance with Contract requirements. The DOR or Contractor is responsible for the resolution and incorporation of government comments into the project design. At each submittal, return and address previous review comments. Provide responses to review comments that clearly indicate what action is being taken to resolve the comment. If the comment was incorporated into the design, a response must so indicate; otherwise, provide acceptable technical justification for comments not being incorporated. Prior to the next submittal, contact the Government reviewer to discuss and resolve each comment that will not be incorporated.

The DOR is responsible for using professional judgment and technically evaluating user comments that suggest technical changes to design.

3-1.5 Final Approval.

The DOR reviews and gives final approval for contract project documents prepared under their direction. The DOR must be registered in the discipline for the documents they approve as described in Chapter 2, paragraph 2-5 Registration.

3-2 OTHER GOVERNMENT ORGANIZATIONS.

3-2.1 Commander, 1st Naval Construction Division.

Projects scheduled for accomplishment by Naval Construction Forces are reviewed at an early Design Development stage by Commander, 1st Naval Construction Division, for construction methods and procedures.

3-2.2 Reviews for Health Hazards During Facilities Design Process.

For facilities projects that require industrial hygiene technical assistance and that involve potential health hazards such as toxic materials, non-ionizing radiation, noise, or other health hazards, consult the appropriate Naval Environmental Health Center (NEHC) for the activity. The NEHC activity is required to participate in design and RFP development reviews and reviews of plans, specifications, or RFP for these projects. The NEHC activity will ensure that engineering designs properly consider and provide for adequate environmental controls for the elimination of health hazards. Also use this review process for medical facility designs in excess of $1 million.

3-2.3 Naval Information Warfare Center (NIWC).

NIWC provides reviews and design input for projects where NIWC is providing and installing equipment as identified in the DD Form 1391. The drawings of cable and equipment layout are often provided by NIWC to the DOR, for incorporation into the design. Coordinate closely with Government Project Manager and their NIWC representative to receive timely input and to reduce impact to design and construction schedules and project costs.

Projects, even if prepared by NIWC, must bear the standard NAVFAC title blocks and drawing numbers. On drawings that require NIWC approval, NIWC signature can be applied in the NAVFAC Signature Block in the supplemental location and the NIWC drawing cross reference number can be provided on the border sheet. NIWC may also need to review where project impacts an adjacent facility, such as electro-magnetic radiation from police stations or hospitals affecting antennae, transmitters, and receivers.

3-2.4 Civil Works.

NAVFAC approves drawings and specifications prepared for civil works subcontracts. Assign NAVFAC drawing numbers to civil works contract drawings and approve and sign the drawings as "Satisfactory to" the prime contractor of the particular Navy industrial plant for whose use the facility is provided.

3-2.5 Historic Preservation Compliance.

Section 106 of the National Historic Preservation Act requires Federal agencies to take into account the effects of their undertakings on historic properties that are eligible for listing in the National Register of Historic Places (NRHP). Historic properties may include archaeological sites, individual buildings, historic districts, landscapes, structures, objects, and traditional cultural properties. In accordance with established procedures at each installation, an action proponent files a National Environmental Policy Act (NEPA) Compliance Checklist plus a copy of the Work Request or Project Description with the Installation Cultural Resource Manager (CRM). The CRM then reviews the Project Description and determines whether the project has the potential to affect historic properties or whether it is exempt from Section 106 compliance. The CRM will then either record that the undertaking is exempt or engage in consultation for Section 106 Compliance in accordance with 36 CFR 800.

3-2.6 Overseas Cultural Resources.

At Installations outside of the United States, coordinate with the applicable host nation regarding possible adverse effects to cultural resources.

3-2.7 NAVFAC Medical Facilities Design Office (MFDO).

Special coordination is required for coordination of medical facilities. Coordinate in accordance with UFC 4-510-01.

3-2.8 Sensitive Compartmented Information Facilities (SCIF) and Special Access Program Facilities (SAPF).

Special coordination is required for projects associated with a SCIF or SAPF. A designated Government Site Security Manager (SSM) is assigned to the project. The SSM is responsible for the project’s security requirements and will prepare a Construction Security Plan (CSP), Fixed Facility Checklist (FFC) and the TEMPEST addendum to the FFC (referred to as the TEMPEST Form A) for the project. The SSM will submit these documents to the Accrediting Official (AO) for approval. The DOR assigned to the project must assist the SSM in documenting the facility and site requirements necessary for the preparation of these documents. The AO-approved CSP, FFC and TEMPEST Countermeasure Review contains project requirements that must be incorporated into the project, in order for the facility to be accredited. Refer to UFC 4-010-05 for additional information.

3-3 COMMANDER, NAVFAC.

Authority and responsibility for formal approval of drawings and specifications and RFPs by, or for, the Commander, NAVFAC, is vested in the Facility Engineering Systems Command, Chief Engineer, Design Director (PDC4), and PMEB Design Director.

The level of approval and responsibility for DB drawings and documents, submitted by the Contractor and signed by the Government, are defined in the RFP contract.

This Page Intentionally Left Blank

CHAPTER 4 DELIVERABLE: FIELD INVESTIGATION

4-1 PURPOSE AND SCOPE.

The site approval process includes field investigation and verification. This early effort provides more defined project scope and cost and can rule out a site. Many of the functions identified under this heading are also essential during the DD Form 1391 validation process to assure the project has the appropriate funding based on the scope of work. This section is not applicable for post-award design services of DB contracts unless specifically addressed in the RFP.

4-2 RESPONSIBILITIES.

The Government installation planners are responsible for obtaining information required for project site approval prior to design. The DOR must obtain site and building data and investigate existing site conditions, utilities, and facilities to properly integrate the design of the project with existing conditions. Except as otherwise contracted, field investigations must include complete and accurate site investigation, topographic survey, and verification of location, ownership, and availability of utility and drainage systems. When available, research existing record drawings for information. Field verify record drawings information and other site features that may influence project design.

In a DB contract, the DOR is responsible to verify site information furnished in the Government issued RFP. In addition, the DOR must provide additional field investigations and verification of existing site conditions as may be required to support the development of the design and construction of the project.

4-3 COORDINATION.

Coordinate site work, including topographic and soil surveys, with representatives of the Public Works, Utilities and Energy team, Utility System Owners on privatized Installations, and other NAVFAC design personnel. Obtain technical review by Installation utilities engineers to ensure alignment and compatibility with existing and proposed utilities systems as part of the QA/QC review process. For utilities projects, ensure requirements are obtained from the Installation utilities engineers and that they are included in charrettes and reviews. During execution of field investigation work, the DOR is responsible for obtaining necessary permits, and complying with applicable laws, codes, and regulations, including OSHA regulations. The exact location of the geotechnical excavation, whether by drilling or digging, must be approved by the appropriate authorities, be it the local utility service or by a company hired by the geotechnical engineering firm to “scope” utilities. The DOR is responsible for damages to persons and property that occur as a result of their fault or negligence. The DOR must take proper safety precautions to protect the public, the property of the public and the Government from physical hazards and unsafe conditions. Upon completion of field investigation, return the property to its original condition except as released in writing by the client activity.

4-4 TOPOGRAPHIC SURVEY.

Provide a topographic survey of the project site in accordance with the National Society of Professional Surveyors (NSPS) *Model Standards for Topographic Surveys* with the following modifications:

- Project drawings by the Government must be in English or Metric as directed for each specific project.
- Ensure that adequate adjacent areas are included within the survey limits to clearly indicate and accommodate standoffs required by antiterrorism criteria, offsite drainage and offsite utility connections impacting the project.
- Provide a boundary survey and location of easements, standoffs, and security clear zones within the limits of the scope of work.
- Show horizontal control used during field survey. Indicate the reference coordinate plane and provide two permanent control points for reference. Include description of points (such as PK nail in cap). Provide a minimum of three reference distances to existing permanent structures (reference points) so that control can be re-established.
- Show elevations on paved or impervious surfaces (including rims of utility structures) to the nearest 0.01 feet (0.005 meters for metric designs). Show elevations on unpaved or pervious surfaces to the nearest 0.1 feet (0.05 meters for metric designs).
- Indicate the name of the surveying firm and date of survey.
- If match lines are used involving more than three sheets, provide a key map with current sheet highlighted. Remove extraneous lines and text from key map.
- Orient North toward the top (or left edge) of the plotted sheet. Coordinate north direction with other disciplines so that plans are oriented the same.
- Accurately locate (by means of structures visible from the surface and through research of Activity utility maps, record drawings, data from local utility companies) the following list of utilities (both above and below ground), structures and features. Provide notes indicating the sources, limitations, or assumptions of the data, and that the Contractor must field verify the location of utilities prior to construction. Include in the survey the following specific items and their related appurtenant above-ground features, but is not limited to:
    - Buildings: Describe building material and number of stories.
    - Pavements: Include type of material. In areas where pavement demolition is to occur, note each pavement thickness, including layer thicknesses and joint patterns for replacement. Pavement layer thicknesses may be obtained by reviewing record drawing information,

digging at the edge of the pavement, core drilling, and consulting with Activity personnel. Where proposed pavements are expected to abut existing pavements, provide pavement markings, joint pattern, and indicate joint types of the existing pavements.

- Surface Drainage Features: Indicate normal water level for permanent standing water.
- Utilities: Include rim elevations for utility structures; location and identification of lines as underground or aboveground; pipe sizes and materials. Identify water system as potable, non-potable, high pressure or saltwater as applicable. **\1** Ensure communication lines are identified. **/1/**
- Fences: Note height, type of fabric, barbed wire, direction of outrigger, top or bottom rails, tension wires, gate locations and types.
- Foundations: Indicate visible foundations of demolished buildings.
- Fuel Pipes and Storage Tanks: Include information such as fill ports, vent lines, and tank drains.
- Pump Stations: Include invert of influent pipe and elevation of force main. Locate above ground elements including controls.
- Railroads and Crane Rails: Include turnouts, rail sizes, compromise joint locations, and curve information, such as P.C., P.T., and P.I. as they may be applicable to the design requirements of the proposed project.
- Tidal Shoreline: Note water elevation, time of day, date, and tidal condition at time of survey. Indicate normal high/low water elevations referenced to the datum used.
- Trees/Woods: In wooded areas, locate outside drip line of wooded area, include general density and type of trees. Where selective clearing will be accomplished, locate individual trees and tree size over a 6-inch (152.4 mm) diameter.
- Wetland Areas: Wetland and marsh areas must be flagged and numbered by the Government prior to the survey. Locate flags and label in the same manner as marked in the field. If unanticipated wetlands are found during the survey, advise the Government’s Civil Reviewer to establish additional survey requirements.

4-5 GEOTECHNICAL INVESTIGATIONS AND REPORT.

4-5.1 Existing Information.

Each Facility Engineering Command maintains record files pertaining to the geotechnical aspects of previously constructed projects. Architecture and engineering firms preparing, planning, or designing documents are encouraged to use this resource to research existing conditions or past design approaches for facilities, structures, or pavements. Viewing or discussion of the files' contents is possible by contacting the Government. For DB contracts, relevant geotechnical or pavement information that is available will be furnished in the DB RFP for solicitation.

4-5.2 Foundation and Soils Investigation.

Perform foundation and soils investigations, including sampling, testing, and evaluation, with requirements and guidance set forth in the IBC, UFC 3-220-01, UFC 3-250-01, and UFC 3-260-02. In using the IBC, the terms "owner," "applicant," and "building official" are synonymous with the "Government." In addition, the following requirements apply:

4-5.2.1 General.

Investigations and evaluations (including soil borings, test pits, ground penetrating radar surveys, seismic refraction surveys, and electrical resistivity testing, laboratory testing) must be in accordance with ASTM standards to the fullest practical extent. The classification and investigation of the soil must be supervised by a registered professional engineer. Where ASTM methods are not applicable, procedures and apparatus used must be in accordance with generally accepted engineering practice.

4-5.2.2 Qualifications of the Testing Firm.

The qualifications of the geotechnical testing laboratory and personnel must meet ASTM D3740.

4-5.2.3 Use of Global Positioning System with Soil Investigation.

Global Positioning System (GPS) coordinates, with an accuracy of at least 3 feet (1 meter), must be taken at each soil boring, coring, or test pit location and stated on the boring/coring/test pit logs. The coordinates must reference WGS84 and be stated in degrees of latitude and longitude. Data Interchange for Geotechnical and Geoenvironmental Specialists (DIGGS) data files must be geo-located to the same standard.

4-5.2.4 Field Testing.

Field testing for geotechnical investigation typically consists of soil borings and standard penetration tests (SPT) or cone penetration tests (CPT). Conduct and provide the soil borings, SPT, and CPT in accordance with ASTM D1452, ASTM D1586, and ASTM D5778, respectively. For standard penetration testing, modify the ASTM D1586 procedure to make continuous standard penetration and sampling tests for the initial 12 feet (3.74 meters) of the boring. If the proposed building will have a basement level, the ASTM D1586 procedure must be modified to make continuous standard penetration and sampling tests for the initial 12 feet (3.74 meters) of the boring below the proposed basement floor elevation. During drilling, visually classify each soil type in accordance with ASTM D2488. If soft cohesive materials are discovered within 20 feet (6 meters) below the ground surface, or within the anticipated depth of loading influence, take undisturbed samples for laboratory testing. Undisturbed sampling and testing must be performed at the discretion of the Geotechnical Engineer responsible for performing the investigation. Perform other testing, such as percolation testing, seismic refraction surveys, and soil resistivity testing, in accordance with the contract, or by the Contractor's Geotechnical Engineer or DOR in a DB contract.

4-5.2.5 Use of Piezometers.

If drilling techniques are used that prevent the measurement of the water table levels, provide at least two piezometers per drilling site to measure the depth more accurately to the water table. Piezometers are required for storm water pond investigations. Piezometers are not required if the ground water levels can be accurately measured during drilling operations or there is good evidence that the water table is not within the depth of the borings or zone of influence for the foundation or structure.

4-5.2.6 Seismic Site Class Determination.

Base seismic site class on field testing for projects.

For DB projects, state in the RFP the seismic site class to be used for design. This can be determined by the cognizant NAVFAC Geotechnical engineer. NAVFAC is the ultimate authority on site class determination for design.

4-5.2.7 Laboratory.

The minimum laboratory testing must include grouping like samples, conducting a sieve analysis and Atterberg Limits tests, and performing natural moisture content determinations to effectively depict in-situ conditions. Update the field logs in accordance with ASTM D2487. Perform other testing, such as California Bearing Ratio, unconfined compressive strength, consolidation testing, triaxial testing, and potential volume change in suspected expansive clay areas, in accordance with the contract, or by the Contractor's Geotechnical Engineer or DOR in a DB contract.

4-5.3 Geotechnical Report.

Provide a geotechnical report on contracts unless waived by the Government's Contract Technical Representative or as stated otherwise in the contract. Describe in the report the regional geology, topography, and other physiographic information that may influence the geotechnical design. Describe and discuss the investigation program, exploration and testing techniques/procedures used to characterize the site. Depict in the report the soil stratigraphy, materials, and groundwater conditions at the site. Specifically address in the report the groundwater levels expected to be encountered in construction under normal conditions, and site-specific factors (such as tidal action, climate, seasonal flooding, or droughts) that may influence the groundwater levels. Include copies of pertinent U.S. Geological Survey Maps used. Geotechnical Reports must be signed by a registered Professional Engineer. Provide a digital copy of the report in Adobe Acrobat (PDF) format to the Design Manager and the government civil or geotechnical project engineer via DoD SAFE (https://safe.apps.mil/). Produce the

PDF copy of the report directly from the report's authoring software. Each heading, subheading and appendix in the PDF version of the report must be bookmarked. Format the document so that the bookmark panel opens when the report file is opened. Reports not meeting these requirements will not be accepted. Upload geotechnical data in a DIGGS compatible format.

4-5.4 Boring Logs.

Provide a scaled location plan, boring logs, ground water observations, laboratory data, and boring log legend and description notes on NAVFAC drawings as indicated in Chapter 12. Summarize the laboratory data in tables. No scanned boring logs will be accepted.

4-5.5 Foundation and Site Preparation.

Discuss the facility under design and make recommendations for the foundation type. Describe and specify the improvements that are required for shallow foundations, such as compaction, removal and replacement, surcharging, and wick drains. Describe the soil bearing capacity, anticipated settlements, seismic aspects, pile capacity, pile length, pile type and special instructions such as jetting, pre-drilling, and testing required. Discuss earthwork associated with foundation design and construction or site improvements, including settlement, liquefiable soils, expansive soils, slope instabilities or near surface groundwater. The discussion must address existing conditions, studies, or analysis performed, and recommendations for mitigation of the effects of these conditions. Address dewatering, and sheeting/shoring considerations, in design and construction, as applicable. If required by the DOR, state the pavement design parameters and the pavement design. If the pavement design is to be completed by others, provide design parameters determined from the subsurface investigation. If multiple structures are being designed, address structures on an individual basis. Discuss the site preparation and susceptibility to rain and construction equipment. Discuss soil conditions relating to potential concrete or piping corrosion and recommendations to mitigate effects thereof.

4-5.6 Airfield Pavement Evaluations.

Provide Airfield Pavement Evaluations in accordance with UFC 3-260-03.

4-6 FIRE PROTECTION INVESTIGATIONS AND SURVEY.

4-6.1 Utilities and Infrastructure.

4-6.1.1 Water Flow Testing.

4-6.1.1.1 Existing Water Supply.

Water flow testing of the existing water supply system(s) is required to determine the capability of the available water supply to support the expected fire flows and fire suppression system demands. Perform testing in accordance with NFPA 291. Provide a fire protection water flow test report in the Basis of Design. Comply with UFC 3-600-01. While historical flow data may be a valuable resource when performing an analysis of the existing water supply system, historical data must not be the sole source of data. A water flow testing must be performed by the Qualified Fire Protection Engineer (QFPE) during the field investigation.

4-6.1.1.2 Combined Sprinkler and Hose Stream Demand.

During water supply testing, flow sufficient water to meet or exceed the combined sprinkler and hose stream demand. If the Installation’s existing water distribution system or dedicated fire main includes existing fire booster pumps, conduct testing with pump controller(s) configuration configured based on activity policy for normal operating conditions. If there is a requirement for a redundant pump, disable one pump for the duration of the test. If, at the time of design, the booster pumps cannot be run and accurate flow testing cannot be conducted, include the following information in the contract documents:

- Show water distribution piping back to the booster pumps. Show the location of water supplies such as elevated water storage tanks.
- Identify make, model, rated characteristics of each booster pump and the number of booster pumps expected to be operating, based on the anticipated hydraulic demand. For stations with multiple pumps, confirm that one pump was designated “redundant” when there is a requirement for redundancy.
- Identify available water supply (flow test data) at the suction side of the booster pump(s).

4-6.1.2 Hydraulic Supply Analysis.

Evaluating the available water supply is critical for buildings with and without sprinkler protection. Documents cannot be released for advertisement with expectations of the contractor determining the available water supply. The capability of the water supply to support the required fire flow demand must be confirmed prior to advertisement. The QFPE, as defined in UFC 3-600-01, is responsible for obtaining water distribution maps, establishing flow testing procedures and coordinating flow testing with the base fire department and public works. If the station does not allow contractors to conduct the flow tests, the station personnel can perform the flow test under the direct supervision of the QFPE. The QFPE must not, under any circumstance, rely on data from flow tests which they did not personally supervise. The QFPE is responsible for conducting the actual flow testing for facilities that are not on federal property. The QFPE must graph the results for comparison with the anticipated hydraulic demand. This analysis is required for both sprinklered and non-sprinklered facilities.

4-6.1.3 Base-wide Fire Reporting and Mass Notification Systems.

Obtain information regarding the exterior fire alarm reporting system and the base mass notification systems.

4-6.2 Site and Building Surveys.

Design services must include surveys to obtain information about adjacent structures and property lines, existing building construction, and existing building systems and features.

4-6.2.1 Site Planning and Adjacent Structures.

When the proposed construction is within 60 feet (18.3-m) of existing adjacent structures, conduct a site survey to obtain information regarding the adjacent structures. Information about adjacent structures must include construction type, fire resistive rating of exterior walls, number of floors, area per floor, total building area, occupancy classification, and if the building is fully protected with an automatic fire sprinkler system.

4-6.2.2 Work in Existing Facilities.

Projects involving repairs, renovations, or modifications to existing facilities must include a survey, to establish the existing conditions regarding compliance with current life safety code and building code requirements, based on the intended use of the building facility. Survey must also include a description of the active fire protection systems (fire alarm and fire control/suppression). Determine the make, model, type, and year of the building fire alarm system. Projects modifying existing fire protection systems must include a thorough investigation of existing systems and site conditions to determine capabilities of the existing utilities to support the modifications/expansions of the effected fire protection systems. The existing systems being modified must also be thoroughly investigated to determine that compatible products, devices, and components are available.

4-6.2.3 Building Additions.

Building additions must include a building code and a life safety code survey to establish the existing conditions and, based on the intended use of the building, the level of compliance with the current editions of the IBC and Life Safety Code. Conduct an existing building survey to obtain construction type, fire resistive rating of exterior walls, number of floors, wall openings, area per floor, total building area, occupancy classification, types of fire protection systems and extent of protection. Building code assessment must establish the maximum allowable size (height and area) based on the existing building features and the proposed building expansion. Determine the make, model, type, and year of the building fire alarm system. Determine expansion capabilities of the existing fire alarm system, power supply and circuits to support the additional devices, appliances, and functions. Validate that new devices are available and compatible with the existing fire alarm system. Provide a Life Safety Code assessment of the existing building. Perform Building Code and Life Safety Code surveys must be in accordance with UFC 3-600-01.

4-7 ENVIRONMENTAL REQUIREMENTS.

Conduct surveys, information gathering, and analytical testing required by the contract. Provide in accordance with UFC 3-810-01N, which is a requirement, as invoked by this FC.

This Page Intentionally Left Blank

CHAPTER 5 DELIVERABLE: BASIS OF DESIGN

5-1 GENERAL REQUIREMENTS.

The Basis of Design is a narrative presentation of facts, sufficiently complete, to demonstrate that the project concept is fully understood, and that subsequent design details, and their ultimate presentation in the final drawings and specifications, will be based on sound architectural and engineering decisions. For DB RFP Development, the Basis of Design requirements are provided in PART 3 - Project Program and throughout the document.

Submit the Basis of Design required at each design stage in accordance with the contract, the Core UFC's, and the additional Discipline requirements herein. If another UFC adequately describes the requirement for a Discipline's deliverable, a paragraph for that Discipline is not provided below. For each Discipline in the Core UFC and contract, provide a discussion and description of the design and describe the functional requirements of the project and the expectations of how it will be used and operated, including, but not limited to: system goals, measurable performance criteria, cost considerations, applicable benchmarks, additional success criteria required by the project, and supporting UFCs, Codes, and Standards referenced.

5-2 FORMAT.

Format the Basis of Design as an 8 1/2 x 11-inch (216 x 279 mm) document, organized by Discipline. **\1** Bookmark Basis of Design as a PDF for the electronic submittals. Bookmark each discipline and chapter along with each appendix. **/1/** Provide a cover sheet identifying the document as the Basis of Design, and include the following:

- Submittal stage
- The project title
- The location
- A-E Contract or Construction Contract number (Post-Award DB Contracts only)
- Contract Task Order Number (if Indefinite Quantity contract)
- Contract Type (DB or DBB)
- The eProjects Work Order Number
- The Firm's name
- The Command, or the Contractor name; and
- The date

Only use the Maximo number, in lieu of the eProjects Work Order Number, if eProjects is not required for the project.

5-3 KEY PROJECT CONTACTS.

Identify the Key Project Contacts including Role, Organization, Name, Email, and Phone. Sample tables for inclusion in the Basis of Design are located in Appendix C.

5-4 BIM PROJECT EXECUTION PLAN (PXP).

For projects that require, or opt to utilize, BIM, provide a comprehensive Chapter in the Basis of Design that summarizes:

- Project Goals, BIM Objectives, and Unique BIM Requirements (3D Parametric Design Model, Record Model, DOR Edited Model, and Facility Data Matrix tab from eOMSI Facility Data Workbook)
- Organizational Roles and Staffing for each BIM use (Design Facility Data, Design Modeling, and Clash Detection are required by NAVFAC)
- Strategy for Quality Control of the model including Review Frequency and Software Utilized (Visual Review and Clash Detection are required)
- Technological Infrastructure Needs for each BIM use (Include Software and Version)
- Model Organization (Model Structure and Measurement System)
- BIM Project Deliverables by Design Phase (Include the format in which the information will be delivered)

Sample tables for use in the BIM Chapter are located in Appendix C.

5-5 SUSTAINABILITY.

Provide a comprehensive Sustainability Chapter in the Basis of Design that summarizes how the design will achieve the requirements of UFC 1-200-02 and Third-Party Certification (TPC) (where applicable). Address each discipline in the summary, elaborate on the various requirements, and where full compliance is not possible, include proper justification. Provide the following:

- Sustainability chapter
- The NAVFAC High Performance Sustainable Building (HPSB) Checklist for each applicable building in the project
- TPC Checklist (where applicable) for each applicable building in the project, and
- Justification for each missed or partially met requirement (where applicable)

No variations or substitutions to the Checklist(s) are allowed without Government approval.

5-5.1 Guiding Principles Validation.

The DOR is responsible to verify Guiding Principles Validation, in accordance with UFC 1-200-02 requirements, by including design requirements in the contract documents and verifying construction submittals when required by the contract.

5-5.2 Pre-award Commissioning Services.

When the project requires pre-award Commissioning services, incorporate comments, reports, (Owner Project Requirements (OPR) where required by third-party certification program), and other documentation related to commissioning effort, in accordance with UFC 1-200-02.

5-6 ANTITERRORISM (AT).

Provide an Antiterrorism (AT) section in the Basis of Design that summarizes how the design complies with the DoD minimum AT standards in UFC 4-010-01 and the applicable Geographic Combatant Commander’s AT Construction Standards. As a minimum, include the following in the summary:

- Facility description including occupancy (low occupancy or inhabited)
- Narratives of how each applicable standard is met
- Site plan dimensioning standoff distances
- Protective measures above the minimum
- Identify applicable Geographic Combatant Commander’s AT Construction Standards
- Level of Protection

Note: Do not identify explosive weights to avoid disclosure of CUI information.

5-7 GEOTECHNICAL.

Include in the Basis of Design (BOD) a paragraph briefly describing the geotechnical investigation program, the recommendations for the site preparation, and the recommendations for the building foundation and pavement design.

It is preferred that the geotechnical report be included in the BOD as an appendix. However, the schedule may preclude the completion of the field investigation prior to the submittal of the BOD. If this is the case, describe the assumed basis of design for the foundations and pavement, and submit the geotechnical report as soon as possible, and as acceptable to the Government.

5-8 CIVIL.

Identify the governing codes and criteria including federal and military handbooks being used for the design. References may be noted in the related sections listed below. Include reference titles and date of publications. Provide BOD with adequate narrative to describe design logic and assumptions. Show adherence to scope of work.

5-8.1 Existing Conditions.

Include the following:

a. Describe general site topography and vegetation type (grass, lightly wooded, brush). Describe existing site features.

b. Identify whether existing underground features, such as footings, foundations, or steam pits, exist, and describe.

c. Describe existing soil conditions.

d. Describe existing utilities, including size, type, and general location. Discuss impact that this, and future projects, will have on utility systems.

e. Identify predominant drainage features, including required downstream improvements. State whether field survey has been coordinated with delineation. Indicate the parties that have been notified of the presence of wetlands and are actively involved in this issue.

f. Identify and describe if endangered species inhabit area.

g. Identify and describe existing traffic patterns on and around site.

h. Provide horizontal and vertical datum and other pertinent survey information.

5-8.2 Demolition.

Discuss demolition relating to Civil issues only, typically 5 feet (1.5 m) outside of building line. Identify buildings slated to be demolished by building number. Generally, describe structure types (examples: 1-story frame, 2-story block); include building specifics under the Architectural BOD. Describe pavement to be demolished, including existing pavement section. Describe underground and overhead utility demolition, relocation, and abandonment. Describe other features to be removed (examples: play equipment or fencing).

5-8.3 Site Work.

Describe building and its function with respect to civil issues, such as vehicle ingress/egress and pedestrian movement. Address internal functions under Architectural BOD. Describe pedestrian access. Identify number of parking spaces; include stall and aisle widths. Describe handicap access in and around site, number, and size of handicap parking spaces. Identify physical security requirements, such as intrusion detection provisions, fencing type and height, and lighting requirements. Also identify antiterrorism standoff distance requirements for the specific site conditions. Identify vehicle type expected on project site; note non-standard vehicle sizes and weights. Identify design wheel loading. Define projected traffic volume. Define pavement types and sections. For airfield pavement, discuss design parameters, including pavement use, loadings, design life adopted in design, design methodology to be used, and availability of materials anticipated for construction, and possible impacts construction may have on airfield operations, such as haul routes and closures. For railroads and crane rail, state type of service for which rail track will be provided; anticipated volume and type of traffic; and the ruling grade and the maximum curvature. Describe proposed type, source and thickness of ballast, weight of rail and source, treatment, and dimensions of ties. For small arms ranges, list expected weapons and ammunition including the most powerful weapons/ammunition combination that the design is based on. Discuss critical features such as impact berms (including height and slope), side berms, firing lines, firing directions, target locations, bravo flag poles, road gates, fencing, access roads, supporting facilities, and other prominent feature. Do not include the Surface Danger Zone since this has nothing to do with the construction project.

5-8.4 Water Supply.

State design parameters such as domestic flow, fire flow, residual pressure, and recent flow test data. State anticipated demand. Coordinate with the QFPE to establish fire flow requirements. Describe water main and supply line sizes, capacities, and water velocities. Identify connection points. Identify connection methods. Identify whether existing infrastructure has capacity to support project. Identify requirements for backflow protection and freeze protection. Identify needs for metering. Identify need for booster pumps or pressure reducing valves. State the number of new fire hydrants. Provide number of wells and proposed pump rates.

5-8.5 Sanitary Sewer.

Describe waste stream and whether it is from domestic or industrial source. Include sources of hazardous substances. Identify design population, peak and average flows. State whether sewer will be gravity or force main. Identify pre-treatment requirements and solutions. State minimum pipe slopes and velocities. Identify special installation requirements. State new pipe sizes and capacities. Identify pump station type, wet/dry well, types of pumps, pump capacity and total dynamic head, horsepower, telemetry requirements and compatibility with existing on-base systems, backup power requirements, and assumed response time by Activity personnel. Consult Activity as to whether existing system is operating at or near capacity. Discuss adequacy of existing system to handle current and future flows.

5-8.6 Wastewater Treatment.

Identify completed treatability studies. Briefly describe recommended process noting deviations from the treatability study. Define impact of stream condensation and cooling water discharges on sewer piping and treatment plants and the estimated cost of distribution and treatment of this additional loading.

5-8.7 Storm Drainage System.

Identify factors such as receiving waters, classification (if applicable), storm frequency, and C factors. Discuss adequacy of existing storm system and its effects on downstream facilities and systems. Discuss whether existing system will require upgrades. Identify use of collection system versus sheet flow. Describe materials and pipe sizes. Describe how upstream flows that impact site will be handled.

5-8.8 Stormwater Management.

Identify Integrated Management Practices (IMP's) and approach to stormwater management. Discuss compliance with UFC 3-210-10, Navy LID Policy, Activity, State, and local requirements.

5-8.9 Erosion & Sediment Control.

Identify total disturbed area acreage. Discuss erodibility of soil, devices, or methods to be used to control erosion and sediment losses, and protection devices at outfalls. Discuss compliance with Activity, State, and local requirements.

5-8.10 Permits.

Identify the permits necessary for both construction and operation of facilities. Identify fees associated with each permit. Submit Permit Record of Design (PROD) form with BOD.

5-9 STRUCTURAL.

Provide a narrative report on how the design concept satisfies the customer's requirements, meets criteria, and is cost effective. Include statements on the following:

- List a summary of the criteria upon which the structural design is based. Including a statement of each load: dead, live, wind, snow, earthquake, and other significant load.
- List assumptions required for the structural design where the design criteria is undefined, unclear, conflicting, or unknown. State the basis of the assumption made.
- Describe the structural floor and roof systems. Include a discussion of both the gravity and lateral force resisting systems. Clearly describe the gravity and lateral load paths providing pertinent information such as, capacity, size, dimensions, materials, and design strengths. Define how

foundations and slabs on grade are used to distribute lateral forces between the structure and the ground.

- Provide a narrative summary of the foundation system, including method for determination of the bearing capacity, maximum allowable bearing capacity, and lateral force capacity of the foundation, as well as other soil parameters used in the design. Provide pertinent information, such as capacity, size, dimensions, and a list of materials with design strengths.
- When appropriate, provide a statement of special considerations that affect the design (such as “superflat floors” for high stack warehouses, special corrosion resistance requirements, fire-resistive requirements, or crane or monorails). Describe applicable special inspections, testing, and observations required in accordance with IBC Chapter 17, as modified by UFC 3-301-01, and IEBC, as modified by UFC 3-301-01. The generic schedule of special inspections is maintained on the WBDG as referenced in paragraph 17-11 Statement of Special Inspections.
- When using U.S. Geological Survey seismic information, provide a map showing the Latitude and Longitude of the project site.
- Provide a narrative summary of the Serviceability limits for the structure. Include the lateral drift limit for the primary lateral load resisting system for wind or seismic, roof framing deflection limit for DL + LL and LL only, floor framing deflection limit for DL + LL and LL only, and composite floor framing deflection limit for DL + LL and LL only.

5-10 FIRE PROTECTION.

Projects requiring the services of a QFPE must include a Fire Protection Basis of Design that includes the following information. Identify both the requirement and the actual design provided.

5-10.1 Project Summary.

Provide a brief summary of the project and scope of work. General information can be obtained from the DD Form 1391. Identify the purpose and use of the facility, including the following:

5-10.1.1 Specific Hazards.

Identify hazardous areas (such as chemicals, fuels, ordnance), processes, and special hazards or features requiring special fire protection considerations, such as Radio Frequency (R-F) Shielded Rooms, Secured Rooms, Computer Rooms, commercial kitchen appliances. Provide relevant information pertaining to the hazards and how they are protected.

5-10.1.2 Summary of Fire Protection Features.

Provide a brief summary of the active and passive features of fire protection. Provide a description and identify the location of new and existing fire extinguishing systems, detection systems, fire alarm systems, or fire pumps to be provided or existing systems to remain or be modified.

5-10.1.3 Summary of Existing Conditions.

Provide a brief summary of existing conditions impacting the project, such as existing detection/suppression systems or existing building construction features.

5-10.1.4 Summary of Design Enhancements.

Specifically identify items in excess of the contract, criteria, or code requirements.

5-10.1.5 Summary of Other Design Features.

Provide a brief summary of the other features of the design relevant to the fire protection of the project. Examples of “other features” include**\1\ /1/** structural engineering evaluation of existing floor systems supporting gaseous agent **\1\ /1/** concentrate storage tanks.

5-10.2 Building Code Analysis.

Include the following information: occupancy classification; height and area calculations (area per floor & total); type of construction; required building separation or exposure protection; rating of structural components; classification of interior finishes; location of fire-rated walls and partitions; description of construction; whether rated floor and roof assemblies are restrained or unrestrained; interior fire or smoke rated wall/partition requirements, fire rating of each floor, ceiling system, roofing system when applicable. Discuss if and how the proximity to, and classification of, adjacent structures factors into the analysis.

5-10.3 Life Safety Code Analysis.

Base the life safety code analysis on NFPA 101, Life Safety Code. Identify occupancy classification, number of exits, type of exits, exit travel distance, total exit width, total occupant load, common path of travel, and other applicable provisions of NFPA 101.

5-10.4 Water Supply Analysis.

Provide a summary of the data obtained from the water flow test (refer to Chapter 4) and provide a determination of the adequacy of the water supply (even for facilities without sprinkler protection), along with sketches of the water distribution system. If fire flow demands cannot be met, cite the deficiencies and recommend design alternatives/solutions to correct the problem of an insufficient water supply (such as fire pump(s), or water storage tank(s)).

5-10.5 Hydraulic Demand Analysis.

5-10.5.1 Analysis.

Using computer program generated hydraulic calculations, calculate the “anticipated” demand of a facility to validate the adequacy of the available water supply, or to establish the minimum water supply required. Refer to UFC 3-600-01 for hazard classifications and design criteria determination. Proposed piping layout must accompany the hydraulic sprinkler calculations included with the Fire Protection Calculations submittals.

5-10.5.2 Plot.

Plot the available water supply versus the hydraulic demand on the Q1.85 Hydraulic Graph Paper. Present hydraulic information in graphical format as discussed in the FM Global Property Loss Prevention Data Sheet 3-0.

5-10.5.3 Adequacy of Water Supply for Fire Protection.

5-10.5.3.1 Pre-award Design Services.

If the water supply analysis determines that the water supply cannot support the anticipated hydraulic fire flow or fire sprinkler demand, contact the DFPE, as defined in UFC 3-600-01 as soon as possible. Provide appropriate supporting calculations and propose design options or alternatives for consideration.

5-10.5.3.2 Post Award Design/Construction Services.

- Design assumptions must be based on the water supply data cited in the solicitation. This data must be used as the basis for fire flow and sprinkler design even if flow testing performed by the QFPE or Sprinkler Subcontractor reveals more favorable results.
- If flow testing performed by the QFPE or Sprinkler Contractor reveals flow/pressure less than that specified, immediately submit a “Request for Information (RFI) citing the concern. Provide supporting information and calculations to substantiate the claim and request clarification or direction.

5-10.6 Active Fire Protection Features.

Provide the following information as applicable:

5-10.6.1 Description of Fire Suppression System(s).

- The area(s) that will be protected, the hazard classification of these area(s) and the type of system protecting these area(s).
- For sprinkler systems, the design density, demand area and hose stream allowance to be specified for each different area.

- The method for connecting the suppression system to the fire alarm system, as well as the method of annunciating the systems, and a description of power disconnects or pre-alarms, that are required.

5-10.6.2 Sketches.

Where appropriate, provide sketches representing the water distribution system, sprinkler demand areas, and show hydraulic reference points for the hydraulic sprinkler calculations.

5-10.6.3 Description of Fire Alarm/Mass Notification System(s).

5-10.6.3.1 Description.

- Provide information for areas of the facility and what type of initiation devices and notification appliances will be provided.
- Identify areas that may have challenging features that will make it difficult to achieve intelligibility requirements.
- Provide information for connecting to the base-wide fire reporting system and the base-wide mass notification system.
- Provide drawings or sketches.

5-10.6.3.2 Existing Conditions.

Provide detailed information on existing fire detection and suppression systems for existing buildings (examples: type of systems; area of coverage; make and model of equipment; why system is or is not being replaced). For fire alarm systems, provide the following information (at a minimum): number of spare zones and spare spaces for modules, capacity of control panel(s), list of existing fire alarm zones, list of outputs, number of audio/visual circuits, and standby battery capacity. Indicate the working order of each system (condition or status).

5-10.7 Host Nation Requirements.

Refer to UFC 3-600-01.

5-11 CYBERSECURITY.

Provide cybersecurity design in accordance with the contract and UFC 4-010-06. As a minimum, include the following:

- Facility description generally describing facility’s mission.
- Confidentiality-Integrity-Availability (C-I-A) ratings for each FRCS.

- **\1** For work in existing buildings, identify and document existing FRCS infrastructure, to support project scoping and design of FRCS in project scope. **/1/**
- List of cybersecurity controls for each FRCS that can be satisfied within the design.
- Narrative of how each applicable cybersecurity control is met for each FRCS.

This Page Intentionally Left Blank

CHAPTER 6 DELIVERABLE: CALCULATIONS

6-1 GENERAL REQUIREMENTS.

Submit design calculations required at each design stage in accordance with the contract, the Core UFC's, and the additional Discipline requirements listed herein. If another UFC adequately describes the requirement for a Discipline's deliverable, a paragraph for that Discipline is not provided below.

Prepare calculations in metric units when metric design is required. Provide reference to the source (Navy and non-Navy criteria used) to produce the calculations.

6-2 COMPUTER GENERATED CALCULATIONS.

Provide the software program name, version and source used to produce each computer output or report.

6-3 FORMAT.

Format calculations as an 8 1/2 by 11 inch (216 by 279 mm) document. Provide a cover sheet with the title "Calculations;" the stage of the submittal; the project title and location; the A-E Contract or Construction Contract number; the eProjects Work Order Number; the Firm's name, Command, or Contractor's name; and the date. Organize calculations by Discipline, in the same order as the drawings, and in a manner appropriate for the number of sheets provided. Number each sheet. Provide an index, following the title sheet, with sub-indexes for disciplines having a very large number of sheets, and include Discipline name and page numbers. Only use the Maximo number, in lieu of the eProjects Work Order Number, if eProjects is not required for the project.

6-4 SUSTAINABILITY AND ENERGY.

Provide calculations in accordance with UFC 1-200-02 for life cycle cost analysis.

6-5 GEOTECHNICAL REQUIREMENTS.

The geotechnical calculations normally appear in the geotechnical report; however, they may be in a separate package if another consultant other than the geotechnical consultant prepares the calculations for foundations or pavement. The calculations must indicate the loadings, ultimate and allowable capacities, the safety factors, and the text or reference from which the calculations were based for the foundation and pavements. Graphs and formulae must be clearly indicated along with the derivation of curve slopes and data derived from the laboratory testing.

6-6 CIVIL.

Provide design calculations for erosion and sediment control, **\1** earthwork, **/1/** stormwater drainage system, stormwater management, pavement, and utility systems.

Calculations must be legible, orderly, and easily understood and checked by a registered practicing civil engineer.

6-6.1 Low Impact Development (LID).

Comply with UFC 3-210-10. The DOR is responsible for completing and submitting the Low Impact Development (LID) Verification Report (https://www.wbdg.org/FFC/NAVGRAPH/Navy_LID_Verification_Report.pdf) and the LID Data Card (https://www.wbdg.org/FFC/NAVFAC/NAVFAC_LID_Data_Card_v3.0.pdf). The DOR must complete the design portion of the LID Verification Report and attach it to UFGS 33 40 00. Annotate the LID Verification Report as a “G” submittal, requiring Government approval.

6-6.1.1 Submittals.

The DOR is responsible for submitting the LID Data Card to the Government during pre-final and final submittals, annotating changes involving LID, and coordinating changes with the LID Verification Report. The Government’s Civil Engineer reviews the LID data submitted by the DOR and Contractor LID Verification Report, and documents this information on the eProjects LID tab. When the Government's Civil Engineer is the DOR, design projects must be reviewed and approved by either the Civil Engineer’s supervisor or the Civil Technical Discipline Coordinator (TDC).

6-6.1.2 Navy LID Policy.

For Navy and Marine Corps projects, comply with Navy LID Policy (commonly referred to as the Penn Memo). The Navy LID policy sets a goal of no net increase in stormwater and sediment or nutrient loading from major renovation and construction projects. Major renovation projects are defined as having a stormwater component and exceeding $5 million. Major construction projects are defined as exceeding $750,000. Projects exceeding these dollar values must be documented on the LID Data Card and LID Verification Report as indicated in the paragraph 6-6.1 Low Impact Development. If LID is not implemented to the METF as defined in UFC 3-210-10, a waiver must be obtained from the Regional Engineer. The DOR is responsible for submitting the LID waiver request. The NAVFAC LID Waiver Form is located at: https://www.wbdg.org/FFC/NAVFAC/NAVFAC_LID_Waiver_Form_v4.doc. Coordinate the waiver and approval with the Government’s Civil TDC.

6-7 STRUCTURAL REQUIREMENTS.

Provide calculations to support items and details outlined on the drawings and specifications. Include calculations for the main framing systems and beams, columns, walls, foundations, bracing, diaphragms, equipment supports, and component inter-connections to provide a safe, stable efficient and cost-effective structural system, considering design loads and criteria. They must be legible, orderly, and easily understood and checked by a registered practicing structural engineer.

Also include the following:

- A cover sheet indicating the project title, location, construction contract number and names of the persons originating and checking the calculations.
- Table of contents.
- A brief statement describing the structural system, significant design parameters and restrictions that may affect the design.
- Applicable design criteria.
- Loads: Include loadings, forces, temperature changes, induced settlements, and other internal and external actions that may affect the design of the structure. The list must include the orientation and location, magnitude, and units of measure for each load.
- Restrictions: Include limiting factors such as horizontal and vertical deflections limits, height restrictions, installation or operating tolerances for equipment or building components and other limits to the structural system.
- Materials: Include materials used and their allowable stress limits, yield strengths, type, grade, class, or other applicable material properties.
- References: Include criteria, accepted standards, manuals, codes, texts, papers, or other references used in the analysis and design that are accepted in a public domain. Appropriately identify references; abbreviations such as AISC, ASTM, and ACI are acceptable. Document the origin of customer-specific criteria in the calculations.
- Sketches with sufficient detail and clarity to communicate design intent. Note assumptions and references to codes, standards, criteria drawings, and computer output.

6-7.1 Calculations and Test Reports for Antiterrorism.

When in project, provide calculations or test reports for the following systems demonstrating compliance with applicable Antiterrorism (AT) requirements:

- Blast resistant window systems
- Structural analysis of building elements where stand-off distances are less than the conventional stand-off distance
- Progressive collapse calculations

Note – Do not identify explosive weights as explosive weights to avoid disclosure of CUI information.

6-7.2 Design for Lateral Forces.

Design for lateral forces must include design calculations for wind, seismic, and other potential loadings. The construction drawings must depict the governing design elements base on both seismic and wind design requirements.

6-7.3 Computer Generated Calculations.

Provide input data, including loads, loading diagrams, node diagrams, and adequate documentation to illustrate the design. The schematic models used for input must show, as a minimum, nodes/joints, elements/members, materials/properties, and each loading, induced settlements/deflections, and a list of load combinations. Results must include an output listing for maximum/minimum stresses/forces and deflections for each element, and the restrictions for each loading case and combination. If required, submit narratives. In addition, provide the following:

- Submit graphical plots of structural models which must include, but not be limited to, main structural elements, boundary conditions, loading diagrams, and deflected shapes. Submit graphical plots with each deliverable at each submittal stage. Provide in both native, editable format and in PDF.
- If a modal analysis is performed, submit plots of mode shapes and a listing of the dominant natural frequencies.
- If blast or progressive collapse analysis is performed, submit comparison tables of computed rotations/residual strength ratios and response limits listed in UFC 3-340-01 and UFC 4-023-03.

If software not commonly commercially available, or widely accepted in the structural community, is used, submit validation documentation of the software (such as hand verification of the software solution of a significant, representative portion of the structure).

6-8 FIRE PROTECTION CALCULATIONS.

Provide calculations at the earliest possible stage in design, but no later than the Design Development Submittal and as further required by Chapter 15 of this FC.

6-8.1 Hydraulic Demand Analysis.

Calculate the fire flow demand for the facility. Provide calculations showing that the anticipated suppression systems and hose stream demands can be designed to the available water supply. For hydraulic calculations, deduct the hose stream requirement at the point of connection to the existing distribution systems or the closest fire hydrant; whichever is closer to the sprinkler riser and building.

6-8.1.1 New Sprinkler Systems.

Buildings requiring sprinkler systems must be hydraulically designed. Include a floor plan with the calculated piping layout.

6-8.1.2 Existing Sprinkler Systems.

Provide hydraulic calculations for additions to, or modifications of existing sprinkler systems to ensure the system demand can meet the hazard it is protecting. Establish if the existing system is hydraulically designed or a pipe schedule system. Contact the Installation Public Works Office or Installation Fire Department for information on an existing system.

6-8.1.2.1 Hydraulically Designed Systems.

Indicate the size and location of cross and feed main piping from the point of connection to the existing system back to the sprinkler riser. Indicate grid branch line piping for grid systems. Do not assume the available water supply will be that identified with the existing design. Obtain current information.

6-8.1.2.2 Pipe Schedule Systems.

When the project modifies an existing pipe schedule system, determine the hazard classification and whether the existing cross and feed mains, and the riser pipe sizes can support the new piping and sprinklers. Identify the size of the pipe at the point of connection. Identify existing piping requiring replacement. Small renovations to existing pipe schedule systems may be designed by the pipe schedule method as permitted by NFPA 13 and up approval of the DFPE.

6-8.2 Fire Pumps.

Provide the following calculations verifying pump selection:

- Calculations supporting selected rated capacity and pressure.
- Power calculations for motor driven pumps.
- Fuel supply calculations for engine driven pumps.
- Calculations for suction supply tanks when applicable.

6-8.3 Special Systems.

\1\ /1/

6-8.3.1 Gaseous Fire Extinguishing Systems.

- Provide calculations verifying agent quantity, number of required tanks and intended tank location.
- When systems are installed in existing facilities, ensure a structural analysis is provided for the intended tank location as required.

6-8.4 Fire Alarm/Detection and Reporting Systems.

6-8.4.1 Modifications to Existing Systems.

- Provide a power supply analysis. Submit calculations for power supply and standby battery capacity requirements of existing system and new devices. Ensure the power supply is capable of supporting the electrical load of the new devices.
- Provide a circuit analysis. Ensure the panel has the initiating and signaling expansion capabilities.

CHAPTER 7 DELIVERABLE: DRAWINGS

7-1 GENERAL REQUIREMENTS.

Provide drawings in accordance with the Core UFCs, the contract, Chapter 12, and the additional Discipline requirements herein, for every stage of design. If another UFC adequately describes the requirement for a Discipline's deliverable, a paragraph for that Discipline is not provided below.

7-2 BUILDING INFORMATION MANAGEMENT AND MODELING (BIM).

BIM is required on DB and AE-Designed DBB New Construction projects greater than $1M and Major Renovation Projects greater than or equal to 50% of the Plant Replacement Value (PRV) at Navy Installations, Joint Bases, Department of Defense (DoD) Agencies, or Field Activities where NAVFAC is the Maintenance Provider, or when required by the contract. BIM is not required on Navy in-house-designed DBB projects.

The deliverables of BIM are outlined in Chapter 12. Use the Facilities Data Workbook (FDW), that prescribes the BIM Level of Detail (LOD) required by system or subsystem, with UFGS 01 78 24.00 20.

Table 7-1 BIM and FDW Requirements.

BIM/EOMSI By Service				
DELIVERABLE	NAVY	MARINE CORPS	AIR FORCE	USACE/ ARMY
BIM – 3D Parametric Model	REQUIRED	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE
eOMSI Facility Data Workbook	REQUIRED	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE
UFGS 01 78 23 eOMSI Manuals	REQUIRED	OPTIONAL*	OPTIONAL*	OPTIONAL*

*When required by contract.

7-3 PRESENTATION.

Drawings must be consistent in presentation and format. If one discipline shows material selections directly on the details, other disciplines must conform to that format, and not use numbers to refer to a numerical legend elsewhere on the drawings.

7-4 DRAWING NUMBERS.

Request NAVFAC drawing numbers from the Government Design Manager. Provide them with the following information:

1. The amount of numbers required;
2. The eProjects Work Order Number, and
3. The project title. Request enough numbers that additional sheets can be added if necessary (usually 10% more).

Only use the Maximo number, in lieu of eProjects Work Order Number, if eProjects is not required for the project.

7-5 PROPER USE OF NOTES ON DRAWINGS.

- Be consistent with grammar used in notes on drawings. Wherever possible use imperative statements to describe work to be accomplished by Contractor.
- Do not use “Contractor must provide,” use “provide.” It is understood that the notes are directed to the construction Contractor. The Contractor is responsible for performing the work as shown and specified; therefore, there is no reason to use the phrase.
- Do not use “to be” for describing work that will be accomplished by the Contractor. “To be” implies that someone will accomplish the work other than the Contractor, such as the Government or another Contractor. Similarly, do not use “proposed,” as it can be interpreted to mean future work by others or work not in this contract. If work is to be accomplished by Government, for example, say “Government will remove storage building prior to start of construction.”
- Do not use the term "furnish" unless only delivery of material to the site is required. Similarly, do not use the term “install” unless the Government or others will furnish equipment or materials and Contractor will install. Use "provide" to mean "furnish and install."
- Do not use “new” for work in the contract. Work shown on the drawings is considered new, unless indicated otherwise. Inconsistent use of “new” throughout the drawings could mean that only some of the work is required.
- Do not use vague words and phrases or escape clauses such as "in this specification," "as may be required," "as necessary," "an approved type," "as approved/directed/determined by the Contracting Officer," "first class workmanship," "securely," "thoroughly," "suitable," "properly," "good working order," "neatly," "carefully," and "installed in a neat and workmanlike manner."

- Be careful with statements like “remove and replace,” which means to remove old item or material and replace that item or material when work is completed. This statement would be appropriate for work in a pump station where pumps were removed prior to the work and those same pumps replaced after the work is completed. On the contrary, if a portion of a concrete walk is cracked and requires replacement, say “remove and provide concrete walk.”
- Use the term "Contracting Officer" when referring to requirement for coordination between Contractor and Government agency; do not use terms such as "Officer in Charge of Construction," "Contracting Officer Representative," "Government Representative," “Navy,” “ROICC,” or “PWD”.
- Do not use the word "per", use "in accordance with" instead.
- Avoid the use of colloquial terms or jargon. For example, do not use "bulkhead" for wall, "deck" for floor, or "head" for toilet.
- Eliminate redundant wording such as "conforming to," "all," and "type." For example, when stating “paint doors”, **all** doors are implied.
- Do not use indefinite items such as "etc.," "any," and "and/or."
- Do not use long, compound, or hyphenated words such as "hereinbefore" and "hereinafter."
- Do not use words that have multiple meanings, requiring opinions, or judgmental decisions, such as “timely,” “nearly,” “good-condition,” “suitable,” “well-balanced,” “suitable for intended use,” “reasonable,” “approximately,” “reliable,” “proper,” “usable,” “appropriate,” “adequate,” or “qualified.”
- Do not use terms that are not biddable by the Contractor nor enforceable by the Government, such as “recondition,” “as directed,” “equal to,” “as required,” “similar to,” “as necessary,” “as close as possible,” “repair,” “match existing,” or “refurbish.”
- Some terms are only enforceable if quantities are shown on the drawings or included in the specifications, such as “as indicated,” “as shown,” “specified herein,” and “as noted.”
- Be careful when using the word, “typical,” especially if there are exceptions to the detail.
- Use “must” instead of “shall” to prescribe mandatory requirements, actions and procedures. “Shall” imposes an obligation to act, but may be confused with prediction of future action. “Must” imposes obligation and indicates a necessity to act.

- Do not use the word "should" in the specification text for mandatory requirements as "should" implies a recommendation. "Should" may be in the Notes to indicate desirable procedures that are advisory in nature.

7-6 CODE COMPLIANCE SUMMARY SHEET(S).

The Code Compliance Summary Sheet(s) must be prepared by the QFPE and must be included as “General Sheets” immediately following the title sheets. At a minimum, include the following information:

7-6.1 Building Code Site Plan.

Identify the following elements on the Building Code Site Plan:

- Line of encroachment identifying minimum separation distances from adjacent buildings and assumed property lines of the new construction and of the adjacent structures.
- Building perimeter used for frontage increases.
- Exit discharge paths.
- Fire Department vehicle access to building.
- Fire lane width, marking and locations, approach roads and turn radius and location.
- Intended fire department main entrance to building.
- Location of fire department connections.
- Fire hydrants, post indicator valve or valves and their connected water distribution mains serving building.
- Fire pump room.
- Water storage tanks.
- Hazardous material spill containment tanks.
- Backflow prevention assembly or assemblies serving water-based fire protection systems (if located outside of building).

7-6.2 Building Code Summary.

Identify each of the following elements in the Building Code Summary:

- Classification of occupancy.
- Allowed vs. provided type of construction.
- Basic allowable heights & areas vs. actual heights & areas.
- Allowable vs. provided height or area increases per floor and total.

- Calculations supporting height and area modifications/increases.
- Required vs. provided exterior exposure protection.
- Required vs. provided interior fire rated occupancy separations.
- Required vs. provided internal fire area separations.
- US Required vs Host Nation Required vs Provided (for OCONUS projects only).

7-6.3 Life Safety Code® Summary.

Identify the following elements in the Life Safety Code® Summary:

- Classification of occupancy of each room, area or compartment (on the drawings or in tabular form);
- Occupant load factor(s) and total calculated load;
- Required vs. provided number of exits;
- Required vs. provided capacity of means of egress;
- Required vs. provided arrangement of means of egress including remoteness of exits, horizontal exits, travel distance, common path of travel, dead-end corridor lengths. When suites are used, indicate type, location, area and arrangement;
- Required vs. provided accessible means of egress;
- Required vs. provided discharge from exits;
- Required vs. provided fire rated separation of exits and exit access;
- Required vs. provided fire rated separation of hazardous areas;
- Flame spread/smoke development ratings of interior finishes;
- Requirements (if any) for smoke control systems based on the specific occupancy chapter and building design considerations;
- Requirements for special locking arrangements such as delayed-egress locks or access-controlled egress doors. Specify the rooms/area.
- US Required vs Host Nation Required vs Provided (for OCONUS projects only).

7-6.4 Life Safety Plans.

The Life Safety Plans must be prepared by the QFPE and must be included as “General Sheets” immediately following the title sheets and code compliance summary sheets. Scale the floor plans so the entire footprint fits on a single sheet provided that information is clearly legible, and the scale is no smaller than 1/16-inch (1:200). At a minimum, include the following information:

- Location and rating of fire walls, fire barriers, fire partitions, smoke barriers and smoke partitions (both horizontal and vertical). Barriers requiring fire resistance rated supporting construction must be specifically identified for coordination with the structural design partition locations with fire rated partitions and horizontal exits identified.
- Building areas having different occupancy and hazard classifications.
- Room numbers, corresponding occupancy classification and calculated occupant load. Include occupant load of each room, area, or compartment (on the drawings or in tabular form). Similar occupancies can be grouped together for occupant load calculations.
- Capacity and number of occupants using each major means of egress component (such as stairs, stair doors, exterior doors, assembly exit doors.)
- Rooms or areas requiring special life safety or fire protection features.
- Location of hazardous materials storage, handling and use that exceed the maximum allowable quantities.
- Egress travel requirements (such as travel distances, common paths of travel, dead-end corridors).
- Structural fireproofing locations and associated ratings.
- When required, fire extinguisher cabinet and surface-mounted fire extinguisher locations.
- When required, fire extinguisher type/quantity table identifying the total number and type of extinguishers required.
- Location of primary fire alarm/mass notification control panel.

7-7 CIVIL DRAWINGS.

7-7.1 Cover Sheet, Drawing Index, Vicinity Map, Location Plan, Abbreviations, Legend, and Notes, or First Civil Sheet.

If project is not a Civil Engineering lead, assure that the following items are coordinated with the lead discipline responsible for creating cover sheet:

a. If General Development Maps (GDM) are used for the Vicinity and Location Maps, edit for the specific project being designed. Ensure street names, main gates, and the Public Works office of the base are identified. Ensure that text is legible at the plotted scale and remove extraneous lines.

b. The Vicinity Map must identify the Activity and have enough main highway names and street names to allow an out-of-town contractor to locate the work.

c. The Location Plan must allow the contractor to find the project on the base. This is generally a good place to show laydown areas, haul routes, construction traffic routing restrictions, and off-site benchmark locations. Provide street names to allow coordination between the Vicinity Map and the construction plans.

d. In general, it is desirable to show the Vicinity Map and the location Plan on the Cover Sheet along with the project title.

e. Coordinate with Contracting Officer and Activity for laydown area.

f. Edit standard details, abbreviations, legends, and general notes for the specific project being designed.

g. Provide a single Civil legend on one sheet (preferably sheet C-001).

h. Datum must be securely tied between project datum and local datum.

i. For projects near tidal waters, show datum sketch indicating project vertical datum and relationship to range of tide and other important datum.

7-7.2 Demolition Plan.

Include the following:

a. Clearly show what is to be demolished at an appropriate scale. Coordinate/edit the legend to match the demolition plans.

b. Indicate the beginning and ending points of utility removals and methods of plugging pipes (such as cap, brick & mortar). Show locations of valves to be used for isolating work.

c. Show limit of pavement removal and pavement thickness.

d. Describe the existing items in detail with supplemental descriptions if necessary. Indicate depth of pavements/bases to allow uniform contractor bids.

e. Provide a sequence of demolition if necessary. Include known requirement for continuous operation and limited shutdown requirements. These must be identified in the special scheduling paragraphs of the specification.

f. Do not show items that are being demolished with the current project on subsequent Civil plan sheets.

g. Show locations of erosion and sediment (E&S) control items and add E&S notes. Show erosion control details on drawings or refer to applicable details in the State Erosion and Sediment Control Handbook or manual. Verify that the erosion control legend is edited, clear and coordinated with the drawings.

h. Provide a Tree Protection Detail for existing trees, which are to be preserved during construction. Trees are not amenable to the same barrier fence application. Consult a Registered Landscape Architect or State Certified Arborist. As a minimum, show a 4 foot (1.2 m)- high safety-orange, plastic barrier fence with metal or 4 x 4 inch (101 x 101 mm) wood stakes at 8 foot (2.5 m) on center spacing, continuously located around the tree's drip-line, unless otherwise directed by a certified arborist. If trees are in a group or cluster, use only one fence to surround the entire cluster.

7-7.3 Site Plan.

Include the following:

a. Show aboveground features including features required by the BOD (examples: airfields, railroads, crane rail, small arms ranges) with adequate layout data and existing aboveground features, after demolition has occurred.

b. Label baselines to be used for project layout as 'construction baseline' as opposed to survey baseline.

c. Provide layout dimensions from the construction baseline, or another readily identified (and easily established) alignment in the field. Include horizontal control point locations and descriptions. Use of coordinates for layout purposes is discouraged, however their use may be considered on a case-by-case basis. Contact Government's Civil Reviewer for approval of coordinate layout prior to project submittal.

d. Show areas requiring pavement patching, repairs, and pavement. Provide pavement jointing plans for rigid pavements. Include separate pavement marking plans for airfield projects.

e. Eliminate extraneous items that may congest the drawing (such as contours, elevations) and detract from the layout information.

f. Show locations of additional E&S control items not already included on the Demolition Plan. Coordinate with E&S notes, details, and legend.

g. Indicate trees and plant material to remain.

h. Provide statement concerning location of soil borings and soil information.

7-7.4 Water and Sanitary Sewer Plan.

Include the following:

a. Indicate whether connections will be made by wet tap (tapping sleeve/valve) or by dry connection. Show nearest valve(s) for system isolation if the latter is the case. Indicate known scheduling issues in the special scheduling paragraphs of the specification.

b. Indicate surface materials (such as grass, bituminous, or concrete).

c. Provide numbers (or letters) for each sanitary structure and water fitting so that plans and profiles are easily coordinated. This labeling system must be clearly distinct from that used for the storm drainage system and preferably distinct from labels used by other utility systems (such as electrical).

d. Provide manhole rim and invert elevations, pipe slopes, pipe diameters and pipe materials. If profiles are provided, indicate slopes on the profile sheets and do not provide on the plan sheets.

e. For water treatment plants, provide details process and instrumentation diagram (P&ID).

f. Provide reference to drawings and specifications for cathodic protection of fire protection water storage tanks, piping, or water lines, including metallic components of non-metallic lines (for example, PIVs, fire hydrants, change of direction devices, and valves).

7-7.5 Water, Storm, and Sanitary Sewer Profiles.

a. Show profiles where needed for clarity and to avoid potential conflicts. Discuss profile requirements with Government's Civil Reviewer.

b. Indicate structure tops, pipe invert elevations, slopes, lengths, and diameters of gravity lines.

c. Coordinate structure numbers with plan sheets.

d. Reference the plan sheets where pipes/structures are shown.

e. Show and label existing and surface materials, such as concrete pads, curbs, and roads, traversed by the lines. Accurately show depth of existing pavements.

f. Show and label crossing utility lines, both existing and new.

g. If depths of existing utilities are unknown, indicate the horizontal location of the utility and indicate the vertical location with a line representing the anticipated range of elevations where the utility will be found in the field. Indicate the method of utility installation routing above or below conflicts (such as concrete encasement or pressure pipe).

7-7.6 Grading and Drainage Plan.

Include the following information:

a. Provide existing spot elevations and existing contours at intervals to clearly indicate existing drainage patterns.

b. Provide spot elevations and contours when appropriate to clearly indicate grading and drainage patterns. Spot elevations/contours must be easily distinguished (bolder font) from existing.

c. Indicate where grading ties to existing grading (limits) and verify that work will not block existing adjacent drainage.

d. Show benchmarks, temporary benchmarks (tbm's), other vertical control, and datum notes on this plan.

e. Show finish floor elevations on grading plans. Do not show finish floor elevations on the architectural or structural plans in order to avoid conflicts. Coordinate adjacent exterior grading with the architectural/structural plans to ensure positive drainage patterns away from the building.

f. Verify that the slopes indicated on the plans are suitable for the surface material involved (such as earth slopes, bituminous pavements, and concrete pavements. Consider if these slopes are maintainable for the service life of the facility.

g. Coordinate with the Landscaping Plans (L sheets) to prevent plantings from blocking site drainage.

h. Provide numbers (or letters) for each drainage structure so that plans and profiles are easily coordinated.

i. Provide erosion and sediment control details.

7-7.7 Site / Utility Details.

Incorporate details as follows:

a. If applicable, edit and update standard details provided by the Government's Civil Reviewer to apply to the particular conditions and requirements of the project.

b. Details of items shown in the construction standards of the Department of Transportation, or other agencies of the state in which the project will be constructed, or other appropriate local/commercial standards are required on the plans.

c. Pavement Sections.

7-8 LANDSCAPE ARCHITECTURAL DRAWINGS.

7-8.1 Landscape Demolition Plan.

Coordinate existing site improvements and existing trees or other plant materials to be demolished with Civil Engineer. If a Civil Engineer is not involved with the project, conform to the requirements listed in Civil Drawings section under Demolition Plan.

7-8.2 Landscape Site Plan.

Coordinate site improvements with Civil Engineer. For projects with detailed Landscape Architectural features provide a Landscape Site Plan. Include the following:

a. Show new aboveground features including features required by the BOD (examples: buildings, existing site features to remain, utilities and other infrastructure improvements, vehicular and pedestrian circulation, parking, hardscape, fire lanes, Indicate hardscape, plazas, courtyards, child play equipment, monuments, memorials, site furniture, fences, walls, trash enclosure, signage, landscape drainage, and other site structures, streetscapes, LID and other bio-retention features, and AT standoff distances) and unobstructed space with adequate layout data and existing aboveground features, after demolition has occurred. Provide enlargement plans to delineate appropriate detail in plan view.

b. Label baselines to be used for detailed Landscape Architectural features layout as ‘construction baseline’ as opposed to survey baseline.

c. Provide layout dimensions from the construction baseline, or another readily identified (and easily established) alignment in the field. Include horizontal control point locations and descriptions. Use of coordinates for layout purposes is discouraged, however their use may be considered on a case-by-case basis. Contact Government’s Landscape Architectural Reviewer for approval of coordinate layout prior to project submittal.

d. Eliminate extraneous items that may congest the drawing (such as contours, elevations) and detract from the layout information.

7-8.3 Landscape Construction Details.

Provide details, sections, and elevations for site improvements required for construction.

7-8.4 Landscape Planting Plan.

Show locations of facilities (such as buildings, parking areas, roads, sidewalks, plazas or patios, existing vegetation to remain, and other surface improvements) and new plantings (such as trees, shrubs, ground cover), LID features, and bio-retention treatments.

7-8.5 Plant Material Schedule and Details.

Include the following:

- Provide a schedule for plant material showing as a minimum: botanical name, common name, quantity of plants, tree trunk caliper, minimum height and spread at time of planting, root condition (for example, balled and burlapped, containerized, and boxed), and a keyed reference to a planting detail.
- Provide separate details for plant types (such as trees, shrubs, ground covers) and other elements (such as root barrier, headers or edging, mulching).

7-8.6 Landscape Irrigation Plan.

When a Landscape Irrigation Plan is required by the Statement of Work, show locations of facilities (such as buildings, parking areas, roads, sidewalks, plazas and patios, existing vegetation to remain, and other surface improvements). Show pressure pipe and lateral lines, sprinkler heads, drip tubing and emitters, valves, backflow preventers, water source connections, wells, rain sensors, automatic controllers, rainwater harvesting (and other sustainable design features), and similar items.

7-8.7 Irrigation Equipment Schedule and Details.

When a Landscape Irrigation Plan is required by the Statement of Work, include the following:

- Provide an Irrigation Equipment Schedule showing at a minimum: graphic symbol, description of the item, manufacturer, model number, irrigation nozzle type (for example, full, half, quarter, or bubbler), optimum nozzle pressure (PSI), nozzle radius, and nozzle flow (GPM).
- Provide separate details for irrigation equipment (such as sprinkler heads, automatic controller, backflow preventer, valves, and other accessories).
- Provide pressure loss calculations.
- Provide water budget watering schedule, and equipment manufacturer's specifications, operations, and other information.

7-9 GEOTECHNICAL DRAWINGS.

Include subsurface investigation results on the drawings for record-keeping purposes. As a minimum, the drawings must include each of the logs/records as they appear in the Geotechnical Report; a summary table of the laboratory testing results; legend and descriptive notes concerning the drilling, logs and testing; groundwater level observations/conclusions; and site preparation notes and details, such as undercutting and surcharging. Include accurate figures showing the testing locations in the geotechnical drawings, or preferably, show the testing locations in the existing conditions or civil drawings.

7-10 STRUCTURAL DRAWINGS AND NOTES.

Provide structural drawings that sufficiently detail the structural work. The drawings must contain a set of "Structural Notes" in accordance with UFC 1-200-01, and which provide critical reference information for future building modifications or evaluations. As a minimum, note Design Criteria, Design Standard References, General Construction requirements, and the following:

- Loads: Provide loading information and identify sources for listed loads.
- Foundation Conditions: Fully describe the foundation conditions and list the type of foundation system and method employed to determine allowable soil bearing values. Indicate the minimum allowable bearing capacity for shallow foundations, or the pile or pier capacity in both tension and compression for deep foundations. Indicate passive, active and at rest design pressures, the coefficient of friction and the sub-grade modulus. Indicate if a site-specific design spectrum is to be used in the design and give the site class in accordance with the seismic design criteria used.
- Materials: Clearly define the types, grades, and properties of materials for each structural element and system.
- Quality Assurance: Provide a summary of the quality assurance requirements.
- Ammunition and Explosive Facilities: Drawings that include a standard approved for Ammunition and Explosive storage facilities must include a note clearly identifying the source, name, and date of the standard design.
- Marine Structures: List mooring berthing and deck loads for marine structures, including ship classes (such as DDG 51, CG 47, CVN) with associated displacements.

7-11 FIRE PROTECTION.

Provide floor plans showing the following information. Scale the floor plan so the entire footprint fits on a single sheet provided that information is clearly legible, and the scale is no smaller than 1:200 or 1/16-inch. Where a building has multiple hazard classifications or areas protected with special fire suppression systems, differentiate each area by border or hatching.

Information pertaining to electronic control/release systems may be shown on the Fire Alarm/Mass Notification Systems drawings specified below.

7-11.1 Fire Sprinkler Systems.

Provide the following information:

- Locations of sprinkler riser room.
- Fire department connections.
- Post indicator valves.
- Isolation control valves.
- Sprinkler branch lines or feed main piping if a specific routing is required, such as single feed to computer room or elevator equipment room and hoistway.
- Location of control panels used for release of pre-action or deluge systems.
- Fire pump and associated equipment.

7-11.2 Gaseous Fire Extinguishing Systems.

Provide the following information:

- Outline of area/hazard to be protected.
- Location of storage cylinders and releasing panel.
- System initiating devices (such as manual releases, automatic detection devices).
- Notification appliances.
- Main/reserve transfer switches.
- Control devices such as dampers, shunt trip breakers for computer equipment shutdown, and air conditioning units to be shut down, and electromagnetic door hold-open devices.

\1\ /1/

7-11.3 Fire Suppression Detail Sheets.

Provide fire suppression detail sheets showing the following information:

7-11.3.1 Fire Sprinkler Systems.

- Enlarged plan view of sprinkler riser room showing sprinkler risers, control valves, backflow prevention device and service entrance (supply) manifold drawn to scale.
- Cross-sectional elevations of sprinkler and standpipe risers.
- Enlarged plan view of fire pumps and piping arrangement, jockey pump, and associated controllers and equipment drawn to scale.
- Cross-sectional elevations of fire pump supply and discharge piping arrangement.
- Releasing system riser diagram for pre-action or deluge sprinkler systems. Identify zones, circuit inputs and circuit outputs necessary for controls, including interconnection with building fire alarm control panel.

7-11.3.2 Gaseous Fire Extinguishing Systems.

- Releasing system riser diagram identifying zones, circuit inputs and circuit outputs necessary for controls, including interconnection with building fire alarm control panel.
- Elevation view of storage cylinders and manifold.
- Isometric detail drawing of agent distribution piping including storage cylinder manifold and discharge nozzles.
- Sequence of Operation Matrix. See NFPA 72 for sample.

\1\ /1/

7-11.4 Fire Alarm/Mass Notification System Plans.

Provide floor plans identifying location of field installed components and interconnected devices. Plans may identify fire suppression control/release system information identified above. At a minimum, identify the location of the following information:

- Control panel(s).
- Notification appliance circuit extender panels.
- Radio transmitter or master box.
- Line and low voltage surge arrestors.
- Initiating devices (including duct smoke detectors). In lieu of locating devices on the plans, and as authorized by the DFPE, provide the following information on the plans:
    - Ambient sound pressure levels and audible design sound pressure levels

- Area boarders or other means to identify differing distinguishable spaces (ADS)
- Area borders to indicate the type of detection system, initiating devices, notification appliances and releasing service
- Area borders for detection and notification zones
- Rooms and spaces that will have visible notification and those where visible notification will not be provided
- Rooms and spaces that will have initiating devices and the design performance requirements for those devices

- Supplemental equipment interfaced with the fire alarm system such as voice evacuation panels, electromagnetic door holders, delayed-egress or access-controlled doors, elevator system components.
- Supplemental fire suppression equipment control panels such as fire**\1\ /1/** pump controllers, Fire suppression control/release panels.

7-11.5 Fire Alarm/Mass Notification System Detail Sheets.

Detail sheets may identify fire suppression control/release system information identified above.

7-11.5.1 Riser Diagram.

Provide a riser diagram showing hierarchy, arrangement, and zoning of the system. Identify typical circuits, interconnections, and interlocks necessary for associated controls. Do not identify every field device individually, such as smoke and heat detectors. Identify required line and low voltage surge arrestors. Interface with security systems for required delayed-egress or access-controlled doors. Identify interface with fire suppression control/release panels.

7-11.5.2 Sequence of Operation Matrix.

See NFPA 72 for sample.

7-12 DRAWINGS PREPARED FOR OTHER GOVERNMENT ORGANIZATIONS.

Approval of drawings for projects of other Government organizations or approval of modifications or revisions of drawings prepared by such organizations is required as follows:

- Indicate approval by other Government departments or agencies by appropriate signature in the supplemental locations provided on the NAVFAC Title Block (in accordance with Chapter 12).

- When NAVFAC drawings are prepared for construction projects for other Government departments or agencies, submit fully developed concept designs to the appropriate departments or agencies for formal approval.
- For drawings prepared under the direction of NAVFAC, the other Government organization provides approval solely for functional and operational sufficiency.
- When definitive, standard, or project drawings of other Government departments or agencies are used by NAVFAC for design of projects for those departments or agencies, make modifications or revisions to such drawings only with the approval of the department or agency concerned, unless NAVFAC has been authorized otherwise.

This Page Intentionally Left Blank

CHAPTER 8 DELIVERABLE: SPECIFICATIONS

8-1 GENERAL REQUIREMENTS.

Provide specifications in accordance with UFC 1-200-01, the Core UFCs, UFC 1-300-02, and Chapter 12. Provide specifications that are as brief as possible, definitive, and free of ambiguities and omissions that may result in controversy and contractor claims for additional compensation.

8-2 GUIDE SPECIFICATIONS.

Specifications offer criteria for materials, equipment, and test methods. Guide specifications are documents that describe products and materials and the work necessary to incorporate them into a construction project. A guide specification facilitates the preparation of project specifications by standardizing products and processes, and their order of presentation. DoD uses the Unified Facilities Guide Specifications (UFGS) database, provided on the WBDG (https://www.wbdg.org), which is updated quarterly. Edit guide specifications to specific project requirements for incorporation into the contract documents. Guide specification and project specification sections describe the following in detail:

- Product or system to be provided,
- Salient design features or performance requirements of the product or system,
- Quality of that product or system and methods used to ensure the quality, including on-site and off-site testing,
- Method to be used to incorporate the product or system into the project, and
- Other features and functions necessary.

Guide specification section numbers, up to 10 digits, in CSI MasterFormat®, are grouped in pairs. Each of these groupings is referred to as a “level,” from one to five. Refer to CSI MasterFormat® (https://www.csiresources.org/standards/masterformat/masterformat-number) for further explanation.

8-2.1 Unified Facilities Guide Specifications (UFGS).

Use Unified Facilities Guide Specifications (UFGS) for projects, including DB. UFGS are available at the WBDG (https://www.wbdg.org/). Tailor and modify the UFGS to suit the work required by the specific project, including editing for metric or inch-pound. In addition, modify and edit to reflect the latest proven technology, materials, and methods, for the project.

There is only one current version of a guide specification at any time. The guide specification with the latest revision date and change number automatically cancels specifications of the same number with a previous date and change number.

8-2.2 Regional Guide Specifications.

Some Supported Commands have modified some of the UFGS for their region; these are referred to as Regional Guide Specifications. Use Regional Guide Specifications when sections are available by the Region and Activity for the project location, and in accordance with the contract. Regional specifications are located on the WBDG (https://www.wbdg.org/navy/nfgs) and where indicated in the contract.

Regional specifications are limited in number and scope to selected subjects particular to a location and contain a majority of local requirements. Regional specifications are used in the same way as the UFGS except that they are used only in the area of the specific facility engineering command jurisdiction. Regional specifications are numbered the same as the UFGS that has been used as a basis for the regional specification, with the exception of a regional designation at the fifth level for specifications in CSI MasterFormat®; for example, in UFGS Section number, 01 13 30.00 22, “22” indicates the region. Assigned regional designations can be found with the Regional specifications on the WBDG (https://www.wbdg.org/navy/nfgs).

8-2.3 Other Guide Specifications.

Other guide specifications are only allowed as a basis for information when not available in the UFGS. These developed specifications must be provided in UFGS format and modified to meet requirements of UFC 1-300-02.

8-2.4 UFGS Selection Order of Precedence.

Unless specified otherwise in the contract, the order of precedence for selecting which UFGS to start from, for CONUS jobs that require the use of the UFGS, is as follows:

1. Regional Guide Specifications (for the project location and where sections are published on WBDG).
2. UFGS, Navy only (UFGS with a “20” at the fifth level in CSI MasterFormat®).
3. UFGS (unified, no designator at the fifth level).
4. Other DoD UFGS (Army UFGS with .00 10 designation and modified for Navy job).

8-2.5 DB Performance Technical Specifications.

Develop Performance Technical Specification (PTS) sections in accordance with requirements of Chapter 11.

8-3 PROJECT PREPARATION POLICIES AND GUIDANCE.

Prepare specifications in Format and Styles required by UFC 1-300-02.

8-3.1 UFGS Version Date.

Download, use, and edit the most current UFGS database available from the WBDG (https://www.wbdg.org/dod/ufgs). Unless otherwise specified by the contract, the version that is current at the official start of the Pre-Final design phase for DBB must be used; or the version current at the last phase of RFP issuance for DB; and continue to be used, through Final design. Coordinate the version of the UFGS database used with the Government Design Manager and report this date to them.

8-3.2 Editing of Specifications for Project.

Modify and edit the guide specification to fit the project and to meet UFC requirements. Follow the Notes to the Designer to make selections in the UFGS. Use language and format in accordance with UFC 1-300-02. Delete portions of the guide specification not included in the project design and scope.

Use guide specifications only as source documents, and do not reference them in project specifications. Do not combine work covered by various UFGSs into one section unless the project is small and work is of a minor nature, and the Government Design Manager concurs.

8-3.2.1 Geotechnical and Civil Specifications.

Do not edit outside of the guide specification’s bracketed selections for Geotechnical and Civil UFGS sections in Divisions **\1** 31, 32, and 34 **/1/** without prior approval of the Government Design Manager.

8-3.3 Standard Plates, Sketches, and Details.

Provide plates, sketches, boring logs, and details on the drawings, and not in the specifications.

8-3.4 Unrestricted Bidding.

Provide only the actual minimum needs of the Government in the specifications and describe the salient characteristics of materials and installation so as to encourage maximum competition in bidding. Eliminate, insofar as possible, restrictive features that might limit acceptable offers to one supplier's product, or to the products of a relatively few suppliers, and in accordance with UFC 1-300-02. Do not list manufacturers unless

Contracting Officer approval is received in accordance with NFAS 6.304. Master UFGSs that list manufacturers must have a class justification on file.

8-3.5 Contract Parties.

Do not designate part of the work to be performed by a particular subcontractor (such as the plumbing contractor) in constructing the project, except for some specific instances. The Government recognizes only one Contractor (the prime or general contractor) and it is the Contractor's responsibility to divide up the work.

8-3.6 Facilities Electronic Operation and Maintenance Systems Information (eOMSI).

eOMSI (UFGS 01 78 24.00 20) is required on New Construction projects greater than or equal to $1 Million and Major Renovation Projects greater than or equal to 50 percent of the Plant Replacement Value (PRV), at Navy and Marine Corps Installations Joint Bases, Department of Defense (DoD) Agencies, or Field Activities, where NAVFAC is the maintenance provider of the facility. Also, use UFGS 01 78 24.00 20 for projects using BIM or when required by the contract. Use both UFGS 01 78 23 and UFGS 01 78 24.00 20.

The eOMSI Facility Data Workbook (FDW) is required for facilities operated and maintained by NAVFAC and Marine Corps. For BIM projects, use the FDW to prescribe the Level of Detail.

8-4 COORDINATION OF SPECIFICATIONS AND DRAWINGS.

FAR 52.236-21 states: "Where 'as shown’, 'as indicated’, 'as detailed’, or words of similar import are used, the reference is made to the drawings accompanying this contract unless stated otherwise."

8-4.1 DBB Contract Order of Precedence.

For DBB contracts, the Contract Order of Precedence is defined in FAR 52.236-21. In general, treat anything mentioned in the specifications but not shown on the drawings or shown on the drawings but not included in the specifications, as if shown or mentioned in both. In the case of discrepancies between the drawings and specifications, the specifications take precedence.

8-4.2 DB Contract Order of Precedence.

Refer to the RFP and the contract for Order of Precedence on DB contracts.

8-4.3 Coordination.

Coordinate the drawings and the specifications to ensure that items depicted in the drawings are covered by an appropriate specification section and that specification sections relate to items in the drawings.

8-5 USE OF UFGS AND SPECSINTACT.

Edit and provide UFGS sections in accordance with UFC 1-300-02, using SpecsIntact software and UFGS format. SpecsIntact is the word processing software used to edit the UFGS database. SpecsIntact software is available for download, free of charge, at the SpecsIntact website (https://specsintact.wbdg.org/).

8-6 SPECIFICATIONS PACKAGE ORGANIZING STRUCTURE.

8-6.1 Coversheet.

Include an overall cover sheet, for signature, with project specification package. Type in the name and title of the principal DOR, who must sign in the "Submitted By" location. The coversheet for electronic signature is available on the WBDG (https://www.wbdg.org/navy/project-information-form-specifications-cover-sheet/spec-coversheet).

Use the eProjects Work Order Number; only use the Maximo number on coversheet and other project documents if eProjects is not required for the project.

8-6.2 Contract Documents.

The DOR prepares and provides the following documents to the Government's Project Manager for the Contract Specialist. The Contract Specialist consolidates bidding and contract requirements, along with the drawings and specifications, into a single solicitation package.

8-6.2.1 Project Synopsis.

The scope in the project synopsis is taken from the Description of Work located in UFGS Section 01 11 00. This description of work must be concise, and summarize the location, facilities, and type of work involved. A sample synopsis is provided in Appendix A. Provide the scope of work for the Synopsis at Pre-Final and Final in accordance with contract requirements.

8-6.3 Format.

Provide specifications in UFGS format in accordance with UFC 1-300-02. Print job headers with the job title, exactly as it appears on the drawings, justified to the left, and with the eProjects Work Order Number justified to the right. For Prefinal submittals, follow the job title with "(Prefinal)."

8-6.4 General Requirements (Division 00 and 01) Specifications.

Edit the UFGS Division 00 and 01, General Requirements Divisions, to describe the general project requirements of the project. Provide additional requirements of a general nature, rather than of a technical nature, in General Requirements.

The UFGS sections in Table 8-1 are typically used in a DBB project. Use other Division 01 sections as required, depending on the scope of the project, or in accordance with the Contract. Provide UFGS Document 00 01 15 as part of the specifications package, or separately, in accordance with Contract requirements.

Table 8-1 Commonly Used DBB UFGS Division 00 and 01 Sections

UFGS Number	TITLE
00 01 15	LIST OF DRAWINGS (sometimes not provided in TOC)
01 11 00	SUMMARY OF WORK
01 14 00	WORK RESTRICTIONS
01 20 00	PRICE AND PAYMENT PROCEDURES
01 30 00	ADMINISTRATIVE REQUIREMENTS
01 32 17.00 20	COST-LOADED NETWORK ANALYSIS SCHEDULES (NAS)
01 33 00	SUBMITTAL PROCEDURES (attach Submittal Register)
01 33 29	SUSTAINABILITY REQUIREMENTS AND REPORTING
01 35 26	GOVERNMENTAL SAFETY REQUIREMENTS
01 42 00	SOURCES FOR REFERENCE PUBLICATIONS
01 45 00	QUALITY CONTROL
01 50 00	TEMPORARY CONSTRUCTION FACILITIES AND CONTROLS
01 57 19	TEMPORARY ENVIRONMENTAL CONTROLS
01 58 00	PROJECT IDENTIFICATION (attach Project Signboards)
01 78 00	CLOSEOUT SUBMITTALS
01 78 23	OPERATION AND MAINTENANCE DATA
01 78 24.00 20	FACILITY DATA WORKBOOK (FDW) (attach Facility Data Workbook)

8-6.5 DB RFP.

For Part 2, “General Requirements,” of the six part DB RFP, use the UFGS sections provided in Part Two of the NAVFAC DB Master on the WBDG (https://www.wbdg.org/navy/ndbm) as appropriate. Table 8-2 shows commonly used DB RFP Part Two UFGS sections.

Table 8-2 Commonly Used DB RFP PART Two UFGS Division 01 Sections

UFGS Number	TITLE
01 14 00	WORK RESTRICTIONS
01 20 00	PRICE AND PAYMENT PROCEDURES
01 30 00	ADMINISTRATIVE REQUIREMENTS
01 31 19.05 20	CONCEPT DESIGN WORKSHOP (CDW)
01 32 17.00 20	COST-LOADED NETWORK ANALYSIS SCHEDULES (NAS)
01 33 00.05 20	CONSTRUCTION SUBMITTAL PROCEDURES
01 33 10.05 20	DESIGN SUBMITTAL PROCEDURES
01 33 29	SUSTAINABILITY REQUIREMENTS AND REPORTING
01 35 13	SPECIAL PROJECT PROCEDURES
01 35 26	GOVERNMENTAL SAFETY REQUIREMENTS
01 45 00	QUALITY CONTROL
01 50 00	TEMPORARY CONSTRUCTION FACILITIES AND CONTROLS
01 57 19	TEMPORARY ENVIRONMENTAL CONTROLS
01 74 19	CONSTRUCTION WASTE MANAGEMENT AND DISPOSAL
01 78 23	OPERATION AND MAINTENANCE DATA
01 78 24.00 20	FACILITY DATA WORKBOOK (FDW)

8-6.6 Project Reports.

Many projects include special requirements due to the presence of environmentally sensitive materials, such as asbestos, lead containing paint, PCBs, or other hazardous materials. Typically, as part of the Design or RFP Development contract, investigations are conducted to determine the presence, levels, and limits of sensitive materials. The investigative firm then provides reports, from which the information is used to design the project or provided in the DB RFP. The Government provides this information to the Contractor as part of the contract documents.

8-6.6.1 DBB.

Provide and attach reports to the end of the appropriate UFGS specification section (example: provide the asbestos report at the end of UFGS 02 82 00 *Asbestos Remediation*).

8-6.6.2 DB.

For DB, provide project reports in Part 6 of the RFP.

8-6.7 Combining Multiple Projects into One Bid Package.

Occasionally, several projects that have been independently prepared, or need to be easily separated, will be combined into one solicitation package. One solution is to combine the packages into at least three Parts.

8-6.7.1 DBB Parts.

In Part A, provide one General Requirements (Division 01) specification for the entire package. This Division 01 must be edited and accurate for the combined projects. The header in Part A must list the titles of each project, justified to the left, and the corresponding eProjects Work Order Number for each project, justified to the right. Example is provided in Figure 8-1.

Part B consists of the technical specifications (Divisions 02-49) for the first project and Part C consists of the technical specifications for the second project. Add additional parts depending on the number of projects being combined. Provide a Divider, a Table of Contents, and the technical specification sections. The header in each part must contain only the title of that Project and the corresponding eProjects Work Order Number for that project. An example is provided in Figure 8-1.

Figure 8-1 Sample Table of Contents for Combined DBB Projects

GATE 5 SECURITY IMPROVEMENTS, NSA NORFOLK 222088
SECURITY IMPROVEMENTS, GATE 10, NAS OCEANA 235341

PROJECT TABLE OF CONTENTS

PART A: GENERAL REQUIREMENTS

DIVISION 34 – TRANSPORTATION

34 71 13.19 CRASH RATED ACTIVE VEHICLE BARRIERS AND CONTROLS

-- End of Part B --

PART C: SECURITY IMPROVEMENTS GATE 10, NAS OCEANA, VIRGINIA BEACH, VA (WON 235341)

DIVISION 02 - SITE WORK

02 41 00 [DEMOLITION][AND][DECONSTRUCTION]

DIVISION 31 – EARTHWORK

31 23 00.00 20 EXCAVATION AND FILL

DIVISION 08 - OPENINGS

08 11 13 STEEL DOORS AND FRAMES
08 71 00 DOOR HARDWARE

-- End of Part C –

8-6.7.2 DB Parts.

Part A consists of the General Requirements Division (Division 01), Part B consists of the RFP (Parts 3-6) for the first project, and Part C consists of the RFP for the second project. Add additional parts depending on the number of projects being combined. Provide a Divider, a Table of Contents, and the RFP sections (Parts 3-6). The header in each part must contain only the title of that Project and the corresponding eProjects Work Order Number for that project.

For RFPs in which Parts are shared, such as Part 2, Part 4, and Part 5, projects may be combined by simply using a Part 3 for each project, distinguished by the cover page and title, and inserted in Part 3; and a Part 6 for each project, distinguished by the title, and inserted in Part 6. In this case, parts A, B, and C dividers may not be required. Reflect the layout in the overall Table of Contents.

8-6.7.3 DB and DBB Hybrid.

For contracts where a DB RFP is combined with a DBB project, provide one project, complete, in Part A, and the other project, complete, in Part B; do not combine the General Requirements (Division 01) of these two different types of projects. An example is provided in Figure 8-2.

Figure 8-2 Sample Combined DB and DBB Project

PART A: GATE 5 SECURITY IMPROVEMENTS, NSA, NORFOLK, VA (WON 222088)

DIVISION 01 – GENERAL REQUIREMENTS

01 11 00	SUMMARY OF WORK
01 14 00	WORK RESTRICTIONS
01 20 00	PRICE AND PAYMENT PROCEDURES
01 30 00	ADMINISTRATIVE REQUIREMENTS
01 32 17.00 20	COST-LOADED NETWORK ANALYSIS SCHEDULES (NAS)
01 33 00	SUBMITTAL PROCEDURES
01 33 29	SUSTAINABILITY REQUIREMENTS AND REPORTING
01 35 26	GOVERNMENTAL SAFETY REQUIREMENTS
01 45 00	QUALITY CONTROL
01 50 00	TEMPORARY CONSTRUCTION FACILITIES AND CONTROLS
01 57 19	TEMPORARY ENVIRONMENTAL CONTROLS
01 57 19.01 20	SUPPLEMENTAL TEMPORARY ENVIRONMENTAL CONTROLS FOR GATE 5
01 57 19.02 20	SUPPLEMENTAL TEMPORARY ENVIRONMENTAL CONTROLS FOR GATE 10
01 58 00	PROJECT IDENTIFICATION
01 78 00	CLOSEOUT SUBMITTALS
01 78 23	OPERATION AND MAINTENANCE DATA

DIVISION 02 - SITE WORK

02 41 00	[DEMOLITION][AND][DECONSTRUCTION]

DIVISION 26 – ELECTRICAL

26 08 00	APPARATUS INSPECTION AND TESTING
26 32 15.00	ENGINE-GENERATOR SET STATIONARY 15-2500 KW, WITH AUXILIARIES

DIVISION 31 - EARTHWORK

31 00 00	EARTHWORK

DIVISION 34 – TRANSPORTATION

34 71 13.19	CRASH RATED ACTIVE VEHICLE BARRIERS AND CONTROLS

--End of Part A --

PART B: GATE 2 SECURITY IMPROVEMENTS, NSA NORFOLK, VA (WON 352025)

PART 1 – CONTRACT DOCUMENTS
(Included under separate attachment)
PART 2 – CONTRACT REQUIREMENTS
PART 3 – PROJECT PROGRAM
PART 4 – PERFORMANCE TECHNICAL SPECIFICATIONS (PTS)
PART 5 – PRESCRIPTIVE TECHNICAL SPECIFICATIONS
PART 6 – ATTACHMENTS

-- End of Part B --

8-6.7.4 Coversheet.

Provide one overall coversheet for signature. The coversheet must contain each of the eProjects Work Order Numbers. Contact the Government for which Work Order Number to use first as the primary. Also include project titles and if different Designers of Record prepared the RFP or specification, the information of each DOR firm or agency to be included. Be careful not to change the location of the electronic signature portlets when adding information to the coversheet.

8-6.7.5 List of Drawings.

Provide UFGS 00 01 15 listing drawings in the entire package. Group drawing lists by Project.

8-6.7.6 Table of Contents.

Provide a single, overall Table of Contents, listing each Part and the sections or documents in each Part. Note that SpecsIntact uses Courier New (10 pt) as the default font. Use this font to generate the Table of Contents and other documents in Word. A sample Table of Contents is provided in Figure 8-1 and Figure 8-2.

8-6.7.7 Submittal Registers.

Provide submittal registers for each Part at the end of UFGS 01 33 00 (for DBB) or UFGS 01 33 00.05 20 (for DB). Separate the submittal register for each part with a Divider; for example, bookmark “Part A: Submittal Register” (for Division 01 only), “Part B: Submittal Register,” and “Part C Submittal Register,” within the PDF package.

CHAPTER 9 DELIVERABLE: COST ESTIMATES

9-1 GENERAL REQUIREMENTS.

Provide cost estimates at each submittal in accordance with the applicable provisions of UFC 3-701-01, UFC 3-730-01, and UFC 3-740-05 unless specifically indicated otherwise in this chapter or in the contract documents. Cost estimates include budgetary estimates, current working estimates (CWE), independent government estimates (IGE), and independent cost estimates (ICE).

Provide cost and schedule risk analysis (CSRA), **\1\ /1/**value engineering study (VES) and independent cost estimate (ICE) when required by the scope of services. Provide construction schedules in support of the cost estimate.

9-2 COST ESTIMATE CLASS STANDARDS.

Cost estimate classifications based on the maturity of the project definition deliverables is provided in Appendix B, Table B-1.

Table 9-1 indicates the appropriate AACE RP 56R-08 cost estimate class with the commensurate project phase.

Table 9-1 Cost Estimate Classification by Project Phase

Project Phase	Estimate Class
Final Design; Pre-Final Design	2,1
Design Development (35% - 50%)	3,2
DB RFP - Final	3
DB RFP - Draft	4,3
Budgetary; Preliminary Design (MILCON **\1** Checklist– see Paragraph 13-5 **/1/**); Schematic Design; Studies	4,3
Planning; Installation Level DD1391; Rough order of magnitude (ROM), comparison or screening; square foot (square meter)	5

9-3 COST ESTIMATE DEVELOPMENT REQUIREMENTS.

Base the cost estimate on the defined process as described in UFC 3-740-05. Unless otherwise directed, prepare cost estimates using latest MII software (Micro Computer Aided Cost Estimating System). Update cost estimate to the latest Cost Book and regional equipment library.

When the level of design does not support a quantity takeoff, the PACES software (Parametric Cost Estimating System) may be used and is to be exported to MII. The export is to be transferred into the appropriate NAVFAC MII template and updated to requirements in this chapter.

NAVFAC MII templates are provided on the WBDG website: https://www.wbdg.org/navy/ceg. Unless otherwise directed, use the latest version of these templates at the initiation of the cost estimate.

9-3.1 Level of Detail.

The level of detail for each cost estimate must be commensurate with the project phase. The detailed cost items are to appear at the appropriate locations and levels in the work breakdown structure (WBS). See Table 9-2. Each of the folders in the NAVFAC template includes notes indicating the unit of measure (UOM) to be used for that folder in accordance with UNIFORMAT II. Update the quantity at the folder level and use the indicated UOM. Segregate MILCON costs from Non-MILCON costs. Develop the price schedule line items in the cost estimate by maintaining the WBS for each line item.

\1

9-3.2 Labor Costs

Obtain current local pricing for labor rates at the time the cost estimate is developed.

9-3.3 Local Pricing for Projects OCONUS

Host nation consultant to provide current local pricing for major cost items and labor rates. This information is to be included as part of the backup documentation.
/1/

Table 9-2 MII Template Project Items Crosswalk

Source	MII Folder Levels	MII Folder Level Title	Sample Level Description	UNIFORMAT II		Use
				Levels	Values	
Template	0	Project	*Project Name*	N/A	N/A	Mandatory
Template	1	Project Phase [1]	*Base Bid*	N/A	N/A	Mandatory
Template	2	Facility Type[2]	*Primary Facilities*	N/A	N/A	Mandatory
Template	3	Project Element[3]	*Primary Facility 1*[4,5]	N/A	N/A	Mandatory
Template	4	Major Group Element	*Shell*	1	B[6]	Mandatory
Template	5	Group Element (System)	*Superstructure*	2	B10[6]	Mandatory
Template	6	Individual Element (Subsystem)	*Floor Construction*	3	B1010[6]	Mandatory
Template	7	Sub-Element (Assembly)	*Floor Decks and Slabs*	4	B101003[6]	Mandatory
User	8	Sub-Assembly or Unit Price	*Floor Slabs*	N/A	N/A	Optional
User	9	Unit Price Line Items	*Detail Items*	N/A	N/A	Optional

Notes:
1. Project Phase is associated with large projects, such as Phase 1 of 4.
2. Facility Type values are either Primary, Supporting, or Other.
3. For Primary Facilities, include Cat Code as Source Tag.
4. For Primary Facilities Title use Cat Code Description
5. Include number of stories above and below grade in the Primary Facilities Title.
6. These UNFORMAT II values are used as MII Source Tags at the corresponding MII Folder Levels.

9-3.4 Escalation.

Use the NAVFAC Building Cost Index (BCI) for escalation, unless supporting market analysis dictates otherwise. Update the cost estimate at each submittal to reflect the current escalation. The NAVFAC BCI can be found on the WBDG website (https://www.wbdg.org/navy/ceg).

Include the escalation variance as a consideration in the sensitivity analysis and CSRA.

9-3.5 Job Office Overhead (JOOH).

Inform the duration of JOOH costs from the construction schedule. It is permitted to define the rate of JOOH as a percentage in earlier phases of design up to a Class 4 cost estimate. Itemized JOOH is required on Class 1, 2 and 3 cost estimates.

9-3.6 Markup Requirements.

The markups defined below are to be addressed in the cost estimate.

9-3.6.1 Direct Cost Markups.

- Productivity.
- Overtime.
- Sales Tax.
- Cost Data Escalation – Used to escalate direct material, labor and equipment costs from the cost data source date(s) to the date of the cost estimate.
- Design Contingency – Global application of this markup is allowed for an early design level, by pre-final submittal it is expected the markup be applied at a system level. The cost engineer owns this markup. Design contingency may also be addressed by including allowances.

9-3.6.2 Contractor Markups.

The following contractor markups are to be addressed for prime and subcontractors.

- JOOH
- Home Office Overhead (HOOH)
- Profit
- Bond and Insurances
- Excise Tax
- DB Fee
- Competition Premium - Used to account for markets with low competition. Do not use if a CSRA is included in the project as it is expected that the level of competition will be considered as a risk factor in the model.

9-3.6.3 Owner Markups.

These markups must be applied in the following order within MII.

- Market Escalation: used to escalate the project from the date of the cost estimate to the mid-point of construction.

- Risk Contingency: If a CSRA was developed as part of the scope of the project then the resulting contingency is to be applied as an owner markup.

9-3.6.4 Construction Contingency.

Construction contingency is not included as a part of the cost estimate. This cost is accounted for outside of the cost estimate.

9-3.6.5 Supervision Inspection and Overhead (SIOH).

SIOH is not included as a part of the cost estimate. This cost is accounted for outside of the cost estimate.

9-3.7 Development of Specific Task.

Clearly identify specific tasks with unique source tags.

9-3.5.1 Cost Overrides and Modified Cost Task.

Clearly document in the cost estimate overrides or modifications to component of the cost item that originates from published data.

9-3.5.2 User Items.

Clearly document user items in the cost estimate.

9-3.5.3 Assemblies.

Clearly document assemblies used in the cost estimate.

9-4 SENSITIVITY ANALYSIS.

\1 Perform a sensitivity analysis in accordance with UFC 3-740-05 for NAVFAC cost estimates. The results of the sensitivity analysis are used to inform the cost estimate, **/1/** CSRA and the ICE. For PEO II projects, utilize the value from the upper end of the uncertainty range in the base cost estimate and do not model the variation of the uncertainty item in the CSRA. Update the sensitivity analysis at each cost estimate submittal.

9-5 COST AND SCHEDULE RISK ANALYSIS (CSRA).

Perform the Cost and Schedule Risk Analysis (CSRA) in accordance with UFC 3-740-05 on projects greater than $20 million unless otherwise directed by NAVFAC Cost TDC. The Tri-Service CSRA template is located under Related Materials on the WBDG website for UFC 3-740-05. Develop CSRA models using the Crystal Ball add-in to MS Excel unless otherwise approved by the NAVFAC Cost TDC. Base the default risk contingency on an 85% Confidence Level unless otherwise directed or specifically required by governing policy or directive. Update the CSRA at each cost estimate submittal.

9-5.1 Budgeting CSRA.

The budgetary estimate is to consider each risk to inform the final Program Amount. Consider pre-award and post-award risk as well as uncertainty items in the CSRA.

9-5.2 Design CSRA.

During the design phase, consider risk to predict the price of the project in market. Each modeled risk must have identified risk reduction measures that are updated at each submittal. Consider each risk that the contractor will take into account during bidding. Keep track of post-award risks in the risk register but do not model them.

9-5.3 Construction CSRA.

If required during the construction phase of the project, the CSRA is leveraged to develop both the total contingency value and when those contingency dollars will be needed (FY). The model is to be updated on a continual basis as directed by the NAVFAC PM to better inform the contingency position. Include post-award risks focused on items that could occur during construction. Utilize to the greatest extent possible, the schedule of prices, cost loaded schedule, and the contract unit prices for informing and quantifying the risks.

9-5.4 Schedule Risk.

If a schedule risk is modeled, always model the associated cost from schedule impact regardless of magnitude. The quantified value accounts the JOOH monthly rate as well as the cost of escalation incurred by the additional duration. Calculate the monthly cost of escalation by determining the total dollar value of escalation in the base estimate divided by the construction duration.

9-6 VALUE ENGINEERING STUDIES (VES).

When required, provide a VES in accordance with Appendix B3.

9-7 INDEPENDENT COST ESTIMATE (ICE).

When required, an ICE is developed in addition to the DOR's cost estimate. The ICE is prepared by a qualified, third-party cost estimator independent of the project stakeholders. It is prepared in accordance with cost criteria and includes sensitivity analysis as well as a construction schedule to support comparative evaluations. The ICE must be developed with the same design documents and use the same WBS used to generate the DOR's cost estimate. To restrict potential bias, information from the DOR's cost estimate must be withheld from the ICE estimator to the maximum extent practical. The Government may provide supplemental information to the ICE estimator such as Charrette report, studies, and CSRA risk register. The ICE will be reviewed by the Government in the same manner as the DOR's estimate.

At the initiation of the ICE process (awarding an ICE contract), the Government cost engineer will schedule and hold a kickoff meeting for the ICE process to be attended by the DOR and the ICE estimator teams. During the development period, there will be bi-weekly meeting with the DOR and ICE estimator as scheduled by the Government cost engineer.

9-7.1 Reconciliation.

Reconciliation occurs at defined milestones and is a collaborative process between the Government, DOR, and ICE estimator. The Government cost engineer is responsible for leading the reconciliation process. This process will be repeated for each design submittal, except Final. The Government cost engineer will compare the ICE and DOR cost estimates in two steps. The first step of the analysis will focus on quantities and the cost estimates' sensitivity analyses. In this first step the Government cost engineer will summarize the results of the comparison in a report and forward it to the DOR and the ICE estimators for their review. The Government cost engineer will then schedule and facilitate a Quantity Reconciliation meeting to reconcile quantities and sensitivity analysis differences. The DOR and ICE cost estimates will be updated based on this meeting.

Using the DOR and ICE cost estimates updated from the first step, the Government cost engineer will compare the two estimates focusing on remaining differences in cost and schedule. In the second step of the analysis, the Government cost engineer will summarize the results in a comparison report. This report will be forwarded the DOR and the ICE estimators for their review. The Government estimator will then schedule and facilitate a Reconciliation Workshop to reconcile remaining cost and schedule differences.

9-7.2 Documentation.

The DOR retains the responsibility for the CWE developed for each design submittal. During the reconciliation workshop, the DOR will document discussions and inform their cost estimate at their discretion. The DOR's basis of estimate will be updated to document the key recommendations from the workshop as well as which recommendations were considered in the reconciled CWE. Recommendations that were not considered need to be documented with appropriate rationale for exclusion.

9-8 CONSTRUCTION SCHEDULE.

Provide a construction network analysis schedule (NAS) in support of the cost estimate and CSRA. **\1** Prepare construction schedules using Primavera P6 or Microsoft Project, unless otherwise approved by the NAVFAC Cost TDC. **/1/** Use the duration, crew hours, and labor hours from the cost estimate to inform the construction schedule. In turn, the cost estimate must include itemized job overhead costs informed by the construction schedule. This construction schedule is part of the cost estimate supporting documentation and will not be shared with the Contractor. Update the construction schedule at each cost estimate submittal.

9-8.1 Construction Schedule Class Standards.

Construction schedule classifications based on the maturity of the project definition. Unless otherwise directed by the NAVFAC cost engineer, the construction schedule is to be roughly equivalent to a Class 3 schedule as defined in AACE Recommended Practice 27R-03.

9-8.2 Construction Schedule Development Requirements.

The schedule must incorporate the following best practices from GAO-16-89G.

1. Capture activities defined in the schedule WBS at a sufficient level of detail to accomplish the project’s objectives.
2. Sequence activities in logic-driven predecessor-successor relationships, minimizing the use of lags and date constraints.
3. Establish durations for activities. These durations are to be informed by the cost estimate.
4. Verify that the schedule can be traced horizontally and vertically.
5. Identify and validate the critical path.
6. Identify a reasonable total float.
7. Incorporate the schedule information in the CSRA.

The schedule must also incorporate the following.

1. Environmental requirements (i.e., permits, fish windows, or SHPO.)
2. Impact of known installation activities upon the construction contractor’s operations.
3. Seasonal weather considerations including impact on the site soils.
4. Durations for submission and approval of administrative submittals.
5. Durations for material lead time and installation.
6. Interface of work trades within the project.
7. Productivity losses triggered by lack of lay-down/storage space.

The level of activity detail within the construction schedule is to be in accordance with Table 9-3.

Table 9-3 \1\ /1/Activity Detail by Schedule Class

Class	Activity with Duration Greater than
5	12 Weeks
4	10 Weeks
3	4 Weeks
2	2 Weeks
1	1 Week

9-8.3 Cost-Loaded Construction Schedule.

When directed, develop a cost-loaded construction schedule based on the values from the cost estimate. Assign cost respective to the construction activities. Activities assigned Government responsibility are to have zero cost. No contractor cost is to be assigned to an activity designated as a Government responsibility.

9-9 SUBMITTAL REQUIREMENTS.

Provide a cost estimate package in a separate submittal to the PM/DM only. In a single PDF combine the basis of estimate (BOE), MII cost estimate report, CSRA report, sensitivity analysis, VES, basis of schedule (BOS), **\1** construction schedule, and backup data for a complete report. **/1/**

9-9.1 BOE.

For each submittal, provide a narrative BOE. In addition to the requirements defined in the UFC 3-740-05, the BOE must include the following information:

- Provide a complete schedule of cost estimate submittals.
- Establish and maintain a table summarizing the cost development at each submittal in accordance with the WBS and using ASTM E1804 as guidance. The initial table entry is to be the budget or DD1391 estimated costs. Subsequent entries are to be added during the design development. Evaluate and describe the causes of variances exceeding 10% of UNIFORMAT II Level 1 and Level 2 cost elements, sub-totals, or

totals between the current cost estimate submittal and the previously submitted cost estimate.

- State the estimating methodology used to develop the cost estimate.
- Provide a narrative of the current construction market and expectation for changes through the planned construction period at the project location. This is to include availability of labor and materials and market drivers. Describe how the cost estimate accounts for the current construction market, including markups applied.
- Include the assumed minimum number of bidders.
- Include a summary of work self-performed by the prime contractor and work to be performed by subcontractors.
- Describe the development of the applied direct markups and include details backed up by industry data and/or calculations justifying percentages used for direct markups. Do not make broad statements such as “based on historical data.”
- Describe the development of the contractor markups and include details backed up by industry data and/or calculations justifying percentages used for contractor markups. Do not make broad statements such as “based on historical data.”
- Describe the development of the risk contingency markup.
- Describe the development of the market escalation markup.
- Describe the development design contingencies incorporated into the cost estimate and provide a defensible position.
- Describe the software tools and associated databases used in the development of the cost estimate.
- Describe the sources of cost data for material, labor and equipment.
- Describe the reasonableness of the proposed construction schedule to meet the contract award within the budget year or meeting the defined Initial Operational Capability (IOC) date.
- Describe the results from the sensitivity analysis identifying key cost drivers impacting the total construction cost by 5% or greater. The results of this analysis are to be captured in a table identifying the parameters or assumptions and the range of variation assumed for each key cost driver.

9-9.2 MII Cost Estimate Report and Native File.

Prepare and submit cost estimate reports using NAVFAC MII Standard Report Templates (https://www.wbdg.org/navy/ceg). Provide the native MII (.mlp) file.

9-9.3 Sensitivity Analysis.

Provide a report describing the process and documenting the results. The report is to include a graphical summary of the results to illustrate the relative impact of each factor identified in the analysis.

9-9.4 CSRA Report and Model.

\1 Provide **/1/** the native Excel macro-enabled CSRA model file and CSRA Report. The CSRA Report Template is available under Related Materials on the WBDG website for UFC 3-740-05.

9-9.5 VES Report.

If a VES is required, provide a copy of the latest version of the VES report.

9-9.6 Basis of Schedule.

Provide a schedule narrative to accompany the schedule. The scope of the schedule narrative will vary with project and contract complexity, but include at a minimum:

- Status of key milestone dates, including the project finish date.
- Explanations for key dates.
- Changes in network logic, including lags, date constraints.
- Relationship logic, and their effect on the schedule.
- Description of the critical paths, near-critical paths, and longest paths along with a comparison to the previous period’s paths.
- Description of significant scheduling software options that have changed between update periods, such as the criticality threshold for total float and progress override versus retained logic and whether or not resource assignments progress with duration.

9-9.7 Construction Schedule Native \1\ File and /1/ Report.

Provide the native construction schedule file (Primavera P6 or Microsoft Project, **\1** unless otherwise approved by the NAVFAC cost TDC) and a PDF schedule report. The report is to include fields for activity ID, activity name, the WBS of the activity parent folder, activity original duration, activity start, activity finish, predecessors, and successors. **/1/**

This Page Intentionally Left Blank

CHAPTER 10 DELIVERABLE: CONTRACTING REQUIREMENTS

10-1 GENERAL REQUIREMENTS.

The Contract Specialist incorporates line items from the information provided in the Project Information Form (PIF) and Price Schedule. Provide the PIF and Price Schedule in Microsoft Word or Adobe PDF format to the Government Project Manager who will provide it to the Contracting Specialist.

10-2 PROJECT INFORMATION FORM (PIF).

Prepare and provide a Project Information Form (PIF). The PIF communicates to the Contract Specialist which contract clauses to include in the solicitation. The Government Project Manager provides the PIF to the Contracting Specialist to prepare the contract clauses for the solicitation. A downloadable version of the PIF is available on the WBDG (https://www.wbdg.org/navy/project-information-form-specifications-cover-sheet/project-info-form).

10-3 SELECTION OF LINE ITEMS.

The Base Price line item must provide a complete and usable facility (primary facility, supporting facilities, and design for DB projects). Option items and additive items must be able to be logically separated from the project without rendering the facility unusable. Intention is for the Base Price, together with the line items, to provide the maximum, usable facility within the funds available. Do not use Additive and Option items in the same contract; use one or the other. Additive items are only allowed for sealed bids; do not use unless authorized by Contracting Officer.

Use multiple line items for cost breakdown of facilities and site, and unit prices as established in the price schedule template. Use multiple line items for multiple funding sources (such as when combining one or more projects into one contract package), and option or additive line items. Provide separate SUB-CLINs for (1) Each facility (as indicated by the Category Code), (2) The total project supporting facility (utility) cost (outside the 5 foot (1.5 m) line), and (3) Design Fee (if a DB project). The number of items and the estimated cost per item depends upon the nature of the project. Provide no more than four contract line items (base item, plus three), unless specifically approved by the Contracting Officer. Each estimated option or additive item should tend to approximate 2% to 10% of the estimated base item.

A downloadable version of the Price Schedule is available on the WBDG (https://www.wbdg.org/navy/project-information-form-specifications-cover-sheet/price-schedule).

10-4 OPTIONS AND ADDITIVES.

Options and Additives can change up to award of the contract. Do not indicate line items on the drawings, or reference anywhere in the specifications, unless approved by the Government, who may allow only if a description of the line item in the price schedule does not adequately describe the work.

Do not use the term “alternate” to represent line items. Do not use terms, such as “base item” to indicate items in the primary contract line item.

10-5 OPTION ITEMS.

Option items provide a means to separate the funding sources or to obtain and hold competitive prices for future award of items of work. Use option items when different funding sources are used (examples: Furniture, Fixture, and Equipment (FF&E), Electronic Security System (ESS) equipment, Audio Visual System (A/V) Equipment), or when funding is not available to cover certain portions of the work at the time of proposal opening, but there exists a high probability of attaining the funding in the near future. Typically, the price for the option item(s) is added to the base item price to determine the low offer. Options need not be listed in a particular order. They are executed individually at the Government’s discretion. A time limit is given in the contract documents for the Government’s right to execute each option. Use of options in construction contracts must be approved by the Contracting Officer prior to advertisement.

10-6 ADDITIVE ITEMS.

Since additive line items are only allowed in sealed bid, do not use these unless authorized by the Contracting Officer. If used, arrange additive items such that the most essential portion of the work is added first. Arrange succeeding items in decreasing importance. During evaluation of the offers, additive items are added to the base item in the order listed. As each additive item is added, a new bid price is computed and compared to the available funds. As additive items are determined to be within the funds available, they are added to the Offeror’s bid price. If they are not within the funds available, they are skipped. Each additive item must be independent of the others.

10-7 DEDUCTIVE ITEMS.

Do not use deductive items. The Base Price line item must contain the minimum requirements of the contract. Using deductive items implies that the project is designed above the minimum requirements. Use Options instead.

CHAPTER 11 DELIVERABLE: DB REQUEST FOR PROPOSAL (RFP)

11-1 GENERAL REQUIREMENTS.

Requirements for preparation of RFP are also provided in Chapter 12.

11-2 DB REQUEST FOR PROPOSAL INTRODUCTION.

NAVFAC Design-Build (DB) RFPs are developed by organizing project requirements into the NAVFAC DB Six Part Format to procure facilities for our Navy Customers and Users. Requirements included in the RFP are driven by the need to control the design and the construction of the facility. Because the Contractor is designing and constructing the facility, design issues are just as important as construction issues and must be given equal consideration. The RFP information may be gathered from many sources such as:

- DD Form 1391 Documentation
- Funding Documents
- Site conditions and Restraints
- User Requirements
- Local and Regional Requirements
- Applicable Standards and Codes
- Applicable NAVFAC and DoD Criteria and Clauses
- Performance and Prescriptive Product, Material, and System Requirements

RFPs are a combination of performance and prescriptive requirements, but give preference to performance requirements for DB. However, many times prescriptive requirements are necessary to define a minimum acceptable solution or expected level of quality. Therefore, mold the type of information included in the RFP to meet the anticipated level of quality and needs of the User. Create performance and prescriptive requirements that comply with the following characteristics of each.

- Performance requirements state the function, desired results, and durability to control the Contractor’s design and selection of products, materials, and systems.
- Prescriptive requirements define the products, materials, and system or their characteristics to control the facility function, performance, and quality.

11-3 DB REQUEST FOR PROPOSAL WEBSITE, FORMAT, AND DOCUMENTS.

Guidance on preparing the RFP for DB projects and DB Template documents are available on the NAVFAC DB Master website (https://www.wbdg.org/navy/ndbm). This site is intended to (1) familiarize those new to the NAVFAC DB process with the RFP format and typical RFP specification sections and (2) allow those preparing a DB RFP to download the current and archived electronic documents. The DB RFP website is organized using links to major components of the DB RFP, including:

- Overview and Training - NAVFAC RFP Format, UniFormat® Information Structures, and NAVFAC Technical Contacts responsible for document maintenance.
- Design Guidance.
- Standard Template – This is the foundation template that can be used on projects. The Standard Template is designed to cover most of the building types routinely designed and built by NAVFAC. Industrial and specialized facilities are examples of building types that require additional information to be added to the Standard Template to cover the design, materials, and equipment that are unique to these building types.
- Model RFP Templates - The Model RFP Templates use the Standard Template as its foundation. Each Model Template modifies the Standard Template to suit a particular building type. These Models are an advanced starting point toward creating an RFP, however they do require coordination with User and facility requirements to properly define the final RFP. The building type templates in the DB Master website are:
    - Armory
    - Child Development Centers
    - Dining Facility
    - Entry Control Facility
    - Fire Station
    - Fitness Center
    - Hangar
    - Magazine
    - Marine Corp BEQ
    - Market Style BEQ

- Small Project Template (SPT): The SPT is a scaled down version of the Standard Template to be used on projects of low-complexity and a limited number of construction trades. SPT projects utilize routine designs with limited plans and specifications and fit within monetary thresholds.

  o The table "Small Project Design-Guidance" is located with the SPT on the WBDG (https://www.wbdg.org/navy/ndbm/small-project-template) to provide guidance in the application of the SPT.

11-3.1 RFP Format.

The RFP must include the six RFP Parts indicated below unless they are not applicable to the project. The typical facility project will have information in every RFP Part, with the possible exception of RFP Part Five, "Prescriptive Specifications." Typically, Part One is not prepared by the RFP developer, but is provided by the NAVFAC Contracting office after RFP Parts Two through Six have been completed by the RFP developer. The RFP developer is required to provide certain information such as the Project Information Form (PIF) for the NAVFAC Contracting office to properly prepare the RFP Part One. Verify with the NAVFAC Facility Engineering Command, what provisions are necessary to allow for the RFP Part One to be integrated into the RFP.

The DB Templates utilize different types of information in different Parts of the RFP. Therefore, there are different information structures employed to organize the information in the different RFP Parts. The following list indicates the type of information and information structures are used in the RFP Parts:

- **Part One** includes the Proposal Form and Documents and specifies the contractual requirements.

  o This Part uses the Standard Procurement System documents that are organized using the CSI MasterFormat®.

- **Part Two** contains the General Requirements Specification Sections – some only available at the DB website.

  o This Part uses specification sections organized using CSI MasterFormat®.

- **Part Three** contains the Project Program for the project.

  o This Part predominately uses a paragraph format; Chapter Six of Part 3, the Engineering Systems Requirements uses UniFormat®.

- **Part Four** contains the Performance Technical Specifications.

  o This Part uses UniFormat®.

- **Part Five** contains Prescriptive Specifications required for the DB RFP.
  - o This Part uses CSI MasterFormat®.
- **Part Six** includes attachments to define existing conditions and design requirements (such as Boring Logs, reference drawings).
  - o This Part is a combination of various attachments that have no predominate format.

11-3.2 Recommend Change to DB Documents.

Submit a Contract Change Request (CCR) on the DB website to recommend a change to the DB documents.

11-4 DB REQUEST FOR PROPOSAL DOCUMENT PREPARATION.

The DB documents are updated and changed regularly. Because the DB documents change regularly, it is necessary to use the updated documents when creating an RFP. Download the most current versions available on the DB website. Each DB Template and Model RFP Templates has a DOWNLOAD feature. Download individual documents or documents organized into RFP Parts.

11-4.1 Combining Multiple RFPs into One Bid Package.

Refer to Chapter 8 for guidance, when multiple RFPs are combined into one solicitation package.

11-4.2 Project Information Form (PIF).

Provide and complete the PIF for Prefinal and Final submittals. Refer to Chapter 8 for further PIF requirements.

11-5 RFP ELECTRONIC DELIVERABLES.

Provide RFP electronically in accordance with Chapter 12. Organize the RFP into one or two PDF files, with order shown in the following Table of Contents. Bookmark each item below, and the additional items indicated.

1. RFP Coversheet
2. RFP PART 1 Divider (when directed by the Command)
3. Overall, RFP Table of Contents (Parts 2-6)
4. RFP PART 2 Divider

   \1\ /1/

   a. RFP Part 2 Specification Sections (bookmark first page of each section)

5. RFP PART 3 Divider
    a. RFP Part 3 Project Program Coversheet

    \1\ /1/

    b. RFP Part 3 Project Program
    c. Each Chapter of RFP Part 3 (bookmark first page)
    d. Each ESR in Chapter 6 (bookmark first page)
6. RFP PART 4 Divider

    \1\ /1/

    a. RFP Part 4 Performance Technical Specifications (bookmark first page of each PTS)
7. RFP PART 5 Divider (if prescriptive specifications are included in the RFP)

    \1\ /1/

    a. RFP Part 5 Specification Sections (bookmark first page of each section)
8. RFP PART 6 Divider

    \1\ /1/

    (1) Attachments (bookmark first page of each attachment)

11-6 DB DESIGN SUBMITTALS.

Provide design submittals electronically in accordance with Chapter 12. Include information and organize DB design submittals in accordance with this FC and UFGS 01 33 10.05 20.

11-7 DESIGN AND CONSTRUCTION SUBMITTAL REQUIREMENTS.

Because the DB projects require design and construction submittals, the submittals are more complex than DBB. The DB process utilizes the RFP and the UFCs to define design submittals and the RFP and the UFGS to define construction submittals.

11-7.1 Locations of DB Submittal Requirements.

Because the DB submittals are spread into different documents, the preparers of DB submittals are required to refer to multiple locations to obtain the complete submittal requirement. The design and construction requirements are found in the six major locations designated in the following table:

Table 11-1 Design and Construction Submittal Summary

DB DESIGN and CONSTRUCTION SUBMITTAL SUMMARY			
NO	DOCUMENT	LOCATION	SUBMITTAL REQUIREMENT
1	RFP Part Two UFGS Specs	NAVFAC DB RFP Website	
	A, Most RFP Part Two	RFP Part Two	Lists *Project Specific* Administrative Submittals for Government Approval
	B. UFGS 01 33 00.05 20 *Construction Submittal Procedures*	RFP Part Two	Lists *Project Specific* Government Reserved Construction Submittals for Approval or Surveillance
	C. UFGS 01 33 10.05 20 *Design Submittal Procedures*	RFP Part Two	Lists *Project Specific* Design Submittals
2.	Engineering System Requirements (ESR)	RFP Part Three	Lists *Project Specific* Design Requirements
3.	Performance Technical Specification (PTS)	RFP Part Four	Lists *PTS Specific* Critical Construction Submittals for DOR approval and Construction Submittal requirements
4.	Unified Facility Guide Specifications (UFGS)	Whole Building Design Guide Website	Edited UFGS specification required by RFP Part Two for Contractor's Design Submittal and Compliance to UFGS technical requirements
5.	FC 01-300-09N Navy and Marine Corps *Design Procedures*	Whole Building Design Guide Website	Lists *Discipline Specific* Design Submittals for NAVFAC to supplement Core UFCs
6.	Discipline Specific UFCs (Arch, Struct, Civil, Geotech, Mech, Elect, Fire Protection, Force Protection Anti-Terrorism)	Whole Building Design Guide Website, some temporarily on DB Website in Design Guidance web page	Lists *Discipline Specific* Design Requirements and Explanation of FC 01-300-09N listed design submittals

11-7.2 Government Approval and Surveillance of DB Submittals.

The RFP DB submittals are organized to allow the RFP editor the flexibility to evaluate the project needs, determine the availability of Government resources to review submittals, and modify the submittal approval requirements to suite the project. The following Government approvals are built into the RFP Part Two DB Templates but may need input from the RFP editor to tailor the submittal to the project:

a. RFP Part Two, UFGS 01 33 00.05 20, Submittals Reserved for Government Approval - RFP Part Two UFGS section submittals denoted with a "G" submittal action code.

b. RFP Part Two, UFGS 01 33 10.05 20, Government Approving Authority – Government approves each design submittal.

c. RFP Part Two, UFGS 01 33 10.05 20, Exception to Contractor Construction Actions – Identifies certain Government design submittals approvals that have to be accomplished before construction related to that design submittal can begin.

d. RFP Part Two, UFGS 01 33 10.05 20, Design Documents, and UFGS 01 33 00.05 20, Contractor Reviewing, Certifying, Approving Authority - Government identified construction submittals required to be incorporated in the design submittals. DOR approval of identified construction submittals precedes Government approval of associated design submittals.

e. RFP Part Two, UFGS 01 33 00.05 20, Submittals Reserved for Government Approval - Construction submittals reserved for Government approval. The approval of these identified construction submittals prevents the contractor from beginning construction on that portion of the work until Government approval is obtained.

11-7.2.1 Surveillance Submittals.

The Government requires the contractor's DOR to approve most of the construction submittals; however, the RFP identifies certain construction submittals for Government surveillance. Government surveillance does not prevent the contractor from proceeding with construction but allows the Government a chance to confirm the submittal approvals of the DOR. Surveillance of construction submittals are built into the DB Template at the following location:

RFP Part Two, UFGS 01 33 00.05 20, Submittals Reserved for Government Surveillance - Construction Submittals Reserved for Government surveillance.

11-7.2.2 Critical Path Submittals.

Contractor submittals in DB may be designated as Critical Path Submittals, as further described in UFGS 01 33 10.05 20 of the RFP. In this situation, the submittal may only contain the design of one or a few disciplines, for example, civil and structural. Follow the submittal requirements as applicable for the disciplines pertaining to that critical path submittal. Ensure that work is included and coordinated with the other disciplines that are affected by that critical path work; for example, electrical and mechanical site work is included and shown on the civil site work critical path submittal, and provisions are made for the utility service entrances through foundation and for major pieces of equipment for the foundation work critical path submittal.

This Page Intentionally Left Blank

CHAPTER 12 ELECTRONIC DESIGN DELIVERABLES (EDD) FORMAT

12-1 SUMMARY.

This Chapter sets the policy for NAVFAC compliance with DoD and Navy policy for paperless contracting systems. The DoD requires implementation of electronic bid solicitation at NAVFAC components for construction projects. These EDD requirements provide NAVFAC specific format guidance. Regardless of contracting method, projects must follow these EDD requirements. DB RFP submittals follow the requirements for the phase of design in the following paragraphs.

12-2 EDD.

The following electronic deliverables are required for projects:

- Contract Drawing source files
- Contract Drawings
- Input and output source files for structural calculations
- Specifications or RFP
- RFP source files
- Specification source files
- Calculations
- Cost Estimate
- Reports, Surveys and Studies
- Basis of Design
- eOMSI Facility Data Workbook (FDW)
- Project Execution Plan (PxP)*
- Design Model*
- Record Model*
- Record Drawings source files
- Record Drawings
- Shop Drawings/ transmittals
- Architectural Color Boards (photos) (where applicable)
- Submittal Register
- Other (such as Photos or Project background/ support files)
- Price Schedule (when required)
- High Performance and Sustainable Building Checklist (where applicable)
- TPC Checklist (where applicable)

* - Applies to BIM Projects Only

12-3 EDD FORMAT REQUIREMENTS.

12-3.1 Specifications.

Develop Project Specifications in accordance with the requirements of this FC and UFC 1-300-02, using SpecsIntact software. Organization of PDF for Specifications is described in Chapter 8. Organization of PDF for RFP is described in Chapter 11.

12-3.1.1 Specification Source Files.

From the SpecsIntact Job File, provide the following source files: “Pulldata” and “Submittal Register.” “Printdata” does not have to be provided.

12-3.1.2 DB RFP Part 2 Source Files.

Develop RFP and Part 2 specifications in accordance with Chapter 11 of this FC.

If a program other than SpecsIntact is allowed to be used, original source data must be provided as follows:

- The native authoring application file format.
- A PDF format print of the original authoring data. No scans, copied images, or third party reproductions of paper prints will be accepted.

12-3.2 Electronic Operation and Maintenance Support Information (eOMSI) Facility Data Workbook (FDW).

When required by the contract, provide the Excel workbook, which contains the Model & Facility Data Matrix tab (used to select Mastersystems, Systems, and Subsystems included in the design). Use the original eOMSI FDW source file, as referenced in Appendix E, for each project.

Complete the eOMSI FDW in accordance with the Instructions tab of the eOMSI FDW.

12-3.3 Drawings.

12-3.3.1 Drawing Definitions.

12-3.3.2 Drawing Source Files.

Produce source drawings using vector-based Computer Aided Design (CAD) software. Provide source drawing files in native format meeting the following requirements.

12-3.3.2.1 Contract Drawing Source Files.

Contract drawing source files are the native CAD files (such as plans, elevations, sections, details) created by the DOR for the project. The Contract Drawing Source Files are not the legal record of the project Design.

12-3.3.2.2 Contract Drawings.

The PDF files created from the Contract Drawing Source Files represent the scope of the projects. The Contract Drawings are the legal record of project Design which are awarded to the construction contractor (KTR) which includes amendments.

12-3.3.2.3 As-Built Drawings.

The hard copy prints of the Contract Drawings marked up by the KTR (in accordance with the project specifications) to represent approved changes to the Contract Drawings.

12-3.3.2.4 Record Drawing Source Files.

The Contract Drawing Source Files edited by the KTR or DOR (depending on contract requirements) to reflect the changes shown on the approved As-Built Drawings. Prepare Record Drawing Source Files as described in this Chapter, Record Drawing Preparation. Record Drawing Source Files are not a legal record of the Project.

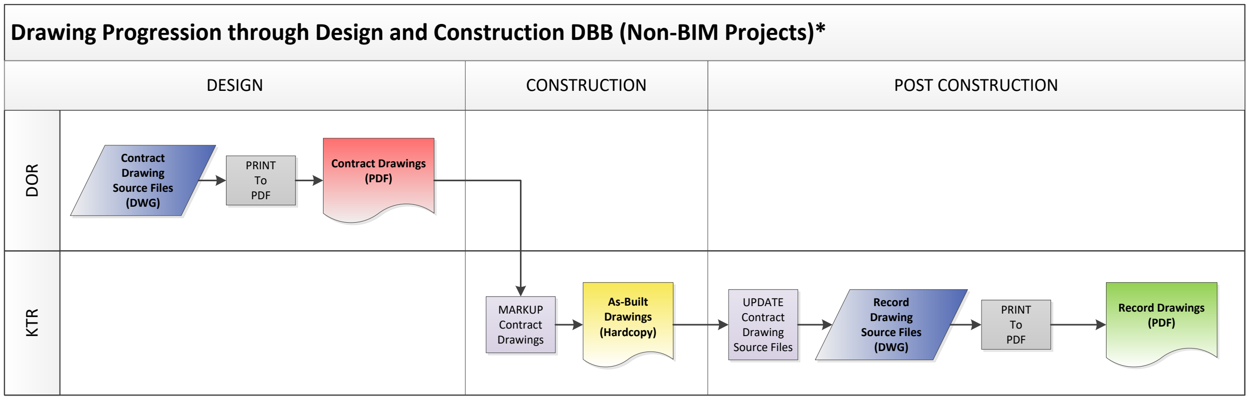
12-3.3.2.5 Record Drawings.

The PDF files created from the Record Drawing Source Files that represent the final installed condition of the project. Prepare the project Record Drawings as described in this Chapter, Record Drawing Preparation. The Record Drawings are the legal record of the completed project.

12-3.3.3 Drawing Progression.

Naming conventions and procedures as drawing progresses through design, construction, and post-construction are indicated in Figures 12-1 and 12-2.

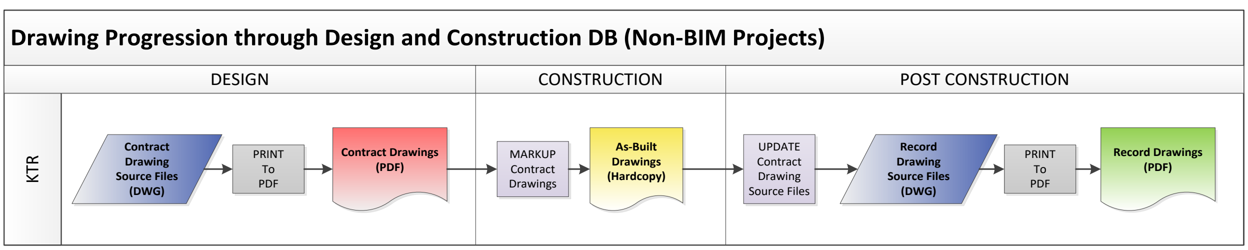
Figure 12-1 Drawing Progression Chart DBB



***This example reflects the KTR producing the record drawings.**

PRINT To PDF	**Print the source drawings to PDF files. The PDF becomes the legal record.**
MARKUP Contract Drawings	**KTR marks up the PDF Contract Drawings to reflect approved changes to the Contract.**
UPDATE Contract Drawing Source Files	**KTR updates the Contract Drawing Source Files to reflect the changes shown on the As-Built Drawings.**

Figure 12-2 Drawing Progression Chart DB



PRINT To PDF	**Print the source drawings to PDF files. The PDF becomes the legal record.**
MARKUP Contract Drawings	**KTR marks up the PDF Contract Drawings to reflect approved changes to the Contract.**
UPDATE Contract Drawing Source Files	**KTR updates the Contract Drawing Source Files to reflect the changes shown on the As-Built Drawings.**

12-3.3.4 CAD Standards.

CAD standards order of precedence are the requirements of this Chapter, then the latest versions of the DoD A/E/C CAD Standard and A/E/C Graphics Standard (A/E/C) then the National CAD Standard (NCS). In cases where the DoD A/E/C standards version changes after a project has commenced, the project PM must be consulted prior to adoption and integration of the newer standard into the drawing source files.

12-3.3.4.1 NAVFAC Standard Drawing Format.

Sheet drawings must use the NAVFAC standard title block (border sheet). Provide sheet drawings in ANSI D (22 x 34 inches) size format for projects using imperial units. Provide sheet drawings in ISO A1 (594 x 841 mm) for projects using metric units (ANSI D is assumed in other parts of this FC but modify and scale as appropriate if ISO A1 is used). See 12-3.7 NAVFAC Supported EDD Standard Components for border sheet templates and pen configuration table.

AutoCAD Source drawings must contain only one plotted sheet. Drawing source files which contain more than one sheet will be rejected with the following exceptions:

- Civil Sheet Files and other site plans (such as site utilities - electrical and telecommunications) in which the entirety of the project site cannot be legibly shown on a single sheet.
- Plan Sheet Files which the entirety of the project plan cannot be legibly shown on a single sheet at 1/8” = 1’– 0” (1 = 100) scale.

In both cases consult with the project PM prior to developing sheet files to ensure concurrence.

12-3.3.4.2 Plotting Guidelines.

AutoCAD pen weights and colors must be in accordance with the NAVFAC pen table. NAVFAC has developed a comprehensive pen table that utilizes the NCS 255-pen table as a basis but has added thinner lines and grayscale pens. Color numbers are assigned to “black” or “halftone” except where the pen table provides for color in other plotting applications. In the NAVFAC Revit templates, lineweights of model elements are scaled annotatively by default. Annotation lineweights have been adjusted to match the NAVFAC pen table for consistent plot results across disciplines. For BIM applications not using the Revit template or other BIM software, the plotted lineweights must match the NAVFAC pen table.

The NAVFAC Revit templates, the NAVFAC AutoCAD standard border, and the NAVFAC pen table references are provided on the WBDG (See paragraph 12-3.7 NAVFAC Supported EDD Standard Components). This pen table and corresponding line weights were established to be legible when printed at half-size (11 x 17 inches (279 x 431 mm)). Plotted files (hardcopy or PDF) must be monochrome unless color plots are specifically requested, for example, 3D representation (isometrics, perspectives, photographs).

12-3.3.4.3 Text Font and Size.

\1 Use standard and consistent text heights for a plotted full-size drawing throughout the project of 3/32 inch (2.4 mm) minimum, 1/8 inch (3 mm) preferred, for dimensions, notes, callouts, tables, schedules, and general typical text. Use 3/16 inch (5 mm) minimum for view title text, and 1 inch (25 mm) maximum for project titles on cover sheets. For existing features on plotted full-size civil drawings, a maximum oblique angle of 12 degrees is allowed. The text width factor must not be less than 0.8 for fonts in the body of the construction document. All fonts in the border, gutter, and cover sheets are 1.0 width factor, regardless of height. **/1/**

- Use the ARIAL.TTF font file for text less than or equal to 1/4 inch (6 mm).
- Use SWISS.TTF (Swis721 BT) font file for text larger than 1/4 inch (6 mm).

12-3.3.4.4 Translations.

Construction drawings are required to be prepared in dual language at a majority of overseas locations. For drawings developed in dual language, provide adequate space for the foreign language translation for objects such as notes, titles, and symbols. The final drawing must not appear cluttered or congested. Use italic font to distinguish the foreign language translation.

Location of translated text must be consistent across the drawing package, regardless of discipline. English on top, and the Host Nation language beneath, or on a following sheet when separate translation sheets are used. Refer below for acceptable locations:

- Translated text for Drawing Notes, Titles within the Drawing Area, and Symbols must be located directly beneath the English text.
- The following are acceptable locations for translated text pertaining to General Notes, Sheet Keynotes, or Schedules:
    - Beneath English text of each individual note or line item.
    - Grouped beneath the entire English General Notes, Sheet Keynotes, or Schedule table.
    - Where entire sheet consists of notes or schedules only, a separate translation sheet immediately following the English language sheet may be used. Use the proceeding sheet number and NAVFAC number for the separate translation sheet.

Consult with the project PM and DM prior to developing sheet files to ensure concurrence.

12-3.3.4.5 File Naming Conventions.

Use File Naming Convention for CAD Files as specified in the DoD A/E/C standard except as noted in Figures 12-3 and 12-4 below:

Figure 12-3 Model Files

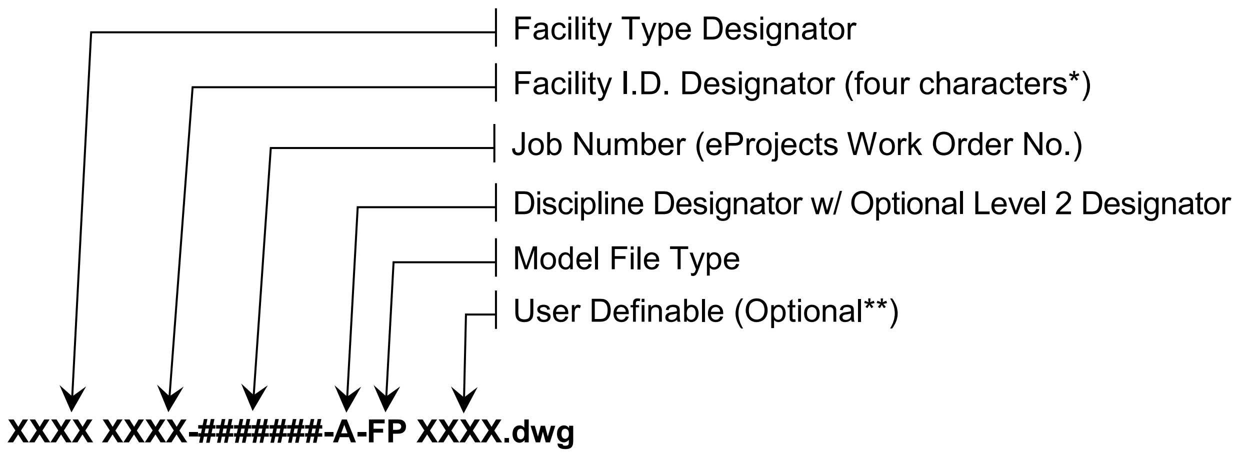
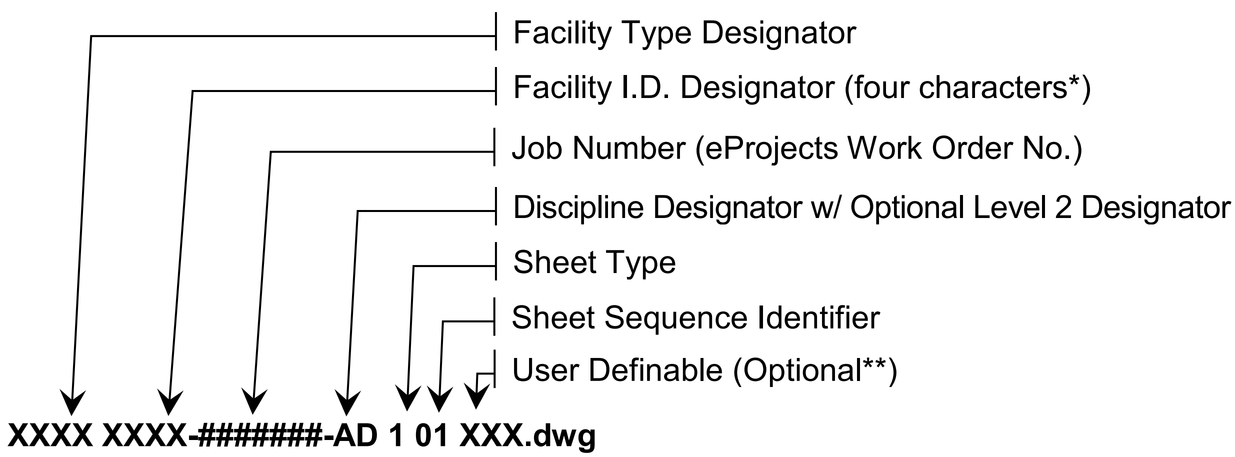


Figure 12-4 Sheet Files



* If no building designation has been assigned, such as for new construction prior to completion, then utilize the project number (P-number) for the Facility Type and I.D. designators. If installation has an alternate building identification system, that designator may be utilized in lieu of the Facility Type and Facility I.D. Designator.

** When used, typically the first two characters of the User Definable suffix address the floor number. Use the last two characters to further specify quadrants, phases, or wings. For example: BLDG0001-eProjectWON-C-101-12.dwg; The User Definable suffix "-12" is used here on a Civil plan sheet where multiple tabs/layouts contain (12) adjacent sheets that are connected by match lines.

Model file types, sheet file types, and discipline designators are found in the DoD A/E/C CAD Standards. Obtain the Facility I.D. Designator and Job Number from the Contracting Officer.

12-3.3.4.6 Facility Type and I.D. Designators.

Use Facility Type and I.D. designators in Table 12-1.

Table 12-1 Facility Types and I.D. Designators

Facility Type

AFLD	=	AIRFIELD
BLDG	=	BUILDING
DRDG	=	DREDGE
DRYD	=	DRYDOCK
BRTH	=	BERTH
PIER	=	PIER
SLIP	=	WET SLIP
PRKG	=	PARKING LOT
ROAD	=	ROAD
RAIL	=	RAIL
FENC	=	FENCE
GATE	=	GATE
UTIL	=	UTILITY
CRAN	=	CRANE

.

For **Utility** projects the Facility I.D. Designator must be as follows:

SWTR	=	SALT WATER
FWTR	=	FRESH WATER
PWTR	=	POTABLE WATER
NGAS	=	NATURAL GAS
STEM	=	STEAM
SSWR	=	SANITARY SEWER
STRM	=	STORM DRAIN
CAIR	=	COMPRESSED AIR
POWR	=	POWER
COMM	=	COMMUNICATIONS
CATV	=	CABLE TV

For **Rail** projects the Facility I.D. Designator must be as follows:

CRAN	=	CRANE RAIL TRACK
TRAK	=	RAILROAD TRACK

12-3.3.5 Drawing Support Files.

Support files necessary for initializing, editing, and plotting drawing files must be a standard DWG or Microsoft Windows® component (or they must be an integral and standard component within the drawing file that require no third party custom utility or program to use). Support files include, but are not limited to, line types, hatch patterns, font styles, layer filters, display configurations and object styles. DWG files containing objects, styles, or definitions that require external files (such as SHX, LIN or LAY) to initialize, operate and display properly will be rejected.

12-3.3.6 Cost Estimates.

Submit the cost estimate as indicated in Chapter 9 with each submittal.**\1\ /1/**

Use the following file naming convention for MII files incorporating the Award Fiscal Year (AFY) and WON:

AFY_WON_P#_Short Description_Location_Submittal_Date

Use the following file naming convention for the cost estimate package:

AFY_WON_P#_Short Description_Location_Submittal_Date_CEP

12-3.4 Preliminary Design Documents.

Preliminary design includes previous phases of design except for the Final Design phase. Source drawings and their associated PDFs must maintain a “PRELIMINARY NOT FOR CONSTRUCTION” stamp across the signature areas of the title block, until the actual final design submittal. The NAVFAC AutoCAD border has this block on the default layer “G-ANNO-TTLB-PRLM”. That layer must be frozen at the time of creating the final deliverables. Except for the final submittal, indicate the submittal phase designation, such as “PREFINAL”, after the project title on the coversheet of the drawings, and in the header and on the coversheet of the specifications or the RFP. Combine drawings into a single PDF file to facilitate ease of use unless file size requires a multi-file submission.

12-3.5 Final Design Documents.

12-3.5.1 General.

Convert source drawings to PDF format directly from their authoring software. Drawing PDF file sizes must be a maximum of 50Mb with digital signatures or a maximum of 50 sheets. There is no limit on file size for specifications or RFPs.

12-3.5.2 Format of Final Design Drawings.

Combine drawings into a single PDF file to facilitate ease of use unless file size requires a multi-file submission.

Bookmark PDF files and create visual “thumbnails.” Create a bookmark for the beginning of each drawing discipline. Create a sub-bookmark for individual drawing sheets. Bookmark wording must be as descriptive as practical (such as S-101 Foundation Plan). When complete, the files must open to the “bookmarks” view as the default view with the drawing sheets visible in “fit to page” magnification. Before submission to NAVFAC, the professional must electronically sign and seal sheets and appropriate locations on the NAVFAC Title Block(s). (See paragraph 12-4 NAVFAC Signature Electronic Requirements.)

12-3.5.2.1 Multi-File Drawings.

If the PDF drawing set must be broken into several PDF sets due to the file size restrictions given in paragraph 12-3.5.1 General, every attempt should be made to package complete discipline sets (do not break-up discipline specific sheets).

12-3.5.3 Format of Final Design Specifications.

Convert specifications to PDF format directly from their authoring software.

12-3.5.3.1 Preparation of PDF for Final Design Specification.

1. Merge PDF files for each section into one PDF file.
2. Combine the PDF files of the Coversheet, Table of Contents, and other project specific files including the Submittal Register. Insert blank pages where needed so that sections, graphics, and reports begin on an odd number page. Blank pages must include the following statement: “This Page Intentionally Left Blank.” Create “thumbnail” images of each page. Refer to Chapter 8-6 for NAVFAC Coversheet location.
3. Bookmark the Coversheet, Table of Contents, each Division, Section, and inserted graphics, including the Submittal Register and Environmental Forms, following the respective UFGS section. Each Division bookmark must read “DIVISION XX - DIVISION TITLE”, each Section bookmark must read “XX XX.XX XX - SECTION TITLE” and is a sub-bookmark of its corresponding division. SpecsIntact allows printing of the PDF in this format automatically; however, the coversheet and graphics must be inserted at the appropriate location and Bookmark.
4. Set the Document Properties of the PDF such that it opens to the first page and to the “bookmarks” view as the default view with the specification or RFP pages visible in “fit page” magnification.
5. Before submission to NAVFAC at Final, the principal design professional(s) must electronically sign the documents in accordance with paragraph 12-4 NAVFAC Electronic Signature Requirements.

12-3.5.4 Format of PDF for Final DB RFP.

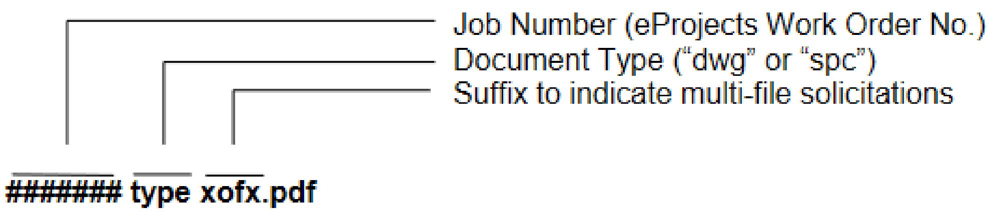
Provide PDF of RFP following the requirements for Specifications in paragraph 12-3.6.2 Source Documents, except add a bookmark for each Part. Insert attachments following the same convention.

If the RFP contains drawings, provide a separate PDF for the RFP and the drawings. Typically, reference drawings are provided in Part 6. This should be a separate file because of the sheet size (11 x 17 inches (279 mm x 432 mm) or 22 x 34 inches (558.6 mm x 863.6 mm)) and will facilitate printing of this file separately by the Contractor.

12-3.5.5 File Naming Convention for Final Design PDF Files.

File naming convention for the final design drawings and specifications is shown in Figure 12-5 below:

Figure 12-5 File Naming Convention for Final Design PDF Files



12-3.5.6 File Naming Convention for Amendments.

File naming convention for the Continuation Sheet is as follows:

Job Number (eProjects Work Order No.) Amend XXXX .pdf

For example, **55555Amend0001.pdf**.

File naming for attachments to the amendment follows guidance for naming specifications and drawings, with the exception that the amendment number must be included.

For example, **55555Amend0001dwg.pdf** or **55555Amend0001spc.pdf**

Combine attached drawing files into a single PDF file and attached specification files into a single PDF.

12-3.5.7 Password Protection of PDF Files.

Password protection to prevent changes to the PDF files is not allowed.

12-3.6 Record Documents.

12-3.6.1 Record Drawing Preparation.

Prepare Record Drawings in accordance with the drawing format guidelines of this Chapter and the following additional requirements. Make sheet changes **\1** directly in the authoring software format incorporating modifications and as-built conditions. In a BIM project, the authoring software DWG exports are from the BIM Record Model. **/1/** Use the CAD standards used for the Contract Drawings Source Files for as-built modifications and the following guidelines:

- AutoCAD: Make revisions on the original layer of the object being changed. Draw a "cloud" around the changed portion and place it on layer Z-ANNO-REVC. Place revision symbols, notes, and "Record Drawing Stamp", including those placed in each drawing's revision block, on the Z-ANNO-REVS layer.
- Revit: Make revisions to the Record Model elements. Using per sheet revision numbering, add the required Sequence Number(s) / Letter(s), Description(s), and Date(s) for the Amendment(s) / Mod(s). Draw revision cloud(s) around the changed portion(s) at the sheet level and assign the proper Revision sequence. Tag the cloud(s). The Revision Schedule on that sheet will populate MARK, DESCRIPTION, and DATE for Amendment(s) / Mod(s) clouded on that sheet. Make date entry in format MMM YYYY (ex. SEP 2023).
- Place a "Record Drawing Stamp" on each drawing sheet, as illustrated in Figure 12-6 below, for maximum visibility without conflicting with other pertinent data:

Figure 12-6 Record Drawing Stamp Example

RECORD DRAWING LETTER DATED – dd/mm/yy

Provide the following information on the revision block of Record Drawings:

- Sheets with No Changes → "**As-Built**"
  - Sheets with revisions to match final field conditions → "**As-Built Conditions Shown**"
  - Cover Sheet → "**RECORD DRAWINGS INCLUDE AS-BUILT CONDITIONS AND MAY NOT MATCH THE ORIGINAL CONTRACT DRAWING SHEETS.**"
- Type in the signatures, initials, dates, and SAT-TO information, in the title block area on the contract drawings, as text on the record drawings. The record drawings are not signed again by the DOR. The record drawings do not have to be sealed, and the seal from the DOR is not transferred.
- Provide extra sheets as required to accommodate sketches, amendments, and field changes. Obtain NAVFAC drawing numbers from the Design Activity for added sheets; these numbers will be out of sequence for inserted sheets. Typically, use the previous sheet designation followed by "A," "B," and so on for inserted sheets. Update the sheet index to reflect the final record drawing titles, sheet numbers, and NAVFAC numbers.

- Upon completion of the drawing modifications, save drawing files named as specified in this chapter.
- Produce a PDF file of each individual record drawing using a PDF page size that corresponds to the original document sheet size. Provide a PDF print resolution that results in clear detail of drawing features. Electronic signatures are not required.
- For DB Contractor provided drawings, the RFP reference or definitive drawings are not required for inclusion in the Record set of drawings.

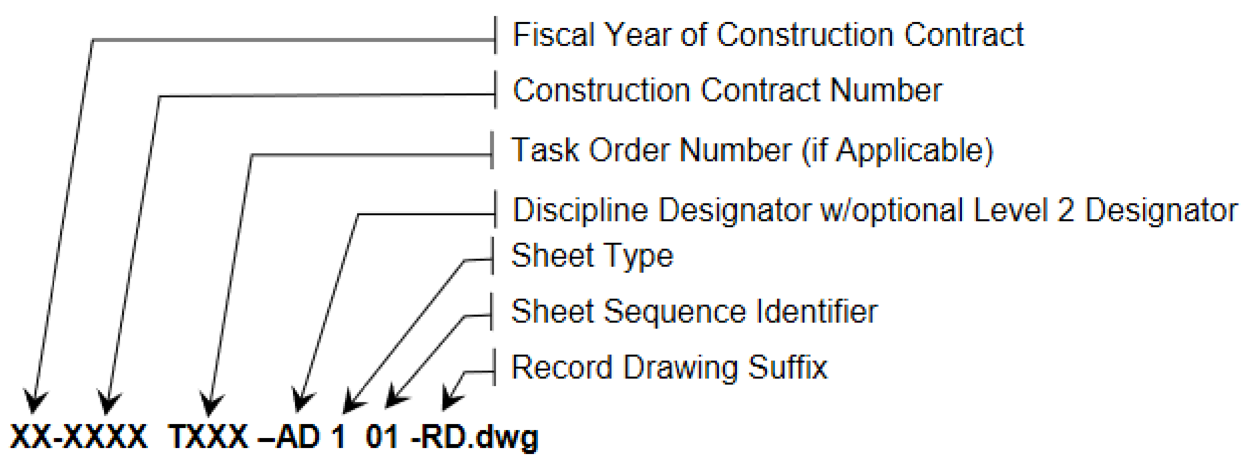
12-3.6.2 Source Documents.

In addition to the drawings, provide the specifications, design analysis, reports, surveys, calculations, and other contract documents utilized in creating the design package (drawings, specifications, and cost estimate) **\1** electronically on DODSAFE (https://safe.apps.mil/) or other approved secure site (coordinate with the Government Project Manager), **/1/** as specified in paragraph 12-6.3 Minimum Record Drawing Submittal Requirements. Provide the cost estimate and cost estimate backup (such as, quantity take-off or material or equipment quotes) on separate media.

12-3.6.3 Record Drawing Source File Naming.

The file naming convention for record drawing sources is shown in Figure 12-7:

Figure 12-7 Record CAD Files



12-3.7 NAVFAC Supported EDD Standard Components.

The WBDG contains the following NAVFAC standards for use on developing project deliverables: NAVFAC Standard CAD title blocks (border sheet templates) and pen configuration table at https://www.wbdg.org/navy/cad.

The standard CAD templates have incorporated the NAVFAC standards along with the DoD A/E/C CAD and National CAD Standards (NCS). The templates are available in

AutoCAD and Revit. These templates are available for use, but NAVFAC does not guarantee that they are without error and are not responsible for inaccuracies. NAVFAC is continually updating and improving the templates.

12-4 NAVFAC ELECTRONIC SIGNATURE REQUIREMENTS.

Federal legislation has established the legality and acceptability of electronic signatures (in accordance with Public Law 106-229). NAVFAC requires the use of electronic signatures for the certification of drawings and specifications. The following sections outline the requirements for electronic signatures on NAVFAC deliverables.

12-4.1 General Requirements.

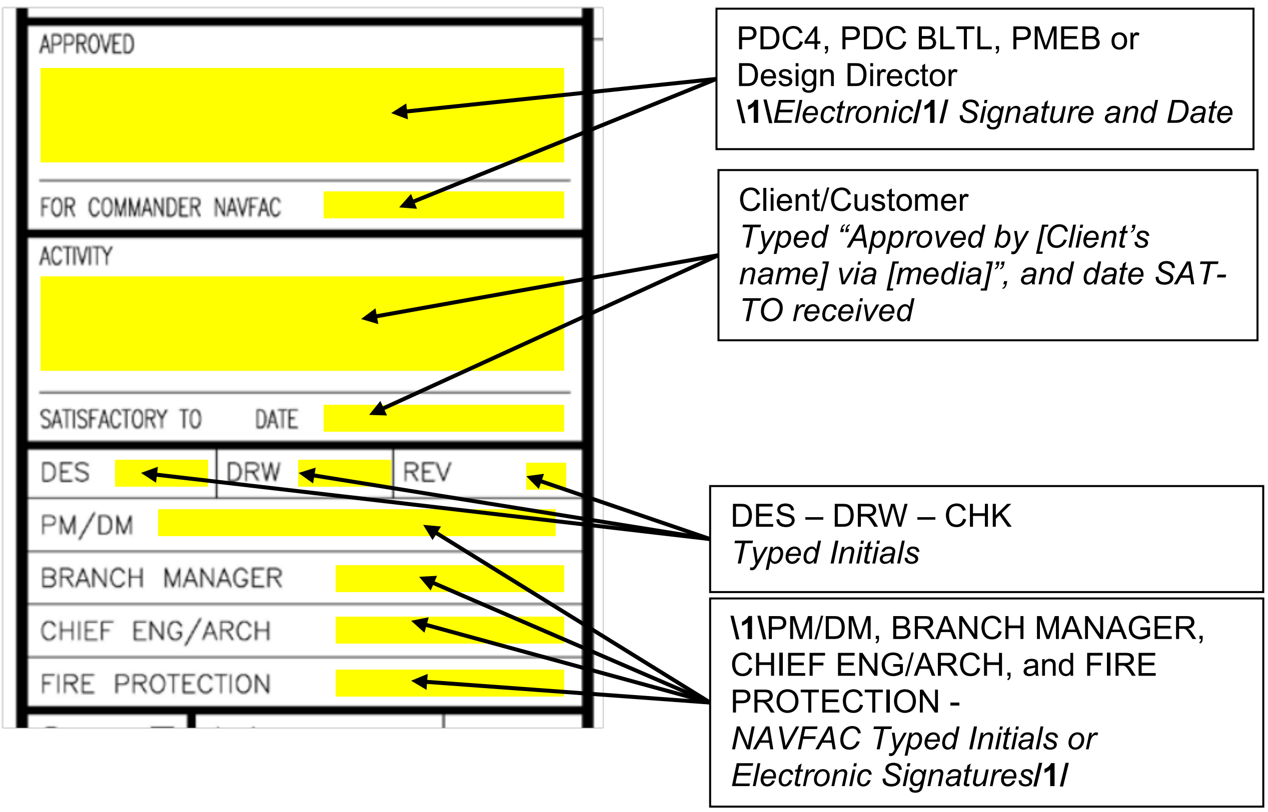
Prior to final NAVFAC signature, the following steps must be completed:

- Government Project Manager receives SATISFACTORY TO (SAT-TO) from the Client.
- Type “Approved By [Name of Client Representative] via [media (such as email or fax)]” in the ACTIVITY field, and the date the SAT TO was received, in the DATE field. SAT TO must appear on every drawing sheet in the CAD file.
- **\1\ /1/**
- Type in the initials of the “DES, DRW, and CHK” areas on the border to indicate the individual(s) who designed, drafted, and checked the sheet, respectively. These areas must display the responsible individual’s initials in the CAD file. The CHK initials CANNOT be the same as the DES and DRW initials.
- The “PM/DM, BRANCH MANAGER, CHIEF ENG/ARCH, and FIRE PROTECTION” fields are for use by NAVFAC **\1** and may be signed with Sign-it®, Bluebeam, **/1/** or initialed with CAD text. **\1** Signatures in these fields must be **/1/** a supervisor or has delegated signature authority under NAVFACINST **\1** 5216.1O. The CHIEF ENG/ARCH CAD text can be changed to reflect the signatory’s title; if this field is not used, the CHIEF ENG/ARCH CAD text in this field must be removed. **/1/** A signature block is shown in Figure 12-8.
- Provide an electronic seal in the title block labeled “SEAL” for each CAD sheet per the discipline responsible for the work contained on the sheet.
- **\1** The DOR must **/1/** electronically sign the PDF of the specification coversheet (RFP coversheet for DB RFP Preparer) and **\1\ /1/** the seal on each drawing PDF sheet, using Sign-it® **\1** or Bluebeam **/1/**. If the professional is required to submit “wet-signed” documents to be in compliance with their state regulations, then a separate “wet-signed” drawing and specification set may be submitted, meeting the requirements

of paragraph “Wet-Signed Documents”. A fully electronic solicitation, including electronic signatures is still required.

When the above steps are completed, NAVFAC will **\1** electronically **/1/** sign the “For Commander NAVFAC” in the title block on each Drawing sheet and on the coversheet of the Specifications. This is required on final designs including designs prepared under DB contracts.

Figure 12-8 NAVFAC Signatures



12-4.2 Specific Software Requirements.

Sign design documents using the Sign-it® **\1** or Bluebeam **/1/** software. Current version information, points of contact, and order forms for Sign-it® are located on the WBDG (https://www.wbdg.org/navy/cad).

12-4.3 Wet-Signed Documents.

If required, produce wet-signed documents from the final electronic PDF documents (prior to electronic signature application) submitted to NAVFAC.

12-5 BUILDING INFORMATION MANAGEMENT/MODELING (BIM) REQUIREMENTS.

For projects that require BIM, comply with requirements for Drawings and as follows.

12-5.1 BIM Definitions.

12-5.1.1 BIM Project Execution Plan (PxP).

The DOR is responsible for the PxP, which is a mandatory document that identifies in detail: key contacts, quality control, software used, model organization, and project deliverables when designing with a BIM application.

Download the PxP file found on the NAVFAC BIM Page of the WBDG (https://www.wbdg.org/navy/bim-eomsi).

12-5.1.2 3D Parametric Modeling Application.

A software application which uses select criteria, parameters, and variables to determine the characteristics (including length, width, height) of a Model Element and defines relationships between other model elements.

12-5.1.3 Model.

A digital representation of the physical and functional characteristics of a facility or a part thereof, comprised of Model Elements with Element Data.

12-5.1.4 Model Element.

A self-contained object within a Model with a unique identification, whose behavior and properties are defined by data fields (Element Data). Model Elements can represent a physical entity, such as a pump or a concrete wall, and range from the simple (a standalone pump) to the complex (a multi-component wall system).

12-5.1.5 Element Data.

The non-graphical information of a Model Element that defines the various characteristics of the object. Element Data can include properties such as parametric values that drive physical sizes (length, width, height), material definitions and characteristics (wood, metal), manufacturer data, industry standards (AISC steel properties), and project identification numbers. The required Element Data fields can be found in the Required Facility Asset Fields of the Model & Facility Data Matrix tab in the eOMSI FDW.

12-5.1.6 Design Model.

The Model created and delivered by the DOR which is developed to a specific Level of Detail (LOD) as defined in the Model & Facility Data Matrix tab of the eOMSI FDW.

12-5.1.7 Record Model.

The Design Model modified by the KTR or DOR (depending on contract requirements/delivery method) which incorporates the real-world conditions of the facility as constructed.

12-5.1.8 Facility Data Workbook.

The Facility Data Workbook (FDW) defines the BIM Levels of Detail (LOD) required for each system, during design. The FDW is initially populated during design and completed during construction with the actual components and systems provided. The FDW is provided as part of UFGS 01 78 24.00 20 and required in accordance with paragraph 7-2 Building Information Management and Modeling (BIM).

12-5.2 Minimum Modeling and Data Requirements.

12-5.2.1 General.

Use 3D Parametric Modeling Application(s) to develop the Design Model(s) based on the project scope.

12-5.2.2 Model & Facility Data Matrix.

DOR completes the Model & Facility Data Matrix tab of the eOMSI FDW (XLS) utilizing the Instructions tab found in the eOMSI FDW. Download the eOMSI FDW from the NAVFAC BIM Page of the WBDG (https://www.wbdg.org/navy/bim-eomsi).

12-5.2.3 Model Files.

Produce an independent Design Model for each discipline that can be linked to each other. Document the Model names and Model links in the PxP.

12-5.2.4 Element Data.

Use the Required Facility Asset Fields (Element Data) specified in the Model & Facility Data Matrix tab of the eOMSI FDW for modeled elements.

12-5.2.5 Room Space Data.

Include room space data defining net square footage and net volume to develop the room finish schedule including room names and numbers.

12-5.2.6 Schedules.

Produce Schedules (Finish, Room, Lighting, Plumbing, Equipment, Openings) from the Model Elements and Element Data within the Model.

12-5.3 Design Model.

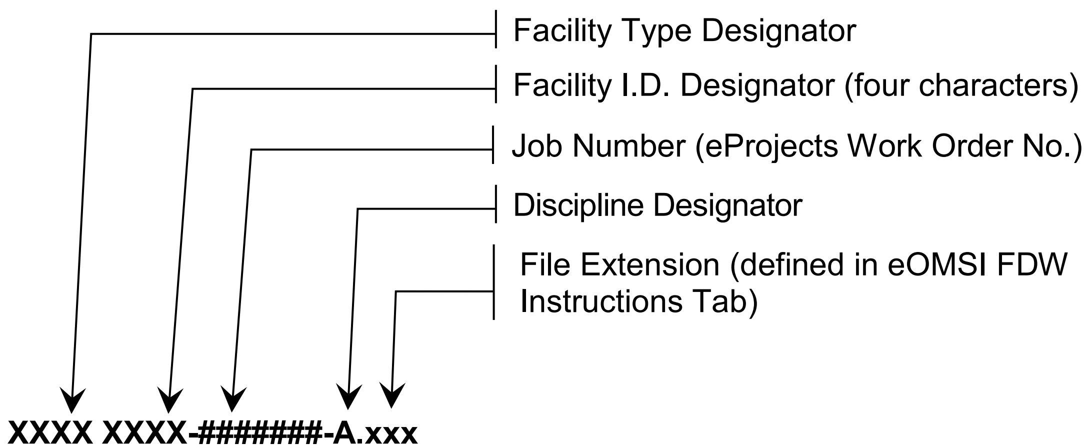
DOR develops the Design Model using a 3D Parametric Modeling Application to produce a complete set of Contract Drawings. Submittals must be compatible and editable using their native software as defined in the PxP.

12-5.3.1 Design Model Naming Convention.

Refer to Table 12-1 for the Facility Type and Facility I.D. Designators.

Use the naming convention found in Figure 12-9 for BIM Design Models files:

Figure 12-9 BIM Design Model Naming Convention



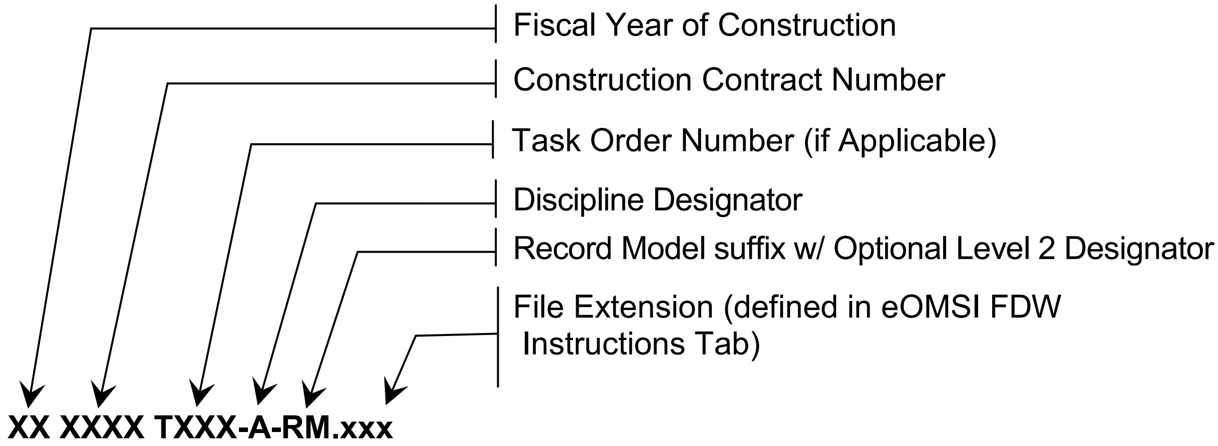
12-5.4 Record Model.

KTR develops the Record Model by modifying the DOR's Design Model as the facility is being constructed. Utilize the Record Model Grade specified in the Model & Facility Data Matrix tab in the eOMSI FDW.

12-5.4.1 Record Model Naming Convention.

The file naming convention for record models is shown in Figure 12-10 below:

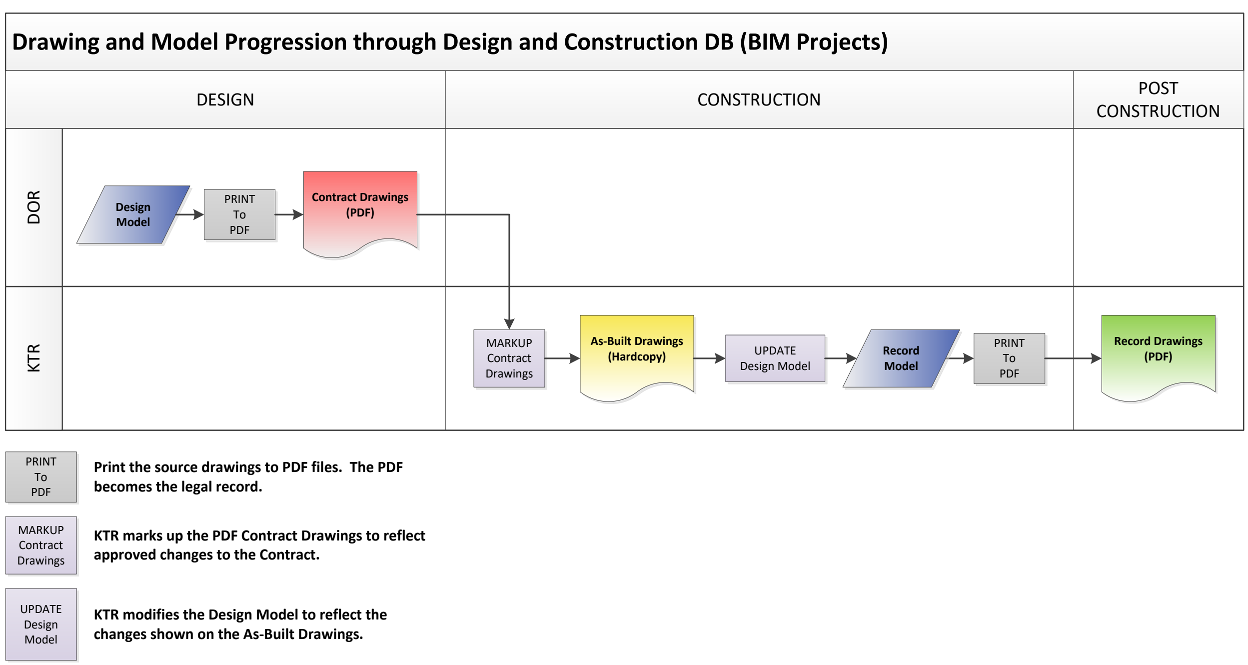
Figure 12-10 Record Model Naming Convention.



12-5.5 Drawing and Model Progression.

Model and Drawing naming conventions and procedures are indicated in Figure 12-11.

Figure 12-11 Drawing and Model Progression DBB



12-5.6 BIM Submittal Requirements.

12-5.6.1 Visual Review Report.

The DOR must produce a report (PDF) which compares the Mastersystems, Systems, and Subsystems list in the Design Model with the Mastersystems, Systems, and Subsystems list identified in the Model & Facility Data Matrix tab in the eOMSI FDW at each Design Phase. Identify discrepancies (omitted and unintended Model Elements) between the two lists, including an explanation for each. Address omitted and unintended Mastersystems, Systems, and Subsystems in the Design Model by Final Design. Provide a written explanation for omitted and unintended Model Elements that remain in the Design Model.

12-5.6.2 Clash Detection Report.

The DOR must conduct a clash detection of the Design Model at each design phase. Provide a report (PDF) at each phase showing existing clashes in the Model. The final Clash Detection report must reflect zero clashes.

12-5.6.3 Format of PxP in Preliminary Design.

Provide PDF file of PxP.

12-5.6.4 Format of Final Design Model.

Provide the final Design Model in native format and exported CAD files in DWG format.

12-5.6.5 Format of Final Record Model.

Provide the final Record Model in native format and exported CAD files in DWG format.

12-5.6.6 Facility Data Workbook (FDW).

Provide the Facility Data Workbook in Excel format.

12-6 EDD MEDIA AND ORGANIZATION.

12-6.1 General.

Provide Official submittals **\1** electronically on DODSAFE (https://safe.apps.mil/) or other approved secure site (coordinate with the Government Project Manager). **/1/** Submit CAD files in native Drawing (*.DWG) format in the NAVFAC supported version. Drawing files must be uncompressed and unzipped. Purge files of unused items (blocks, layers, line types, and nested items). Do not submit single drawing files with multiple layouts except as described in paragraph 12-3.3.4.1 NAVFAC Standard Drawing Format. Do not bind cross referenced parent and child drawings. If the submitted native DWG files are not the native file format for the authoring software, provide native design data in the original authored format in addition to the native DWG compliant format.

12-6.2 Minimum Final Submittal Requirements.

Provide the following as a minimum at final design submittal. NAVFAC Components may require additional submittals**\1\ /1/**.

\1\ /1/ #1 - Final Design or RFP for Government Signature\1\ /1/

Drawing PDF file(s) electronically signed by the Professional(s) in Responsible Charge

RFP or Specification PDF file electronically signed by the Professional in responsible charge in the "Submitted By:" Section

\1\ /1/ #2 - Source Files\1\ /1/

/CAD Native CAD Files for disciplines; include X-refs, images, or other external reference files.

/BIM (for BIM projects only) Native BIM models, PxP, Visual Review Report, and Clash Detection Report.

/eOMSI FDW

/Specifications folder - Specification source files

/PullData folder (*.sec files)

/RFP folder - Source files of RFP package, further divided by subfolders into Parts, except for specification section files or CAD files.

/Calculations folder (pdf and input/source files)

/Support folder

/Reports-Surveys - Studies folder

/Basis of Design folder

/Architectural Color Boards folder (photos)

/Other folder (such as Photos, Project background/support files)

\1\ /1/ #3 - Cost Data\1\ /1/

12-6.3 Minimum Record Drawing Submittal Requirements.

Submit **\1** record drawings **/1/**. Each must have the following folders and content.

/Record Drawings/

/CAD - Record CAD files and X-refs for disciplines must be stored in the same folder (directory).

/PDF

/Specs

/Calcs

/Cost

/Basis of Design

/Other

CHAPTER 13 PHASE: PRELIMINARY DESIGN: DON MILCON

13-1 GENERAL REQUIREMENTS.

Preliminary Design for the Department of the Navy, Military Construction (MCON) requires development of Preliminary Design Deliverables to ensure that projects submitted for Congressional and Presidential approval contain sufficient planning, accurate construction scope, adequate documentation, and a valid cost estimate for successful execution. For "Blue Navy" MCON projects, Preliminary Design begins upon substantial completion of advanced planning after the issuance of Budget Project Readiness Index (PRI) Authority (BPA). For "Green Navy" MCON, MCNR and Family Housing projects, Preliminary Design begins with issuance of Preliminary Design Authorization (PDA).

13-2 PRELIMINARY DESIGN.

Preliminary Design is authorized for development of Preliminary Design Deliverables including a budget-ready DD Form 1391 for submission into the Department of Navy's (DoN) Military Construction budget, through the facility programming process. The purpose of Preliminary Design is to validate planning requirements and develop Preliminary Design Deliverables and cost estimate for MCON projects. Upon issuance of authority to start Preliminary Design, Preliminary Design Deliverables and a cost estimate are prepared to ensure MCON projects submitted for Congressional and Presidential approval contain sufficient planning, accurate scope, a minimum set of design deliverables, and a construction cost estimate for successful contract award and execution.

Preliminary Design Deliverables as described in this chapter do not have the same level of detail as the Schematic Design Submittal described in Chapter 14. Although many of the same requirements are contained in both submittals, they are developed for different purposes.

13-3 PROJECT PLANNING DD FORM 1391 ASSESSMENT.

Conduct an assessment of the existing project planning documentation, including the DD Form 1391, developed during the advance planning phase. **\1** Refer to the Consistency Review Board (CRB) Guidelines and DD Form 1391. **/1/**

13-4 ROLES AND RESPONSIBILITIES.

DD Form 1391 documentation is the combined result of a team project development effort from planning through the end of preliminary design. DD Form 1391 content is divided into blocks. Some blocks cover Designer or Project Manager prepared information, while other blocks are dedicated to Planning data. Responsible entities for DD Form 1391 content are as follows:

- Block 9, Cost Estimates: Project Team

- Block 10, Description of Proposed Construction: Project Team
- Block 11, Requirement: Public Works (PW) Directorate Real Property Manager and Activity/Region
- Block 12, Supplemental Data: PW Directorate Real Property Manager
- Block 12, Budget Estimate Summary Sheet: Project Team
- Block 12, Estimated Design Data: Project Manager
- Block 12, Equipment from Other Appropriations: Project Manager, PW Directorate Real Property Manager and Government Activity/Region

13-5 PRELIMINARY DESIGN DOCUMENTATION.

The project documentation establishes the basic requirements needed to meet the mission of the Support Command.

13-5.1 Preliminary Design Element.

Elements of the project documentation for most facility projects include: a DD Form 1391 in **\1** Programming Administration and Execution (PAX) **/1/** format with detailed construction scope, collateral equipment list with cost, and preliminary budgetary cost information for primary facility and supporting facilities (for example, utilities, connections, and site work). Authority for Preliminary Design will only be issued once the advanced planning is substantially complete and the Project Planning DD Form 1391 sufficiently addresses the following elements:

- Site Identification & Approval
- Economic Analysis with updated costs
- Facility Planning Data
    - o Basic Facility Requirement (BFR)
    - o Facility Planning Document (FPD)
    - o Planning Study (for example, utility, traffic, asbestos, lead, radon)
- Equipment List and Cost
- Project Cost
- Environmental, Historic, Cultural Resources Impacts
- Project Requirements Schedule, and Engineering Studies (Utilities, Anti-Terrorism (AT), Physical Security, Geotechnical, Site, and Structural)

13-5.2 Preliminary Design File Naming Convention.

Use the file naming convention shown in Figure 13-1 for Preliminary Design files and Element Extensions provided in Table 13-1. **\1** This is required for uploading documents into PAX. **/1/**

\1\ /1/

Figure 13-1 Preliminary Design File Naming Convention

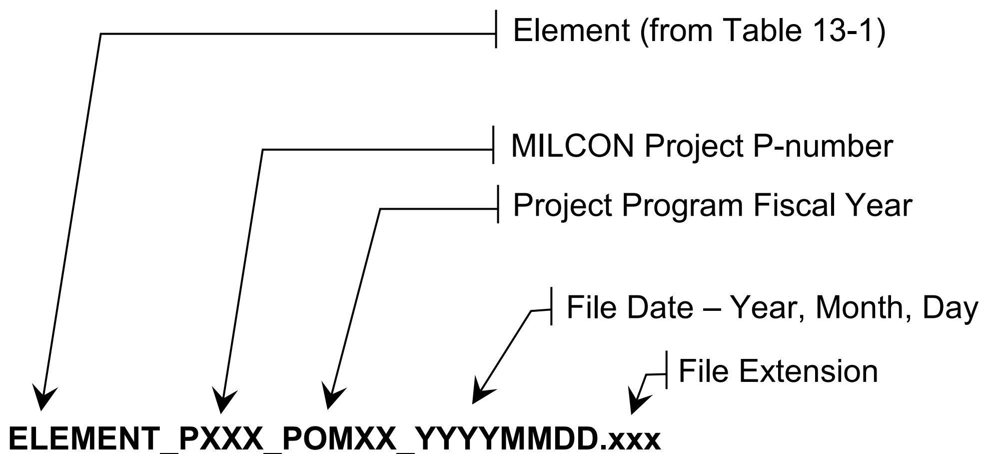


Table 13-1 Element Extensions and Examples

Element Description	Element	Example
Site Identification and Approval	SITE PLAN	SITE PLAN_P001_POM19_20150501
Economic Analysis	ECON ANALYSIS	ECON ANALYSIS_P001_POM19_20150501
Facility Planning Data	BFR	BFR_P001_POM19_20150501
	FPD	FPD_P001_POM19_20150501
Planning Study (Utility, Traffic, Asbestos, Lead, Radon)	PLAN STUDY	PLAN STUDY_P001_POM19_20150501
Equipment List	EQUIP LIST	EQUIP LIST_P001_POM19_20150501
Cost Estimate Package	CEPBKUP	CEPBKUP_P001_POM19_20150501
Design Deliverables	DDBKUP	445BDDBKUP_P001_POM19_20150501
Environmental & Cultural/ Historical Resources Impacts	ENV	ENV_P001_POM19_20150501
Engineering Studies (Utility, Independent Facility Structural, Seismic Assessments, Geotechnical, Energy, AT, Physical Security)	ENGR STUDY XXX (XXX = Type of Study)	ENGR STUDY UTILITY_P001_POM19_20150501

\1 The exception to the naming conventions shown in Table 13-1 is for the MILCON Checklist, where FYXX is the fiscal year of the Project and PXXX is the Project's P-number. The submittal name is either RegFEC_Team_Final, Program_Final, or Certified_Final. See below Table 13-2. **/1/**

Table 13-2 MILCON Checklist File Naming Conventions

File Name
FYXX PXXX_MILCONChecklist_Submittal_Name

13-6 PRELIMINARY DESIGN CHARETTE.

Conduct a charrette with project stakeholders and multi-disciplines as applicable to develop Preliminary Design Deliverables. The multi-disciplinary design effort examines project functions, validates requirements, and analyzes alternate concepts.

13-6.1 Format.

The preliminary design charrette format consists of multiple work-sessions (usually 2-3 work-sessions), over a week-or-greater timeframe. Both the number of work-sessions and the time between work-sessions is dependent on project size and complexity, as well as the completeness of prior project planning efforts. Complete the site engineering investigation, described in paragraph 13-12 Cost Estimate, prior to or coincident with the preliminary design charrette.

Initial charrette work-sessions focus on validating project planning documents, analyzing project functions, and presenting notional concepts and alternatives for the site and facilities. The preliminary design charrette format is iterative; follow-on work-sessions feature presentation of revised project concepts and discussion leading to refinement of the product.

13-6.2 Participation.

Engage project stakeholders in the preliminary design charrette. As a minimum, include the following team members:

- Project Manager, Cost Engineer/Estimator and Project Technical Team, including the Design Manager, Architects and Engineers from disciplines needed to support the preliminary design.
- Customer Representatives, including but not limited to: End User, Project Sponsor, Subject Matter Experts.
- Base Facilities Representatives, including Planners, Utility Managers and Technical Staff, Installation Security Officer, Environmental Technical Staff, Construction Management Staff, Base Communications Officer (BCO), Cybersecurity Stakeholders (for example, NAVFAC Echelon IV CIO4 and CIO2).
- Privatized utility system owners.

13-7 IDENTIFICATION OF UNIQUE PROJECT REQUIREMENTS.

Identify and coordinate unique project requirements during the preliminary design charrette. Coordinate costing and development of unique requirements identified by the Project Technical Team, or other appropriate personnel, of issues not related to design. Unique requirements that are prone to be overlooked include:

- Construction restrictions due to airfield/waterfront operations

- Explosive Safety Site Approval
- Temporary facility requirements
- Laydown areas which may include offsite areas that increase project cost, such as batch plants for large pavement projects and stockpiling area for contaminated material
- Construction phasing requirements
- Locating property lines and other land restrictions, such as easements
- Security and Anti-terrorism requirements (Controlled Areas)
- Environmental issues, including hazardous material abatement, radon mitigation, permitting, and NEPA
- Cost of disposing hazardous materials
- Seismic, fire protection and sustainability triggers for renovation projects
- Host Nation Requirements (for overseas projects; for example, verify if energy or renewable requirements)
- On Installations with privatized utilities (such as gas, water, electric), coordination with the Privatized utility system owners for utility system connections and upgrades to the utility system. Utilities cannot be disturbed without the written consent of the privatized utility owner. Ensure utility system costs are included in the DD Form 1391.

13-8 DD FORM 1391.

Prepare updates to the project's DD Form 1391 documentation for submission in **\1** PAX **/1/**. Conform to the following, latest guidance provided by the Government MILCON Manager:

- Consistency Review Board (CRB) Guidelines & DD Form 1391 Development
- Budget Quality DD Form 1391 Editing and Style Guidelines
- POM Preliminary Design Guidance for applicable MILCON Program Budget Year

13-9 PRELIMINARY PROJECT NARRATIVE.

The project narrative, along with the drawings, documents the preliminary project design that facilitates the budget-ready project cost development. Preliminary design is driven by the requirements identified by Project Stakeholders, Government Project Planners, and applicable design criteria. The preliminary design is not constrained by a pre-determined budget.

Identify the following in the project narrative document:

13-9.1 Description of Proposed Construction.

Revise and enhance Block 10 statements in the prior DD Form 1391 that was prepared during planning. Prepare description of proposed construction in compliance with Block 10 requirements in "CRB Guidelines & DD Form 1391 Development" and "Budget Quality DD Form 1391 Editing and Style Guidelines." Use verbiage prepared for this portion of the Project Program for Block 10 of the budget-ready DD Form 1391.

13-9.2 Project Objectives.

Identify the Mission Statement and Facility Function. Describe issues that need to be considered in future project development, including, but not limited to: Project Specific Priorities, Workflow Processes, Appropriate Design, Special Design Challenges, Adaptability and Flexibility, and target dates for Initial and Full Operating Capability (IOC/FOC).

13-9.3 Site Analysis.

Define existing site conditions and site development requirements. Identify constraints that restrict development. Project cost can increase for sites that are developable but constrained – and require special considerations to build on the site. Describe situations where the site location is associated with other-agency or Command approval processes (for example, NOSSA, SHPO, NEPA, NAVAIR). Refer to Paragraph 13-13 Site Engineering Investigation.

13-9.4 Building Requirements.

Develop the facility preliminary design concept. Describe primary blocks, such as, interior spatial areas, workflow/processes, functional relationships, circulation patterns, equipment/storage requirements, and security issues. Schematically tabulate facility floor area requirements on a room-by-room basis. Verify that floor plan area requirements identified by the functional analysis match Facility Planning Documents (FPD), prepared by Government project planners.

13-9.5 Host Nation Requirements.

For OCONUS projects, identify host-nation requirements, such as energy or renewable requirements or others.

13-10 DISCIPLINE-SPECIFIC BASIS OF DESIGN.

Develop separate and condensed summaries for core disciplines (in reference to the Core UFCs defined in UFC 1-200-01) including: Geotechnical, Civil, Landscape Architecture, Architectural, Structural, Fire Protection, Mechanical, and Electrical.

Provide sufficient definition in the discipline-specific Basis of Design to support the development of a cost estimate for that discipline.

13-10.1 Building Systems.

For the building systems (such as architecture, structural, mechanical, electrical, fire protection), identify the discipline-specific design assumptions, as required to support a parametric estimate on the Primary Facility. Consult with interior design personnel for select projects, where unique interior design requirements cannot be captured by standard parametric estimating techniques for the facility-type. Ensure that risks associated with facility systems identified, typically on the Preliminary Hazard List (PHL) or Preliminary Hazard Analysis (PHA) if developed prior to the Preliminary Design, are mitigated, or have engineering controls to eliminate the risk.

13-10.2 Site.

For the site, including utility systems (for example, civil, electrical, telecommunication) identify the design assumptions for Supporting Facilities, as required to support quantities and unit costs. Consult with landscape architecture personnel for select projects, where a portion of total costs may be associated with landscape architectural requirements.

13-10.3 Cybersecurity Impact Level.

Indicate the Cybersecurity Impact Level for the control systems. Provide project-specific requirements.

13-10.4 Ratio of Renovation Cost to Replacement Cost.

For renovation projects, provide an analysis of the ratio of renovation cost to replacement cost (see UFC 3-701-01 for the definition of replacement cost). Clearly identify ratios that trigger additional facility upgrades (such as AT, Physical Security, seismic evaluation and retrofit, and sustainability). Re-address the costs in the Economic Analysis provided from the Project Planning development phase.

13-10.5 Narratives.

In addition to basis of design narratives for core disciplines, provide separate narratives for the following cross-disciplinary elements. Devote special attention to issues that may have significant impact such as:

- AT – Discuss AT with the customer and identify AT requirements that have significant cost impact including full compliance with UFC 4-010-01 and progressive collapse avoidance.
- Sustainability – Indicate the feasibility of meeting Guiding Principle requirements and other sustainability goals for the project in accordance with UFC 1-200-02. Include a draft NAVFAC High Performance Sustainable Building (HPSB) Checklist. Where TPC is an anticipated requirement, develop a draft TPC checklist. Discuss the scope for

commissioning, to include systems to be commissioned, development of required documents, and Commissioning Provider contracting method.

13-11 PRELIMINARY DRAWINGS.

Prepare preliminary design drawings or sketches, for the purpose of:

1. Clearly illustrating the basic project scope to stakeholders, and
2. Supporting development of the parametric cost estimate.

Preliminary design drawings or sketches need not feature the level-of-detail or format specified in Chapter 7; especially where highly complex drawings could detract from the primary intent. Include the following:

- Vicinity Map and Location Plan
- Demolition Plan: Show facilities to be demolished (if required)
- Site Plan(s):
    - Show the layout (size and possible shape) of the new facility in relation to major landmarks.
    - Show the possible location of access roads, parking, landscaping, pedestrian walkways, plazas and patios, landscape structures, roads, and sidewalks, as applicable.
    - Indicate approximate dimensions and orientation.
    - Clearly indicate site constraints such as explosive safety arcs, flood zones, wetlands, or other environmentally sensitive areas.
    - Where AT and Physical Security is applicable, clearly depict setback distances to vulnerabilities, including parking, roadways, and obstructions.
    - Provide a Building Code site plan showing the assumed property lines of adjacent structures.
- Utilities Plans:
    - Show utility lines and their points of connection in relation to existing adjacent structures, roads, and utilities.
    - Show off-site utility upgrade requirements needed to support the project.
    - Show civil, mechanical, electrical and telecommunication utilities to clearly convey the scope and quantities associated with various utility improvements.

o On large utility distribution projects, provide one-line diagrams of electrical and telecommunication utilities.

o Show mechanical building utilities coming into the building (for example, water, sanitary sewer, gas piping, and steam.

- Building Floor Plans:

  o Provide floor plans depicting functional utilization of spaces. Incorporate Collateral Equipment (CEQ) and Furniture, Fixtures and Equipment (FF&E) into the design development and indicate on building floor plan(s).

  o For renovation projects, provide separate drawings to identify existing conditions, demolition, and new construction elements.

  o Provide mechanical and plumbing floor plans to include utilities coming into the building (for example, water, sanitary sewer, gas piping, and steam), and major pieces of equipment with clearances (for example, water, heater/storage tank, HVAC equipment, and pumps).

- Building Elevations: Provide elevations that depict the building character and indicate materials.

13-12 COST ESTIMATE.

Cost estimate class requirements are a minimum Class 3 in accordance with AACE RP 56R-08. NAVFAC Headquarters may issue project specific guidance at Preliminary Design start. Cost estimate methodology and cost tools are addressed in Chapter 9.

Project definition deliverables are required to be commensurate with the required estimate class. Refer to Appendix B, Table B-1 for class-specific project definition deliverables requirements. Appendix B, Table B-2 is the minimum requirement for Preliminary Design.

13-13 SITE ENGINEERING INVESTIGATION.

Supplement known site information/studies and examine high risk cost elements by conducting on-site utility investigation and site engineering studies to include soil borings and analysis, topographic analysis, fire flow tests, and flood projections and mitigation studies.

Evaluate if site information obtained as part of the preliminary design effort is sufficient to proceed with the full-design of the proposed facility. If sufficient data is not available, provide a list of additional site investigation needed to proceed with design.

13-13.1 Utility Investigation.

Locate and identify the nearest points of connection for utilities. If the points of connection are outside the project boundaries, provide additional information that shows the locations.

- Verify Project Planning DD Form 1391 identified point of connection.
- Retrieve and review the Installation's utility plans and consult with Government utilities personnel; where utility systems are privatized, consult with privatized utility system owner.
- Validate adequate utility capacities at points of connection.
- For Government-owned utility systems, conduct waterflow testing in accordance with UFC 3-600-01; for privatized utility systems, request waterflow testing data from privatized utility system owner.
- For utilities projects: Retrieve and review the utility study that supports the scope and type of work to be performed.

13-13.2 Subsurface/Geotechnical Investigations.

Consult with a Geotechnical Engineer to determine if the site can be characterized and foundation systems conceptualized based on known geologic conditions. If known geologic data can be used, the Geotechnical Engineer must document in the Basis of Design that the conceptual design for pavement and foundation design is based upon available soils information.

If existing geological data is not sufficient, and for large projects with anticipated Special Foundation costs (for example, pile foundations, mat foundations, significant grading and over-excavation, ground improvement), conduct a full soils investigation at the preliminary design stage. Perform foundation and soils investigations, including sampling, testing, and evaluation, with requirements set forth in Chapter 4. If ground source heat pumps are being considered, determine the soil characteristics for the geothermal well field.

13-13.3 Topographic Survey.

Utilize existing topographic data to the maximum extent possible.

For projects where costs associated with grading and dredging are significant, conduct topographic surveys at the preliminary design stage. Conduct topographic surveys in accordance with Chapter 4. Topographic Surveys must indicate significant site elements, including, but not limited to, utility points of connection, natural resource boundaries, fish and wildlife habitats (including buffer zones), rookeries, wetlands, and other environmentally sensitive areas.

13-13.4 Existing Building Surveys.

For repair, renovation, or rehabilitation projects, perform engineering studies to assess extent of the work, and to provide budget-level costs. These studies include, but are not limited to, structural, electrical, mechanical, fire protection, AT, Physical Security, building envelope, accessibility, and roof systems and components.

When triggered, conduct Tier I or Tier II seismic evaluations in accordance with UFC 3-301-01 and identify mitigation costs. Defer Tier III investigations until subsequent design phases (Final Design Authority, FDA). For renovations of historic properties: Coordinate with the NAVFAC Environmental Cultural Resources Office to determine special construction elements and other project constraints. For fire protection requirements, refer to the paragraphs titled “Planning” and “Existing Facilities” in UFC 3-600-01.

13-13.5 Hazardous Materials Investigation.

Validate and address findings from Field Investigation Report conducted during planning prior to Preliminary Design and conducted in accordance with UFC 3-810-01N. Hazardous Materials, along with their associated costs, must be identified and addressed in the DD1391. MCON Design Appropriations may only be used for comprehensive investigations hazardous materials investigations that are directly in support of a project design solution. For example, investigations that directly support development of design drawings and specifications.

13-13.5.1 Survey and Research.

As a minimum, for budget-ready costs, conduct a visual survey of existing field conditions. Consult with Government Environmental personnel, and research records for existing hazardous materials documentation and known site contamination issues. Determine if the site is part of an installation restoration program/project. Base the preliminary design on conservative assumptions from the visual survey and records search.

13-13.5.2 Demolition, Renovation, Repair, or Contaminated Sites.

For projects that include significant demolition, renovation, or repair, or sites with significant known environmental contamination issues, verify the presence of hazardous materials such as, but not limited to, asbestos, RCRA 8 metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver), PCB, and mercury. For specific requirements, comply with UFC 3-810-01N.

13-13.6 Building Code Assessment of Adjacent Structures.

When the proposed construction is within 60 feet (18.3-m) of existing adjacent structures, conduct a building code assessment of the adjacent structures. Information about adjacent structures must include construction type, fire resistive rating of exterior walls, wall openings, number of floors, area per floor, total building area, occupancy classification, and if the building is fully protected with an automatic fire sprinkler system. The purpose of obtaining this information is to assure the new building (or addition) does not encroach on minimum separation requirements or assumed property line based on the design assumptions and building code analysis of the existing building(s).

13-14 CALCULATIONS.

13-14.1 Plumbing.

Provide the following plumbing calculations:

- Domestic water size coming into the building (looking for a preliminary calculation on the water size. Needed to determine if the existing water main has the size/capacity for demand).
- Available Water pressure (If the water pressure is suspect, a water pressure calculation is needed to determine if domestic water pump is required).
- Water Heater Size/Storage (preliminary calculation on the water heater/storage tank size).
- Sanitary sewer size coming into the building (preliminary calculation on the sanitary sewer size to determine if the existing main has the size/capacity for demand).
- Sanitary Sewer piping elevation/slope (preliminary calculation to determine if a grinder pump is required).
- Building Utilities (such as Steam and Gas) (preliminary calculation on the utility size to determine if the existing main has the size/capacity for demand).
- Sustainability (such as solar hot water or rainwater harvesting).
- Preliminary calculations and LCCE as needed to support position.

13-14.2 Mechanical.

- Building Cooling Load (Block Cooling Load Calculation)
- Building Heating Load (Block Heating Load Calculation)
- ASHRAE 62 Calculation (preliminary Calculation needed for DOAS systems).

- Preliminary Equipment Sizes (with clearances to size mechanical rooms if required).
- Life Cycle Cost Analysis (LCCA) (Performed on the mechanical systems such that a single system is selected during Preliminary Design.)
- Commissioning/Acceptance (determine if required for cost estimate).

13-14.3 Fire Protection.

Provide water supply and fire flow calculations. Refer to UFC 3-600-01.

CHAPTER 14 PHASE: SCHEMATIC DESIGN SUBMITTALS (10-15%)

14-1 GENERAL REQUIREMENTS.

The Schematic Design Submittal is intended to convey the extent of the work in a preliminary conceptual manner. Deliverables are approximately 10% to 15% complete at this stage. Appendix B Preliminary Design requirements may not apply for non-Preliminary Design projects. In addition to the requirements of the Core UFCs and the contract, include the deliverables described herein, as a minimum.

14-2 DB SCHEMATIC DESIGN SUBMITTAL.

For DB, if defined by the RFP, the Schematic design may be the Contractor's technical response to the RFP, including layout, functional drawings, and design. When this is used, exceptions to the UFC requirements must be outlined in the RFP solicitation.

14-3 BASIS OF DESIGN.

The discipline-specific Basis of Design needs to provide sufficient definition to support the development of a Class 4 cost estimate for that discipline. Submit a preliminary version of the Basis of Design addressing items defined in the contract, the Core UFCs, Chapter 5, and as follows.

14-3.1 Geotechnical.

Include the Geotechnical Report, if available, as an appendix. It is encouraged to have this report at this submittal to obtain review comments at the earliest possible date.

14-3.2 Sustainability.

Provide completed HPSB Checklist(s) and TPC Checklist(s) (where applicable) for each applicable building in the project. Provide copy(ies) of TPC registration information (where applicable), and comprehensive Sustainability Chapter.

14-3.3 Cybersecurity.

Provide a single submittal indicating criteria and describing requirements for integrating cybersecurity into the design and construction of the FRCS. The basis of design must describe specific guidance for control systems with the assigned Confidentiality, Integrity and Availability (C-I-A) impact ratings and must list the security controls with recommendations and justifications for future tailoring of the security control set. **\1** For existing building work, include documentation of existing FRCS infrastructure and how new work is integrated. **/1/**

14-4 DRAWINGS.

Provide drawings required by the contract, the Core UFCs, and herein as applicable to the project:

14-4.1 Architectural.

- Floor Plans – Provide floor plans, new and demolition, indicating room names and basic dimensions.
- Building Elevations – Provide building elevations indicating exterior materials.
- Building Section – Indicate heights of critical building elements.

14-4.2 Civil.

- Schematic Site Plan - Indicate above and below grade utility lines, vehicular and pedestrian circulation paths, buildings, parking, paved areas, and existing site features to remain.
- AT Standoff Distances.

14-4.3 Landscape Architecture.

- Site Inventory and Analysis Plan.
- Schematic Landscape Site Plan - Indicate buildings, existing site features to remain, utility lines and improvements, vehicular and pedestrian circulation, hardscape, plazas and patios, walls, structures and other above ground features, streetscapes, planting concept, Low Impact Development (LID) and other bio-retention areas.
- AT standoff distances.
- Provide types and purpose of plant materials used on the plan (for example, tall broadleaf evergreen shade tree or medium-sized flowering accent tree).
- Provide type of irrigation, water source, and how it is controlled.
- Provide additional information unique to the project.

14-4.4 Electrical.

Provide the following in accordance with UFC 3-501-01. The drawings need not provide extensive details but must be complete enough to thoroughly express the Designer's intentions:

- Existing Site and Demolition Plan.
- Site Plan.

- Single Line Diagram.
- Preliminary floor plans with dedicated space clearly identified for electrical and telecommunications rooms.

14-4.5 Fire Protection.

Provide the following. The drawings need not provide extensive details but must be complete enough to thoroughly express the Designer's intentions:

- Code Compliance Summary Sheets.
- Life Safety Floor Plan. At a minimum, identify building areas having different occupancy and hazard classifications and identify egress travel requirements.
- Fire Suppression Plans. At a minimum, provide floor plans identify hazard classifications. Where a facility has multiple hazard classifications, differentiate each classification area by border or hatching. Identify areas to be protected with special fire suppression systems.

14-4.6 Geotechnical.

Boring log drawings are encouraged but not required.

14-5 BIM PXP.

Provide a completed PxP within 30 days after the Charrette, Functional Analysis Concept Developments (FACDs) or Design Kick-Off Meeting for government review and approval. Format in accordance with Chapter 12.

14-6 CALCULATIONS.

Provide calculations complete and in sufficient detail to support the items outlined in the preliminary Basis of Design, as indicated on the drawings, in accordance with the Core UFCs, Chapter 6, and as follow:

14-7 SUSTAINABILITY.

14-7.1 TPC Registration.

When TPC is required in accordance with UFC 1-200-02, register each applicable building in the project with TPC organization within 30 days of the design kickoff meetings.

14-7.1.1 Format.

Use the following format to register with TPC:

- Project Title First Line: U.S. Navy or U.S. Marine Corps, Building Name (if applicable)
- Project Title Second Line: P-(#); (DD Form 1391 Project Name)
- Project Address First Line: UIC (Installation Code)
- Category Code: RPUID (Real Property Unique Identifier) Number
- Project Owner Organization: U.S. Navy or U.S. Marine Corps
- Primary Contact, Owner: NAVFAC Project Manager
- Additional Contact, Bldg. Owner: Choose Either: Public Works Officer/Deputy Public Works Officer or a Designee

14-7.1.2 Management and Documentation.

Provide TPC management and documentation online (or offline, with secure facilities) throughout the design of the project. Maintain TPC Checklist and obtain TPC Design Review.

14-8 CHARETTES AND FUNCTIONAL ANALYSIS CONCEPT DEVELOPMENT (FACD) STUDIES.

Charrettes and FACDs may be used in DBB to develop the design of the project or in DB to develop the Project Program in the RFP. Both use value-engineering techniques to develop concept designs. The formal Value Engineering process is required for DBB MCON projects over $30 Million and is suggested for other high value multidisciplinary DBB projects. Provide charrette or FACD when required by the contract, and the formal Value Engineering process defined in the contract.

14-8.1 Description.

FACD studies and design charrettes are cooperative efforts by the design team, user and client representatives, installation planning staff, DD Form 1391 project team members, other appropriate Regional staff, facility engineering command personnel, and other interested parties. A charrette may last one to three days, while a FACD may last one to two weeks. They include on-site development of a Schematic design in response to functional, aesthetic, environmental, base planning, site, budgetary, and other requirements. Submittals include meeting minutes, schematic design, and documentation of the decision and information that led up to that decision, including a partnering agreement signed by the principal participants.

CHAPTER 15 PHASE: DESIGN DEVELOPMENT SUBMITTALS (35% - 50%)

15-1 GENERAL REQUIREMENTS.

The Design Development Submittal is intended to convey the complete extent of the work in a preliminary manner. The deliverables are typically about 35% to 50% complete at this stage. Update and include submittals from the previous submittal stage and provide additional detail to bring them to the required completion percentage. In addition to the requirements of the Core UFC's and the contract, include the following as a minimum:

15-2 BASIS OF DESIGN.

Update and submit a complete Basis of Design addressing items defined in Chapter 5 and the Core UFCs.

15-2.1 Sustainability.

Provide updated HPSB Checklist(s) and TPC Checklist(s) (where applicable) for each applicable building in the project. Provide updated Sustainability Chapter.

15-3 DRAWINGS.

Provide updated drawings from the previous submittal and additional drawings required by the contract, the Core UFCs, and herein as applicable to the project. Plan views, including enlargements, and excluding Site Plans, must include vertical and horizontal column lines within the range of the view.

15-3.1 Architectural.

- Legend and Abbreviations
- Floor Plans – Provide floor plans, new and demolition, indicating room names and dimensions
- Building Elevations – Provide building elevations indicating exterior materials
- Roof Plan – Provide a plan of roof areas, indicating direction of slope and method of drainage
- Building Section – Indicate heights
- Typical Wall Sections – Provide sufficient wall section(s) to indicate materials and different conditions
- Finish Schedule – Indicate proposed finishes

15-3.2 Interior Design.

Provide Structural Interior Design (SID) to include the following:

- Interior and Exterior Material and Finish samples in loose format
- FF&E Plan indicating built-in and movable items
- FF&E Summary List corresponding to the FF&E Plan with estimated item costs

15-3.3 Landscape Architecture.

- Overall Landscape Site Plan. Provide an overall landscape site plan with matchlines (if site plan is divided into multiple sheets) and specific sheet references, general notes, and options (if applicable).
- Landscape Site Plan. Provide enlargement plans as required to delineate appropriate detail.
- Landscape Construction Details.
- Landscape Planting Plan.
- Plant Material Schedule and Details.
- Landscape Irrigation Plan. When a Landscape Irrigation Plan is required by the Statement of Work, provide a sprinkler head layout, remote control valves, automatic controller, pressure pipe and lateral lines, backflow prevention device, and point of connection.
- Landscape Irrigation Equipment Schedule and Details. When a site irrigation plan is required by the Statement of Work, provide an irrigation equipment schedule.

Drawings indicated above can be combined. Contact Government's Landscape Architectural Reviewer for approval of combined drawings prior to project submittal. For example, on small projects a Landscape Site Plan and Landscape Planting Plan can be shown on the same sheet.

15-3.4 Geotechnical.

- Results of subsurface investigation, such as boring logs, test pit logs and laboratory test results, and special site preparation requirements.

15-3.5 Civil.

- Cover sheet, Drawing Index, Vicinity Map, Location Plan, Abbreviations, Legend and Notes.
- Existing Conditions / Demolition Plan.
- Site Plan.

- Water and Sanitary Sewer Plan.
- Grading and Drainage Plan.

Drawings indicated above can be combined. Contact Government's Civil Reviewer for approval of combined drawings prior to project submittal. For example, on small projects, a Site and Water and Sewer Plan can show the Site Plan and Water and Sanitary Sewer Plan on the same sheet or, the Site and Grading and Drainage Plan can show the Site Plan and Grading and Drainage Plan on the same sheet.

15-3.6 Structural.

- Foundation Plans. Include for structures, showing dimensions, arrangements, elevations, locations referred to a column line grid system, type of foundation and foundation obstructions. Include the layout of parts, including but not limited to, slabs, footings, piers, grade beams, and piles, showing foundation features of the design.
- Framing Plans. Include a framing plan for each structural level of the facility, showing dimensions, elevations, and column locations and numbering referenced to a column line grid system, and overall sizes of major members and components. Show the layout of system, including, but not limited to, beams, joists, and stringers.
- Structural Details. Show typical details of construction, indicating the connection and relationship between major components of the structural system.
- Structural Elevations. Show general sizes, location, and arrangement of significant features of the vertical framing system, such as columns, walls, and beams.
- Structural General Notes.

15-3.7 Mechanical.

- Plumbing Floor Plan. Show plumbing fixtures, floor drains and equipment locations.
- Site Plan. Show connections, such as to base steam distribution, location of propane and oil tanks, and layout of ground coupled heat pump well fields.
- HVAC Floor Plan. Show equipment locations, one or two-line duct layout and preliminary piping runs.
- Mechanical Room Plan. Show major equipment and maintenance access space. Provide section view(s) to clarify layout and supports.

15-3.8 Electrical.

- Existing Site and Demolition Plan.
- Site Plan.
- Single Line Diagram.
- Preliminary floor plans with dedicated space clearly identified for electrical and telecommunications rooms.
- Legend and Abbreviations.
- Lighting Plan(s).
- Power Plan(s).
- Lightning Protection Plan.
- Cathodic Protection Plan.
- Communications Plans.
- Special Systems Plans.
- Additional Plans/Risers.

15-3.9 Fire Protection.

- Code Compliance Summary Sheets (Updated from Schematic Design Submittal).
- Life Safety plan (Updated from Schematic Design Submittal). Identify locations of fire rated partitions and horizontal exits).
- Fire Suppression plans. (Updated from Schematic Design Submittal. Refer to Chapter 7-11, except that cross-sectional elevations/details of suppression system risers are not required at this submittal phase.)
- Fire Alarm and Mass Notification System Plans. (Updated from Schematic Design Submittal. Refer to Chapter 7-11.)
- Detail Sheets. (Updated from Schematic Design Submittal. Refer to Chapter 7-11.)

15-4 BIM DESIGN MODEL.

Provide Visual Review Report and Clash Detection Report.

15-5 OUTLINE SPECIFICATIONS.

Provide outline specifications, in the form of a list of specification sections the DOR intends to use in the job.

Use Unified Facilities Guide Specifications, as required in Chapter 8. Provide a listing of the UFGS used in the job by Section Number, Title, and Section Date. Follow the Order of Precedence for choosing UFGS master guide specifications in Chapter 8, unless required otherwise by the contract.

15-5.1 eOMSI Facility Data Workbook (FDW).

Provide Model & Facility Data Matrix tab of the Facility Data Workbook in sufficient detail to document the level of design completed in this phase. The FDW is an attachment to UFGS 01 78 24.00 20 in subsequent phases. The Facility Data Workbook is available for download at https://www.wbdg.org/navy/bim-eomsi.

15-6 CALCULATIONS.

Provide calculations complete, and in sufficient detail to substantiate the design level in this preliminary Basis of Design, as indicated on the drawings, in accordance with the Core UFCs, Chapter 6, and herein, and updated from the previous design phase.

15-6.1 Structural and Geotechnical.

Provide Structural and Geotechnical calculations in sufficient detail to support the items outlined in the Basis of Design and indicated on the drawings.

15-6.2 Civil.

Provide calculations in sufficient detail to indicate compliance with LID criteria, Navy LID Policy, and state or local stormwater regulations. Provide calculations for utility systems and pavements in sufficient detail to support items outlined in the Basis of Design and indicated in the drawings and specifications.

15-6.3 Architectural.

Provide acoustical calculations in accordance with UFC 3-101-01.

15-6.4 Mechanical.

Provide a bookmarked Adobe PDF **\1\ /1/** of input and output data, and summary sheets for Energy Analysis, Life Cycle Cost Analysis, Building Heating and Cooling Loads, and ASHRAE 90.1 Compliance Calculations in accordance with UFC 3-410-01.

15-6.4.1 Energy Analysis.

Provide an Adobe PDF copy of the computerized energy analysis that includes input and output data in their entirety.

15-6.4.2 Life Cycle Cost Analysis.

Submit the computerized LCC analysis utilizing the latest edition of the NIST Building Life-Cycle Cost Program.

15-6.4.3 Building Heating and Cooling Load.

Provide an Adobe PDF copy of the computerized load calculations with input and output data in their entirety.

15-6.4.4 ASHRAE 90.1 Compliance Calculations.

Submit calculations and compliance forms indicated in the Basis of Design.

15-6.4.5 Plumbing Calculations.

Provide Design Basis in accordance with UFC 3-420-01.

15-6.5 Electrical.

Provided calculations required by Core UFCs and also include:

- Load Analysis.
- Service size.
- Feeder size.
- Larger special circuit sizes.
- Lightning Risk Assessment.

15-6.6 Fire Protection.

Submit calculations supporting fire suppression and fire alarm/detection systems for the project. Calculations for systems, features, or elements other than fire suppression or detection will be required as applicable. Fire suppression system calculations must be prepared using commercially available computer software.

15-6.7 Environmental Report.

Provide reports in accordance with UFC 3-810-01N.

15-7 QUALITY CONTROL (QC) REVIEW AND DOCUMENTATION.

15-7.1 Review.

Provide a quality control review by a third party not involved in the design of the project. Evaluate both technical accuracy and discipline coordination. The QC review must include, but is not limited to, the following:

- Eliminate errors, omissions, interferences, and inconsistencies among design disciplines and among drawings, specifications, and cost estimates.
- Verify current criteria, lessons learned, and responses to approved review comments are incorporated.
- Ensure the constructability of the facility as detailed in the drawings, specifications, and technical documents.
- Ensure documents are biddable.

15-7.2 Documentation.

With the submittal, provide Design Quality Control (DQC) documentation that demonstrates that cross-checking of documents has taken place. Provide a single set of documents highlighted to validate that the review was performed, and that the corrections were made.

This Page Intentionally Left Blank

CHAPTER 16 PHASE: PRE-FINAL DESIGN SUBMITTALS (100%)

16-1 GENERAL.

The intent of the Pre-Final submittal is to provide a complete set of design deliverables. The following are the minimum requirements of a Pre-Final submittal:

16-2 BASIS OF DESIGN.

Submit Basis of Design for each of the core disciplines, including updated information and incorporating responses to previous government review comments.

16-2.1 Geotechnical.

The Geotechnical DOR must validate that findings and design recommendations from the latest edition of the Geotechnical Report are valid, and construction and site preparation recommendations have been correctly incorporated into the pertinent drawings and specifications. Provide a draft verification letter from the Geotechnical DOR, certifying that a review of the Pre-Final drawings and specifications, as they relate to the Geotechnical Report, has been conducted and that these drawings and specifications comply with the Geotechnical Report findings and recommendations.

The Geotechnical Report, if modified during the previous review, must be re-submitted as an appendix to the Basis of Design; otherwise, do not submit.

16-2.2 Sustainability.

Provide updated HPSB Checklist(s) and TPC Checklist(s) (where applicable) for each applicable building in the project. Provide updated Sustainability Chapter.

16-3 DRAWINGS.

Drawings must be 100% complete, minus final signatures, and incorporate responses to the previous review comments. The drawings must be complete to the extent that they may be released for bid or constructed as submitted. Provide a complete set of construction drawings organized by discipline as described in this document and the Core UFCs. Upon submittal of the Pre-Final package, request NAVFAC Drawing Numbers from the Government. For DB projects, follow the requirements of the RFP when shop drawings are used as design drawings.

Provide drawings updated from the previous submittal level, drawings specified in the Core UFCs, Chapter 7, and the following, as a minimum:

16-3.1 Civil.

Provide updated drawings from the previous submittal and the following:

- Water, Storm and Sanitary Sewer Profiles

- Site / Utility Details.

16-3.2 Landscape Architecture.

Provide updated drawings from the previous submittal to substantiate design level, and the following, in accordance with UFC 3-201-02:

- Landscape Irrigation Plan. When a site irrigation plan is required by the Statement of Work, update irrigation system with pipe sizing and remaining associated requirements for a complete and operational system.
- Landscape Irrigation Equipment Schedule and Details. When a site irrigation plan is required by the Statement of Work, update irrigation equipment schedule. Provide irrigation details.

16-3.3 Electrical.

Provide updated drawings from the previous submittal to substantiate design level, and the following in accordance with UFC 3-501-01:

- Existing Site and Demolition Plan.
- Site Plan.
- Single Line Diagram.
- Legend and Abbreviations.
- Lighting Plan(s).
- Power Plan(s).
- Lightning Protection Plan.
- Cathodic Protection Plan.
- Special Systems Plans.
- Additional Plans/Risers.
- Lighting: Interior and Exterior Foot-candles.
- Load Analysis.
- Service size.
- Feeder size.
- Larger special circuit sizes.
- Lightning Risk Assessment.
- Communications Riser Diagram.
- Intercommunication Riser Diagram.

- Other Riser Diagrams for Television, Security, and similar systems.
- Panel Schedules.
- Switchboards and Motor Control Center Schedules.
- Lighting Fixture Details.

16-4 BIM DESIGN MODEL.

Provide Visual Review Report and Clash Detection Report.

16-5 SPECIFICATIONS.

Provide edited, marked-up specification sections, using the SpecsIntact "Show Revisions" function when editing and printing, to show deletions from and additions to the UFGS master sections. Use the default settings in SpecsIntact that displays deletions lined out and additions underlined. Run verification reports when printing. Print project specification sections, using the SpecsIntact "Show Section Dates" function, to display the official date of release of the master guide specification and version of the specification used. This date appears immediately below the specification section title.

Design submittal must be complete at this stage and require only minor corrections if any. Organize specifications in accordance with Chapter 8. Provide a submittal register with the specifications.

16-5.1 Sustainability.

Attach completed HPSB Checklist(s) and TPC checklist(s) (where applicable) for each applicable building in the project to UFGS 01 33 29.

16-5.2 Environmental.

Provide environmental specifications in accordance with UFC 3-810-01N.

16-5.3 eOMSI Facility Data Workbook.

Provide the source file (Excel format) of the eOMSI FDW in a separate file folder. Provide the PDF of the completed Model & Facility Data Matrix tab of the eOMSI FDW attached to UFGS 01 78 24.00 20.

16-6 CONTRACT SOLICITATION.

Provide a PIF, which includes the Bid Schedule as specified in Chapter 10, and a complete scope for use in the project Synopsis.

16-7 INTERIOR DESIGN.

16-7.1 Structural Interior Design (SID).

Include the following:

- Interior and Exterior Material and Finish samples submitted in presentation board or binder format.
- Signage plans, details, and schedules.
- FF&E Plan indicating built-in and movable items.
- FF&E Summary List corresponding to the FF&E Plan with estimated item costs.

16-7.2 FF&E.

Provide Preliminary FF&E to include the following, and present to the Activity and NAVFAC personnel:

- Cover Title Page (project name, project #, submittal date, submittal title).
- FF&E list (Cost Summary).
- Furniture placement plans coded to the FF&E list and furnishings specifications.
- Specifications and procurement data sheets (such as furniture, furnishings), indicating final finish and fabric selections.
- Catalog cuts and finish samples for each specified item.
- 16 x 20 inch (406 x 508 mm) color boards of furniture/furnishings and finishes specified for Activity presentation to indicate overall design intent.
- Best Value Determination (BVD) Analysis including copy of the BVD Analysis cover letter, performance specifications, project specific typical, pricing spreadsheet and questionnaire.

16-8 CALCULATIONS.

Provide calculations, updated from previous submittal, to substantiate design level and to reflect resolution of previous government review comments, and in accordance with the Core UFCs and Chapter 6. Provide design analysis that is 100% complete. In addition, provide the following:

16-8.1 Mechanical.

Submit calculations to support the plumbing and mechanical systems and the major equipment comprising those systems. Submittals must include, but not be limited to, cooling loads, heating loads, air balance, and outside air calculations. Update the energy analysis, provided at the Design Development phase, with the equipment efficiencies scheduled on the drawings.

16-8.2 Electrical.

Provide updated and complete calculations required by Core UFCs and include photometric calculations for interior and exterior lighting.

16-9 STATEMENT OF SPECIAL INSPECTIONS.

Prepare special inspections specification UFGS 01 45 35 (DBB and DB). This specification contains the DOD process for implementing the special inspections, testing, and observations required in accordance with IBC Chapter 17 as modified by UFC 3-301-01 and the International Existing Building Code as modified by UFC 3-301-01. The generic Schedule of Special Inspections is maintained on the WBDG (https://www.wbdg.org/dod/ufgs/ufgs-forms-graphics-tables).

16-10 DRAFT DD FORM 1354.

Provide a Draft DD Form 1354 in accordance with UFC 1-300-08. A blank, editable form is available for download at https://www.esd.whs.mil/portals/54/documents/dd/forms/dd/dd1354.pdf.

Break out assets by construction categories, provided on the form, and by the Navy-specific "Category Codes for Military Real Property" found in FC 2-000-05N. Coordinate the identification of appropriate asset construction categories with the Government's Real Property Accounting Officer. Include quantities and units of measure; however, cost breakdown is not required.

16-11 FACILITY RECOGNITION PLAQUE.

Design for and specify a professionally designed and manufactured recognition plaque commemorating the opening of the facility and recognizing the leadership participants of the project. Coordinate the building recognition plaque location(s) with the TPC plaque location(s) (where applicable). Provide design details for wall blocking to support the weight of hanging the plaque(s). If multiple facilities are in the project, design a plaque for each major facility. Indicate requirements of plaque on drawings and specify in UFGS 10 14 00.20. Include the following information:

- Facility Name
- Identify recognition applied to the facility or person for which the facility has been dedicated
- Date of occupancy (month/year)
- Sustainability TPC achieved (if applicable)
- Using Activity Commander/ Commanding Officer

- Base Commander/ Commanding Officer
- NAVFAC Component Commander/ Facility Engineering Component Commanding Officer
- Prime Contractor
- Architect/ Engineer (DOR)

16-12 DB RFP DEVELOPMENT.

Provide edited, red-lined RFP, showing deletions from and additions to the DB template and UFGSs. Follow Specifications requirements in Chapter 8 for prescriptive specifications provided in Part 5 of the RFP.

RFP submittal must be complete at this stage and require only minor corrections if any. Organize Part 2 specifications in accordance with Chapter 11.

16-13 OVERSEAS TRANSLATIONS.

Provide translated documents in accordance with the contract.

16-14 QUALITY CONTROL (QC) REVIEW AND DOCUMENTATION.

16-14.1 Review.

Provide a quality control review by a third party not involved in the design of the project. Evaluate both technical accuracy and discipline coordination. The QC review must include, but is not limited to, the following:

- Eliminate errors, omissions, interferences, and inconsistencies among design disciplines and among drawings, specifications, and cost estimates.
- Verify current criteria, lessons learned, and responses to approved review comments are incorporated.
- Ensure the constructability of the facility as detailed in the drawings, specifications, and technical documents.
- Ensure documents are biddable.

16-14.2 Documentation.

With the submittal, provide Design Quality Control (DQC) documentation that demonstrates that cross-checking of documents has taken place. Provide a single set of documents highlighted to validate that the review was performed, and that the corrections were made.

CHAPTER 17 PHASE: FINAL DESIGN SUBMITTALS

17-1 GENERAL REQUIREMENTS.

The Final Submittal provides a complete and final set of contract documents ready for bid solicitation by the Government, or in the case of DB, ready for construction by the Contractor. Previous government review comments must have been addressed.

Unless specified otherwise by the Contract, provide final submittals in electronic format in accordance with Chapter 12. Update deliverables from the previous submittal stages, and in addition to requirements from the Core UFCs, provide the following, as a minimum, for the Final Submittal:

17-2 BASIS OF DESIGN.

Submit final Basis of Design for each of the core disciplines, including updated information and incorporating responses to previous government review comments.

17-2.1 Geotechnical.

The Geotechnical DOR must validate that findings and design recommendations from the latest edition of the Geotechnical Report are valid, and construction and site preparation recommendations have been correctly incorporated into the pertinent drawings and specifications. Provide a verification letter from the Geotechnical DOR, signed and sealed, certifying that a review of the Final drawings and specifications, as they relate to the Geotechnical Report, has been conducted and that these drawings and specifications comply with the Geotechnical Report findings and recommendations.

17-3 SUSTAINABILITY.

Provide updated HPSB Checklist(s) for each applicable building in the project. Provide updated Sustainability Chapter. Provide updated TPC Checklist(s) (where applicable) for each applicable building in the project as a separate PDF.

17-3.1 TPC Design Review.

For projects that require TPC certification, submit TPC requirements for Design Review to TPC organization, no later than 60 days after Final Design Submittal.

17-4 DRAWINGS.

Provide complete construction drawings updated from the previous submittal level and organized by discipline in accordance with the Core UFCs and herein. Ensure NAVFAC drawing numbers are entered into the appropriate location on the NAVFAC standard drawing border within the native software format.

17-4.1 Plotstamp Record.

Provide a Plotstamp Record for each contract drawing. This history begins with the final design submittal and continues with subsequent submissions and modifications of that drawing. Maintain this record and make it available at the jobsite for review. Locate the Plotstamp Record on the lower left corner of the sheet, outside the border, and at the staple edge with the text rotated 90 degrees. Include the following:

- File Name: (Include the file location)
- Layout Name (if applicable)
- Plotted: Date and Time
- User: First name and last name of the person who printed the drawing

17-4.1.1 DB Plotstamp Records.

In addition, provide an updated Plotstamp Record at the following developmental stages of the contract drawings:

a. DOR signed Final Critical Path Submittal or the Final Design Submittal.

b. Government approved Final Critical Path Submittal or the Final Design Submittal. This development stage may be combined with "c." below, if issued at the same time.

c. Incorporation of the Final Critical Path or Final Design drawings in the contract by modification.

d. Submissions to Government and modifications of the Final Critical Path or Final Design drawings incorporating variations in the contract.

17-4.2 DB Shop Drawings.

For DB projects, follow the requirements of the RFP when shop drawings are used as design drawings.

17-5 BIM DESIGN MODEL.

Provide Clash Detection Report, Visual Review Report, and Final Design BIM Model in accordance with Chapter 12 and PxP. There must be zero clashes.

17-6 SPECIFICATIONS.

Provide complete, final specifications with redlines executed. Organize and compile the package as detailed in Chapter 8.

17-6.1 eOMSI Facility Data Workbook.

Provide complete Model & Facility Data Matrix tab of the eOMSI FDW and attach to UFGS 01 78 24.00 20. In addition, provide the native Excel file of the FDW with the electronic files.

17-6.2 Sustainability.

Attach final HPSB Checklist(s) and TPC Checklist(s) (where applicable) for each applicable building in the project to UFGS 01 33 29.

17-6.3 Environmental.

Comply with UFC 3-810-01N for environmental specifications.

17-6.4 DB Design Submittal Specifications.

For DB projects, follow the requirements of the RFP when manufacturer's catalog data are used with the UFGS during design.

17-6.4.1 Fire Protection Specifications.

For Fire Protection systems, combine design and construction submittal information on the design documents. In addition to the UFGS specification, provide proprietary information, such as catalog cuts and manufacturers data that demonstrates compliance with the RFP. Fire protection systems include fire suppression systems, fire pumps, fire alarm and detection systems, fire-stopping, and spray-applied fireproofing.

17-6.5 Report Source File.

As part of the Final submittal of the specifications, provide the source files of Reports included in the specifications.

17-7 CONTRACTING DOCUMENTS.

Provide a final, completed PIF, including Bid Schedule. Provide final scope for Project Synopsis.

17-8 INTERIOR DESIGN.

17-8.1 Structural Interior Design (SID).

Update deliverables for Interior Design from Pre-Final. Include Interior and Exterior Material and Finish samples submitted in presentation board or binder format.

17-8.2 FF&E.

Provide the final FF&E submittal with final submittal package. Present to NAVFAC and to the Activity. Update FF&E deliverables from Pre-Final.

- Cover Title Page (project name, project #, submittal date, submittal title)
- Table of Contents and Manufacturer Contact List
- FF&E list (Cost Summary)
- Furniture placement plans coded to the FF&E list and furnishings specifications
- Specifications and procurement data sheets, such as for furniture and furnishings, indicating final finish and fabric selections.
- Catalog cuts and finish samples for each specified item.
- 16x20 inch (406 x 508 mm) color boards of furniture/furnishings and finishes specified for Activity presentation to indicate overall design intent
- BVD Sheets signed by the Offeror’s Interior Designer with required supporting information.

17-9 CALCULATIONS.

Revise design analysis and calculations as required to reflect resolution of previous government review comments and in accordance with this document and the core UFCs.

17-10 DRAFT FORM DD 1354.

Provide completed Draft Form DD 1354.

17-11 STATEMENT OF SPECIAL INSPECTIONS.

Prepare special inspections specification Section 01 45 35 (DBB and DB). This specification contains the DOD process for implementing the special inspections, testing, and observations required in accordance with IBC Chapter 17 as modified by UFC 3-301-01 and the International Existing Building Code as modified by UFC 3-301-01. The generic Schedule of Special Inspections is maintained on the WBDG (https://www.wbdg.org/dod/ufgs/ufgs-forms-graphics-tables).

17-12 RFP.

Provide complete, final RFP with redlines executed. Organize and compile the package as detailed in Chapter 11.

17-12.1 Report Source File.

As part of the Final submittal, provide source file of Reports included in the RFP, in either Word or SpecsIntact.

17-13 FIRE PROTECTION DESIGN COMPLIANCE DOCUMENT.

This design compliance document must be submitted with the final design submission as part of the design analysis and must bear the signature and professional seal of the QFPE. Refer to UFC 3-600-01.

17-14 QUALITY CONTROL (QC) REVIEW AND DOCUMENTATION.

17-14.1 Review.

Provide a quality control review by a third party not involved in the design of the project. Evaluate both technical accuracy and discipline coordination. The QC review must include, but is not limited to, the following:

- Eliminate errors, omissions, interferences, and inconsistencies among design disciplines and among drawings, specifications, and cost estimates.
- Verify current criteria, lessons learned, and responses to approved review comments are incorporated.
- Ensure the constructability of the facility as detailed in the drawings, specifications, and technical documents.
- Ensure documents are biddable.

17-14.2 Documentation.

With the submittal, provide Design Quality Control (DQC) documentation that demonstrates that cross-checking of documents has taken place. Provide a single set of documents highlighted to validate that the review was performed, and that the corrections were made. Provide a stamp on the cover page of the drawing set and specifications as shown in Figure 17-1.

Figure 17-1 Quality Review Block.

QUALITY CONTROL REVIEW	
Signature	Date

17-14.3 DB Quality Control.

For DB projects, this review must be a coordinated effort between the Contractor and their DOR. Additional Overseas Submittals Requirements.

17-14.4 Code Compliance Certification.

Design must comply with the applicable U.S. & Host Nation norms, regulations, and applicable U.S. Military criteria. Plans and Specifications must be certified by a Host Nation architect or engineer, registered on the country's professional rolls, for compliance with applicable codes and laws.

Provide this certification on the cover sheet of project drawings and specifications, in dual languages. If the specifications coversheet does not have sufficient space for this certification, provide directly behind the coversheet on a separate page, including the project information from the coversheet. The code compliance certification must be provided as indicated in Figure 17-2 below, and dated, signed, and stamped in accordance with the requirements set forth in Chapter 7 of this document.

Figure 17-2 Code Compliance Certification

HAVING PARTICIPATED IN THE DESIGN OF PROJECT No. (Identify project number, project title, location), AND HAVING THOROUGHLY REVIEWED THE COMPLETED PROJECT DOCUMENTS, I DECLARE THAT THE FACILITY DESIGN INCLUDED HEREIN COMPLIES WITH ALL APPLICABLE (Identify Host Country) CODES AND LAWS.

Date Signature (Professional Seal)

17-14.5 Host Nation Life Safety/Building Code Compliance Documentation.

Provide the following in accordance with UFC 3-600-01:

- Host Nation Life Safety and Building Code analysis.
- Comparisons of Host Nation requirements with NFPA Codes, UFC 1-200-01, and UFC 1-200-02
- Items of conflict and approved resolutions
- Additional costs, both engineering effort to prepare the design modification and estimated construction costs

17-14.6 Geotechnical Report Translation.

Translate the Geotechnical Report into English. Unless stated otherwise in the contract, the boring logs must be shown in two languages, English and the local language of country of bidding and construction.

This Page Intentionally Left Blank

CHAPTER 18 PHASE: POST-DESIGN OR POST-RFP DEVELOPMENT SUBMITTAL REQUIREMENTS

18-1 GENERAL REQUIREMENTS.

Submissions after final design or RFP development must integrate changes resulting from Contractor Pre-Proposal Inquiries (PPI) and Requests for Information (RFI) into Amendment and Contract Modification documents. Submissions may include additions or corrections to drawings, specifications, or RFP, and an explanation of changes. Changes to the Contract Documents before contract award are Amendments; changes after contract award are Contract Modifications.

18-2 PRE-PROPOSAL AND REQUESTS FOR INFORMATION.

Responses to PPIs and RFIs must be responded to as quickly as possible to prevent delay to construction contract award. It is expected that the DOR will provide response to a PPI or RFI no later than three working days after notification. Where the response to a PPI or RFI requires additional time, the DOR must notify the Government Project Manager/Design Manager or Contracting Officer of the expected date of response. The DOR must indicate if an Amendment or a Contract Modification is required in response to the PPI or RFI.

18-3 CHANGE NUMBERS OR LETTERS.

Prior to submission, the Contracting Officer for the procurement/contract assigns the Amendment number or Contract Modification letter and provides to the PM and DM. Numbers or letters are assigned in numerical order as required. Amendment numbers are prefixed by three ciphers, for example, the first Amendment is numbered "0001".

18-4 COST ESTIMATE CHANGES.

Accompany Amendment or Contract Modification with detailed cost estimates to indicate changes in construction cost of the project, or to substantiate a statement of no change in cost. Accompany Contract Modification with a detailed cost estimate that can be used in the negotiation of Contract Modification.

18-5 CHANGE FORMAT.

The Contracting Officer prepares the Standard Form SF 30, *Amendment of Solicitation/Modification of Contract,* coversheet for an Amendment. Block 14 of this form is the “Description of Amendment” with enough space for a brief description, thus, the first page of the changes text starts on page two called the Continuation Sheet with an explanation of the changes. Submit the Continuation Sheet to the Contracting Officer for processing.

Provide a Proposed Change Sheet for a Contract Modification with an explanation of the changes. Include the Modification letter, contract number, and task order number (if available), eProjects work order number, project title, and project location. Submit the Proposed Change Sheet to the Contracting Officer for processing.

Where drawings, RFP sections, or specifications are replaced or added, attach the document PDF file separately, and reference in the Continuation Sheet or Proposed Change Sheet in accordance with guidance below. When multiple drawing, RFP section, or specification files are replaced or added, combine the documents by type into a single file, and bookmark each document. Follow file size limitations in accordance with Chapter 12.

18-5.1 Continuation Sheet, Modification, and Language Format.

Use Figure 18-1 Sample Amendment/Modification for guidance on how to format the language for revisions and changes. List specification changes, additions, deletions, or replacement of complete specification sections only under the specifications PROJECT TABLE OF CONTENTS. For drawing changes, additions, deletions, or replacements of a complete drawing must be listed in specification 00 01 15 LIST OF DRAWINGS and on the DRAWING INDEX sheet.

When drawings are revised and replaced, use a cloud to highlight the change. For Amendments, place a triangle with a sequential number in it and place it next to the cloud or the item(s) changing for each sheet. For Modifications, use a triangle with a sequential letter. Provide the number or the letter on the sheet revision block and provide the same brief over-arching description on the revised sheets. Insert the date that the change was made; this distinguishes the revised drawing from the original drawing. Also, note that a sheet has been added or replaced in the DRAWING INDEX sheet. Do not change sheet numbers or sheet designations for revised drawings. Listing the Amendment or Contract Modification number is not appropriate.

Best Practices:

Minimize narrative only description of changes on Continuation Sheets. Recommend reissuing the sheet(s) or specification section(s).

Maximize practice of indicating changes by issuing replacement Drawings and Specification Sections. NOTE: Previous narrative only changes must be incorporated.

Apply above guidance as much as practicable, without significant slow-down in communications with bidders or impacts to pre-award execution.

Figure 18-1 Sample Amendment/Modification

[CONTINUATION SHEET] [MODIFICATION "modification letter"]

DRAWINGS:

On NAVFAC Drawing No. [NAVFAC DWG No.] (G-101)
ADD the following drawings to the DRAWING INDEX under the corresponding discipline and drawing number. These drawings accompany this [Amendment] [Modification]:

S-213 [NAVFAC DWG No.] BRACED BAY FRAMING ELEVATIONS - ADDED SHEET
M-504 [NAVFAC DWG No.] DETAILS – ADDED SHEET

REPLACE the following drawings to the DRAWING INDEX under the corresponding discipline and drawing number. These drawings accompany this [Amendment] [Modification]:

A-301 [NAVFAC DWG No.] ELEVATIONS – REPLACED SHEET
P-503 [NAVFAC DWG No.] DETAILS – REPLACED SHEET

On NAVFAC Drawing No. [NAVFAC DWG No.] (CS510)
A5/CS510 Detail: **DELETE** "9'-10"" vertical dimension and **REPLACE** with "10'-0"".

On NAVFAC Drawing No. [NAVFAC DWG No.] (S-101)
Foundation Plan Notes: Note 3, **DELETE** "THE BOTTOM OF THE FOOTING" and **REPLACE** with "THE TOP OF THE FOOTING".

On NAVFAC Drawing No. [NAVFAC DWG No.] (A-505)
B5/A-505 Breakroom Elevation, **DELETE** note "PNT4" and **REPLACE** with "PNT5".

SPECIFICATIONS:

PROJECT TABLE OF CONTENTS

ADD the following section(s) that accompany this [Amendment] [Modification]. Add date in the footer to distinguish the added section.*

01 45 35 Special Inspections, dated May 17, 2023
09 29 00 Gypsum Board, dated May 17, 2023

REPLACE the following section(s) with the attached section(s) that accompany this [Amendment] [Modification]. Add date in the footer to distinguish the replaced section.*

07 11 13 Bituminous Dampproofing, dated May 17, 2023
09 68 00 CARPETING, dated May 17, 2023

(*NOTE to specification editor: To change the date, for subsequent additions/replacements of the section, a date must be manually typed into the footer on the 'Print Processing > Header/Footer' tab in SpecsIntact. See the eLearning Module in Chapter 4: Process and Print/Publish, Header/Footer Tab.)

DOCUMENT 00 01 15 LIST OF DRAWINGS

1.2 Contract Drawings

ADD the following drawings. These drawings accompany this [Amendment] [Modification].

DRAWING NO.	REVISION NO.	NAVFAC DWG NO.	TITLE
S-213	1	[********]	BRACED BAY FRAMING ELEVATIONS
M-504	1	[********]	DETAILS

DELETE and **REPLACE** the following drawings as of [date]. These drawings accompany this [Amendment] [Modification].

DRAWING NO.	REVISION NO.	NAVFAC DWG NO.	TITLE
CU102	1	[********]	SITE UTILITY PLAN
LP102	1	[********]	LANDSCAPE PLANTING PLAN

SECTION 01 50 00 TEMPORARY CONSTRUCTION FACILITIES AND CONTROLS

1.4 Construction Site Plan

DELETE this paragraph and **REPLACE** with: “Prior to the start of work, submit a site plan showing the locations and dimensions of temporary facilities (including layouts and details, equipment and material storage area (onsite and offsite), and access and haul routes, avenues of ingress/egress to the fenced area and details of the fence installation.”

SECTION 03 30 00 CAST-IN-PLACE CONCRETE

1.3 Submittals, SD-02 Shop Drawings

ADD “Survey Plan; G”.

ADD subpart “1.6.3.5 Survey Meeting

Coordinate a meeting with surveyor, QC Manager, field superintendent, concrete subcontractor, and Contracting Officer to discuss a plan to survey the formwork and the embedded components prior to concrete placement. Discuss the schedule, coordination issues, timing, and efficiency issues.”

--End of [Amendment] [Modification]—

CHAPTER 19 PHASE: POST-CONSTRUCTION DOCUMENTS

19-1 PROJECT CLOSE-OUT.

The DOR may be required to execute specific project tasks during project close-out. These tasks may include preparing DD Form 1354, "Real Property Record," for Government signature, attending project close-out meetings, or performing other tasks. Refer to the design contract (if a DBB project) or the DB RFP for project close-out related tasks.

19-1.1 Interim Form DD 1354.

Update the Draft DD Form 1354 to include additional assets, improvements or alterations that occurred during construction. Identify costs. Submit completed form for approval to the Government. Attach to each DD Form 1354, updated HPSB Checklist(s) and TPC Checklist(s) for each applicable building in the project. For these DD Form 1354, ensure Block 14, “Sustainability Code” is marked with “1” for compliant.

19-1.2 Record Drawings.

Prepare record drawings in accordance with Chapter 12.

19-1.3 BIM Final Record Model.

Provide the final Record Model in accordance with Chapter 12.

19-1.4 Sustainability.

No later than 60 days after Beneficial Occupancy Date, provide updated HPSB Checklist(s) for each applicable building in the project to the Government Project Manager. Obtain TPC for each applicable building in the project when TPC organization requirements are complete. For projects with post-occupancy sustainability or energy requirements (such as commissioning), provide updated HPSB Checklist to the Government Project Manager. Ensure copies of the following are archived to the project’s electronic sustainability folder:

- Copy of the Final Commissioning Report, and copy of the Updated Final Commissioning Report, when applicable, for projects that use Government-hired Commissioning Provider.
- Copy of the Final report, validation, or certification for projects that apply Sustainable TPC.
- Contractor's completed submittal of the Sustainability eNotebook, and the Updated Sustainability eNotebook when applicable.

This Page Intentionally Left Blank

APPENDIX A SAMPLE DELIVERABLES

A-1 PRICE SCHEDULE FORM FOR DBB PROJECT

Price Schedule Form is located at: https://www.wbdg.org/navy/project-information-form-specifications-cover-sheet/spec-coversheet

Line Item	Description	Quantity	Unit	Unit Price	Sub-Total	Total Price
1	BASE PRICE: Total Price for the entire work for [Project P### – Insert description of the project scope here] in accordance with the [drawings and specifications][RFP], complete, but excluding work provided in another Priced line Item.	1	EA			$_____
1A	Subtotal of Base Price for the entire work for [Insert Primary Facilities Description] complete to the [1.5-meter] [5-foot] line outside of the building in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item	1	EA		$_____	
1B	Subtotal of Base Price for the entire project sitework, outside the facility [1.5-meter][5-foot] line, for [Insert Site Work Description here], complete in accordance with the [drawings and specifications][RFP], but excluding work described in another line Item.	1	EA		$_____	
1C	Subtotal of Base Price for entire Design of the Project, complete, but excluding work provided in another line item.	1	EA		$_____	
1D	Unit Price for providing Foundation Piling complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	[LM] [LF]	$_____	$_____	

1E	Unit Price for providing Pile Load Test, complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	EA	$_____	$_____	
1F	Unit Price for mass rock excavation and disposal complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	[CM] [CY]	$_____	$_____	
1G	Unit Price for trench rock excavation and disposal complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	[CM] [CY]	$_____	$_____	
1H	Unit Price for removal and disposal of asbestos containing pipe insulation (by pipe diameter ranges [_____]) complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	[LM] [LF]	$_____	$_____	
1J	Unit Price for removal and disposal of asbestos containing floor tile complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	[SM] [SF]	$_____	$_____	
1K	Unit Price for removal and disposal of asbestos containing siding complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	[SM] [SF]	$_____	$_____	
1L	Unit Price for providing removal and disposal of oily water and sludge inside tanks [_____], complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	[L] [Gal]	$_____	$_____	

1M	Unit Price for removal and disposal of contaminate stockpiled soils complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	[CM] [CY]	$_____	$_____	
1N	Unit Price for provision and compaction of fill in place of removed contaminate soil, complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another line item.	[_____]	[CM] [CY]	$_____	$_____	
2	Option Item No. 1: Price for providing all work in connection with [_____], complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another Priced line item.	1	EA			$_____
3	Option Item No. 2: Price for providing Electronic Security System (ESS) equipment, testing, and associated training, but excluding work provided in another Priced line item. The ESS includes, but is not limited to, Intrusion Detection System (IDS), Access Control System (ACS), and Video Systems complete in accordance with the [drawings and specifications] [RFP]. Equipment includes items such as Premise Control Units (PCU), central processing units, field panels, sensors, card readers, keypads, cameras, switches, video recorders, workstations, and the communication cabling connecting these devices together. Include the price for supporting, permanent infrastructure under the Base Price. Interior supporting infrastructure includes items such	1	EA			$_____

	as conduit, junction boxes, electronic door strikes, door-hardware, mounting hardware, and power connections. Exterior supporting infrastructure includes items such as exterior duct banks, manholes, utility poles, utility connections, and power connections.					
4	Option Item No. 3: Price for providing Audio Visual System (A/V) Equipment, testing, and associated training in accordance with the [drawings and specifications] [RFP], but excluding work provided in another Priced line item.. Equipment includes, but is not limited to, items such as flat panel monitors, projectors, wall input boxes, touch screens, push button control panels, video teleconferencing codecs, microphones, speakers and the communication cabling connecting these devices together. Include the price for supporting, permanent infrastructure under the Base Price. Interior supporting infrastructure includes items such as conduit, junction boxes, mounting hardware, and power connections.	1	EA			$_____
5	Option Item No. 4: Price for providing work in connection with labor, material, equipment, transportation and supervision required for the Furniture, Fixtures, and Equipment (FF&E), complete in accordance with the [drawings and specifications][RFP], but excluding work provided in another Priced line item.	GOV Estimated Price: [$_____]	HAR Percent (NTE 5%) ___%		HAR Subtotal $_____	Total FF&E Estimated Price $_____

A-2 SAMPLE SYNOPSIS

Synopsis for P236 FITNESS CENTER, CLDJ

THIS NOTICE IS PROVIDED FOR INFORMATION PURPOSES ONLY. THIS PROCUREMENT WILL BE SOLICITED ON AN UNRESTRICTED BASIS. SOLICITATION DOCUMENTS WILL NOT BE AVAILABLE FOR DOWNLOADING UNTIL APPROXIMATELY 17 DECEMBER 2012.

This is a one step design/bid/build construction project that will construct a two-story fitness center at Camp Lemonnier, Djibouti (CLDJ), Africa. The building is a pre-engineered metal building on reinforced concrete slab and foundations with insulated metal wall and roof panels, translucent wall panels, hydraulic elevator, interior concrete partitions, metal stud and gypsum board partitions, interior finishes, fire alarm and sprinkler system, plumbing, mechanical, electrical and incidental related work. Scope requirements include site preparation necessary for the construction of the fitness center also requiring installation of 75 new Containerized Living Units (CLUs), relocation of 75 existing CLUs encumbering the site, and replacing the artificial turf on the existing athletic field. Once the 75 new CLUs are constructed then the occupants of G-Block CLUs can relocate thus allowing those CLUs to be moved, triple stacked, and retrofitted with fire alarm and sprinkler systems.

Other scope requirements include the demolition of the existing fitness center after the new facility is constructed.

The period of performance is approximately 18 months after notice to proceed.

This project will be awarded as a firm-fixed price contract. The Government reserves the right to enter into negotiations or limit the competitive range. The construction range is between $10,000,000 and $25,000,000.

This contract will require a Performance Bond pursuant to FAR 52.228-15, through an approved surety under the United States Treasury Department Circular 570. Based on the feasibility of a contractor to furnish a Performance Bond, offerors may provide a 10% Performance Guarantee, in accordance with NFAS 5252.228-9306, in lieu of a Performance Bond.

The Request for Proposals (RFP) will be available for viewing and downloading on or about 17 December 2012. The proposal due date will be on or about January 31, 2013, 2:00 p.m. Eastern Standard Time North America.

The solicitation will be formatted as an RFP in accordance with the requirements designated by Federal Acquisition Regulation (FAR) 15.203 for a negotiated procurement utilizing procedures of FAR 36.2. This method permits evaluation of proposals based on price competition, technical merit and other factors; permits impartial and comprehensive evaluation of offerors' proposals; permits discussions if necessary; and ensures selection of the source whose performance provides the best value to the Government.

This Page Intentionally Left Blank

APPENDIX B COST ESTIMATE CLASSIFICATION AND VALUE ENGINEERING STUDY REQUIREMENTS

B-1 INDUSTRY COST ESTIMATE CLASSIFICATION.

AACE International publishes Recommended Practice 56R-08, *Cost Estimate System – As Applied for the Building and General Construction Industries*. This recommended practice (RP) defines the relationship between the maturity of the construction project definition deliverables and the accuracy of the cost estimate based on those deliverables. The RP defines five classes of estimates based on the level of project definition maturity. These five levels overlap to account for factors of the project such as project complexity and quality of cost data.

AACE International RP 56R-08 applies to the majority of projects undertaken by NAVFAC. In the cases where a project is similar to projects from the process industry, AACE International RP 17R-97 would be acceptable as a guidance to estimate accuracy classification. It is similar in its definition of estimate maturity but does not include a table that is analogous to Table 3 from AACE RP 56R-08.

Table B-1 Cost Estimate Class Comparison from AACE RP 56-08.[2]

Table 3 Estimate Input Checklist and Maturity Matrix from AACE International RP 56R-08 Copyright © 2020 by AACE International; all rights reserved	**ESTIMATE CLASSIFICATION**				
	Class 5	**Class 4**	**Class 3**	**Class 2**	**Class 1**
MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES	**0% to 2%**	**1% to 15%**	**10% to 40%**	**30% to75%**	**65% to 100%**
GENERAL PROJECT DATA:					
A. SCOPE:					
Project Scope of Work Description	**P**	**P**	**D**	**D**	**D**
Site Infrastructure (such as Access, Construction Power, Camp)	**NR**	**P**	**D**	**D**	**D**
B. CAPACITY:					
Functional Space – SF or m2	**P**	**P**	**D**	**D**	**D**
Electrical Power Requirements (when not the primary capacity driver)	**NR**	**P**	**D**	**D**	**D**
Mechanical Systems	**NR**	**P**	**D**	**D**	**D**
C. PROJECT LOCATION:					
Building and Other Project Elements	**P**	**P**	**D**	**D**	**D**
D. REQUIREMENTS:					

[2] Reprinted with the permission of AACE International, 1265 Suncrest Towne Center Dr., Morgantown, WV 26505 USA. Phone 304-296-8444. Internet: https://web.aacei.org/ Email: info@aacei.org Copyright © 2020 by AACE International; all rights reserved

Table 3 Estimate Input Checklist and Maturity Matrix from AACE International RP 56R-08 Copyright © 2020 by AACE International; all rights reserved	**ESTIMATE CLASSIFICATION**				
	Class 5	**Class 4**	**Class 3**	**Class 2**	**Class 1**
MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES	**0% to 2%**	**1% to 15%**	**10% to 40%**	**30% to75%**	**65% to 100%**
Anti-Terrorism Force Protection	**P**	**D**	**D**	**D**	**D**
No. of Building Floors	**P**	**P/D**	**D**	**D**	**D**
Security System	**NR/P**	**P**	**D**	**D**	**D**
Sustainability Requirements (and TPC Level where applicable)	**NR/P**	**P/D**	**D**	**D**	**D**
Codes and Standards	**NR**	**P**	**D**	**D**	**D**
Communication Systems	**NR**	**P**	**D**	**D**	**D**
Exterior Closure Description	**NR**	**P**	**D**	**D**	**D**
Finishes Descriptions	**NR**	**P**	**D**	**D**	**D**
Fire Protection and Life Safety	**NR**	**P**	**D**	**D**	**D**
Environmental Monitoring	**NR**	**NR**	**P**	**P**	**D**
E. TECHNOLOGY SELECTION:					
N/A					
F. STRATEGY:					
Contracting/Sourcing	**NR**	**P**	**D**	**D**	**D**
Escalation	**NR**	**P**	**D**	**D**	**D**
G. PLANNING:					
Logistics Plan	**P**	**P**	**P**	**D**	**D**
Integrated Project Plan	**NR**	**P**	**D**	**D**	**D**
Project Code of Accounts	**NR**	**P**	**D**	**D**	**D**
Project Master Schedule	**NR**	**P**	**D**	**D**	**D**
Regulatory Approval & Permitting	**NR**	**P**	**D**	**D**	**D**
Risk Register	**NR**	**P**	**D**	**D**	**D**
Stakeholder Consultation /Engagement / Management Plan	**NR**	**P**	**D**	**D**	**D**
Work Breakdown Structure	**NR**	**P**	**D**	**D**	**D**
Startup and Commissioning Plan	**NR**	**P**	**P/D**	**D**	**D**
Storm Water Management Plan	**NR**	**P**	**P/D**	**D**	**D**
H. STUDIES:					
Environmental Impact / Sustainability Assessment	**NR**	**P**	**D**	**D**	**D**
Environmental Existing Conditions	**NR**	**P**	**D**	**D**	**D**
Soils and Hydrology	**NR**	**P**	**D**	**D**	**D**
TECHNICAL DELIVERABLES					
Site Plan	**S**	**P**	**C**	**C**	**C**
Design Specifications	**NR**	**S/P**	**C**	**C**	**C**
Electrical One-line Drawings	**NR**	**S/P**	**C**	**C**	**C**

Table 3 Estimate Input Checklist and Maturity Matrix from AACE International RP 56R-08 Copyright © 2020 by AACE International; all rights reserved	**ESTIMATE CLASSIFICATION**				
	Class 5	**Class 4**	**Class 3**	**Class 2**	**Class 1**
MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES	**0% to 2%**	**1% to 15%**	**10% to 40%**	**30% to75%**	**65% to 100%**
General Equipment Arrangement Drawings	**NR**	**S/P**	**C**	**C**	**C**
Plot Plans / Facility Layouts	**NR**	**S/P**	**C**	**C**	**C**
Room Classification Data Sheet	**NR**	**S/P**	**C**	**C**	**C**
Room Layout Drawings	**NR**	**S/P**	**C**	**C**	**C**
Construction Permits	**NR**	**S/P**	**P/C**	**C**	**C**
Building Plan Views, Sections and Elevations	**NR**	**S/P**	**P**	**C**	**C**
Civil / Site / Structural / Architectural Discipline Drawings	**NR**	**S/P**	**P**	**C**	**C**
Codes and Standards Drawings	**NR**	**S/P**	**P**	**C**	**C**
Demolition Plan and Drawings	**NR**	**S/P**	**P**	**C**	**C**
Erosion Control Plan and Drawings	**NR**	**S/P**	**P**	**C**	**C**
Exterior Elevations	**NR**	**S/P**	**P**	**C**	**C**
Finish Schedule	**NR**	**S/P**	**P**	**C**	**C**
Fire Protection and Life Safety Drawings and Details	**NR**	**S/P**	**P**	**C**	**C**
Furniture Plans, Schedules and Drawings	**NR**	**S/P**	**P**	**C**	**C**
Interior Section Views	**NR**	**S/P**	**P**	**C**	**C**
Landscape Drawings	**NR**	**S/P**	**P**	**C**	**C**
Plumbing Drawings	**NR**	**S/P**	**P**	**C**	**C**
Roof Plan, Drawings and Details	**NR**	**S/P**	**P**	**C**	**C**
Storm Water Drawings	**NR**	**S/P**	**P**	**C**	**C**
Window Schedules	**NR**	**S/P**	**P**	**P/C**	**C**
Door Schedules	**NR**	**S/P**	**P**	**C**	**C**
Restroom Schedules	**NR**	**S/P**	**P**	**C**	**C**
Signage Drawings and Schedules	**NR**	**S/P**	**P**	**C**	**C**
Partition or Wall Types	**NR**	**S/P**	**S/P**	**C**	**C**
Electrical Schedules	**NR**	**NR/S**	**P**	**P/C**	**C**
Equipment Datasheets	**NR**	**NR/S**	**P**	**P/C**	**C**
Equipment Lists: Electrical	**NR**	**NR/S**	**P**	**P/C**	**C**
Equipment Lists: Process / Utility / Mechanical	**NR**	**NR/S**	**P**	**P/C**	**C**
Instrument and Control Schedules	**NR**	**NR/S**	**P**	**P/C**	**C**
Instrument Datasheets	**NR**	**NR/S**	**P**	**P/C**	**C**
Piping Schedules	**NR**	**NR/S**	**P**	**P/C**	**C**

Table 3 Estimate Input Checklist and Maturity Matrix from AACE International RP 56R-08 Copyright © 2020 by AACE International; all rights reserved	ESTIMATE CLASSIFICATION				
	Class 5	Class 4	Class 3	Class 2	Class 1
MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES	**0% to 2%**	**1% to 15%**	**10% to 40%**	**30% to75%**	**65% to 100%**
Piping Discipline Drawings	**NR**	**NR/S**	**S/P**	**C**	**C**
Spare Parts Listings	**NR**	**NR**	**P**	**P/C**	**C**
Electrical Discipline Drawings	**NR**	**NR**	**S/P**	**P/C**	**C**
Facility Emergency Communications Plan and Drawings	**NR**	**NR**	**S/P**	**P/C**	**C**
HVAC Drawings	**NR**	**NR**	**S/P**	**P/C**	**C**
Information Systems / Telecommunications Drawings	**NR**	**NR**	**S/P**	**P/C**	**C**
Mechanical Discipline Drawings	**NR**	**NR**	**S/P**	**P/C**	**C**
Room Discipline Drawings	**NR**	**NR**	**S/P**	**P/C**	**C**
Interior Lighting Plan and Drawings	**NR**	**NR**	**S/P**	**P**	**C**
Lighting Control Diagram	**NR**	**NR**	**S/P**	**P**	**C**
Lighting Schedules	**NR**	**NR**	**S/P**	**P**	**C**
Lightning Protection Drawings	**NR**	**NR**	**S/P**	**P**	**C**
Mechanical / HVAC Schedules	**NR**	**NR**	**S/P**	**P**	**C**
Motor Control Diagram	**NR**	**NR**	**S/P**	**P**	**C**
Plumbing Details	**NR**	**NR**	**S/P**	**P**	**C**
Security Plan and Drawings	**NR**	**NR**	**S/P**	**P**	**C**
Instrument List	**NR**	**NR**	**S**	**P/C**	**C**
Building Envelope / Moisture Protection / Flashing Details	**NR**	**NR**	**S**	**P**	**C**
Interior Elevations	**NR**	**NR**	**S**	**P**	**C**

Degree of Completion Descriptors

General Project Data:

- **Not Required (NR):** May not be required for all estimates of the specified class, but specific project estimates may require at least preliminary development.
- **Preliminary (P):** Project definition has begun and progressed to at least an intermediate level of completion.
- **Defined (D):** Project definition is advanced, and reviews have been conducted. Development may be near completion with the exception of final approvals.

Technical Deliverables:

- **Not Required (NR):** Deliverable may not be required for all estimates of the specified class, but specific project estimates may require at least preliminary development.
- **Started (S):** Work on the deliverable has begun. Development is typically limited to sketches, rough outlines, or similar levels of early completion
- **Preliminary (P):** Work on the deliverable is advanced. Interim, cross-functional reviews have usually been conducted. Development may be near completion except for final reviews and approvals.
- **Complete (C):** The deliverable has been reviewed and approved as appropriate.

B-2 PRELIMINARY DESIGN COST ESTIMATE.

For Preliminary Design scope development, the project definition is based on the minimum project data and deliverables indicated in Table B-2.

Table B-2 Minimum Project Data and Deliverables.

Crosswalk between AACE International RP56R-08 and Preliminary Design	**Preliminary Design**	**Remarks**
Maturity level of project definition deliverables	Preliminary Design Deliverables	
General Project Data		
Construction Scope Description	Defined	DD1391 requirements govern this.
Project Location	Defined	DD1391 requirements govern this.
Total Building Area - SF or m2	Defined	DD1391 requirements govern this.
Functional Space Requirements -SF or m2	Defined	DD1391 requirements govern this.
No. of Building Stories	Defined	DD1391 requirements govern this.
Exterior Closure Description	Preliminary	Addressed in the Basis of Design.
Finishes Descriptions and Requirements	Preliminary	
Building Code or Standards Requirement	Defined	
Mechanical Systems and Total Capacity	Preliminary	
Electrical Capacity	Defined	
Communication Systems	Preliminary	
Fire Protection and Life Safety Requirements	Preliminary	
Security System	Started	
Antiterrorism	Defined	Provide separate narratives for the following cross-disciplinary elements. Devote special attention to issues that may have significant cost impact. AT – Identify the AT occupancy (low occupancy or inhabited), and protective measures above the minimum, and AT requirements that may have significant cost impact (for example, Geographic Combatant Commander’s AT Construction Standards).

Crosswalk between AACE International RP56R-08 and Preliminary Design	Preliminary Design	Remarks
Sustainability	Started	Sustainability – Indicate the feasibility of meeting Guiding Principle requirements and other sustainability goals for the project in accordance with UFC 1-200-02. Include a draft High Performance Sustainable Building (HPSB) Checklist. Where TPC is an anticipated requirement, develop a draft TPC checklist.
Soils and Hydrology Report	Started	Utilize existing topographic/hydrographic data to the maximum extent possible.
Integrated Project Plan	Preliminary	Other preliminary design deliverables that may not always be supported by the Project Technical Team.
Project Master Schedule	Preliminary	
Work Breakdown Structure	Preliminary	
Project Code of Accounts	None	
Contracting Strategy	Preliminary	Identify DBB or DB costs for considering the application of SIOH to the design effort relative to representing the information on the DD1391.
Escalation Strategy and Basis	Discussed	Include escalation calculations in the Basis of Estimate.
Design Deliverables [3]	RP 56R-08 uses: None [blank]; Started [S]; Preliminary [P]; Complete [C].	
Building Codes and Standards Drawing	None	Separate document not required
Fire Protection and Life Safety Requirements	P	Address requirements in the basis of design.
Site Plan	P	Preliminary design drawing or sketch - Site Plan(s): Show the layout (size and possible shape) of the new facility in relation to major landmarks. Show the possible location of access roads, parking, landscaping, pedestrian walkways, roads, and sidewalks, as applicable. Indicate approximate dimensions and orientation. Site Plans must clearly indicate site constraints such as explosive safety arcs, flood zones, wetlands or other environmentally sensitive areas. Where AT is applicable, clearly depict setback distances to vulnerabilities, including parking, roadways, and obstructions.

Crosswalk between AACE International RP56R-08 and Preliminary Design	Preliminary Design	Remarks
Existing Site Plan	P	Preliminary design drawing or sketch - Vicinity Map and Location Plan
Demolition Plan and Drawings	P	Preliminary design drawing or sketch - Demolition Plan: Show facilities to be demolished (if required)
Utility Plan and Drawings	P	Preliminary design drawing or sketch - Utilities Plans: Show utility lines and their points of connection in relation to existing adjacent structures, roads, and utilities. Show off-site utility upgrade requirements needed to support the project. Show civil, electrical and telecommunication utilities to clearly convey the scope and quantities associated with various utility improvements. On large utility distribution projects, provide one-line diagrams of electrical and telecommunication utilities.
Site Electrical Plan and Drawings	P	
Site Lighting Plan and Drawings	P	
Site Communication Plan and Drawings	P	
Erosion Control Plan and Drawings	S/P	Address requirements in the basis of design - Basis of design for site and utility related disciplines (for example, civil, electrical, telecommunication) must identify the design assumptions for Supporting Facilities, as required to support quantities and unit costs for Supporting Facilities. Consult with landscape architecture personnel for select projects, where a large proportion of total cost is likely to be associated with landscaping requirements.
Stormwater Plan and Drawings	S/P	
Landscaping Plan and Drawings	S/P	
Exterior Elevations	P	Preliminary design drawing or sketch - Building Elevations: Provide schematic elevations indicating the building exterior character.
Interior Elevations	No drawing, plan, diagram or schedule	Address requirements in the Basis of Design - Basis of design for building systems (for example, architecture, structural, mechanical, electrical, fire protection) must identify the discipline-specific design assumptions, as required to support a parametric estimate on the Primary Facility. Consult with interior design personnel for select projects, where unique interior design requirements cannot be captured by standard parametric estimating techniques for the facility-type.
Interior Section Views		
Partition or Wall Types		
Finish Schedule		
Door Schedules		
Window Schedules		
Restroom Schedules		
Furniture Plans, Schedules and Drawings		
Signage Drawings and Schedules		
Fire Protection Plan, Drawings and Details		

Crosswalk between AACE International RP56R-08 and Preliminary Design	**Preliminary Design**	**Remarks**
Room Layout Plan and Drawings	P	Preliminary design drawing or sketch - Building Floor Plans: Provide schematic floor plans depicting functional utilization of spaces. For renovation projects, provide separate drawings where required to identify existing conditions, demolition, and new construction elements.
Foundation Plan and Drawings	No drawing, plan, diagram or schedule	Address requirements in the Basis of Design - Basis of design for building systems (for example, architecture, structural, mechanical, electrical, fire protection) must identify the discipline-specific design assumptions, as required to support a parametric estimate on the Primary Facility. Basis of design for FRCS must indicate the Cybersecurity Impact Level for the control system. **\1** For work in existing buildings, include identification and documentation of existing FRCS infrastructure and how the new work is integrated. **/1/** Provide discussion, where the cybersecurity accreditation process or requirements are expected to significantly impact project cost or schedule.
Foundation Sections and Details		
Structural Plans and Drawings		
Structural Sections and Drawings		
Roof Plan, Drawings and Details		
Material, Equipment and System Specifications		
Building Envelope/moisture protection/flashing details		
Mechanical/HVAC Plan and Drawings		
Mechanical HVAC/Details		
Mechanical HVAC/Schedules		
Flow Control Diagrams		
Plumbing Plan and Drawings		
Plumbing Details		
Plumbing Riser Diagram		
One-Line Electrical Diagram		
Electrical Power Plan		
Interior Lighting Plan and Drawings		
Security Plan and Drawings		
Emergency Communication Plan and Drawings		
Life Safety Plan and Drawings		
Lightning Protection Plan and Drawings		
Motor Control Diagram		
Lighting Control Diagram		
Lighting Schedules		
Electrical Control/Panel Schedule		
Equipment Schedule		
Information Systems/Telecommunication Plan		
Information Systems/Telecommunication Details		

B-3 VALUE ENGINEERING STUDY (VES) REQUIREMENTS.

Provide the service of a Value Engineering (VE)/Value Analysis (VA) team led by a Value Study Team Leader (VSTL) to conduct a Value Engineering Study (VES) to include a Value Engineering Workshop (VEW). The VEW may be combined with other meetings or workshops associated with the project. The VES must follow the methodology advocated by SAVE International and will be documented in a report. Each of the alternatives evaluated as part of the VES must be achievable with the project's construction award amount.

The following industry standards apply to the extent feasible in accordance with the level of design development:

- SAVE Value Methodology Guide, 2020
- ASTM E1699 *Standard Practice for Value Engineering (VE)/Value Analysis (VA) of Projects, Products, and Processes* (Latest Revision)
- ASTM E2013 *Standard Practice for Constructing FAST Diagrams and Performing Function Analysis During Value Analysis Study* (Latest Revision)

B-3.1 VE/VA Team Requirements.

Value Study Team Leader (VSTL): Provide a VSTL certified by SAVE International as a Certified Value Specialist, with experience in preparing Value Studies and conducting VES workshops for projects related to the construction of buildings and other engineered systems. The VSTL will be responsible for leading the VE/VA team, resolving issues to the maximum extent possible, documenting meetings, organizing the study materials for on-site use/approval, and providing the VES Report.

DOR PDT will provide the VE/VA Technical Team.

B-3.2 VES Kick Off Meeting.

Conduct the VES meeting via teleconference and review workshop preparations, scope, expectations, roles and responsibilities, schedules, and documentation requirements. This meeting will generally last one hour and must be attended by the VSTL and the Project Manager (PM) and Design Manager (DM) from the DOR.

B-3.3 Value Engineering Workshop (VEW).

The VEW must be attended by the VSTL as well as the key members of the DOR's PDT. This is to include the DOR's PM, DM, Architect, Structural Engineer, Mechanical Engineer, Electrical Engineer, Civil Engineer, Landscape Architect, Cost Engineer, Fire Protection Engineer, Interior Designer, CTS-D, Geotechnical Engineer, and Sustainability Coordinator. Other technical disciplines may be included if approved by the NAVFAC PM, DM, or Cost TDC. The VSTL will lead the VEW following the six-step job plan consistent with the SAVE International Value Standard, ASTM E1699 and

ASTM E2013. A comprehensive VEW will establish the six steps during the on-site workshop. An abbreviated VEW will accomplish the first three steps during the workshop and the remaining three steps after the workshop. The six phases of the Value Methodology Job Plan are:

1. Information Phase
2. Function Analysis Phase (including FAST Diagrams in accordance with ASTM E2013)
3. Creative Phase
4. Evaluation Phase
5. Development Phase
6. Presentation Phase

B-3.3.1 VEW Preparations.

Provide a meeting facility to accommodate the anticipated number of participants. The facility is to provide access to photocopying for handout material and access to the Internet for Email and research by participants.

Complete the following items prior to the start of the VEW:

a. As a minimum, review the available documentation gathered by the NAVFAC PDT. This includes but is not limited to:
   - Information included or cited in the project's scope of services (SAES or SIHS as appropriate)
   - Design Instructions from other agencies
   - Design authorization and programming documents
   - Studies, cost estimates, and other information

b. **\1** Plan and coordinate for a site visit prior to the workshop to allow the VSTL and the VE/VA Technical Team to become familiar with the project site. Coordinate this effort with the NAVFAC PM/DM. **/1/**

c. **\1** The VSTL is to prepare a sample presentation format for the use of the DOR's VE/VA Technical Team. Submit a copy of this for NAVFAC review and approval. **/1/**

d. Prepare a presentation handout **\1** for VEW participants. Submit this handout for NAVFAC review and approval. This handout is to include: **/1/**
   - A discussion of the overall VES methodology

- A discussion of the scope of work as currently developed
- A discussion of the current program amount allocated for the project
- A discussion of the current estimated construction cost estimate
- A capital cost model as indicated in ASTM E1699, 7.2.8 **\1\ /1/**.
- A discussion of the project documentation provided for this study, noting that copies are available during the workshop
- A discussion of the performance and acceptance requirements for evaluating alternatives in accordance with ASTM E1699, 7.2.5 **\1\ /1/**.

B-3.3.2 VEW Process.

a. The DOR's PDT members will explain how the current scope/design accomplishes the stakeholder objectives.

b. The workshop participants will generate a list of ideas for project improvement followed by an evaluation of those ideas. The evaluation will include input from key stakeholder decision makers before proceeding with development recommendations.

c. The VE/VA Technical Team will develop selected ideas into alternatives with enough documentation to allow decision makers to determine if the alternative should be implemented.

d. The VSTL, with input from NAVFAC, will evaluate each alternative in accordance with the pre-determined performance and acceptance requirements.

e. The VSTL will present the alternatives to the key stakeholder decision makers on the final day of the workshop.

B-4 VES DECISION/IMPLEMENTATION MEETING.

The VSTL must conduct a four hour Decision/Implementation Meeting via teleconference. This meeting is to assist key project stakeholders in the selection of which of the developed alternatives to implement. The VES Decision/Implementation Meeting must be attended by the DOR's PDT who will be working on this project. This is to include the DOR's PM, DM, Architect, Structural Engineer, Mechanical Engineer, Electrical Engineer, Civil Engineer, Landscape Architect, Cost Engineer, Fire Protection Engineer, Interior Designer, CTS-D, and Geotechnical Engineer. Other technical disciplines may be included if approved by the NAVFAC PM, DM, or Cost TDC.

B-5 VES REPORT.

Provide a report documenting the VES process and its application to this project by capturing the process and the alternatives considered or recommended. Provide a report reflecting the type of VEW performed, comprehensive or abbreviated.

Include the following in the report:

- Project Objectives
- Project Description
- Scope Analysis
- VES Procedure
- VES Alternatives and associated savings/improvements considered
- VES Alternatives and associated savings/improvements recommended
- Copy of the original Study Team Presentation Handout

B-5.1.1 Comprehensive Workshop VES Report.

a. Preliminary VES Report: Include a collection of the findings of six phases of the Value Methodology Job Plan at the conclusion of the workshop.

b. Draft Final VES Report: Incorporate revisions from previous submittal comments and include a list of final recommendations.

c. Final VES Report: Incorporate revisions from previous submittal comments and the implementation decisions captured during the Decision/Implementation Meeting.

B-5.1.2 Abbreviated Workshop VES Report.

a. Preliminary VES Report: Include a collection of draft/summaries of the findings at the conclusion of the workshop. As a minimum address the first (3) phases of the Value Methodology Job Plan covered during the workshop.

b. Interim VES Report: Include revisions of the Preliminary VES Report and include draft/summaries of the last (3) phases of the Value Methodology Job Plan.

c. Draft Final VES Report: Incorporate revisions from previous submittal comments and include a list of final recommendations

d. Final VES Report: Incorporate revisions from previous submittal comments and the implementation decisions captured during the Decision/Implementation Meeting.

APPENDIX C BIM (MODELING)

C-1 BIM - BASIS OF DESIGN SAMPLE TABLES.

Examples to assist with completion of the Basis of Design are provided in the following Tables. Modify the text to suit the needs of the organization filling out the template.

Table C-1 Key Project Contacts

ROLE	ORGANIZATION	NAME	EMAIL	PHONE
DOR Project Manager	[NAVFAC / AGENT]	[John/Jane Doe]		
NAVFAC Project Manager	[NAVFAC]			
DOR BIM Manager	[Company]			
DOR Architectural Lead	[Company]			
NAVFAC Architectural Lead	[NAVFAC]			
DOR Structural Lead	[Company]			
NAVFAC Structural Lead	[NAVFAC]			
DOR Interiors Lead	[Company]			
NAVFAC Interiors Lead	[NAVFAC]			
DOR Landscape Architecture Lead	[Company]			
NAVFAC Landscape Architecture Lead	[NAVFAC]			
DOR Civil Lead	[Company]			
NAVFAC Civil Lead	[NAVFAC]			
DOR Fire Protection Lead	[Company]			
NAVFAC Fire Protection Lead	[NAVFAC]			
DOR Mechanical Lead	[Company]			

ROLE	ORGANIZATION	NAME	EMAIL	PHONE
NAVFAC Mechanical Lead	[NAVFAC]			
DOR Electrical/Telecom Lead	[Company]			
NAVFAC Electrical/Telecom Lead	[NAVFAC]			
DOR Plumbing Lead	[Company]			
NAVFAC Plumbing Lead	[NAVFAC]			
NAVFAC Design Manager	[NAVFAC]			
NAVFAC Construction Manager	[NAVFAC]			
DOR Sustainability Coordinator	[Company]			
NAVFAC Sustainability Coordinator	[NAVFAC]			
Other Project Roles	[Company]			

Table C-2 Major BIM Goals and Objectives

BIM GOAL	DESCRIPTION
Models	3D Parametric Design Model and Record Model
Design Facility Data	DOR Edited Model & Facility Data Matrix tab from eOMSI Facility Data Workbook (FDW)

Table C-3 BIM Uses

The BIM Uses currently checked with an (X) are mandatory and required by NAVFAC.

DESIGN	
X	DESIGN FACILITY DATA
X	DESIGN MODELING
X	CLASH DETECTION (3D COORDINATION)

Table C-4 Organizational Roles and Staffing

ROLES / STAFFING			
PROCESS	**ORGANIZATION**	**LOCATION(S)**	**LEAD CONTACT**
DESIGN FACILITY DATA	[DOR]		
DESIGN MODELING	[DOR]		
PROGRESS REVIEWS	**NAVFAC**		
CLASH DETECTION (3D COORDINATION)	[DOR]		

C-2 QUALITY CONTROL CHECKS.

C-2.1 Overall Strategy for Quality Control.

Describe the strategy to control the quality of the model.

C-2.2 Quality Control Checks.

The following checks are required to assure quality. Provide Responsible Party name and title.

Table C-5 Quality Control Checks

REVIEW	DEFINITION	RESPONSIBLE PARTY	SOFTWARE PROGRAM(S)	FREQUENCY
VISUAL REVIEW	Check the DOR Edited Model & Facility Data Matrix tab from the eOMSI Facility Data Workbook against the design intent, so that there are no unintended elements or omissions in the Design Model	John Doe Architect		AT EVERY SUBMITTAL
CLASH DETECTION (3D COORDINATION)	Detect problems in the model where two building components intersect (for example, a structural beam intersects HVAC duct work)			AT EVERY SUBMITTAL

APPENDIX D GLOSSARY

D-1 ACRONYMS.

A-E	Architect and Engineer
A/E/C	A/E/C CAD Standard
\1\ /1/	
BOD	Basis of Design
BPA	Budget Project Readiness Index (PRI) Authority
BRACON	Base Realignment and Closure Office
CAD	Computer Aided Design and Drafting
CATEX	Categorical Exclusion
\1\ /1/	
CFA	Commission of Fine Arts
CMC	Commandant, Marine Corps
CRB	Consistency Review Board
CSI	Construction Specifications Institute TM
CONUS	Continental United States
CLIN	Contract Line Item Number
CSRA	Cost and Schedule Risk Analysis
DB	Design-Build
DBB	Design-Bid-Build
DFPE	Designated Fire Protection Engineer
DIGGS	Data Interchange for Geotechnical and Geoenvironmental Specialists
DoD	Department of Defense
DOR	Designer of Record
DQC	Design Quality Control

\1\ /1/

EA	Environmental Assessment
EBS	Electronic Bid Solicitation
EDD	Electronic Design Deliverables
EIS	Environmental Impact Statement
eOMSI FDW	Electronic Operation and Maintenance Support Information (eOMSI) Facility Data Workbook
FACD	Facility Analysis Concept Design
FACP	Fire Alarm Control Panel
FC	Facility Criteria
FF&E	Furniture, Fixtures, and Equipment
FOSSAC	Fitting Out and Supply Support Assistance Center
HAR	Handling and Administration Rate
HPSB	High Performance and Sustainable Buildings
IFP	Installation Focus Plan
IP	Inch-Pound (English)
KTR	Contractor
LCC	Life-Cycle Cost
LID	Low Impact Development
MCON	Military Construction Navy
MILCON	Military Construction
MOU	Memorandum of Understanding
NAC	Notification Appliance Circuit
NAVFAC	Naval Facilities Engineering Systems Command
NCPC	National Capitol Planning Commission
NEHC	Naval Environmental Health Center

NEPA	National Environmental Policy Act
NFPA	National Fire Protection Agency
NIST	National Institute of Science and Technology
NIWC	Naval Information Warfare Center
NLIDDC	NAVFAC Low Impact Development Data Card
NOSSA	Naval Ordnance Safety and Security Activity (NOSSA)
OSHA	Occupational Safety and Health Administration
OCONUS	Outside the Continental United States
PBI	Pre-Bid Inquiry
PCAS	Post-Construction Award Services
PDA	Preliminary Design Authority
PDF	Portable Document File
PIF	Project Information Form
PM	Project Manager
PPI	Pre-Proposal Inquiry
PRI	Project Readiness Index
PROD	Permit Record of Design
PWD	Public Works Department
PTS	Performance Technical Specification
PxP	Project Execution Plan
QFPE	Qualified Fire Protection Engineer
RAC	Risk Assessment Code
RAMP	Requirements and Management Plan
RFI	Request For Information
RFP	Request For Proposal

RONA	Record of Non-Applicability
SAES	Statement of A-E Services
SAPF	Special Access Program Facility
SCIF	Sensitive Compartmented Information Facilities
SHPO	State Historic Preservation Officer
SI	System International (Metric)
TDC	Technical Discipline Coordinator
TPC	Third-Party Certification
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
VES	Value Engineering Study

APPENDIX E REFERENCES

E-1 GOVERNMENT

FEDERAL GOVERNMENT

36 CFR 800, *Protection of Historic Properties*, https://www.ecfr.gov/current/title-36/chapter-VIII/part-800

DEPARTMENT OF DEFENSE

DFARS 227.71, *Technical Data and Associated Rights,* https://www.acq.osd.mil/dpap/dars/dfarspgi/current/index.html

DFARS 227.72, *Computer Software, Computer Software Documentation, and Associated Rights* https://www.acq.osd.mil/dpap/dars/dfarspgi/current/index.html

DFARS 252.227-7023, *Drawings and Other Data to Become Property of Government*, https://www.acq.osd.mil/dpap/dars/dfarspgi/current/index.html

DoD Directive 4270.5, *Military Construction*, 12 February 2005, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/427005p.pdf?ver=2018-11-08-080607-280

DoD Instruction 5200.48, *Controlled Unclassified Information (CUI)*, 6 March 2020, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/520048p.PDF

MIL-STD-3007, *Standard Practice for Unified Facilities Criteria, Facilities Criteria and Unified Guide Specifications*, https://www.wbdg.org/dod/fedmil/mil-std-3007

Public Law 94-168, *Metric Conversion Act*, https://www.govinfo.gov/content/pkg/STATUTE-89/pdf/STATUTE-89-Pg1007.pdf

Public Law 106-229, *Electronic Signatures in Global and National Commerce Act*, https://www.govinfo.gov/content/pkg/PLAW-106publ229/pdf/PLAW-106publ229.pdf

UNIFIED FACILITIES CRITERIA (UFC / FC)

https://www.wbdg.org/dod/ufc

FC 4-721-10N, *Navy and Marine Corps Unaccompanied Housing*

UFC 1-200-01, *DoD Building Code*

UFC 1-200-02 *High Performance and Sustainable Building Requirements*

UFC 1-300-02, *Unified Facilities Guide Specifications (UFGS) Format Standard*

UFC 1-300-08, *Criteria for Transfer and Acceptance of DoD Real Property*

UFC 3-101-01, *Architecture*

UFC 3-201-02, *Landscape Architecture*

UFC 3-210-10, *Low Impact Development*

UFC 3-220-01, *Geotechnical Engineering*

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*

UFC 3-260-02, *Pavement Design for Airfields*

UFC 3-260-03, *O&M Manual: Standard Practice for Airfield Pavement Evaluation*

UFC 3-301-01, *Structural Engineering*

UFC 3-340-01, *Design and Analysis of Hardened Structures to Conventional Weapons Effects (FOUO)*

UFC 3-410-01, *Heating, Ventilating, and Air Conditioning Systems*

UFC 3-420-01, *Plumbing Systems*

UFC 3-501-01, *Electrical Engineering*

UFC 3-600-01, *Fire Protection Engineering for Facilities*

UFC 3-701-01, *DoD Facilities Pricing Guide*

UFC 3-730-01, *Programming Cost Estimates for Military Construction*

UFC 3-740-05, *Construction Cost Estimating*

UFC 3-810-01N, *Navy and Marine Corps Environmental Engineering for Facility Construction*

UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*

UFC 4-010-05, *SCIF/ SAPF Planning, Design, and Construction*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

UFC 4-023-03, *Design of Buildings to Resist Progressive Collapse*

UFC 4-510-01, *Design: Medical Military Facilities*

UFC 4-610-01, *Administrative Facilities*

UFC 4-722-01, *Design: Dining Facilities*

UFC 4-740-02, *Fitness Centers*

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS)

https://www.wbdg.org/dod/ufgs (unless otherwise noted)

UFGS 00 01 15, *List of Drawing*

UFGS 01 11 00, *Summary of Work*

UFGS 01 33 00, *Submittal Procedures*

UFGS 01 33 00.05 20, *Construction Submittal Procedures*, https://www.wbdg.org/FFC/NAVFAC/NDBM/UFGS/01_33_00.05_20.pdf

UFGS 01 33 10.05 20, *Design Submittal Procedures*, https://www.wbdg.org/FFC/NAVFAC/NDBM/UFGS/01_33_10.05_20.pdf

UFGS 01 33 29, *Sustainability Requirements and Reporting*

UFGS 01 45 00, *Quality Control*

UFGS 01 45 35, *Special Inspections*

UFGS 01 78 23, *Operation and Maintenance Data*

UFGS 01 78 24.00 20, *Facility Data Workbook (FDW)*

UFGS 02 82 00, *Asbestos Remediation*

UFGS 10 14 00.20, *Interior Signage*

UFGS 33 40 00, *Stormwater Utilities*

UNITED STATES ARMY

DoD A/E/C CAD Standard, https://cadbimcenter.erdc.dren.mil/aeccadstandard

UNITED STATES NAVY

\1\ /1/

Naval Facilities Acquisition Standards, (NFAS), Part 6.304, *Competition Requirements, Other Than Full and Open Competition, Approval of the justification*, https://www.navfac.navy.mil/Portals/68/Documents/Business-Lines/Office-of-Small-Business/Opportunities/Contracting%20Guidelines/Contracting%20with%20NAVFAC/sb_navfac_naval_facilities_acq_standard_oct_2018_change1_aug2019.pdf?ver=ftqB6mpXivX_Q1pTxGnPcg%3D%3D

FC 2-000-05N, *Facility Planning for Navy and Marine Corps Shore Installations*

NAVFAC Design-Build Master RFP website, https://www.wbdg.org/navy/ndbm

\1Programming Administration and Execution (PAX), Naval Facilities Engineering Systems Command. Contact government administrator for intranet address and access.**/1/**

\1SECNAV Instruction (SECNAVINST) 3070.2A, *Operations Security,* 09 May 2019, https://www.secnav.navy.mil/doni/Directives/03000%20Naval%20Operations%20and%20Readiness/03-00%20General%20Operations%20and%20Readiness%20Support/3070.2A.pdf**/1/**

GENERAL SERVICES ADMINISTRATION (GSA)

https://www.acquisition.gov/browse/index/far

FAR 52.217-5, *Evaluation of Options*

FAR 52.236-21, *Specifications and Drawings for Construction*

FAR 52.236-25, Requirements for Registration of Designers

Standard Form (SF) 30, *Amendment of Solicitation/ Modification of Contract*, https://www.gsa.gov/reference/forms/amendment-of-solicitationmodification-of-contract

GOVERNMENT ACCOUNTABILITY OFFICE (GAO)

https://www.gao.gov/

GAO-16-89G, *Schedule Assessment Guide*

E-2 NON-GOVERNMENT

AACE INTERNATIONAL (AACE)

https://web.aacei.org/

Recommended Practice 27R-03, *Schedule Classification System*

Recommended Practice 56R-08, *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Building and General Construction Industries*

AMERICAN SOCIETY OF HEATING, REFRIGERATION AND AIR CONDITIONING ENGINEERS (ASHRAE)

https://www.ashrae.org/

ANSI/ASHRAE Standard 62.1, *Ventilation and Acceptable Indoor Air Quality*

ANSI/ASHRAE Standard 62.2, *Ventilation and Acceptable Indoor Air Quality in Residential Buildings*

ASHRAE 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*

ASTM

https://www.astm.org/

ASTM D1452, *Standard Practice for Soil Exploration and Sampling by Auger Borings*

ASTM D1586, *Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils*

ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*

ASTM D2488, *Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)*

ASTM D3740, *Standard Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction*

ASTM D5778, *Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils*

ASTM E1699, *Standard Practice for Performing Value Engineering (VE)/Value Analysis (VA) of Projects, Products and Processes*

ASTM E1804, *Standard Practice for Performing and Reporting Cost Analysis During the Design Phase of a Project*

ASTM E 2013, *Standard Practice for Developing Functions, Constructing FAST Diagrams, and Performing Function Analysis During Value Engineering (VE)/Value Analysis (VA) Study*

CONSTRUCTION SPECIFICATIONS INSTITUTE (CSI)

MasterFormat®, https://www.csiresources.org/standards/masterformat

UniFormat®, https://www.csiresources.org/standards/uniformat

FM GLOBAL

https://www.fmglobal.com/

Property Loss Prevention Data Sheet 3-0, *Hydraulics of Fire Protection Systems*

INTERNATIONAL CODE COUNCIL (ICC)

https://www.iccsafe.org/

IBC, *International Building Code (IBC)*

IEBC, *International Existing Building Code (IEBC)*

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

https://www.nfpa.org/

NFPA13, *Standard for the Installation of Sprinkler Systems*

NFPA 72, *National Fire Alarm and Signaling Code*

NFPA 101, *Life Safety Code*

NFPA 291, *Recommended Practice for Fire Flow Testing and Marking of Hydrants*

NATIONAL SOCIETY OF PROFESSIONAL SURVEYORS (NSPS)

Model Standards for Topographic Surveys, https://www.nsps.us.com/page/ModelStandards

SAVE INTERNATIONAL

https://www.value-eng.org/

SAVE *Value Methodology Guide*, 2020

UNITED STATES NATIONAL CAD STANDARD

United States National CAD Standard (NCS) for Architecture, Engineering, & Construction http://www.nationalcadstandard.org/

WHOLE BUILDING DESIGN GUIDE (WBDG)

https://www.wbdg.org/

eOMSI FDW, *Electronic Operation and Maintenance Support Information (eOMSI), Facility Data Workbook*, https://www.wbdg.org/navy/bim-eomsi

FACILITIES CRITERIA (FC)

FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

FOREWORD

This publication, *Facility Planning for Navy and Marine Corps Shore Installations* (FC 2-000-05N formerly known as UFC 2-000-05N and the P-80), provides facility planning criteria for use in computing quantitative facility requirements for Navy and Marine Corps installations. This document was reformatted from the October 1982 P-80 document on 31 January 2005 and in accordance with the standards for Unified Facilities Criteria (UFC). Since that time the facility planning criteria has been determined not unified among the various DoD services. Therefore, UFC 2-000-05N was changed to a Facilities Criteria (FC) document on 02 March 2023. The criteria are regularly updated to address emergent facility planning issues. The document includes planning criteria and data applicable to those categories of facilities to which a planning factor or data can be applied for computing facility requirements.

Planning criteria contained in this publication are used in the preparation of Basic Facility Requirements, evaluation of existing assets and the determination of specific facility requirements for shore facilities programs. These criteria apply equally to proposed and existing facilities. Their application to existing facilities provides a basis for planning against deficiencies or disposition of excess property as appropriate.

This Foreword and Chapter 1 include the authority and responsibilities of the Naval Facilities Engineering Command for the preparation and publication of planning criteria for use in calculating facility requirements at Navy and Marine Corps Installations and describe the use and applicability of the facility planning factors. The following sections contain a compilation of planning data and related space criteria developed by the Naval Facilities Engineering Command, furnished by systems commands, bureaus and offices of the Department of the Navy and issued by the Secretary of Defense. Planning criteria are established as a guide and normally will be considered as maximum for facilities listed.

The systems for updating this publication will minimize inconsistencies or contradictions with other applicable current directives. Users are invited to call to the attention of the Planning Criteria Managers any criteria requiring updating, clarification, or revisions due to error.

This publication and its appendices can be found at: https://www.wbdg.org/dod/ufc/fc-2-000-05n.

In all cases the material on the website is considered the most up to date. This publication is certified as an official publication of the Naval Facilities Engineering System Command.

CHAPTER 1

INTRODUCTION

Table of Contents

1-1 PURPOSE OF PUBLICATION

This Facility Criteria publication, FC 2-000-05N was formerly designated as FC 2-000-05N under the same title. It provides the space planning factors, criteria and techniques for use in developing Basic Facility Requirement (BFR) calculations and assessments. Establishing the BFR provides the space demand or support requirement for shore-based facilities, by category code, necessary to perform the peacetime missions of Navy shore activities. A BFR justification is the calculation of an installation, command, or region's facilities allowances based upon established planning criteria. The BFR calculation can be modified (with justification) to accommodate site-specific or unit-specific loading requirements, such as mission, personnel, functions and equipment.

BFRs encompass entire functional categories of use, such as administrative offices, general warehouses or public works shops, for both host and tenant commands. For each of the activity's functional categories, if the sum of all current assets assigned to that category code is greater than the calculated requirement in the BFR, there is a surplus of space; if it is less, there is a deficiency. BFRs should be updated periodically and must be updated when there is a change in loading or a change in mission.

The purpose of this publication is to present the specific criteria and algorithms used to prepare BFRs for different categories of functional uses.

1-2 BFR PROCESS

Information about the process of preparing BFRs can be found in the Naval Facilities Engineering Command (NAVFAC) Business Process Management System (BPMS), which provides a systematic method for the management of various business processes and common practices that produce and/or support production of NAVFAC products and services. The BPMS provides best business processes documentation and links to applicable, appropriate and up-to-date policies, guidance, forms and information.

The BPMS process guide for production of BFRs is located on the NAVFAC portal website at the following secure address:

https://flankspeed.sharepoint-mil.us/sites/NAVFAC-BPMS/SitePages/NAVFAC-BPMS-Overview.aspx

1-3 BFRs FOR USMC INSTALLATIONS

When preparing BFRs for United States Marine Corps (USMC) installations or for any USMC facilities on Navy installations, the facility planner will ensure that requirements are coordinated with the program requirements of *Marine Corps Installation Command (MCICOM) GF-Facilities at Headquarters Marine Corps.*

1-4 ORGANIZATION OF FC 2-000-05N

1-4.1 CATEGORY CODE NUMBERS

Chapter 2 of this FC 2-000-05N publication is organized by Category Code Numbers (CCNs), the sequence of which generally corresponds to functional areas and activities.

A complete database of the Department of the Navy CCNs, with supporting facility type and economic factor data fields is available on the *Internet Navy Facility Assets Data Store* (iNFADS), which is available through the secure NAVFAC SharePoint web portal.

Department of Defense (DoD) Instruction 4165.03 establishes the framework and guidance for categorizing Facility Analysis Categories (FACs) and the facility Category Code Numbers (CCNs). This framework provides for the orderly categorization of Real Property for the planning of facilities and real property inventory designations.

The system of Category Code Numbers is grouped using the following series:

- 100 Series – Operational and Training Facilities
- 200 Series – Maintenance and Production Facilities
- 300 Series – Research, Development, Acquisition, Test and Evaluation Facilities
- 400 Series – Supply Facilities
- 500 Series – Medical Facilities
- 600 Series – Administrative Facilities
- 700 Series – Housing and Community Facilities
- 800 Series – Utilities and Ground Improvements Facilities
- 900 Series – Real Estate Facilities

1-4.2 PAGE NUMBERING AND APPENDICES

The page numbering system in Chapter 2 of this publication corresponds to the first three digits of the category group.

The appendices to this document are:

Appendix A contains a current listing of Dept. of the Navy CCN's, reflecting data recently downloaded from the NAVFAC iNFADS database.
Appendix B is a list of applicable units of measurement and their abbreviations.
Appendix C is the NAVFAC P-80.1: Runway Capacity Handbook - Fixed Wing.
Appendix D is the NAVFAC P-80.2: Naval Mobile Construction Battalion Facilities.
Appendix E is the NAVFAC P-80.3: Airfield Safety Clearances.
Appendix F is the Austere Facilities Planning Criteria.

1-4.3 WEB ACCESS OF PUBLICATION AND COMMENTS

This publication and its appendices can be found at:
https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/fc-2-000-05n.

The criteria elements included in this publication are dynamic. As such, they are subject to continuous comment, review and update in response to changing requirements. Users of this criteria are encouraged to submit comments and recommendations regarding the content, application and/or format of the publication for consideration and review. Comments are submitted through the Criteria Change Request system on the WBDG website, at the following web address: https://cms.wbdg.org/ccrs/new?ufc=2-000-05N. Include your contact information, as well as sufficient explanation for evaluation of the recommended changes to the criteria.

1-5 REQUIREMENTS IN THE REGIONAL CONTEXT

1-5.1 REGIONAL PLANNING

Navy leadership is departing from the traditional paradigm, which managed shore infrastructure at the level of individual shore activities. Under Regionalization and the Installation Claimant Consolidation programs, the Navy is shifting toward managing and planning facilities in a larger, regional context (for example, a collection of military installations in geographic proximity to one another). This comprehensive regional approach to planning broadens the field of opportunities beyond those available on an individual activity to include the geographic and functional context of the region. Regional planning looks to reduce redundant facilities within a geographic region and seeks alternative means of satisfying requirements for infrastructure, such as leasing, outsourcing and privatization.

Therefore, a planner must take into account geographically proximate military installations and civilian communities when developing BFRs. While proximate installations may have significant operational differences, they may all provide similar support services. It is feasible that Navy personnel assigned to one activity, as well as retirees in the area, may choose to use support facilities at another installation, which would reduce or even eliminate facility requirements at the first activity. Additionally, many military installations are located near urban communities, which offer a number of resources to military and their dependents. The services provided by some support facilities in civilian communities, especially morale, welfare and recreation assets, are generally similar to on-base facilities. Planners must account for these community facilities in the BFR process by applying Geographic Adjustment Factors (GAFs), which are multipliers that represent the lower limit of on-base facility requirements. GAFs should not be used when planning at OCONUS installations because personnel usually prefer to use installation facilities, instead of facilities in the local community.

1-5.2 METHODS FOR CALCULATING REGIONAL REQUIREMENTS

There are two methods of calculating requirements for regional planning. For more individualized functions like laboratories, an applicable method is to calculate an individual requirement based on each tenant's loading and then sum the results to produce a final requirement. For common-use functions like golf courses and distribution centers, the preferred method is to add up all the loading to produce a single aggregate requirement and then subdivide the result, as appropriate. While a planner must exercise professional judgment in determining the best method to employ, this document offers specific guidance for the regional planning of supply/logistics facilities and community facilities.

1-5.2.1 REGIONAL PLANNING OF SUPPLY/LOGISTICS FACILITIES. Specific regional considerations are included in the introduction to the CCN 430 and 440 Series. With the goal of seeking economies of scale for regional planning, the planner should view the sum of all available assets in their aggregate, wherever practical. It is in this aggregate view of assets that a requirements summary in cubic feet should be translated into an optimal configuration in square feet. In other words, the planning exercise should answer the question: "What is the most efficient accommodation of the cubic foot requirement within the existing or planned square footage (facilities and systems)?"

1-5.2.2 REGIONAL PLANNING OF COMMUNITY FACILITIES. Various transportation studies were consulted to determine the distance that the average person is willing to walk and to drive to community facilities. These distances are considered the "service radius" of the facility. If a military installation is located in proximity to another military installation or civilian community that offers one of the following community facilities, use of this off-base facility should be taken into consideration. If the off-base facility is within the service radius (as detailed in the following table) from the installation, a similar facility may not be required on the installation. Refer to the introduction for the CCN 740 Series for detailed information about project validation assessments and other topics.

Table 1-1. Regional Travel Times (CCN 740, 750 and 760 Series)

Category(s)	Category Description(s)	Service Radius Walking Time (minutes)	Service Radius Driving Time (minutes)
740-01, -04, -23, -86	Exchange Retail Store; Food Service; Commissary; Warehouse	15	15
740-02, -08, -11	Location Exchange; Food Store/Grocery, ServMart	5	5
740-09, -71	Exchange Service Outlets; Package Stores	15	15
740-03, -13, -16, -90	Exchange Central Admin; Laundry Plants; Maintenance Shops; Distribution Centers	0	45
740-23	Commissary	15	15
740-12, 740-25	Red Cross/Navy Relief, Family Services Center	0	30
740-18, 740-19	Bank, Credit Union	10	10
740-26	Installation Restaurant	15	15
740-27	Armed Forces Radio/TV Station	N/A	N/A
740-30	Exchange Gas/Service & Auto Repair Station	0	15
740-32	Exchange Car Wash	0	10
740-34	Thrift Shop	15	15
740-37	Special Services Issue & Office	15	15
740-38	Auto Skills Center	0	15
740-40, 740-46	Bowling Center, Skating Rink	15	30
740-44, 740-45	Fitness Facilities	15	15
740-47	Information, Ticket & Tours	15	15
740-53	Indoor Swimming Pool	15	15
740-54, 740-55, 740-74	Recreation Centers; Youth Centers, Child Development	15	15
740-56, 750-50	Theater; Outdoor Theater	15	15
740-60, -64, -67, -68, -70	Mess / Clubs / Catering Facilities (all ranks)	10	15
740-76	Library	15	15
740-75, 740-79	Navy Flying Club; Riding Stable	0	30
740-77, 740-90	Community Storage, MWR Equipment Maintenance	0	20
740-88	Educational Services Office	15	30
750-10, -20, -22, -30	Outdoor Playing Courts; Fields; Jogging Track; Pool	15	30
740-80, 750-40, 750-56	Golf Clubhouse; Golf Course; Driving Range	0	60
750-21, 750-23	Batting Cage, Go-Cart Track	0	30
740-52, 750-52	Skeet/Trap Building, Skeet/Trap Range	0	30
750-37, 750-38	Outdoor Adventure Area; Equipment Rental Storage	15	20
740-78, 750-54, 750-57	Recreation Pavilion, Band Stand & Recreation Grounds	10	20
740-81, 740-92, 750-58, 750-59	Rental Lodging & Campground (Support, Tents & RVs)	0	60

Category(s)	Category Description(s)	Service Radius Walking Time (minutes)	Service Radius Driving Time (minutes)
740-87, 750-60, 750-61	Marina Support Building, Marina and Recreational Piers	0	60

1-6 COMPONENTS OF BFR DEVELOPMENT

BFRs are developed using peacetime mission and loading; they should not include contingencies. BFRs are the product of a regional analysis of the following factors:

1. Projected missions, functions, and tasks,
2. Base loading, and
3. Criteria.

1-6.1 PROJECTED MISSION, FUNCTIONS, AND TASKS

Each activity has its own statement of missions, functions, and tasks. Missions are concise, unclassified general statements of what the activity is to accomplish. Functions are workload derived from the main elements of an activity's mission. Tasks are workload accomplished in connection with existing program policy directives or written tasking assignments. The BFR process assesses an activity's missions, functions and tasks in the context of base loading and requirements, and translates the output into infrastructure. A first step in translating the activity's missions into facility requirements is to assign the mission(s) to major functional areas and note the associated facility types, according to the CCN series.

1-6.2 BASE LOADING

1-6.2.1 DETERMINATION OF INCLUSION AREA. Base loading is the number of aircraft, ships, personnel and equipment assigned to perform the tasks and services. To determine loading for use in a regional BFR, the planner should increase the inclusion area to encompass the larger region while ensuring that personnel or equipment are not double-counted. Typically, there is no predefined geographic inclusion area; an inclusion area may fluctuate depending on the facility being planned or the type of study that the BFRs are supporting. The planner should use sound professional judgment to determine the inclusion area and must have the area validated by the stakeholders prior to completing the BFRs.

1-6.2.2 USE OF LOADING PROJECTIONS. BFRs should be prepared using five-year loading projections. Planning beyond the five-year timeframe should be based on approved CNO initiatives. Unapproved, out-year Program Objective Memorandum requests may only be used if no other data is available.

1-6.2.3 EFFECT OF FLEET RESPONSE PLAN. The Fleet Response Plan (FRP), which is a new deployment concept, has had important ramifications for ship, aircraft, and personnel loading numbers used in BFRs. FRP combines training and maintenance schedules, manning requirements, equipment and funding to make six carrier strike groups available to the national leadership within 30 days, with two more available within 90 days in times of war or significant crises. During war and times of crisis, deployments will be made to meet the mission and might be less than or more than six months long. Previously, certain loading categories only counted 67% of the deployable populations at a certain installation, under the assumption that 33% of the population would be deployed. Under FRP, BFRs assume 100% of the aircraft loading requirement and 73% of the ship requirement, plus associated personnel.

1-6.2.4 POTENTIAL LOADING DATA SOURCES. Commander Navy Installations Command (CNIC) and NAVFAC headquarters are developing a loading database that will be the definitive site for use in Navy BFRs. Until this site is developed, the potential sources listed below are meant to be starting points for data, acknowledging that websites and specific departments may become obsolete. It is the planner's responsibility to 1) gather data from accurate sources and 2) have the loading numbers validated by the stakeholders or client before completing the BFRs.

Table 1-2. Potential Aircraft Loading Sources

Categories	Potential Sources
Permanent duty stations of aviation units include the number and type of squadrons including the wing, and the number and type of aircraft assigned to the wing and squadrons.	Information about wings and squadrons assigned to each region is available from the TYCOM.
Transient Aircraft are supported at activities for military transport aircraft or transiting aircraft that are enroute to deployment areas. Installations assigned transient aircraft must include facility requirements for average daily on-board aircraft. Transient aircraft also include visiting aircraft at installations located within close proximity of training ranges (e.g., firing or Fleet Carrier Landing Practice airfields). Peak loadings for exercises or contingencies are not to be used for	Projections of aircraft for each wing/squadron are available in the Primary Assigned Aircraft allowance, which can be provided by the Operations Officers of the wing/squadron. Aircraft procurement data is available from Commander, Naval Air Forces (CNAF). Transient aircraft data must be accounted from the average daily loading of Air

Categories	Potential Sources
determination of allowances. Transient aircraft maintenance is generally supported at home ports and home bases.	Operations records.

Table 1-3. Potential Ship Loading Sources

Categories	Potential Sources
Current and projected homeport assignment of ships. This data requires the collection of ship type and numbers of ships within each ship type.	Naval Vessel Register http://www.nvr.navy.mil
Operational Tempo considers the number of ships in port versus the number of ships at sea (i.e., deployed/rotational units are to be counted at the receiving installation). Under the Fleet Response Plan (FRP), assume that 73% of surface and subsurface ships including personnel are at homeport at any given time. Assume that 27% of surface and subsurface ships including personnel are deployed. Pier-side maintenance scheduling encompasses dredging, fender repairs, mooring repairs, etc. This limits the amount of berthing space for ships. Transient/Other Ships include Military Sealift Command, MARAD, visiting ships, foreign ships, ship commissioning and decommissioning. Average on-board numerical data is required for determining requirements. Peak loadings for exercises or contingencies not to be used.	Fleet Commanders (e.g., LANTFLT, PACFLT) and TYCOMS (e.g., COMNAVSURFLANT, COMNAVSURPAC) Port Operations Officers at individual installations

Table 1-4. Potential Personnel Loading Sources

The majority of space allowances are based on military strength.

Categories	Potential Sources
Military Strength – all officer (O1-O10) and enlisted personnel (E1-E9) assigned to an activity for permanent duty. Military strength may also include "Permanent Change of Station" (PCS) students, who are assigned to a school on orders lasting more than 20 weeks and may be counted as permanent party personnel, especially for bachelor housing requirements. Reservists are considered the military strength population at Reserve Training Centers.	CNI Housing Intranet (MyHSG) site: https://www.emh.housing.navy.mil Maintained by Navy Housing Technical Support at 800-877-8503 or 703-273-5480 or eMH@aemcorp.com. Downloads from the Total Force Manpower Management System (TFMMS), managed by the Navy Personnel Command and found at http://www.npc.navy.mil.
Some CCN series, especially the 500 and 700 series modify the Military Strength calculation and allow the following Transients categories to be included. This will be specifically called out in the CCN series:	
Transients – average daily number of personnel on Temporary Duty (TDY), awaiting transfer for further assignment, or pending separation who are not permanently assigned to the activity. Transients may only be counted when sizing facilities that transients specifically use. Discharged medical personnel awaiting PCS assignment are not included. Transients also include groups (1) through (4) listed below:	
(1) Temporary Duty (TDY) Students – personnel assigned to a school on orders for less than twenty weeks. However, only the average number on board may be used and only for sizing facilities that students specifically use.	Chief of Naval Education and Training. BUMED (for TDY medical students).

Categories	Potential Sources
(2) Reservists – personnel assigned to reserve units. Reservists may be counted with the active duty military populations at active duty installations only for sizing facilities that are specifically affected by this group, such as the 740 and 750 series. Eighty percent of the average onboard count of Reservists on weekend or two-week duty may be counted when located at Commander, Naval Air Reserve commanded air stations; twenty percent	Average daily numbers are available from all Naval shore activities.
(3) Rotational personnel – are the average daily number of personnel deployed with squadrons or mobile units on a scheduled basis at locations other than their homeport. Deployed personnel are counted at the activity to which they are deployed.	
(4) Personnel assigned to ships undergoing overhaul.	Overhaul schedules for the next six years can be obtained from the Naval Sea Systems Command.
The following non-transient populations may be included in some BFR calculations, but must be specifically indicated as such in the CCN explanatory material. These potential populations include:	
Civilians – DoD Civilians and foreign nationals (at OCONUS installations) are counted in category codes where they are	Data about civilians is available from all Naval shore activities (typically the Human Resources Office).
Contractors – private-sector contractors employed by the DoD or employees of other services, agencies or nations working with the DoD.	The contract document or the Memorandum of Understanding usually details the amount and kinds of space required to accommodate these personnel.

Categories	Potential Sources
Retiree Population – number of retirees living within a thirty-minute drive of the installation. Retired personnel may be counted in facility requirements only if indicated in the respective allowance table and to the percentage authorized. Dependents of retired personnel are not counted.	If the installation cannot provide data, use most current FY Statistical Report provided by the DoD Office of the Actuary, http://actuary.defense.gov. In areas with many military installations, consult with the activities to determine the appropriate number of retirees apportioned to each installation.
Dependents – spouses and children of assigned military personnel. Dependents are counted in requirements if the individual CCN's allowance table indicates that they may be counted and only to the percentage authorized. While a reduction in military strength should be made to account for military personnel on deployment, no similar reduction should be made in calculating dependent population, as dependents remain at the homeport location. In BFRs that require calculating "installation population," dependents of military strength assigned to the installation are included.	through Defense Manpower Data Center (DMDC) Data Request System at https://www.dmdc.osd.mil/drs. * Data as of 18 February 2005 is included below in Table 1-5.

Table 1-5. Dependent Data

GRADE	% Distr	% Single	% w/ Depdts	% Married	Avg. # of Children
E-1	3.80%	90.67%	9.33%	8.20%	1.2
E-2	5.79%	83.47%	16.53%	14.67%	1.2
E-3	18.93%	67.42%	32.58%	29.57%	1.4
E-4	19.19%	53.14%	46.86%	41.93%	1.5
E-5	23.82%	33.90%	66.10%	58.26%	1.8
E-6	17.66%	14.10%	85.90%	77.53%	2.1
E-7	7.63%	6.88%	93.12%	85.88%	2.3
E-8	2.19%	4.88%	95.12%	88.51%	2.2
E-9	0.99%	4.58%	95.42%	90.31%	2.1
Enlisted Total					**1.9**
O-1	11.70%	63.70%	36.30%	32.77%	1.9
O-2	13.05%	47.14%	52.86%	48.07%	2
O-3	32.80%	28.37%	71.63%	67.18%	2
O-4	19.47%	12.78%	87.22%	83.33%	2.2
O-5	13.06%	8.39%	91.61%	88.03%	2.3

GRADE	% Distr	% Single	% w/ Depdts	% Married	Avg. # of Children
O-6	6.47%	7.45%	92.55%	89.33%	2.2
O-7	0.20%	3.70%	96.30%	92.59%	1.8
O-8	0.13%	5.88%	94.12%	92.65%	1.5
O-9	0.06%	3.23%	96.77%	93.55%	1.5
O-10	0.02%	0.00%	100.00%	100.00%	0
O-1 to O-10 Total					**2.1**
W-1	1.30%	6.51%	93.49%	74.82%	2.3
W-2	1.15%	5.72%	94.28%	80.72%	2.2
W-3	0.55%	6.19%	93.81%	88.32%	1.9
W-4	0.05%	0.00%	100.00%	100.00%	1.7

Table 1-6. Potential Equipment Assigned Loading Sources

Categories	Potential Sources
Materials requiring storage – quantity (usually expressed in volume) of an item that must be stored.	Host or Tenant Command maintains a "Table of Allowances"
Ordnance requiring storage – type and amount of munitions (by volume, Net Explosive Weight Compatability Group).	Installation ordnance load plans are available from Naval Operational Logistics Support Center (NOLSC), Mechanicsburg, PA. See CCN 421 series for details. Also check with Fleet Commanders Ordnance staff for fleet ordnance download requirements from ships.

1-6.2.5 NEED FOR DOCUMENTATION. BFRs must thoroughly document loading numbers by including citations of the sources used and explanations of the methodology employed. Loading numbers should be cited on each individual BFR justification worksheet and in a summary loading worksheet included at the beginning of a BFR package.

1-6.3 CRITERIA

1-6.3.1 CRITERIA COMPONENTS. The methodology set forth in this publication allows facilities to be appropriately sized and provides uniformity. Specifically, the criteria ensure that the existing and planned facilities are neither too small nor too large to accomplish standard mission objectives. The criteria also establish common planning standards within the Navy. Criteria information in this publication can be separated into several components, as follows:

Description of the facility – The description usually includes: the primary function of the facility; the relationship with operational components; installation types that require this facility; list and relationships of internal functional elements; and references to other publications that provide more detailed data.

Specific planning factors – This is quantitative facility data, which are usually presented in tables as formulas or in fixed gross allowances. Fixed allowances are used when a specific facility type is uniform throughout the Navy. It is important to note that fixed gross allowances do not include such facility components as loading docks and porches. If a planner expects that a facility may have these components, then the planner must adjust the BFR to accommodate them.

Approximate planning factors – For some facilities, development of specific planning factors is not feasible. However, the size of these facilities will usually fall within a limited range that has been identified by engineering surveys. Detailed justification of these requirements may be required.

1-6.3.2 GUIDELINES IN APPLYING CRITERIA. The criteria should be considered guidelines, not regimented formulas. In certain circumstances, a planner may need to modify criteria or even develop new requirements. Some CCNs do not require BFRs, such as the 800 and 900 CCN series, Family Housing, and other individual CCNs per NAVFAC P-72. Likewise, no activity is automatically entitled to a facility size allowance or the facility itself, just because the facility is included in this document. Every facility must be justified on the basis of need. Requirements should neither be based on the size of existing assets simply to justify their retention nor inflated to accommodate existing inefficient or oversized assets.

In fact, a smaller facility than the maximum gross allowance may be adequate to meet an activity’s needs. Although a BFR is initially based on facilities sizing guidelines and established planning criteria, the resulting maximum allowances should be reviewed within the context of existing conditions. If the existing space is sufficient and this amount is less than the derived allowance, then the BFR should be reduced. Likewise, when a facility is sized based on regional loading, it may be smaller than the aggregate of similar facilities whose separate sizes are based on individual activity population. This difference is acceptable because the sizing reflects economies of scale. However, it is incumbent upon the planner to be consistent in the methodology used for both BFR development and actual facility sizing and construction.

1-6.3.3 NET-TO-GROSS FACTORS. In addition to the specific criteria presented under each category code, the net-to-gross factors should also be considered in developing the final space allowance. In some countries, net-to-gross factors for facilities are larger than what this document indicates. This is due to Host Nation laws and norms that require additional space, such as larger and more numerous corridors, stairwells, mechanical rooms on exterior walls, safe rooms accessible via stairwells at each floor, separate mechanical and electrical rooms and wider egress doors. Many countries also have day lighting requirements that may justify the use of atriums or open courtyards and, therefore, restrict the building shape.

Planners must document and apply appropriate net-to-gross factors. This will ensure projects have sufficient building area and cost built into the program in order to prevent functional areas from being reduced during project design. Each project must be considered independently. Higher factors may be justified for increased circulation requirements in multi-story buildings or in buildings with several different functional spaces. Consideration also should be given to the type of facility (for example, warehouse requirements may require higher allowances, as per Table 440A & B), variation of occupant functions, local requirements and site limitations on building size and shape. Also, the number of occupants may dictate allowances; for example, uninhabited facilities like Military Working Dog kennels and armories may not necessitate higher allowances. If a planner decides to adjust the net-to-gross factors based on any of the above situations, appropriate justification must be included in the BFR documentation.

NOTE: All criteria or algorithms listed in this publication produce gross area, unless otherwise noted.

1-7 ADDITIONAL PLANNING GUIDANCE

Commander, Navy Installations has chartered an integrated product team (IPT) to review the two primary BFR types: a Planning BFR, which typically is an “80% solution” used when preparing large quantities of BFRs as part of Regional Overview, Functional, or Activity Plans; and the Project BFR, which is a 100% scope solution used to justify a MCON or Special Project. Once the results are evaluated in the Fall of 2005, the BFR IPT team will release more definitive guidance about the appropriate use of each type. Traditionally, the Navy Audit Service has used this FC 2-000-05N publication as the source document when auditing MCON projects. This publication’s criteria are also enforced to ensure that operational safety and security criteria are followed. Under the regional planning model, however, variations may be necessary and the following topics should be considered when calculating BFRs:

1-7.1 ADJUST FOR OPERATIONAL CONDITIONS

Many operational conditions, circumstances and influences can affect the use of Navy facilities. For example, the use of specific equipment or the conduct of certain operations may require that a facility be larger or smaller than anticipated. In addition, some rooms in the facilities may be unable to be occupied while such equipment is being used or operations are underway. These conditions must be taken into account when determining the requirements for a specific facility.

It is also difficult to develop specific planning factors for unique, one-of-a-kind facilities, such as Research, Development, Testing, and Evaluation facilities. Requirements for these facilities should be based on an engineering analysis of the operation and the specific uses within the facility. Planners may also look to examples in other services, government agencies and in the private sector, keeping in mind that specialized Navy security requirements may alter these facility requirements. Regardless of the example used or method employed, the planner is responsible for providing a detailed justification of the resulting requirement.

1-7.2 UNDERSTAND HOST / TENANT RELATIONSHIPS

The planner must determine if a host activity is responsible for providing common facilities to both personnel assigned to the host and the personnel attached to tenants that are supported by the host activity. The planner must recognize these support relationships and develop base loading figures accordingly. While CNIC is in the process of establishing the formal relationships, interim host/tenant relationship information is available in the Activity Module of iNFADS.

1-7.3 USE SOUND PROFESSIONAL JUDGMENT

The planner must be prepared to provide appropriate justification for any deviations from established criteria. Appropriate justification may include the number and organizational status of the personnel, support space requirements, space needed for each function within the facility, and an industrial engineering analysis of the operations. There are two techniques for preparing industrial engineering analyses: one technique is to indicate each piece of equipment and operational feature with their corresponding working and/or access space requirements in a scaled drawing; the other technique is to list the above components and their sizes in columnar format. The totals obtained from either method, plus an appropriate net-to-gross conversion factor, yield the requirement.

Complete BFR justifications should be in tabular format and should include the date of their preparation and citations of sources that were used. Do not consider “based on experience” to be sufficient justification for a BFR without further clarification or analysis. The example worksheet on the following page provides more information.

1-7.4 REFERENCE DOCUMENTS

This publication, FC 2-000-05N, should serve as the Navy Facility Planners' primary resource for determining facility space requirements. The following documents and resources are among the many sources of supplementary information that can provide supporting data and guidance to assist with establishing and justifying the necessary facility space requirements:

1) DOD Tri-Service Unified Facility Criteria (UFC) and DON Facility Criteria (FC) manuals, which provide technical discipline and facility specific guidance and criteria, and are located on the Whole Building Design Guide (WBDG) website: https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc. Examples are:
    - UFC 1-200-02 *High Performance Buildings*
    - UFC 3-101-01 *Architecture*
    - FC 4-721-10N *Navy and Marine Corps Unaccompanied Housing*
2) DOD Unified Facilities Space Program Spreadsheets, located on the WBDG website: https://www.wbdg.org/ffc/dod/unified-facilities-space-program-sustainability-spreadsheets, which provide space allowance calculations (for a limited number of facility types) based on the criteria presented in this UFC and in the manuals noted in item 1 above.
3) NAVFAC P-970 Planning in the Noise Environment located on the NAVFAC informational documents web-portal page: https://portal.navfac.navy.mil/portal/page/portal/084BACA3D5146AC9E0440003BA8FC471
4) NAVSEA OP5, Vol.1 Ammunition and Explosive Ashore: Explosive Storage and Safety Distance
5) DD Form 805 Storage Space Management Report

Planners should also solicit input from functional area experts and local Activity representatives. Incorporating information from these and other sources will help ensure that there is a correlation between the program needs and the types and sizes of spaces to be provided.

1-7.5 EXAMPLE OF WORKSHEET

The following worksheet is included as an example of how to present the BFR justification calculations. While the exact formats are not mandatory, all worksheets should be dated and include the name of the person who prepared the information.

Figure 1-1. Example Basic Facilities Requirements Justification Worksheet

BASIC FACILITY REQUIREMENTS WORKSHEET

Activity -	NAB Little Creek	**UIC -**	N61414

CCN -	740-76	**DESCRIPTION -**	MWR Library

HOST UIC -	N61414	**Criteria Used:**	
Special Area -		X	**P-80 Criteria**
		X	**Engineering Evaluation**
			Other

LOADING ANALYSIS / JUSTIFICATION OF REQUIREMENT

A. MISSION: The Naval Amphibious Base Little Creek Library is required to provide active duty personnel and their family members professional and educational enrichment materials to enhance the Navy quality of life and to provide leisure and recreational materials for their personal enjoyment.

B. PLANNING CRITERIA: Basic Facilities Requirements (BFR) for Category Code 740-76, MWR Library, was developed in accordance with NAVFAC P-80, Facility Planning Criteria for Navy and Marine Corps Shore Installation.

C. LOADING: Based on a FY02 Base Loading report: Officers (953); Enlisted (7,244); Military Strength total is 8,197.

D. ANALYSIS:

1. Table 740-76A — 1,670 m2 or 18,000 GSF

2. Staff — 2PN x 130 NSF = 260 NSF
   Limited Duty — 4 PN x 90 NSF = 360 NSF
   620 NSF

   620 NSF x 1.25 GSF/NSF = 775 GSF

   Total: 18,000 + 775 = **18,775 GSF or 1,742 m^2**

REQUIREMENT: 18,775 GSF or 1,742 m^2 — **Page 1 of 1**

Date Prepared: January 18, 2002
Prepared by: Jane Doe, Code HBJD, NAVFAC

CHAPTER 2 - FACILITY PLANNING CRITERIA FOR SERIES 100 THROUGH 900

100 Series – Operational and Training Facilities
200 Series – Maintenance and Production Facilities
300 Series – Research, Development, Acquisition, Test and Evaluation Facilities
400 Series – Supply Facilities
500 Series – Medical Facilities
600 Series – Administrative Facilities
700 Series – Housing and Community Facilities
800 Series – Utilities and Ground Improvements Facilities
900 Series – Real Estate Facilities

Version: 100.20242012

FACILITIES CRITERIA (FC)
FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

Series 100: OPERATIONAL AND TRAINING FACILITIES

Record of Changes:

Date	CCN #	CCN Title	Description of Change
08 May 2018	131	Command, Control, Communications, Computers, Combat Systems, Intelligence, Surveillance, And Reconnaissance (C5ISR) Buildings	Updated criteria to meet current mission requirements for Communications, Information, and Intelligence Facilities.
08 May 2018	131 15	Communications, Information, Or Intelligence Facility	Updated criteria to meet current mission requirements for Communications, Information, and Intelligence Facilities.
08 May 2018	131 17	Communications Station	CCN Deleted. Rolled into 131 15.
08 May 2018	131 24	Satellite Communications Facility	Updated criteria to reflect new 131 Introductory criteria.
08 May 2018	131 35	Receiver Building	Updated criteria to reflect new 131 Introductory criteria and eliminate references to CCNs that are being deleted.
08 May 2018	131 40	Telecommunications Distribution Facility	Updated criteria to reflect new 131 Introductory criteria.
08 May 2018	131 42	Automatic Communications Switching Center	Updated criteria reference for 131 40 to the new title name.
08 May 2018	131 50	Transmitter Building	Updated criteria to reflect new 131 Introductory criteria.
08 May 2018	131 60	Military Affiliate Radio Station (Mars	Updated criteria to indicate use for “inventory purposes only” until the CCN is absorbed or eliminated.
08 May 2018	131 65	Communications Analysis Facility	CCN Deleted. Rolled into 131 15.
08 May 2018	137 10	Meteorology And Oceanography Building	CCN Deleted. Rolled into 131 15.
08 May 2018	143 40	Computer Programming Operations Center	CCN Deleted. Rolled into 131 15.

Date	CCN #	CCN Title	Description of Change
08 May 2018	143 65	Region / Installation Emergency Operations Center	Updated criteria to reflect new 131 Introductory criteria.
08 May 2018	143 80	Mission Operation Command And Control Facility	Updated criteria to reflect new 131 Introductory criteria.
08 May 2018	C5ISR	Command, Control, Communications, Computers, Combat Systems, Intelligence, Surveillance, And Reconnaissance (C5ISR) Facilities	A C5ISR BFR Calculator is available on the NAVFAC Portal to be used in tandem with the updated C5ISR Planning Criteria. Use the portal search function to search for "C5ISR BFR Calculator".
13 June 2018	125 20	Shed/Shelter For Pump Station And Ancillary Equipment	Remapped to FAC 1459 as per OSD/RPCP FY18.
13 June 2018	143 09	Expeditionary Ops Support Facility	Changed title from "Expeditionary Ops Support Module" to "Expeditionary Ops Support Facility" as per OSD/RPCP FY18.
13 June 2018	171 21	Decontamination Training Facility	CCN deleted. Not a standalone facility.
24 Oct 2018	143 80	Mission Operation Command And Control Facility	Minor change to language in section 14380-2.
11 June 2019	171 30	Physical Education Building	Minor editorial change to paragraph numbering
12 July 2019	143 12	Operational Storage Laydown	Updated table 14312-1 and 14312-2 and added verbiage
08 Aug 2019	116 55	Tactical Support Laydown Area	Changed Title from "Ordnance Handling Pad" to "Tactical Support Laydown Area"
08 Aug 2019	121 20	Aircraft Truck Fueling Facility	Remapped to FAC 1261.
08 Aug 2019	122 30	Small Craft Ready Fuel Storage	Remapped to FAC 1242.
08 Aug 2019	179 09	Ship Loading and Unloading Mockup	Remapped to FAC 1732. Changed UM to SF
08 Aug 2019	179 11	Air Transport Mockup	Remapped to FAC 8526. Changed UM to SY
08 Aug 2019	179 12	Elevated Training Tower/Platform	Changed Title from "Parachute Landing Fall Platform" to "Elevated Training Tower/Platform". Remapped to FAC 1734.

Date	CCN #	CCN Title	Description of Change
08 Aug 2019	179 13	Suspended Harness Mockup	CCN Deleted in FY19. Assets have been consolidated into CCN 179 12
08 Aug 2019	179 14	Mockup Jump Tower	CCN Deleted in FY19. Assets have been consolidated into CCN 179 12
08 Aug 2019	179 15	Underwater Fording Site	CCN Deleted in FY19.
08 Aug 2019	179 18	Airfield Demolition Range (ADR)	Changed Title from “Road/Airfield Construction Training Site” to “Airfield Demolition Range”
24 Sep 2019	111 30	Runway Overrun-Paved Surface	Revised Table 11130-1 for longitudinal centerline grade, Class A Runway to match recent update of UFC 3-260-01.
24 Sep 2019	141 82	Full Pressure Suit Facility	Revised text to indicate pressure suit maintenance is normally performed in the Aviation Life Support Systems Shop (Non-NAVAIR Depot), Category Code 211 75.
03 August 2020	116 41	Improved Fresnel Lens Optical Landing System (IFLOLS) Pad	CCN added.
03 August 2020	143 08	Expeditionary Ops Boat Maintenance Repair Facility	CCN added.
03 August 2020	143 13	Operational Vehicle/Equipment Canopy	CCN added.
03 August 2020	144 40	Scale House	CCN added.
03 August 2020	148 10	Ship Propulsion Support Facility	Retitled and changed description to remove the term “nuclear”.
03 August 2020	148 15	Ship Weapons Handling Facility	Retitled and changed description to remove the term “nuclear”.
03 August 2020	148 20	Ordnance Demolition Area	CCN deleted but see note under 148 20.
03 August 2020	148 25	Explosive Truck Holding Yard	Remapped to FAC 8526. UM changed to SY.
03 August 2020	148 35	Container Holding Yard	Remapped to FAC 8526. UM changed to SY.

Date	CCN #	CCN Title	Description of Change
03 August 2020	148 40	Container Transfer Facility (Ordnance)	Remapped to FAC 8526. UM changed to SY.
03 August 2020	148 45	Rail/Truck Receiving Station (Ordnance)	Remapped to FAC 8526. UM changed to SY.
03 August 2020	149 20	Aircraft Catapult	CCN deleted but see note under 149 20.
03 August 2020	149 62	Tactical Vehicle Wash Facility	CCN added.
03 August 2020	153 10	Cargo Staging Area	Remapped to FAC 8526.
03 August 2020	179 21	Armored Vehicle Launch Bridge, Raft, and Ford Area	CCN deleted.
03 August 2020	179 53	Enclosed Fire Fighter Trainer Facility	CCN added.
01 April 2021	151 Section 151-1	Pier Facilities	Delete reference to 165-10. Add reference to UFC 4-150-06, Military Harbors and Coastal Facilities
01 April 2021	151 Section 151-4	Pier Facilities	Add complete title, Military Harbor and Coastal Facilities for UFC 4-150-06.
20 Jan 2023	143-11	Operational Vehicle Garage	1. Expand the "Definition" information. 2. Include additional guidance for calculating the space requirements. 3. Add new tables with space requirements.
20 Jan 2023	143-12	Operational Vehicle Parking/Laydown Area	Change Net to Gross factors for Table 14312-1 and added 1B designation to Table 14312-2.
20 Jan 2023	143-22	Navy Explosive Ordnance Disposal Shore Detachment Facility	Redefine EOD Shore DET Facility.
20 Jan 2023	149-10	Protective Barricades	Redefine Protective Barricade/Revetment to support explosives safety requirements.
20 Jan 2023	148-20	Ordnance Demolition Area	CCN was deleted in Aug 2020 but is reinstated and will be remapped to FAC Code 1783 in FY23.
20 Jan 2023	173-40	Observation Tower/Bunker	CCN added to serve as a protective shelter facility at ranges for personnel protection.

Date	CCN #	CCN Title	Description of Change
2 Mar 2023	100 Series	UFC 2-000-05N	Change UFC 2-000-05N to FC 2-000-05N document due to the fact that this planning criteria is not unified among the other DoD services.
17 Mar 2023	141-20	Aircraft Fire and Rescue Station	Change URL to access Space Planning Spreadsheet. Change URL to access Design UFC 4-730-10 Fire Stations.
17 Mar 2023	151 Series, 151-5	Pier Facilities	Change URL to access Design UFC 4-150-06 Military Harbors and Coastal Facilities.
17 Mar 2023	171-15, Section 17115-3.2	Navy and Marine Corps Reserve Training	Change URL to access NOSC Space Planning Spreadsheet. Change URL to access Design Criteria FC 4-171-06N Navy Operational Support Center.
31 Mar 2023	123-30, Section 12330-7	Vehicle and Equipment Ready Fuel Storage	Replace reference CCN 126-50 with CCN 126-15 Petroleum Ready Fuel Storage Facility.
31 Mar 2023	156-10, Section 15610-1	Waterfront Transit Shed	Include reference to Section 440-2 General Supply Requirements in Category Code 440 Series.
11 Jul 2023	126-15	Petroleum Ready Fuel Storage Facility	Change the Unit of Measure (UM) from BL to GA.
30 Aug 2023	131-12 131-13 131-17 135-11 135-12 135-13 135-15 135-21	Communications Maintenance Vault Communications Maintenance Tunnel Communications Maintenance Channel Fiber Optic Communications Lines, Underground in Conduit Fiber Optic Communications Lines, Non-Conductive Riser Rated Fiber Optic Communications Lines, Outside Plant, Armored Optical Ground Wire Fiber Optic Communications Lines, Outside Plant, Marinized (Underwater/Wetland)	Category Code changes included with updated descriptions / definitions for all CCNs listed.

Date	CCN #	CCN Title	Description of Change
	135-31	Copper Communications Lines, Outside Plant, Gel Filled	
	135-32	Copper Communications Lines, Outside Plant, Air Core	
	135-33	Copper Communications Lines, Outside Plant, Marinized (Underwater/Wetland)	
	135-34	Copper Communications Lines, Outside Plant, Armored	
	179-17	Rappelling Training Area	
	179-24	Water Supply Training Area	
	143-10	Emergency Vehicle Garage	
30 Aug 2023	111-12	Runway / Fixed Wing – Unsurfaced	New Category Code information clarified
	179-51	Unenclosed Fire Fighter Trainer	For CCNs 179-51, 179-54, and 179-54, new information included to clarify the distinction between the various types of trainers.
	179-53	Enclosed Fire Fighter Facility	
	179-54	Damage Control (Wet) Trainer	
20 Dec 2024	110-1	Pavements	Reference UFC 3-260-01, P 80.3 deleted, real property records done in accordance with P-78 RPI manual. Added Comment regarding Pavements. Added p-78 Real Property Inventory Procedures.
	110-2	Runway / Fixed Wing – Unsurfaced	Reference UFC 3-260-01, P 80.3 deleted, deleted Table 110-1, Table 110-2, updated basic training outlying fields aircraft type.
	111 10	Runway/Fixed Wing (M2/SY)	Updated Design and Additional Planning Criteria,
	11110-3	Runway Width	Deleted and referenced UFC 3-260-01, Chapter 3.
	11110-4	Length	Added language regarding influences of runway length,
	Table 11110-1	Selected Navy and Marine Corps Aircraft Takeoff Ground Rolls (TGR) and Landing Distances	Updated Table by deleting out of date aircraft.
	11110-6	Basic Length and Correction Factors	Added additional aircraft and referenced older versions

Date	CCN #	CCN Title	Description of Change
			included elevation and mean high temperature.
	11110-6.6	Basic Training Runways	Added additional aircraft.
	11110-8	Runway Separations/Clearances	Reference UFC 3-260-01, P 80.3 deleted.
	11110-8.4	Objects	Reference UFC 3-260-01, P 80.3 deleted.
	Figure 11110-1	Computation 1	Updated figure name deleted references to deleted tables.
	Figure 11110-2	Computation 2	Updated figure name deleted references to deleted tables.
	Table 11110-2	Runway Temperature and Altitude Corrections	Table deleted.
	111 12	Runway/Fixed Wing – Unsurfaced (M2/SY)	Updated Design and Additional Design Criteria.
	111 15	Runway/Rotor Wing (M2/SY)	Updated Design and Additional Design Criteria.
	111115-1	Description	Reference UFC 3-260-01, P 80.3 deleted.
	111115-2.1	Width	Deleted and Reference UFC 3-260-01.
	11115-2.2	Length	Deleted and Reference UFC 3-260-01.
	11115-4	Runway Configurations	Reference UFC 3-260-01.
	11115-5	Distance from Centerline	Reference UFC 3-260-01.
	11115-7	Aircraft Safety Clearances	Reference UFC 3-260-01, P 80.3 deleted.
	111 20	Helicopter Landing Pad/Hoverpoint	Updated Design and Additional Design Criteria.
	11120-1	Description	Added helipad locations on apron, runway and taxiway and referenced appropriate Category Code, referenced UFC 2-360-01.

Date	CCN #	CCN Title	Description of Change
	11120-2	Hoverpoint	Referenced UFC 3-260-01, for criteria and definitions for Standard, Limited Use, admi FR Helipad
	11120-2.1	Types of Helipads	Deleted
	11120-6	Criteria	Referenced UFC 3-260-01, updated to Criteria to delete information that is in UFC 3-260-01.
	11120-7	Airfield Safety Clearances	Reference UFC 3-260-01, P 80.3 deleted.
	111 25	Fixed Wing Aircraft (VTOL) Landing Pad (M2/SY)	Updated Design and Additional Design Criteria.
	11125-1	Description	Updated category code for VTOLS for runways, taxiways, and aprons.
	111 30	Runway Overrun – Paved Surfaced (M2/SY)	Updated Design and Additional Design Criteria.
	11130-1	Description	Updated description
	11130-2	Criteria	Referenced UFC 3-260-01, deleted Table 11130-1
	112 10	Taxiway	Updated Design and Additional Design Criteria.
	11210-2.1	Basic	Inserted introduction regarding and new Figure 11210-1 Basic Airfield Layout
	11210-3	Criteria	Referenced UFC 3-260-01, deleted duplicative information.
	11210-4	Exits for Class B Fixed Wing Runways	Referenced UFC 3-260-01 and provided additional clarity.
	11210-6	Safety Clearances/Separations	Referenced UFC 3-260-01, deleted duplicative information.
	113 20	Aircraft Parking Apron	Updated Design and Additional Design Criteria.
	11320-1	Description	Updated description to provide for reference to UFC 3-260-01 and added Figure 11320-1 Aircraft Parking Aprons and Figure 11320-2 Apron and Taxiway Category Codes.
	11320-2	Criteria	Referenced UFC 3-260-01, deleted duplicative

Date	CCN #	CCN Title	Description of Change
			information.
	11320-4	Spacing of Aircraft	Referenced UFC 3-260-01, and deleted Table 11320-1, Table 11320-2, Table 11320-3, Table 11320-4, Figure 11320-1, Figure 11320-2, Figure 11320-3, Figure 11320-4, and Figure 11320-5.
	11320-4.1	Jet Blast Protection	Reference UFC 3-260-01, for deleted tables/figures.
	11320-4.2	Deviations from Efficient Configuration	Reference UFC 3-260-01, for deleted tables/figures.
	11320-5	Peripheral Taxilanes	Reference UFC 3-260-01, deleted 11320-5.1
	11320-6	Safety/Lateral Clearances	Reference UFC 3-260-01, P 80.3 deleted.
	11320-7	Distance from Apron Edge	Apron edge is defined, deleted contradictory information.
	11320-8	Maintenance Hangar Offset from Apron	Reference UFC 3-260-01 and deleted duplicate information.
	11320-9	Deviation from Criteria	Substituted parallel for through taxiway, referenced UFC 3-260-01 and deleted duplicate information.
	11320-10		Reference UFC 3-260-01 and deleted duplicate information.
	11320-11		Deleted
	11320-11 (new)	Access Taxilanes and Vehicle Roads	Defined Category Code for vehicle roads as part of apron requirements, deleted Table 11320-1, Table 11320-2, Table 11320-3, Table 11320-4, Figure 11320-1, Figure 11320-2, Figure 11320-3, Figure 11320-4, and Figure 11320-5.
	113 40	Aircraft Access Apron	Updated Design and Additional Design Criteria.
	11340-1	Aircraft Access Aprons	Referenced UFC 3-260-01 for peripheral taxilane wingtip requirements.
	116 10	Aircraft Wash Rack Pavement (M2/SY)	Updated Design and Additional Design Criteria.

Date	CCN #	CCN Title	Description of Change
	11610-1	Wash Racks	References UFC 3-260-01 and identified three standard types of wash racks for fixed wing aircraft.
	11610-1.1	Type A (for Fighter and Attack Aircraft and Helicopters)	Updated description of Type A, B and L wash rack use and deleted 11610-1.2. Term “wash rack” is 2 words.
	11610-1.3	Type B (for Patrol and Cargo Transport Aircraft	Updated description and equation of Type B wash rack use and deleted 11610-1.4, deleted Figure 11610-1.
	116 12	Aircraft Pavement Shoulder	Updated Design and Additional Design Criteria.
	11612-1	Description	Updated description and referenced UFC 3-260-01.
	116 15	Aircraft Rinse Facility	Updated Design and Additional Design Criteria.
	11615-1	Taxi-Through	Described rinse facility components, referenced YFC 3-260-01.
	11615-1.1	Type 1	Defines basic length and width.
	11615-1.2	Type 2	Defines basic length and width.
	11615-1.3	Type 3	Defines basic length and width.
	11615-1.4	Type 4	Defines basic length and width including V-22 aircraft.
	116 20	Aircraft Compass Calibration Pad	Updated Design and Additional Design Criteria.
	11620-1	Aircraft Compass Calibration Pad	Referenced UFC 3-260-01 and deleted duplicate information.
	11620-2	Pad Capabilities	Deleted duplicate information
	11620-3	Siting	Referenced UFC 3-260-01 and deleted duplicate information.
	11620-4	Minimum Distances	Referenced UFC 3-260-01 and deleted duplicate information.
	11620-5	Access Taxiways to Calibration Pad	Deleted duplicate information
	11620-6	Gross Area Required for Calibration	Referenced UFC 3-260-01 and deleted duplicate

Date	CCN #	CCN Title	Description of Change
		Pad	information.
	11620-7	Calibration Target	Moved from 11620-5
	116 35	Arming and De-Arming Pad	Updated Design and Additional Design Criteria.
	11635-1	Description	Referenced UFC 3-260-01.
	116 40	Precision Approach Radar	Updated Design and Additional Design Criteria.
	116 41	Improved Fresnel Lens Optical Landing System	Updated Title to more accurately represent 116 41.
	116 42	Blast protection Pavement	Updated Design and Additional Design Criteria.
	11642-1	Description	Added blast protection pavement not intended to fully support aircraft load, added language regarding aircraft exhaust and the use of high temperature concrete, added F-35B aircraft type.
	116 45	Line Vehicle Parking	Updated Design and Additional Design Criteria.
	11645-1	Vehicle Parking Spaces	Identified category codes for peripheral taxilane, reference to UFC 3-250-01.
	116 50	Towway	Updated Design and Additional Design Criteria.
	11650-3	Typical Towway Widths	Referenced UFC 3-260-01 and deleted duplicate information.
	116 55	Ordnance Handling Pad (M2/SY)	Updated Design and Additional Design Criteria.
	11655-1	Description	Referenced UFC 3-260-01 and the term Hazardous Cargo Pad.
	11655-1.1	Types of Pads	Referenced UFC 3-260-01, and specific figures.
	11855-1.2	Dimensions	Referenced UFC 3-260-01, and specific figures, deleted Figure 11655-1, and Figure 11655-2.
	116 56	Combat Aircraft Loading Area	Updated Design and Additional Design Criteria.
	11656-2	Compliance with Explosive Safety Criteria	Reference UFC 3-260-01, P 80.3 deleted.
	11656-4	Criteria	Referenced UFC 3-260-01 and deleted duplicate

Date	CCN #	CCN Title	Description of Change
			information.
	116 60	Fire and Rescue Vehicle Alert Pad (M2/SY)	Updated Design and Additional Design Criteria.
	11660-2	Size and Location	Reference UFC 3-260-01, P 80.3 deleted.
	116 65	Tactical Support Van Pad (M2/SY)	Updated Design and Additional Design Criteria.
	11665-1	Description	Referenced UFC 4-141-10, tactical van pads to be clear of all imaginary surfaces.
	121 10	Aircraft Direct Fueling Station	Updated Design and Additional Design Criteria.
	12110-2	Policy	Referenced UFC 3-260-01.
	12110-4	Siting Requirements	Reference UFC 3-260-01, P 80.3 deleted.
	12110-5	Access Taxiways and Vehicle Roads	Added category codes for access taxiways, and vehicle roads for fueling facility.
	12120-4	Siting	Reference UFC 3-260-01, P 80.3 deleted.
	12150-3	Siting	Referenced UFC 3-460-01.
	122 10	Marine Fueling Facility (GM)	Updated Design and Additional Design Criteria.

100 SERIES
OPERATIONAL AND TRAINING FACILITIES

Table of Contents

110 AIRFIELD PAVEMENTS

110-1 PAVEMENTS

This category group includes all pavements necessary for use by operational aircraft. Planning for pavements shall include all safety clearances and facilities required to provide a fully operational field, complete with accessories such as aircraft tie-downs and pavement marking. Airfield pavement lighting is considered separately under 133/134 series category codes. See UFC 3-260-01, Airfield and Helicopter Planning and Design, for criteria on obstruction clearances and clear zones related to airfields and heliports. Clearances and separations related to a specific pavement type (for example: the separation between parallel runways) is given under the applicable category code within the 110 code series.

[C] 110-1 PAVEMENTS

Information in FC 2-000-05N, Appendix E (NAVFAC P80.3 Airfield Safety Clearances, dated Jan 1982) has been integrated and superseded by UFC 3-260-01. Therefore, P80.3 is no longer applicable.

Facilities considered in this category group are:

111 Airfield Pavements - Runways (includes helipads)
112 Airfield Pavements - Taxiways
113 Airfield Pavements - Aprons
116 Airfield Pavements - Other

When creating or updating real property records for airfield pavement facilities, this will be done in accordance with P-78 Real Property Inventory (RPI) Procedures manual and the Department of Defense Guide for Segmenting Types of Linear Structures.

110-2 CLASS A AND B RUNWAY CRITERIA

The airfield criteria published herein differs from previous criteria in that it has been revised to conform to the standards published in the UFC 3-260-01 and the Air Installations Compatible Land Use Zone (AICUZ) program defined in OPNAVINST 11010.36D. The unified facilities criteria are defined in terms of class A and B runways and their supporting taxiways, aprons, etc. The A and B runways and the application of an A or B designation to a particular runway is explained in UFC 3-260-01. All Navy and USMC supporting pavements such as taxiways, aprons, etc., shall be considered class B unless their use is totally dedicated to supporting a runway which has been designated class A, and the application of class A standard has been approved by Headquarters NAVFACENGCOM and NAVAIRSYSCOM.

RUNWAY CLASSIFICATION. The classification is dependent on the type of aircraft which operate from the runway. Table 3-1 in UFC 3-260-01 provides the runway classifications for all Navy and Marine Corps aircraft as well as aircraft from other services or government agencies. These aircraft are listed by aircraft type. Each type includes all model variants.

Transient aircraft from other services or government agencies are special exceptions in the planning of Navy and Marine Corps air stations. Individual justification must be made for these cases where runway length must be extended to allow for the landing and takeoff of these aircraft.

Class A runways are primarily used by small light aircraft and the runway should not have the potential for development for use by heavier aircraft or have a foreseeable requirement for such use. Ordinarily, Class A runways are less than 8,000 feet (2,440 meters) long and less than 10 percent of the operations involve Class B type aircraft. Class B runways are primarily intended for high performance and large heavy aircraft. Basic training outlying fields used by T-6, T-34, T44, and T-54 aircraft have special criteria in UFC 3-260-01.

The classification of Navy and Marine Corps runways is determined as a part of the Air Installations Compatible Land Use Zone (AICUZ) program and is published in AICUZ study for a particular installation. NAVFACENGCOM and NAVAIRSYSCOM concurrence and CMC/CNO approval is required prior to classifying any runway Class A or B. This approval is obtained via approval of the AICUZ study.

111 AIRFIELD PAVEMENTS - RUNWAYS

Series 111 Category Codes include criteria for runways for fixed wing aircraft and runways or landing pads for rotary wing aircraft. Runways are prepared surfaces for the landing and takeoff of both fixed wing and rotary wing aircraft. Landing pads are prepared surfaces for the Vertical Takeoff and Landing (VTOL) of rotary wing aircraft (including V-22). The number of runways and/or landing pads is determined by the expected traffic density, airfield mission, operational procedures, and environmental factors. Runway orientation is determined from analysis of wind data, terrain, noise levels generated, and local development conditions.

111 10 RUNWAY/FIXED WING (M2/SY)
FAC: 1111
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design,
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11110-1 DESCRIPTION. Runways are prepared surfaces for the landing and takeoff of aircraft. The number of runways required is determined by the expected traffic density, airfield mission, operational procedures and environmental factors. Runway orientation is determined from analysis of wind data, terrain, noise levels to be generated and local development planning.

11110-2 CRITERIA. The following standards apply to fixed-wing runways at all Navy and Marine Corps air installations, including outlying fields, unless specifically noted otherwise. Deviation from these standards must be approved by the Naval Air Systems Command.

11110-3 RUNWAY WIDTH. See UFC 3-260-01, Chapter 3 for criteria regarding runway width.

11110-4 LENGTH. Many factors influence the required runway length. The following paragraphs present a basic outline of the multitude of influencing factors and procedures for determining runway length. Planners must validate required runway length using the aircraft specific Facilities Requirement Document (FRD) and obtain concurrence/approval from NAVAIR.

The maximum planned length of a runway shall be long enough to accommodate selected critical aircraft in takeoff and landing operations under stipulated load and environmental conditions. The critical aircraft for a station is defined as one which:

a. Is or will be assigned to the installation or is to be supported by the installation in accordance with the mission assigned by the major claimant/CNO.

b. Requires the longest Takeoff Ground Run (TGR) or landing roll of those aircraft meeting the above stipulation.

11110-5 CRITICAL AIRCRAFT. The basic TGR or landing roll for the critical aircraft can be obtained from the pertinent Naval Air Training and Operating Procedures Standardization (NATOPS) Manual. Basic TGR is defined as the distance an aircraft requires to lift off at a given gross weight on a level runway surface at sea level (Barometric pressure 29.92 inches Hg.) with 59 degrees Fahrenheit ambient temperature and under conditions of zero wind. The TGR in most cases is the controlling characteristic.

Table 11110-1 provides minimum and maximum TGR and minimum and maximum landing roll for a group of selected Navy and Marine Corps aircraft. The minimum TGR (TGR min) is defined as the minimum takeoff distance an aircraft requires to lift off at minimum takeoff weight on a level runway surface at sea level (Barometric pressure 29.92 inches Hg.) with 59 degrees Fahrenheit ambient temperature and under conditions of zero wind. The maximum TGR (TGR max) is defined as the minimum takeoff distance an aircraft requires to lift-off at maximum takeoff weight (wartime weight) on a level runway surface at sea level (Barometric pressure 29.92 inches Hg.) with 59 degrees Fahrenheit ambient temperature and under conditions of zero wind. When local operating conditions are unavailable, use maximum TGR to compute runway length when TGR is the controlling characteristic.

Table 11110-1. Selected Navy and Marine Corps Aircraft Takeoff Ground Rolls (TGR) and Landing Distances

Aircraft Type	Min. Takeoff Ground Roll (TGR min) (1) (feet/meters)	Max. Takeoff Ground Roll (TGR max) (2) (feet/meters)	Min. Landing Distance (feet/meters) (3)	Max. Landing Distance (feet/meters) (4)
A-6	950/290	5,000/1,524	1,800/549	4,800/1,463
EA-6B	1,400/427	4,010/1,222	1,800/549	2,300/701
C-1	455/139	1,700/518	1,120/341	1,720/524
C-2	1,150/351	2,500/762	1,300/396	2,250/686
C-9	4,000/1,219	4,500/1,372	2,450/747	2,500/762
C-12(B)	1,680/512	1,900/579	1,000/305	1,100/335
C-12(F/M)	1,700/518	1,900/579	1,000/305	1,100/335
C-130	1,800/549	4,700/1,433	1,150/351	2,020/616
KC-130	1,820/555	4,700/1,433	1,150/351	2,020/616
E-1	600/183	1,200/366	2,550/777	2,400/732
E-2	1,200/366	2,100/640	1,300/396	1,500/457
E-6	2,980/908	5,850/1,783	2,300/701	3,820/1,164
F-4	1,200/366	3,500/1,067	2,000/610	2,500/762
F-14(A)	1,600/488	3,650/1,113	2,150/655	3,150/960
F-14(B/D)	1,800/549	4,600/1,402	2,450/747	3,000/914
F/A-18 (5)	1,000/305	3,600/1,097	2,200/671	4,300/1,311
F/A-18 (6)	1,000/305	3,400/1,036	2,200/671	4,400/1,341
F/A-18 (7)	1,305/398	3,680/1,122	Not Available	4,160/1,268
(E)P-3(A/B/E)	1,600/488	3,000/914	1,500/457	2,100/640
P-3(C)	2,100/640	4,000/1,219	1,400/427	2,100/640
(E)S-3(A/B)	1,080/329	3,400/1,036	1,750/533	2,700/823
T-2	900/274	1,600/488	1,950/594	4,300/1,311
T-28(B)	1,000/305	2,050/625	920/280	1,520/463
T-28(C)	1,000/305	2,050/625	920/280	1,940/591

Table 11110-1. Selected Navy and Marine Corps Aircraft Takeoff Ground Rolls (TGR) and Landing Distances (Continued)

Aircraft Type	Min. Takeoff Ground Roll (TGR min) (1) (feet/meters)	Max. Takeoff Ground Roll (TGR max) (2) (feet/meters)	Min. Landing Distance (feet/meters) (3)	Max. Landing Distance (feet/meters) (4)
T-34	1,200/366	1,400/427	850/259	1,000/305
T-39	1,400/427	2,950/899	1,550/472	4,200/1,280
T-44	1,000/305	1,500/457	950/290	1,100/335
T-45	1,340/408	2,250/686	3,200/975	3,950/1,204
AV-8(A)	825/251	2,200/671 (8)	3,500/1,067	5,000/1,524
AV-8(B)	800/244	2,600/792	3,400/1,036	8,250/2,515
(T)AV-8(B)	900/274	2,600/792	3,750/1,143	8,250/2,515
V-22	Not Available	Not Available	0/0 (9)	0/0 (9)

Note:
(1) Minimum takeoff distance at minimum takeoff weight.
(2) Minimum takeoff distance at maximum takeoff weight.
(3) Minimum landing ground roll required at minimum landing gross weight.
(4) Minimum landing ground roll required at maximum landing gross weight.
(5) (A/B/C/D) model Hornet with F404-GE-400 engine.
(6) (A/B/C/D) model Hornet with F404-GE-402 engine.
(7) (E/F) model Super Hornet with F414-GE-400 engine.
(8) Weight limited to 21.3 k-lb by tire speed.
(9) Vertical landing.

11110-6 BASIC LENGTH AND CORRECTION FACTORS. The planned runway length for an aircraft is the TGR or landing roll (whichever governs) of the critical aircraft, corrected for nonstandard conditions of altitude, temperature, and effective gradient, and with an appropriate safety factor applied. The result is rounded to the next 30.5 meters (100 feet). (Additional corrections are to be applied to crosswind runways and runways used by T-6, T-34, T-44, and T-54 aircraft for basic training). The safety factor allows for variation in pilot techniques, runway surface conditions, wind, minor mechanical difficulties, and psychological factors. Older versions of this document included elevation and mean high temperature data. Use elevation and historical weather data to determine applicable data and calculate appropriate correction factors. Correction and safety factors are applied as follows:

11110-6.1 Altitude. Increase runway length (TGR or landing roll) by 1.1 percent for each 30.5 meters (100 feet) the site is above sea level.

11110-6.2 Temperature. Increase above result by 0.66 percent for each degree F the anticipated mean high temperature is above 59 degrees F. The mean highest temperature is defined as the average of the highest temperature recorded each day during the month which has the highest average daily maximum temperature.

11110-6.3 Safety Factor. Multiply the above result by 1.6 for all runways except those at Air Training Command air installations where a safety factor of 2.0 shall be applied.

11110-6.4 Effective Gradient. Increase the above result by 10 percent for each 1 percent of effective gradient. Effective gradient is the maximum difference in elevation along the centerline of the runway divided by the runway length and expressed as a percent.

11110-6.5 Round off. Final runway length is the result of the foregoing calculations rounded off to the next higher 30.5 meters (100 feet).

11110-6.6 Basic Training Runways. At basic training runways used by T-6, T-34, T-44, and T-54 aircraft, 305 meters (1,000 feet) shall be added to the computed runway requirement. The additional runway length is required to practice precautionary emergency landings.

11110-6.7 Example. See the example computation at the end of Category Code 111 10.

11110-7 CROSSWIND RUNWAY. The foregoing discussion applies to the primary runway. When the primary runway provides less than 95 percent wind coverage (that is, when a 15 knot crosswind component occurs more than 5 percent of the time), it becomes necessary to consider a crosswind runway. Justification based on wind data and operational needs is required before planning action is taken. In those cases where a crosswind runway is authorized for planning, the length is computed as for the primary runway with the exception that the takeoff ground run (or landing roll) is reduced by 20 percent. This accounts for headwinds, 15 knots or more, which normally will be encountered on the crosswind runway. If operational conditions, wind data, or runway configuration are such as to indicate that a headwind other than 15 knots should be planned for, then the NATOPS Manual for the critical aircraft should be consulted, and the appropriate TGR computed.

11110-8 RUNWAY SEPARATIONS/CLEARANCES. See UFC 3-260-01 for guidelines for determining obstructions to air navigation and the definition of airfield imaginary surfaces. The following lateral separations are required between runways and other airfield pavements. Deviations from criteria require a waiver from NAVAIR unless specifically exempted from waiver per UFC 3-260-01.

11110-8.1 Parallel Runways. A minimum of 305 meters (1,000 feet) is required between centerlines of parallel runways. The separation shall be increased to 1,311 meters (4,300 feet) if simultaneous Instrument Flight Rule (IFR) operations are to be flown from the parallel runways.

11110-8.2 Parallel Taxiway. A minimum of 152.4 meters (500 feet) is required between the centerline of a runway and the centerline of a parallel taxiway. (Note: Aircraft using the parallel taxiway are under the direction of the air control tower and therefore are not considered an obstruction even though the taxiway lies within the runway primary surface).

11110-8.3 Parking Apron. The edge of a parking apron, including its peripheral taxilane, shall be sited outside the runway primary surface. Aircraft shall be parked such that they do not penetrate the 7:1 transitional surface.

11110-8.4 Objects. Objects shall be sited outside the runway primary surface and such that they do not penetrate the 7:1 transitional surface or other imaginary surfaces defined in UFC 3-260-01.

Figure 11110-1. Computation 1

The following is an illustrative example of the runway length computation:

GIVEN:	*Patrol Plane Air Station*	-	*P-3C is critical aircraft*
	Elevation of Site	-	*(91.5 meters) 300 feet above mean sea level*
	Mean Highest Temperature	-	*70 degrees (F)*
	Effective Runway Gradient	-	*0.8%*

Since TGR max is greater than LD max, use TGR max.

Altitude Correction (1) — *(91.5) 300 / (30.5) 100 x 1.1% = 3.3%*

1,219.5 (4,000) x 1.033 = 1,259.7 meters (4,132 feet)

Temperature Correction (1) — *(70-59) x 0.66% = 7.26%*

1,259.7 (4,132) x 1.0726 = 1,351.1 meters (4,432 feet)

Safety Factor Correction — *1,351.1 meters (4,432 feet) x 1.6 = 2,161.8 meters (7,091 feet)*

Effective Gradient — *0.8 x 10% = 8% increase*

2,161.8 meters (7,091 feet) x 1.08 = 2,334.7 meters (7,658 feet)

Figure 11110-2. Example Computation 2

The following is an illustrative example of the runway length computation:

<u>GIVEN</u>: *Air Station - F/A-18 "Hornet" w/ F404-GE-402 engine is critical aircraft*
- *(15.2 meters) 50 feet above*

Mean Highest Temperature	*-*	*80 degrees (F)*
Effective Runway Gradient	*-*	*0.5%*

-
Since LD max is greater than TGR max, use LD max.

Altitude Correction (1) *<u>(15.2)</u> <u>50</u> x 1.1% = 0.55%*
(30.5) 100

1,341 (4,400) x 1.0055 = 1,348.4 meters (4,424 feet)

Temperature Correction (1) *(80-59) x 0.66% = 13.86%*

1,348.4 (4,424) x 1.1386 = 1,535.3 meters (5,037 feet)

Safety Factor Correction 1,535.3 meters (5,037 feet) x 1.6 = 2,456.5 meters (8,059 feet)

Effective Gradient 0.5 x 10% = 5% increase

2,456.5 meters (8,059 feet) x 1.05 = 2,579.3 meters (8,462 feet)

Round off = 2,591.5 meters (8,500 feet).

111 12 RUNWAY/FIXED WING - UNSURFACED (M2/SY)
FAC: 1114
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11112-1 DESCRIPTION. Runways for rotary wing aircraft, which do not consist of a pavement or hardstand surface. More specific planning criteria is planned for development.

111 15 RUNWAY/ROTARY WING (M2/SY)
FAC: 1112
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design,
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11115-1 DESCRIPTION. Runways/rotary wing are prepared surfaces for the landing and takeoff of helicopters. For planning purposes, helicopter landing/takeoff surfaces greater than 121.9 meters (400 feet) in length shall be considered a runway. Pavements equal to or less than 121.9 meters (400 feet) in length and-width (or diameter) shall be classified as Category Code 111 20, Helicopter Landing Pad. See UFC 3-260-01 for planning and design criteria for airfield safety clearances.

11115-2 CRITERIA. The basic rotary wing runway described below is designed to support normal takeoff and landing operations and may be increased in length when training exercises are to be conducted from the runway. Due to the multiple missions assigned to helicopters and the flexibility of their operating methods, standard size training pavements are difficult to define. However, a 305 meter (1,000 foot) long runway (no temperature and altitude correction is applied) is considered sufficient to conduct proficiency training and autorotation exercises for most Navy air installations.

11115-2.1 Width. See Chapter 4, UFC 3-260-01.

11115-2.2 Length. See Chapter 4, UFC 3-260-01.Temperature Correction. Increase the rotary wing runway length by 4.0 percent for each 10°F that the average daily maximum temperature for the hottest month is above 59°F.

11115-3 MULTIPLE TOUCHDOWN POINTS. Where multiple touchdowns points are provided on a single rotary wing runway, the touchdown points shall be spaced a minimum of 121.9 meters (400 feet) center to center.

11115-4 RUNWAY CONFIGURATIONS. Multiple rotary wing runway configurations that may be planned include parallel runways or arranging three runways as each side of a triangle. See UFC 3-260-01, Chapter 4, for distance between parallel taxiways.

11115-5 DISTANCE FROM CENTERLINE. For distance from the centerline of a Fixed Wing Runway to the centerline of a parallel Rotary Wing Runway under various conditions, see UFC 3-260-01, Chapter 4.

a. Simultaneous VFR operations for Class A Runway = 213.4 meters (700 feet)
b. Simultaneous VFR operations for Class B Runway = 305 meters (1,000 feet)
c. Instrument Flight Rules (IFR) using simultaneous operations (depart-depart or depart-approach) = 762.2 meters (2,500 feet)
d. IFR using simultaneous approaches = 1,311 meters (4,300 feet)

11115-6 IFR OPERATIONS. For rotary wing runways designed for IFR operations, the runway design must take into account the Ground Control Approach (GCA) system to be used and the number of instrumented touchdown points required. For example, two touchdown points located at opposite ends of a 305 meter (1,000 foot) runway could be served by a single GCA located on a turn table offset near the midpoint of the runway.

11115-7 AIRCRAFT SAFETY CLEARANCES. The location of objects adjacent to rotary wing runways is governed by the runway primary surface, transitional surface, and approach/departure surface. These surfaces differ for IFR and VFR operations and are defined in UFC 3-260-01. Also see UFC 3-260-01 for takeoff safety zone criteria for VFR rotary runways.

111 20 HELICOPTER LANDING PAD/HOVERPOINT (M2/SY)
FAC: 1112
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11120-1 DESCRIPTION. A helicopter landing pad (helipad) is a prepared area for the hovering, vertical takeoff and landing (VTOL) of helicopters and other VTOL aircraft. The pad is designed to accommodate only one helicopter/VTOL aircraft at a time. The pad may service a hospital, administrative activity, command headquarters or other installations which require helicopter cargo or passenger service. Helipads may be planned at fixed wing air installations, but only if air traffic density or safety requirements preclude the use of the fixed wing runways by helicopters.

Helipad locations marked on an apron without dedicated helipad lighting are considered part of the apron and fall within the boundary of Category Code 113 20 (Aircraft Parking Apron).

Helipad locations marked on a runway without dedicated helipad lighting are considered part of the runway and fall within the boundary of Category Code 111 10 (Runway/Fixed Wing) or Category Code 111 15 (Runway/Rotary Wing).

Helipad locations marked on a taxiway without dedicated helipad lighting are considered part of the taxiway and fall within the boundary of Category Code 112 10 (Taxiway).

See UFC 3-260-01, Chapter 4 for design criteria and definitions for Standard, Limited Use, and IFR Helipad.

11120-2 HOVERPOINT. A hoverpoint is a prepared and marked surface used as a reference or control point for air traffic control purposes by arriving or departing helicopters. A hoverpoint is generally located in non-traffic areas. See UFC 3-260-01, Chapter 4 for design criteria and definitions for Standard, Limited Use, and IFR Helipad.

11120-2.1 Types of Helipads.

a. Standard VFR Helipad. VFR standards are used when no permanent requirement exists or will exist in the future for an IFR helipad.
b. Limited Use Helipad. This is a VFR helipad used at sites where only occasional operations are conducted. These sites may be, but are not limited to, hospitals, headquarter areas, missile sites, and established airfields or heliports where the Limited Use Helipad may be used to preclude mixing helicopters and fixed-wing traffic. Limited Use Helipads may also be used to separate lighter helicopter (12,500 lbs. (5,670 kg) or less from medium and heavy helicopter traffic.
c. IFR Helipad. IFR standards are used when an instrument approach capability is essential to the mission and no other instrument landing facilities, either fixed wing or rotary wing, are located within an acceptable commuting distance to the site.

11120-3 HELIPAD LOCATION. Helipad location should be selected with regard to mission requirements, overall facility development, approach-departure surfaces, and local wind conditions. When a helipad is to be located near fixed and rotary wing runways, its location should be based on type of operations. Construction of helipads on buildings or on any type of elevated structure above ground shall be subject to review and approval by Naval Air Systems Command.

11120-4 STAND-BY PARKING. At individual helipad sites where it is necessary to have one or more helicopters on standby, an area adjacent to the helipad, but clear of the landing approach and transitional surfaces, should be designated for standby parking. This area is designated as a parking apron (see Category Code 113 20, Aircraft Parking Apron)

11120-5 SAME DIRECTION INGRESS/EGRESS. Helipads with same direction ingress/egress allow a helicopter pad to be in a confined area where approach-departures are made from only one direction. The approach may be either VFR or IFR. Same direction ingress/egress helipads must be individually justified and approved by NAVAIRSYSCOM. See UFC 3-260-01 for typical same direction ingress/egress helipad.

11120-6 CRITERIA. See UFC 3-260-01, Chapter 4, and Table 4-2 for standard helipad and hoverpoint criteria. The size of the helipad may be modified to accommodate specific training or mission requirements, for example, a shipboard-sized pad (approximately 15.2 meters by 15.2 meters (50 feet by 50 feet) for shipboard landing practice. Individual justification must be provided. Where more than one helicopter is to be at the pad location at one time, a connecting taxiway and parking apron is required. Helipads at VTOL training air stations (helipads servicing VTOL aircraft) should be 61.0 meters by 91.4 meters (200 feet by 300 feet) (5,575.4 square meters) (2,222 square yards).

11120-7 AIRFIELD SAFETY CLEARANCES. The location of objects adjacent to helipads and hoverpoints is governed by the primary surface, take off safety zone, transitional surface and approach departure surface. These surfaces differ for IFR and VFR operations and are defined in UFC 3-260-01.

111 25 FIXED WING AIRCRAFT (VTOL) LANDING PAD (M2/SY)
FAC: 1111
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11125-1 DESCRIPTION. This category code includes Vertical Landing (VL) Pads and shore-based Landing Helicopter Deck (LHD) facilities. This category code also includes connecting taxiways between VL or LHD facilities and adjacent runways, taxiways or aprons. In addition, shoulders and paved safety areas for the VL or LHD facility are included in this category code.
VTOL locations marked on a runway are considered part of the runway and fall within the boundary of Category Code 111 10 (Runway/Fixed Wing) or Category Code 111 15 (Runway/Rotary Wing).

VTOL locations marked on a taxiway are considered part of the taxiway and fall within the boundary of Category Code 112 10 (Taxiway).

VTOL locations marked on an apron are considered part of the apron and fall within the boundary of Category Code 113 20 (Aircraft Parking Apron).

See UFC 3-260-01, Chapter 8 for definitions, dimensions and design criteria.

111 30 RUNWAY OVERRUN – PAVED SURFACED (M2/SY)
FAC: 1113
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11130-1 DESCRIPTION. Runway overruns are areas extending at each end of a runway. The runway overrun areas are required to reduce serious damage to an aircraft in the event that the aircraft runs off of the runway end during takeoff or landing. These overrun areas are paved.

11130-2 CRITERIA. UFC 3-260-01, Chapter 3, provides the dimensional requirements for the overrun areas for Class A and Class B runways.

112 AIRFIELD PAVEMENTS – TAXIWAYS

112-1 DESCRIPTION. This basic category covers aircraft taxiway pavements and includes both normal and high-speed runway exits. Criteria for peripheral and interior taxi lanes of aircraft parking aprons are included in Category Code 113 20, Aircraft Parking Apron.

112 10 TAXIWAY (M2/SY)
FAC: 1121
BFR Required: Y

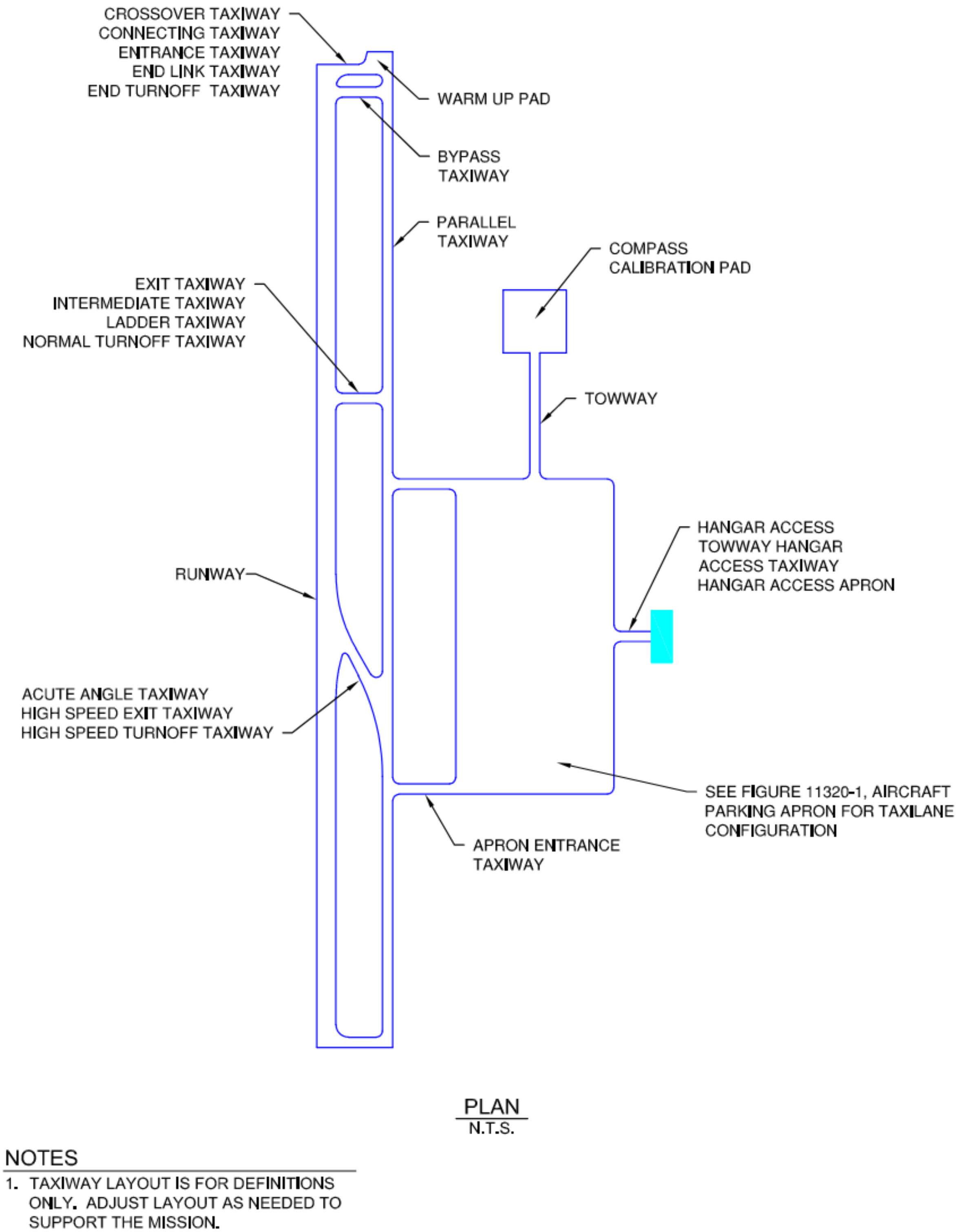
Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11210-1 DESCRIPTION. Taxiways are paved surfaces on which aircraft, both fixed and rotary wing, move under their own power to and from landing, service and parking areas. Criteria for surfaces for towing aircraft are included in Category Code 116 50, Towway.

11210-2 TAXIWAY TYPES.

11210-2.1 Basic. The basic airfield layout consists of a taxiway connecting the center of the runway with a parking apron. This system limits the number of aircraft operations at an airfield. Departing aircraft must taxi on the runway to reach the runway threshold. When aircraft are taxiing on the runway, no other aircraft is allowed to use the runway. If runway operations are minimal or capacity is low, the basic airfield layout with one taxiway may be an acceptable layout. See Figure 11210-1 for basic airfield layout. See Figure 11320-2 Apron and Taxiway Category Codes for typical boundaries of taxiway pavements.

Figure 11210-1 Basic Airfield Layout



11210-2 Parallel Taxiway. A taxiway parallel for the length of the runway, with connectors to the end of the runway and parking apron, is the most efficient taxiway system. Aircraft movement is not hindered by taxiing operations on the runway and the connectors permit rapid entrance and exit to traffic.

11210-2.3 High Speed Taxiway Turnoff. High speed taxiway turnoffs are located intermediate of the ends of the runways to increase the capacity of the runway. The high-speed taxiway turnoff enhances airport capacity by allowing aircraft to exit the runways at a faster speed than turnoff taxiways allow.

11210-2.4 Additional Types of Taxiways. Besides the types of taxiways above, there are other taxiways at an airfield. Taxiways are often Identified based on their function. Common airfield taxiways include, but are not limited to, crossover, connecting, bypass, acute angle, intermediate, and ladder.

11210-2.5 Peripheral and Interior Taxilanes. A taxi route through or around an apron is referred to as a taxilane. Taxilanes are generally an integral part of the aircraft parking apron and as such as included under Category Code 113 20, Aircraft Parking Apron.

11210-3 CRITERIA. The width of a taxiway depends upon the specific airfield configuration and layout of support facilities. Runway exits are part of the taxiway system and include end, normal intermediate and high-speed turn-offs. See UFC 3-260-01, Chapter 5 for taxiway dimensional criteria.

11210-4 EXITS FOR CLASS B FIXED WING RUNWAYS: End turn-offs are planned for each runway end and are 45.7 meters (150 feet) wide, except those from parallel runways to the parallel taxiway which are 61 meters (200 feet) wide. Normal intermediate turn-offs are required for all runways. They are normally 22.9 meters (75 feet) wide and are placed 610 meters (2,000 feet) from each end of the runway and in the remaining runway length at intervals of not more than 915 meters (3,000 feet) or less than 610 meters (2,000 feet). High-speed turn-offs are provided where traffic studies indicate the need for additional runway landing capacity. High-speed turn-offs are 30.5 meters (100 feet) wide at the throat tapering to 22.9 meters (75 feet) and are a minimum of 305 meters (1,000 feet) long. See UFC 3-260-01, Chapter 5.

11210-5 EXITS FOR CLASS A FIXED WING RUNWAYS AND ROTARY WING RUNWAYS: End turn-offs are planned for each runway end and intermediate taxiways shall be placed at intervals appropriate to runway length.

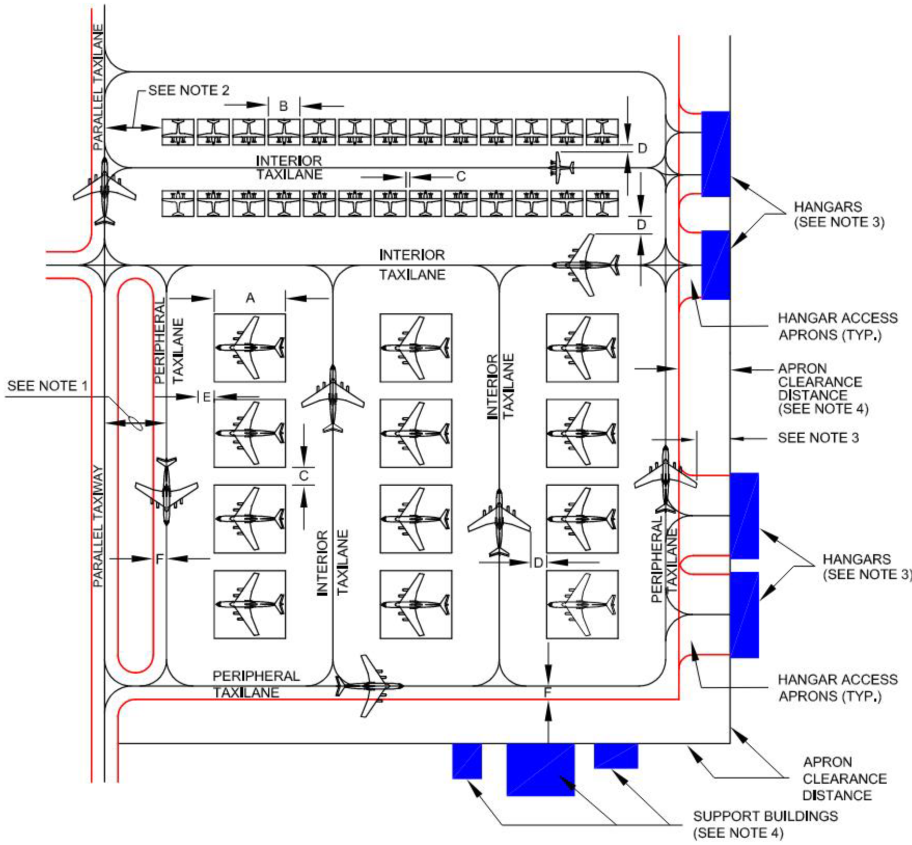
11210-6 SAFETY CLEARANCES/SEPARATIONS: Taxiways are located so as to provide adequate clearance between taxiing aircraft and aircraft in adjacent areas and obstacles. See UFC 3-260-01 for separation clearances.

113 AIRFIELD PAVEMENTS – APRONS – AIRCRAFT PARKING

113 20 AIRCRAFT PARKING APRON (M2/SY)
FAC: 1131
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11320-1 DESCRIPTION. Aircraft parking aprons are required for loading, unloading and servicing of aircraft in addition to providing parking space. There is no standard size or apron configuration. See Figure 11320-1 Basic Aircraft Parking Apron for typical parking apron configuration and limits included in this category code. See Figure 11320-2 Apron and Taxiway Category Codes for typical boundaries of apron, taxiway, and shoulder pavements. The size is based on the type and number of aircraft to be parked, the requirement for squadron integrity and 45 versus 90 degree parking. The area required includes parking space, wing-tip separation between aircraft, interior taxilanes, peripheral taxilanes, and connector taxilanes between aprons and adjacent taxiways. Aprons used for ordnance handling require special siting considerations, see Category Codes 116 55, Ordnance Handling Pad and 116 56, Combat Aircraft Loading Area. For design criteria, see UFC 3-260-01.

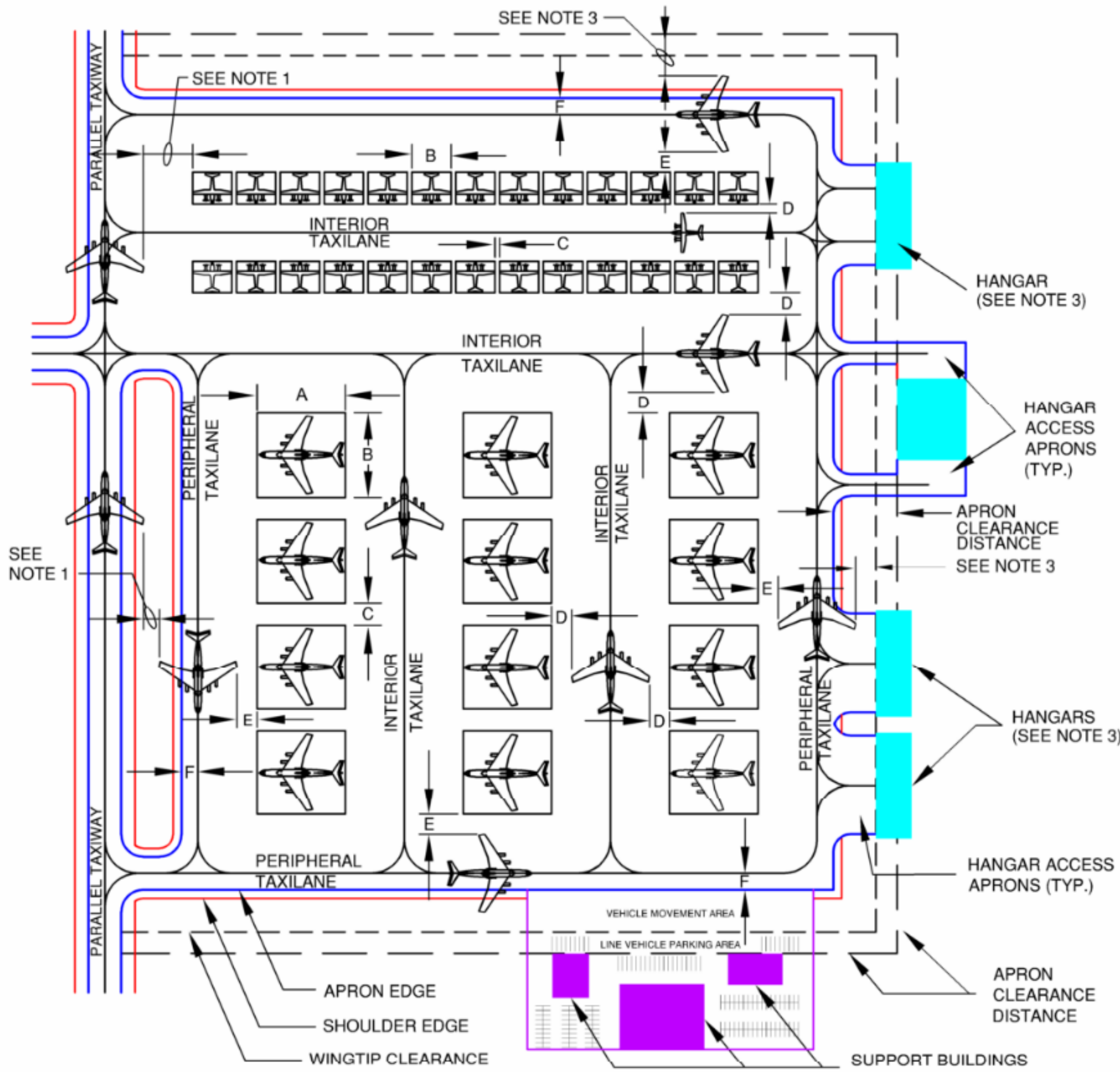


LEGEND

B - AIRCRAFT WIDTH
A - AIRCRAFT LENGTH
D - WINGTIP CLEARANCE FOR INTERIOR TAXILANE (MIN. TAXI CLEARANCE)
E - WINGTIP CLEARANCE FOR PERIPHERAL TAXILANES
C - WINGTIP CLEARANCE FOR PARKED AIRCRAFT
F - DISTANCE FROM PERIPHERALTAXILANE CENTERLINE TO APRON EDGE

NOTES:

1. TAXIWAY CLEARANCE DISTANCE AT FACILITIES WITH PARALLEL TAXIWAYS; SEE TABLE 5-1, ITEM 11.
2. SEE TABLE 6-1 N/MC FOR DIMENSIONAL DEFINITIONS.
3. INSURE MINIMUM WINGTIP CLEARANCE IS PROVIDED TO HANGARS OR OTHER PERMISSIBLE DEVIATIONS (SEE TABLE 6-1 N/MC ITEMS 6 AND 15).
4. MINIMUM 100 FEET BETWEEN APRON EDGE AND OTHER FIXED OBJECTS.



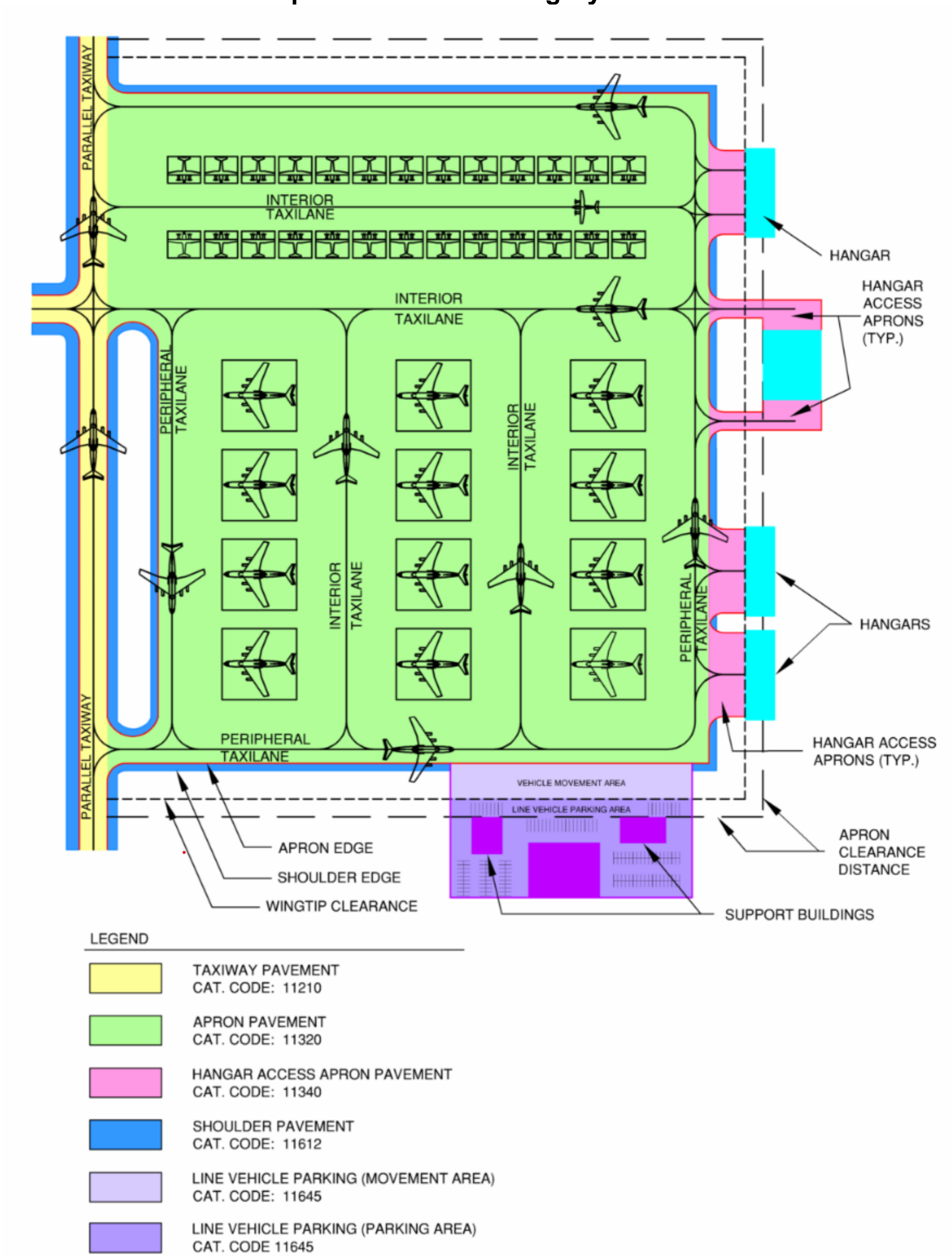
LEGEND

A - AIRCRAFT LENGTH
B - AIRCRAFT WIDTH
C - WINGTIP CLEARANCE FOR PARKED AIRCRAFT
D - WINGTIP CLEARANCE FOR INTERIOR TAXILANES
E - WINGTIP CLEARANCE FOR PERIPHERAL TAXILANES
F - DISTANCE FROM PERIPHERAL TAXILANE CENTERLINE TO APRON EDGE

NOTES:

1. TAXIWAY CLEARANCE DISTANCE AT FACILITIES WITH PARALLEL TAXIWAYS; SEE UFC 3-260-01, TABLE 5-1, ITEM 11.
2. SEE UFC 3-260-01, TABLE 6-1 N/MC FOR DIMENSIONAL DEFINITIONS.
3. ENSURE MINIMUM WINGTIP CLEARANCE IS PROVIDED TO HANGARS OR OTHER PERMISSIBLE DEVIATIONS (SEE UFC 3-260-01, TABLE 6-1 N/MC, ITEMS 6 AND 15).

Apron Pavement Category Codes



11320-2 CRITERIA. The determination of the apron requirements involves the following steps:

1. Determine the number of aircraft parking spaces required.
2. Layout the parking spaces using the dimensions in UFC 3-260-01, Chapter 6 for clearances between aircraft and interior taxilanes.
3. Provide peripheral taxilanes around the perimeter of the apron using the dimensions in UFC 3-260-01, Chapter 6.

11320-3 NUMBER OF PARKING SPACES. The number of parking spaces required is based on the average number of aircraft on board (including transients) reduced by a factor to reflect the number of aircraft expected to be in hangars for scheduled organizational maintenance. For planning purposes, assume that the following percentages of the average on-board aircraft assigned organizational maintenance at a station will be in the hangar for scheduled maintenance:

33% - Carrier and Rotary Wing aircraft
17% - Patrol, Special Mission, and Training aircraft
11% - Transport aircraft

11320-3.1 The above reductions apply except that the reduction to the number of apron parking spaces shall not exceed 50 percent of the hangar spaces available.

11320-3.2 Where organizational maintenance is provided by a commercial contractor, the average number of aircraft in hangars for scheduled maintenance shall be determined on an individual basis. Where an air installation is subject to peak loadings on a regular basis for training exercises or overlap of deployable squadrons, individual justification may be provided for additional spaces to support peak loadings.

11320-3.3 Example Computation: A station supports 6 fleet operational F/A-18 squadrons. Each squadron has 12 aircraft. Determine the number of parking apron spaces required.

a. F/A-18 aircraft are categorized as Carrier aircraft.

b. Total number of aircraft = 6 x 12 = 72

c. Reduction for aircraft assigned organizational maintenance (i.e. parked in aircraft maintenance hangar) (for Carrier aircraft) = 72 x 33% = 23.8 = 24 (rounded to next whole number). However, the reduction shall not exceed 50% of the aircraft maintenance hangar space available. Therefore, the total reduction for aircraft assigned organizational maintenance (i.e. parked in aircraft maintenance hangar) = 24 x 50% = 12

d. Number of aircraft requiring apron parking apron spaces = 72 – 12 = 60

11320-4 SPACING OF AIRCRAFT. See UFC 3-260-01, Chapter 6 for apron spacing and typical apron configurations for 90 and 45 Degree Parking Layouts.

11320-4.1 Jet Blast Protection. Parked aircraft must be separated to maintain proper wing-tip clearances, interior taxilane widths and protection from jet blast. Jet blast protection is achieved by providing the space necessary to dissipate the temperature and velocity of the jet blast to levels that will not injure or damage aircraft personnel and equipment. Typically, this level is approximately 100 degrees Fahrenheit (38 degrees Celsius) and 30.4 knots (35 mph). This level can be easily achieved by parking carrier based aircraft at 45 degrees with their engine blast aimed into the interior taxilane, providing safe and adequate jet blast dispersion (see UFC 3-260-01, Chapter 6).

11320-4.2 Deviations from Efficient Configuration. The most efficient apron size results from parking jet aircraft at either a 45-degree or 90-degree angle, and propeller aircraft and helicopters at a 90-degree angle to the interior taxilane. Use of the most efficient configuration is preferred. Factors impacting designs for aircraft parking configurations could include space availability, operational constraints, type and number of aircraft, taxiing or towing procedures, and clearances. The apron spacing dimensions may be modified when a Fixed Point Utility System (FPUS), starting air and electrical service, or Flightline Electrical Distribution System (FLEDS), electrical system is to be installed in the apron. The FPUS or FLEDS service points and the parking spaces are spaced to accommodate all Navy fighter and attack aircraft rather than designed for a particular aircraft. Coordinate with the FPUS and FLEDS manufacturer and users for specific apron layout criteria.

11320-5 PERIPHERAL TAXILANES. A peripheral taxilane is normally provided on all sides of an aircraft parking apron. The MC-4 Triton does not require peripheral taxilane. Movement of this aircraft in and out of hangar and inside an apron is achieved with a towing tractor. See UFC 3-260-01, Chapter 6 for peripheral taxilane dimensions and clearances.

11320-6 SAFETY/LATERAL CLEARANCES. See UFC 3-260-01 for the definition and application of airfield safety clearances. Parking aprons shall be sited outside the primary surface of the runway (or helipad). The edge of the apron may be adjacent to the outer edge of the primary surface; however, parked aircraft shall not penetrate the transitional surface.

11320-7 DISTANCE FROM APRON EDGE. Aircraft taxiing on the peripheral taxilane are not considered obstructions even though they do penetrate the transitional surface. The apron edge shall be a minimum of 45.7 meters (150 feet) from the centerline of any parallel taxiway of the runway system. The minimum distance any object, except maintenance hangars, shall be sited from the apron edge is 30.5 meters (100 feet).

11320-8 MAINTENANCE HANGAR OFFSET FROM APRON. Maintenance hangars opening to the apron shall be offset 15.2 meters (50 feet) from the apron edge. For criteria regarding access pavement to the hangar see Category Code 113-40, Aircraft Access Aprons

11320-9 DEVIATION FROM CRITERIA: The 45.7 meter (150 foot) separation between an aircraft parking apron and the centerline of a parallel taxiway must be maintained when the taxiway is expected to carry a substantial amount of through traffic, i.e., traffic other than that which starts or terminates at that particular apron. When the anticipated amount of through traffic is minimal and is so justified to NAVAIRSYSCOM, a parking apron may be located such that the parallel taxiway is incorporated within the apron peripheral taxilane. However, in this case, the parallel taxiway becomes a part of the apron and therefore must be located outside the runway primary surface. Any savings in pavement to be gained by combining the parallel taxiway shall be compared to any increases in pavement for runway turnoffs required due to moving the parallel taxiway outside the runway primary surface. This combination shall not be planned without prior approval of NAVAIRSYSCOM. Where minimum apron spacing requirements cannot be met, see UFC 3-260-01, Appendix B Section 1 for Navy and Marine Corps process to obtain NAVFAC UFC exemption to criteria and NAVAIR airfield safety waiver.

11320-10 Peripheral taxilanes are to be provided on all sides of fixed wing aircraft parking aprons. Although such an arrangement is desirable, it is not always necessary. When small numbers of aircraft (one or two rows) are to be parked or when operational requirements allow, the number and/or width of the peripheral taxilanes may be reduced on the advice of local air operations personnel, subject to NAVAIRSYSCOM approval. Peripheral taxilanes for helicopters shall not be reduced from the dimensions shown in UFC 3-260-01, Chapter 6.

11320-11 Tables 11320-1, 11320-2, 11320-3 and 11320-4 list aircraft by type and include all models, such as the S-3 aircraft type which includes S-3A, S-3B, ES-3A, US-3A, and YS-3A. However, in some instances there are size differences between models of the same aircraft, such as the F/A-18A and the F/A-18E. In these cases, the particular aircraft type is also further defined by the model to which the data applies.

113 40 AIRCRAFT ACCESS APRON (M2/SY)

FAC: 1131
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11340-1 AIRCRAFT ACCESS APRONS. Aircraft access aprons provide access to aircraft maintenance hangars from the aircraft parking apron and is normally programmed at the same time as the hangar (Category Code 211 05). The paved area required varies with the hangar dimensions and the hangars displacement from the aircraft parking apron. The access apron requires a minimum 15.2 meter (50 foot) depth and must be at least as long as the hangar door. See UFC 3-260-01, Chapter 6 for peripheral taxilane wingtip clearance requirements that may impact the aircraft access apron length. For pull through hangars with dual access aprons, both access aprons are part of this category code.

116 AIRCRAFT PAVEMENTS – OTHER

116-1 DESCRIPTION. Included in this basic category are airfield pavements, other than runways, taxiways, and aprons, such as wash racks, rinse facilities, compass calibration pads, arming/de-arming pads, Ground Controlled Approach (GCA) pads, blast protective pavement, line vehicle parking, towaways, ordnance handling pads, fire and rescue vehicle alert pads, and tactical support van pads.

116 10 AIRCRAFT WASH RACK PAVEMENT (M2/SY)
FAC: 1163
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11610-1 WASH RACKS. Aircraft washracks are provided at all air installations for cleaning of aircraft in conjunction with periodic maintenance. See Category Code 116 15 for aircraft freshwater rinse facility criteria. A minimum of one washrack is required at each Naval and Marine Corps aviation shore installation. The total number required at an installation depends on numbers and types of on-board aircraft. The number of aircraft that can be serviced by a single washrack is dependent on the frequency of required washes, prescribed in NAVAIR Manual NA01-1A-509, the average time to wash the aircraft, and the availability of the washrack. There are three standard shapes of washracks for fixed wing aircraft as indicated in UFC 3-260-01, Chapter 6: Type F, which accommodates fighters and other small aircraft; Type L, which accommodates heavy bombers and large cargo aircraft; and Type B, which is specifically for Navy/Marine Corps Patrol and Cargo Aircraft. UFC 3-260-01, Figure 6-40 should be used to assist in determining the Wash Rack Type.

11610-1.1 Type F (Fighter, Attack Aircraft, and Helicopters): Type F wash rack can service 80 VA/VF or similar size aircraft or 40 rotary wing aircraft, or a combination of both. The number of combined aircraft that can be serviced on a Type F pad can be determined from the following equation: The number of VA/VF (or similar size) aircraft plus two times the number of helicopters equals 80.

Example: 40 VA/VF plus 20 helicopters as 40 plus 2(20) does not exceed 80.

11610-1.3 Type B (Straight Wing Patrol and Cargo Transport Aircraft): Type B washrack can service 20 VP aircraft or 80 cargo transport aircraft, or a combination of both. The number of combined aircraft that can be serviced on a Type B pad can be determined from the following equation: four times the number of patrol aircraft (VP) plus the number of cargo aircraft equals 80.

EXAMPLE: 18 VP and 8 cargo as 4(18) plus 8 does not exceed 80.

11610-1.4 Type L (Swept Wing Patrol and Cargo Trasport Aircraft): Type L wash rack accommodates heavy bombers and large cargo aircraft.

11610-2 WASH RACK LOCATION. The normal location of the wash racks is adjacent to the hangar with access pavement provided as required. Utilities and an antipollution drainage system are provided.

11610-3 ACCOMPANYING UTILITIES. A utilities control building with a gross area of approximately 58.6 square meters (630 square feet) is planned with each wash rack. It houses detergent metering equipment, air compressor, detergent mixing tank, water heater, utility controls, sanitary facilities for personnel, if required, and storage space for cleaning equipment. A detergent storage tank is located outside of the utilities control center and may be below ground.

11610-4 SAFE ACCESS. An aircraft wash rack must include the capability to provide safe access to all aircraft surfaces with lifelines and/or platforms for personnel safety.

11610-5 RUNOFF. In addition, the wash rack pavement must be curbed and guttered to preclude uncontrolled runoff of wash and rinse water. The wash rack pavement must also include adequate runoff storage capacity to preclude overflow of wash and rinse water and average daily rainfall with daily emptying and disposal of effluent in the sump. For VF/VA and helicopter type aircraft this effluent storage capacity shall be not less than 18,900 L (5,000 GA) per day. For VP and transport type aircraft the effluent collection and storage capacity shall be not less than 15,100 L (4,000 GA) per day. For layout and design criteria for wash racks, see UFC 3-260-01.

116 12 AIRCRAFT PAVEMENT SHOULDER (M2/SY)
FAC: 1165
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11612-1 DESCRIPTION. Unprotected areas adjacent to runways, overruns, taxiways, and aprons are susceptible to erosion caused by jet blast. Shoulders also reduce the probability of serious damage to an aircraft to a minimum in the event that the aircraft runs off the pavement. Paved shoulders are required to be adjacent to all runways, taxiways, and aprons. See UFC 3-260-01 for shoulder dimensional criteria. See Figure 11320-2 Apron and Taxiway Category Codes for typical boundaries of shoulder pavements.

116 15 AIRCRAFT RINSE FACILITY (M2/SY)
FAC: 1167
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
UFC 3-401-01 Mechanical Engineering
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11615-1 TAXI-THROUGH. An aircraft rinse facility provides an unattended taxi-through, treadle operated, freshwater deluge system to rinse aircraft. The aircraft rinse facility is required at each Navy and Marine Corps air installation having aircraft subject to accelerated corrosion due to low-level over-water operations or a corrosive atmosphere at the installation. A facility of appropriate type is planned for each type of aircraft normally stationed at the airfield. A rinse facility includes several components, including pavement, water supply, pumps, sprayers, wastewater collection system, among other components. See UFC 3-260-01, Chapter 6 for an illustration of a typical aircraft rinse facility.

11615-1.1 **Type 1** is for rotary wing aircraft and has a gross area of 913.3 M2 (1,093 SY). The basic length and width for full-strength pavement is 75 feet x 130 feet. Shoulder pavements adjacent to the full-strength pavement must provide a minimum paved width of 100-ft for CH-53 aircraft.

11615-1.2 **Type 2** is for VP type aircraft and has a gross area of 1428.9 M2 (1,710 SY). The basic length and width for full-strength pavement is 75 feet x 205 feet.

11615-1.3 **Type 3** is for VF or VA type aircraft and has a gross area of 760.4 M2 (910 SY). The basic length and width for full-strength pavement is 75 feet x 110 feet.

11615-1.4 **Type 4** is for V-22 aircraft and has a gross area of 913.3 M2 (1,093 SY). The basic length and width for full-strength pavement is 75 feet X 130 feet. Shoulder pavements adjacent to the full-strength pavement must provide a minimum paved width of 100-ft for V-22 aircraft.

11615-2 ACCESS TAXIWAYS AND VEHICLE ROADS. Access taxiways (Category Code 112 10) and vehicle roads (Category Code 851 10) are programmed with the rinse facility as required. The facility should be located in proximity to the most frequently used taxiway and as near to the hangar area as possible. A water supply and drainage area are required.

116 20 AIRCRAFT COMPASS CALIBRATION PAD (M2/SY)
FAC: 1161
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design,
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11620-1 AIRCRAFT COMPASS CALIBRATION PAD. An aircraft compass calibration pad is a paved area in a magnetically quiet zone where the compass in the aircraft is calibrated. See UFC 3-260-01, Chapter 6 and Appendix B, Section 10 for layout, siting, type of pad, and marking requirements.

11620-2 PAD CAPABLILITIES. A minimum of one pad is provided at each station, however, additional pads may be required based on local demand.

11620-3 SITING. See UFC 3-260-01, Chapter 6 for specific siting requirements relative to other airfield facilities and magnetic interference.

11620-4 MINIMUM DISTANCES. See UFC 3-260-01, Appendix B, Section 10 for specific minimum distances between compass calibration pads and sources of magnetic interference.

11620-5 ACCESS TAXIWAY TO CALIBRATION PAD. The access taxiway to the calibration pad is oriented to facilitate moving the aircraft onto the pad, headed toward magnetic north.

11620-6 GROSS AREA REQUIRED FOR CALIBRATION PAD. The gross area required for a compass calibration pad exclusive of access taxiway is provided in UFC 3-260-01, Chapter 6.

11620-7 CALIBRATION TARGET. Each pad requires a target placed at a known but arbitrary bearing at a distance of approximately 805 meters (one-half mile) from the pad and visible from both the aircraft and the compass calibration set.

116 35 ARMING AND DE-ARMING PAD (M2/SY)
FAC: 1131
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design; NAVSEA OP-5 – Volume I, latest revision, Ammunition Ashore Regulations for Handling, Storing, Production, Renovation and Shipping

11635-1 DESCRIPTION. This pad provides a paved area for activating or deactivating weapons systems on-board aircraft. It is utilized at all Navy and Marine Corps air installations where gunnery, rocketry, and/or missile firing are conducted. The average time for arming an aircraft is 20 minutes, and for de-arming an aircraft, 30 minutes. All aircraft on the pad may be either armed or de-armed simultaneously; however, arming and de-arming cannot occur simultaneously on the same pad. The number of pads at an installation depends upon the demand at that installation. The pads are sited at either end of the primary runway and, if additional pads are required, at either end of the crosswind runways. See UFC 3-260-01, Chapter 6 for siting considerations.

11635-1.1 Type A. The gross area of the Type A pad (exclusive of the access taxiway) is 2,138 square meters (30.5 meters by 70.1 meters) (2,556 square yards (100 feet by 230 feet). The Type A pad will accommodate simultaneously four helicopters (AH-1 type).

11635-1.2 Type B. The gross area of the Type B pad (exclusive of the access taxiway) is 5,434 square meters (45.7 meters by 118.9 meters) (6,500 square yards (150 feet by 390 feet). The Type B pad will accommodate simultaneously four fixed wing attack (VA) aircraft or four fixed wing fighter (VF) aircraft.

11635-1.3 Type C. The gross area of the Type C pad (exclusive of the access taxiway) is 6,526 square meters (79.3 meters by 82.3 meters) (7,800 square yards (260 feet by 270 feet). The Type C pad will accommodate simultaneously two fixed wing patrol (VP) aircraft.

11635-2 PARKING AT PAD. Aircraft utilizing the pad normally park parallel to the runway but in any case they park headed in the direction providing the maximum length of undeveloped space along the extended longitudinal centerline of the aircraft. In no case is arming or de-arming of propelled armament conducted when the aircraft is headed towards inhabited areas on or near the air installation.

116 40 PRECISION APPROACH RADAR (PAR) PAD (M2/SY)
FAC: 1164
BFR Required: N

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: Mechanical Manuals for Specified Equipment

11640-1 PAR PAD. The Precision Approach Radar (PAR) pad is a paved hardstand provided to support the PAR equipment in operating position. The hardstand must be a minimum of 146 square meters (12.1 meters by 12.1 meters) (178 SY (40 feet by 40 feet)). Technical manuals provided by the equipment manufacturers should also be consulted in order to determine the most appropriately sized pad. The number of pads required depends on the number of PAR units at the air installation. At installations where PAR approaches are provided to more than one runway by a single

PAR unit, a turntable is provided to allow PAR service more than one runway. Technical manuals for the respective equipment describe acceptable locations for the pad.

116 41 IMPROVED FRESNEL LENS OPTICAL LANDING SYSTEM PAD (M2/SY)
FAC: 1164
BFR Required: N

11640-1 DESCRIPTION. A paved hardstand pad that provides support to the Improved Fresnel Lens Optical Landing System (IFLOLS) equipment in operating position.

116 42 BLAST PROTECTIVE PAVEMENT (M2/SY)
FAC: 1164
BFR Required: N

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design,
UFC 3-260-02, Pavement Design for Airfields
UFC 3-270-01, O&M Manual: Asphalt and Concrete Maintenance and Repair
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11642-1 DESCRIPTION. Blast protective pavement is provided adjacent to the runway threshold and end turnoff for all runways except those at basic training propeller aircraft fields. Blast protection pavement is not intended to fully support aircraft load. However, in cases where the training propeller aircraft is not an exclusive use to the airfield, blast protective pavement is a requirement. Permanently based aircraft and significant transient aircraft and services should be included in determining a requirement for pavement protection. If aircraft exhaust will be directed directly at pavement for extended periods of time, give consideration to using high temperature concrete to mitigate damage that may be caused by hot exhaust. Blast protective pavement may be required in other locations for aircraft, such as the F/A-18 with downward exhausted auxiliary power units, the AV-8B and F-35B with ducted exhaust, and the V-22 with both down turbine exhaust and propeller wash. The area of blast protective pavement required for a particular aircraft may be determined from exhaust plume data in Naval Air Training and Operating Procedures Standardization (NATOPS) or engine manufacturers specifications for developmental aircraft. For aircraft including F/A-18, F-35, and AV-8B the width of the blast protective pavement is 30.5 meters (100 feet) except for Master Jet Air Stations where the length shall be 37.5 meters (125 feet), or in support of F-35B Short Take-off operations where the length shall be 61 meters (200 feet).

116 45 LINE VEHICLE PARKING (M2/SY)
FAC: 1164
BFR Required: N

Design Criteria: Military Handbook 1021/1, Airfield Geometric Design; NAVAIR 00-80T-109
UFC 3-250-01, Pavement Design for Roads and Parking Areas

Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11645-1 VEHICLE PARKING SPACES. Line vehicle parking spaces contiguous to taxiway and parking aprons are allocated for ground support equipment assigned for flight line use. See Table 11645-1 for space requirements. Vehicle parking spaces must be located beyond the peripheral taxilane wingtip clearance and are not part of the aircraft parking apron (Category Code 113 20). Vehicle parking space pavement shall be designed to support using vehicles in accordance with UFC 3-250-01. See Figure 11320-2 Apron and Taxiway Category Codes for typical boundaries of line vehicle parking pavements.

Table 11645.1. Line Vehicle Parking

Equipment	Area (M2)	Area (SY)
Tow Tractor	16.7	20
Refueling Truck (1)	39.3	47
Refueling Trailer (1)	58.5	70
Mobile Electric Power Plant	10	12
Nitrogen/Oxygen Trailer	6.7	8
Air Conditioning Trailer	10	12
Utility Vehicle	16.7	20
Bomb Truck	16.7	20
Bomb Trailer	12	14
Industrial Flatbed Truck	7.5	9
Industrial Platform Truck	7.5	9

Note: (1) Parking for both truck and trailer refuelers should be sited away from the flightline to reduce and/or eliminate hazards. NAVAIR 00-80T-109 states that refuelers and fuel servicing equipment will be parked in designated areas which have a minimum lateral separation of 7.6 meters (25 feet), measured center to center of truck, between trucks. It also states that no refuelers and fuel servicing equipment will be parked closer than 30.5 meters (100 feet) to any inhabited building.

11645-2 PARKING FOR FIRE AND RESCUE VEHICLES. Parking for aircraft fire and rescue vehicles are provided separately. See Category Code 141 20, Aircraft Fire and Rescue Station and Category Code 116 60, Fire and Rescue Vehicle Alert Pad.

11645-3 OPTIMUM EFFICIENCY. Parking areas shall be selected to permit optimum efficiency in the use of equipment (for example, squadron vehicles will normally be assigned space close to the squadron maintenance hangar) and to conform to lateral safety clearances for existing and projected airfield pavements. Where weather requires and the clearances permit, shelter for line vehicles may be provided.

116 50 TOWWAY (M2/SY)
FAC: 1131
BFR Required: N

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11650-1 DESCRIPTION. A towway is a paved roadway used for towing fixed or rotary wing aircraft from one area to another. It differs from a taxiway in that aircraft do not move on it under their own power. Towways may be authorized at air installations where it is necessary to tow aircraft from one operational area to another and in some instances, particularly at air installations with jet aircraft, to minimize noise conditions. Towway pavement is normally provided at industrial seaport air installations where carrier berthing facilities include those for unloading and loading of aircraft. Pavement marking, particularly centerline, should be provided, and lighting provided if operations are to be conducted at night.

11650-2 TOWWAYS ON EXISTING STREETS AND ROADS. In some cases, towways will be on existing streets and roads or abandoned runways and taxiways, which may be tailored for this use. Such modification will include reconstruction or strengthening of existing facilities to support the maximum aircraft loading that will be superimposed at each location, as well as provision for adequate horizontal and vertical clearances. Jet blast criteria and shoulder specification need not be considered.

11650-3 TYPICAL TOWWAY WIDTHS. Towways are planned for air installations based upon the installation mission and type aircraft to be moved. For towway widths see UFC 3-260-01, Chapter 5.

116 55 ORDNANCE HANDLING PAD (M2/SY)
FAC: 1131
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design NAVSEA OP-5 – Volume I, latest revision, Ammunition Ashore Regulations for Handling, Storing, Production, Renovation and Shipping

11655-1 DESCRIPTION. An ordnance handling pad is provided for air installations where there is a requirement for loading or off-loading explosives from cargo aircraft and where no apron is available for use without violating explosive safety distance criteria. The pads are designed for use by cargo aircraft and will generally vary in size depending on the type of ordnance being handled and the number and type of aircraft to be loaded/unloaded simultaneously. Note: Ordnance Handling Pad is referred to as a Hazardous Cargo Pad within UFC 3-260-01.

11655-1.1 Types of Pads:

a. Circular: At aviation facilities used by small cargo aircraft, the Ordnance Handling Pad is a circular pad as shown in UFC 3-20-01, Figure 6-34.

b. Semi-Circular: At aviation facilities used by large cargo aircraft and Aerial Ports of Embarkation (APOE) and Aerial Ports of Debarkation (APOD), the Ordnance Handling Pad is a semi-circular pad as shown in UFC 3-260-01, Figure 6-35. The semi-circular pad is adequate for aircraft up to and including the dimensions of a C-5 aircraft.

11655-1.2 Dimensions. The Ordnance Handling Pad geometric dimensions shown in UFC 3-260-01, Figure 6-34, and Figure 6-35 are minimum requirements. Ordnance Handling Pads may be larger than these if the design aircraft cannot maneuver on the pad.

11655-2 ORDANCE HANDLING PAD SITING. The ordnance handling pad shall be sited in accordance with standards published in NAVSEA OP-5 - Volume I, latest revision (Ammunition Ashore Regulations for Handling, Storing, Production, Renovation and Shipping). Also, the ordnance handling pad should be sited in accordance with all pertinent airfield safety criteria. Barricades shall be provided where required by explosives safety criteria or where installation will produce a net reduction in construction and land acquisition costs.

11655-3 JOINT USE CONSIDERATION. Consideration should be given to a joint use Combat Aircraft Loading Area (CALA), Category Code 116-56, for ordnance handling provided the CALA is sited in accordance with the guidelines stated above.

116 56 COMBAT AIRCRAFT LOADING AREA (CALA) (M2/SY)
FAC: 1131
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design; NAVSEA OP-5 – Volume I, latest revision, Ammunition Ashore Regulations for Handling, Storing, Production, Renovation and Shipping

11656-1 DESCRIPTION. The combat aircraft ordnance loading area is primarily an apron where explosives are loaded/off-loaded from combat aircraft departing and/or returning from weapons training flights. This area is required where there is not space available on the parking apron for loading mass detonating ordnance which will meet the explosive safety requirements specified in NAVSEA OP-5, Volume I, latest revision (Ammunition and Explosives Safety Ashore Regulations for Handling, Storing, Production, Renovation and Shipping). The weapons are not armed on this apron, see Category Code 116-35, Arming and De-arming Pad.

11656-2 COMPLIANCE WITH EXPOSIVE SAFETY CRITERIA. Due to the ordnance handling taking place on this apron, its location with respect to other facilities shall be determined using explosives safety criteria specified in NAVSEA OP-5, Volume I, latest revision. In addition, the airfield safety criteria specified in UFC 3-260-01.

11656-3 Airfield Safety Clearances apply and:

a. The apron must be outside of the runway primary surface
b. Parked aircraft shall not penetrate any transitional surface
c. No objects shall be sited within 30.5 meters (100 feet) of the edge of this apron

11656-4 CRITERIA. There is no standard size for a combat aircraft ordnance loading area. The area required is a function of the number of aircraft to be simultaneously loaded/unloaded and the class and net explosive weight of the ordnance to be carried by each aircraft. Aircraft on the apron shall be separated from each other by the above ground magazine (unbarricaded, K=11) distances specified in OP-5, Volume I, latest revision. The greater the net explosive weight on the aircraft, the greater the required separation. However, as a minimum, the aircraft spaces shall be separated by not less than the A, B, C, and D dimensions specified for parking aprons, Category Code 113 20. Peripheral taxilanes shall be provided as required to provide safe access to parking spaces. See UFC 3-260-01, Chapter 6 for peripheral taxilane requirements.

11656-5 SIZING FOR LOADING SCENERIOS. The apron most likely will have to be sized to accommodate several loading situations. For example, parking locations could be spaced such that twelve aircraft could each be loaded with 227 kgs (500 labs) net explosive weight or six aircraft, parked in alternate spaces, could each be loaded with 2,270 kgs (5,000 lbs) net explosive weight. The maximum net explosive weight to be on the apron at one time shall be used in determining the explosive quantity distance arcs for the apron. These arcs shall be measured from the edge of the apron pavement, including the peripheral taxi lanes. Justification shall be provided for the number of aircraft and the net explosive weight per aircraft chosen for sizing the apron. Strong consideration shall be given to providing a joint use apron for ordnance handling from cargo aircraft, Category Code 116-55, and the combat aircraft ordnance area if these operations can be scheduled on a non-concurrent basis. If supporting facilities such as an ordnance operations building, or fixed point utility system are required, they shall be individually justified.

116 60 FIRE AND RESCUE VEHICLE ALERT PAD (M2/SY)
FAC: 1164
BFR Required: N

Design Criteria: NAVAIR 00-80R-14, Aircraft Firefighting and Rescue NATOPS Manual

UFC 3-260-01, Airfield and Heliport Planning and Design
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

11660-1 DESCRIPTION. This facility provides parking area for Immediate Response Alert Vehicle. The purpose of the Immediate Response Alert is to:

1. Observe all landings and take-offs.
2. Respond immediately to any aircraft accident.
3. Provide timely rescue of personnel involved in emergencies.

11660-2 SIZE AND LOCATION. The pad should be large enough to park one 3,780 liter (1,000 gallon) aircraft rescue and fire fighting vehicle (P-19) and should be located no closer than 45.7 meters (150 feet) from the runway edge. The pad should not include a protective shelter or any other structure, which would violate airfield safety clearance criteria. See UFC 3-260-01 for guidance. The pad should be connected to the runway by a 4.9 meter (16 foot) wide access road to the runway. If there is no access from the crash house to the alert pad other than from the runway, the parking space should be widened as required to allow the truck sufficient space to turn around (see Table 11660-1).

Table 11660-1. 3,780 Liter (1,000 Gallon) Aircraft Rescue and Fire Fighting Vehicle Dimensions (P-19)

Weight	=	15,200 kg (3,600 lbs)
Width	=	2.4 meters (8 feet)
Length	=	8.3 meters (27.1 feet) (over bumpers)
Inside turning radius (“wall to wall”)	=	24.4 meters (80 feet)

11660-3 MULTIPLE ALERT PADS. Normally there will be one alert pad per air station. However, multiple alert pads will be required when more than one runway is in use and operations cannot be observed from a single vantage point. The optimum location is on either side of the runway and near the middle of the airfield but may vary depending upon the best observation of the runway. Consideration should be given to maximum utilization of existing abandoned pavements prior to construction of an alert pad.

11660-4 ELECTRICAL POWER JUSTIFICATION. Normally electrical power is not provided to the Alert Pad. However, when power is required to charge the truck batteries, requirements must be individually justified. For additional information see NAVAIR 00-80R-14 Aircraft Firefighting and Rescue NATOPS Manual.

116 65 TACTICAL SUPPORT VAN PAD (M2/SY)
FAC: 1164
BFR Required: Y

Planning Criteria: NAVAIRINST 13670.1B/MCO 13670.1

11665-1 DESCRIPTION. This facility consists of a concrete pad and support structure to accommodate groups of relocatable tactical shelters or “vans”. Numerous functions at Navy and Marine Corps installations are done in relocatable shelters. These shelters, while referred to by different nomenclatures depending on usage, are commonly called “vans”. They are generally aluminum structures built to commercial standards of 2.4 meters (8 feet) in width and height, and 6.1 meters (20 feet) in length. These vans can be carried by any military or commercial cargo carrier by air, ship, truck, or rail. Vans are designed to be grouped together with removable doors, access panels, and butting kits and can be configured for solo use or grouped in large complexes. Tactical support van pads are not to be used to support airfield operations support facilities per UFC 4-141-10.

Site tactical van pads to be clear of the primary surface, clear zone, and imaginary surfaces as well as clearances relative to runways, taxiways, and aprons.

11665-2 TYPES OF VANS:

16665-2.1 Interconnect Unit (INU). Placed in the center of groups and used to connect vans of the other types together. INUs have a door at each end and three access panels on the sides for the joining of up to five vans to each INU.

11665-2.2 Basic. Internally configured for a specific mission from administrative to maintenance. These vans can be joined only with another van at each end.

11665-2.3 Other (Right, Left, Middle). These types of vans are used in specific configurations to make up double and triple wide vans. These vans can only be joined to a complex at the end of another basic van.

11665-3 MAXIMUM VAN GROUP SIZE. By NAVAIR Instruction, van groups cannot be larger than six INUs connected end to end with a maximum of two vans extending from each side. In this configuration, up to 42 vans can be joined together.

11665-4 EXAMPLES OF VAN COMPLEXES: By combining groups of 42 vans into larger complexes with other temporary structures, an entire Marine Aviation Logistics Squadron (MALS) can set up and operate from an unimproved forward deployed site. By far the largest user of vans is the MALS. Referred to as Mobile Maintenance Facilities (MMF), these vans are deployed in large complexes with the Marine Air group (MAG) to support various missions. Navy activities also use MMFs, primarily for P-3 deployable sites where Intermediate level support does not exist. Other units that utilize vans for tactical shelters when deployed are Mobile Calibration Laboratories (MCC), Marine Wing Support Squadrons (MWSS), Marine Wing Control Squadrons (MWCS), Marine Air Support Squadrons (MASS), and Marine Air Control

Squadrons (MACS). When not forward deployed, these vans are used in various roles. Most MALS units utilize a large part of their vans to provide intermediate level maintenance support to home based squadrons, just as they would if they were deployed. Most other units use their vans for training.

11665-5 REQUIREMENT: All vans require a concrete pad and utility support when at home base. This allows the vans to be used, maintained, and always ready to deploy for their primary mission. This structure consists of two parts, the pad and a nearby support building.

11665-6 PAD SIZE REQUIREMENTS. Pads are built to accommodate the unit and van configuration of a specific mission. They are sized to hold the required quantity of vans established by the holding unit to accomplish the specific mission. The following guidance shall be used to size pads:

a. For groups of up to 42 vans, establish the quantity and layout with the unit. Provide a pad sized to fit the required layout with a 0.152 meter (2 foot border)

b. For groups of 42 vans, provide a 1,120 M2 (1,333 SY) pad.

c. For groups of more than 42 vans, divide the quantity by 42 and multiply number of areas by 1,120 M2 (1,333 SY) and add a 4.6 meter (15 foot) access lane between areas. Add 93 M2 (111 SY) for storage of bogie wheels and other towing gear for van movement.

11665-7 PAD UTILITY REQUIREMENTS. Pads require electrical power, phone and computer line connections, compressed air, and water for washing vans. It will also require an environmental drainage system for wash water runoff.

11665-8 SUPPORT BUILDING. The support building is required if the van pad is built away from other facilities or the existing nearby facilities cannot handle the personnel load that would be placed upon them by the extra personnel working in the vans. The pad size guidance provided above DOES NOT include the space required for the support building.

11665-9 SUPPORT BUILDING SPACE REQUIREMENTS. The support building is required to house personnel space such as restrooms and locker rooms, storage for van parts such as door and access panels that have been removed for complexing of vans, mechanical equipment rooms for power, phone and computer distribution, and air compressors. The following guidance shall be used to size support building:

a. Provide 4.6 M2 (50 SF) of covered storage for every two INUs or every four of the other types of vans.

b. Provide 1.8 M2 (19 SF) per person for restrooms, lockers, showers and dressing rooms.

Either use the actual manning of the van complex
OR assume 1.2 persons per van.

c. Provide 13.9 M2 (150 SF) for mechanical equipment area to support the vans.

11665-10 NET TO GROSS FACTOR. The support building figures listed above are net M2 (net SF). All figures should be multiplied by 1.25 (net to gross factor) to provide areas for aisles, fire protection, HVAC, and structure.

Tactical Support Van Pad Sizing - Computation Example 1

An MWCS unit has eight vans consisting of two INUs and six basic vans laid out as shown in Figure 11665-1 "Typical Small Complex Van Pad Layout".
These vans are occupied by 12 personnel.

Pad Size Calculation:

The layout of the vans is 12.3 meters (40.5 feet) by 14.9 meters (49 feet).
Adding a 0.6 meter (2 foot) border makes the pad 13.6 meters (44.5 feet) by 16.2 meters (53 feet) or 219 M2 (262 SY).
As this is a single group, the 4.6 meter (15 foot) access lane IS NOT required.

Pad Total = 219 M2 (262 SY)

Support Building Size Calculation:

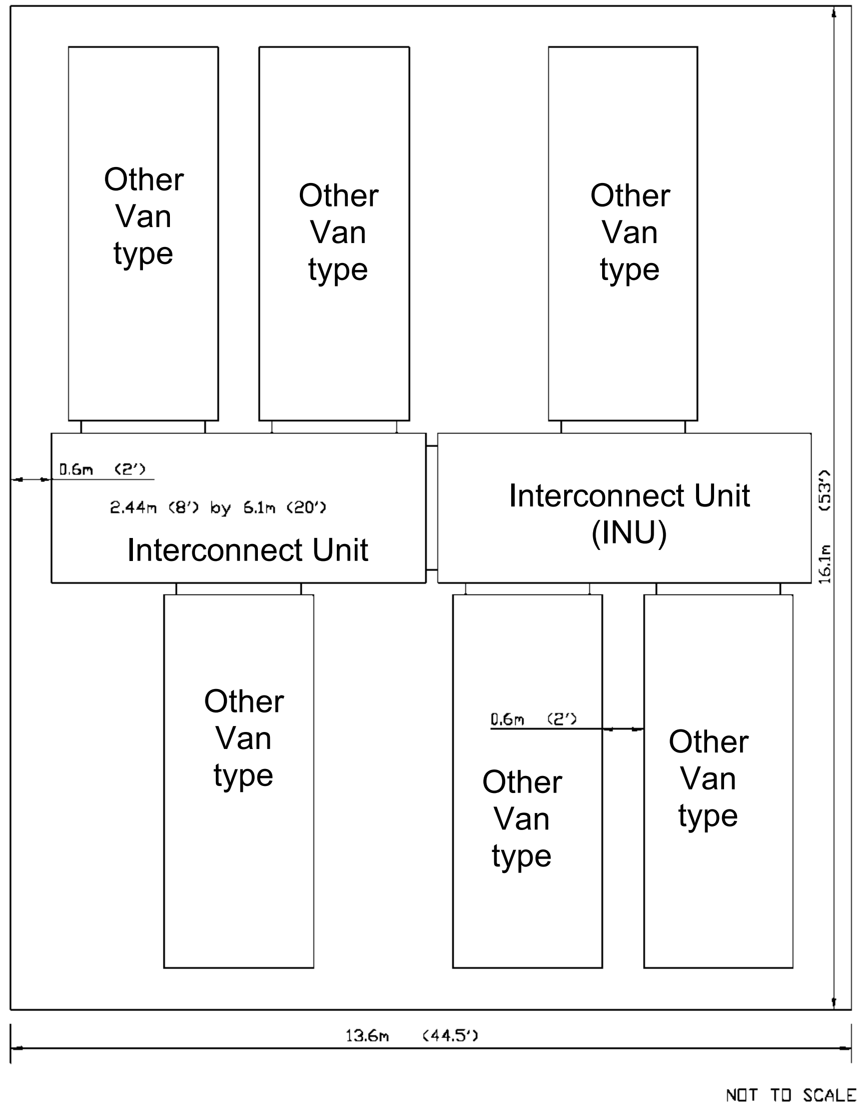
Number of INUs = 2
Number of others = 6
Number of personnel = 12

Covered Storage:
INUs: 2 / 2 = 1.0
Others: 6 / 4 = 1.5
1.0 x 4.6 M2 (50 SF) + 1.5 x 4.6 M2 (50 SF) = 11.5 M2 (125 SF)
Restrooms, Locker Rooms, Showers and Dressing Rooms:
12 x 1.8 M2 (19 SF) = 21.6 M2 (228 SF)
Mechanical Room:
13.9 M2 (150 SF)

Support Building Subtotal (Net)
11.5 M2 + 21.6 M2 + 13.9 M2 = 47.0 M2(net)
(125 SF + 228 SF + 150 SF = 503 SF(net))

Support Building Total (Gross)
47.0 M2 (net) x 1.25 = 58.8 M2 (gross)
(503 SF (net) x 1.25 = 629 SF (gross))

Figure 11665-1. Typical Small Complex Van Pad Layout



Tactical Support Van Pad Sizing - Computation Example 2

A MALS unit has 250 vans laid out as shown in Figure 11665-2. "Typical Large Complex Van Pad Layout".
The personnel loading is unknown.

Pad Size Calculation:

For van complexes consisting of more than 42 vans,
250 / 42 = 5.95, say 6 groups

Place a 4.6 meter (15 foot) access lane between each of the 6 groups gives a pad size of 81.7 meters (268 feet) by 95.1 meters (312 feet) or 7,770 M2 (9,291 SY)

add 93 M2 (111 SY) for storage

Pad Total = 7,770 M2 + 93 M2 = 7,863 M2
(9,291 SY + 111 SY = 9,402 SY)

Support Building Size Calculation:

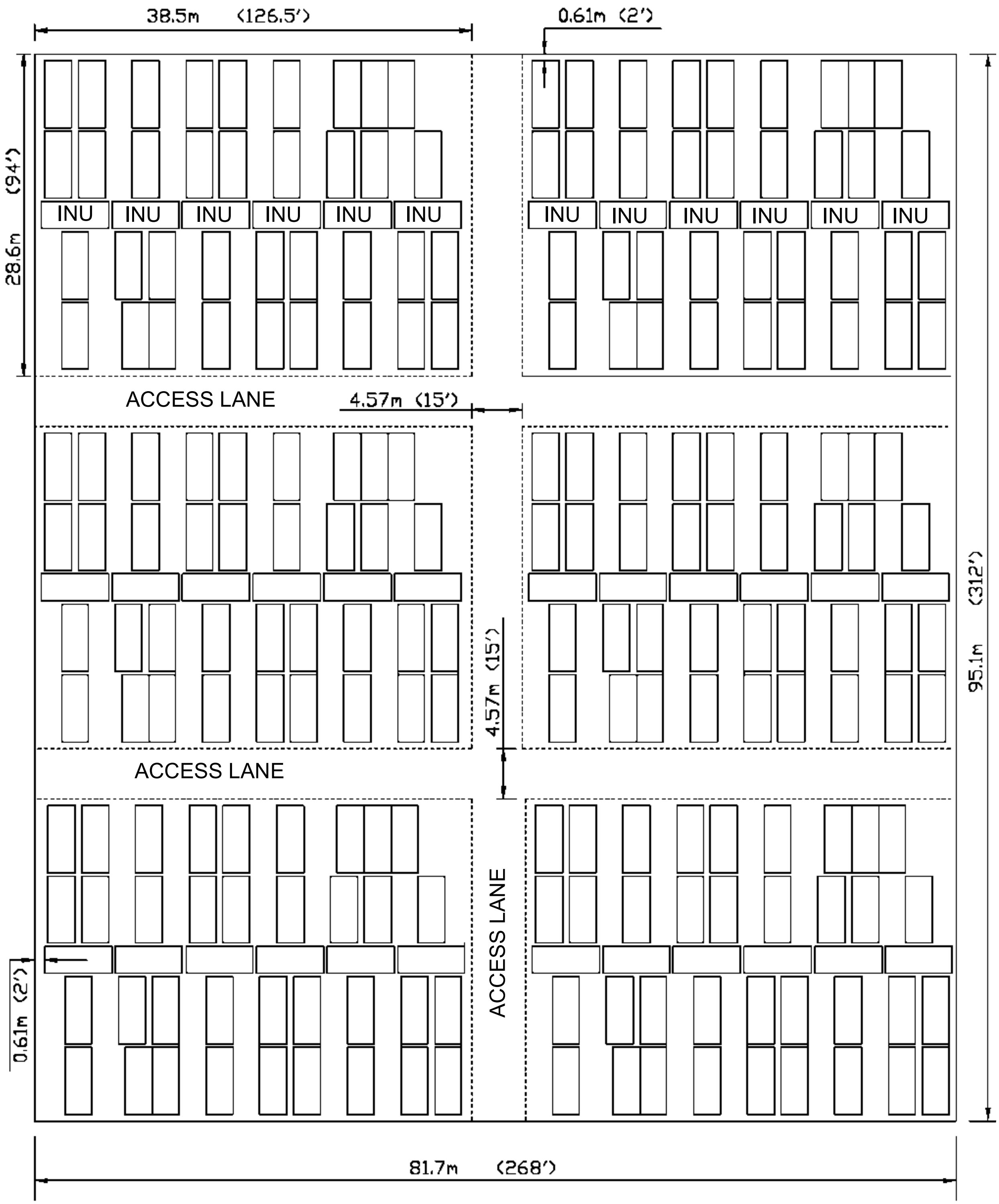
Number of INUs = 6 x 6 = 36
Number of others = 250
Number of personnel = unknown (assume 1.2 pn/van x 250 van = 300 pn)

Covered Storage:
INUs: 36 / 2 = 18
Other: (250 – 36) / 4 = 53.5
18 x 4.6 M2 (50 SF) + 53.5 x 4.6 M2 (50 SF) = 328.9 M2 (3,575 SF)
Restrooms, Locker Rooms, Showers and Dressing Rooms:
1.8 M2 (19 SF) x 300 = 540 M2 (5,700 SF)
Mechanical Room:
13.9 M2 (150 SF)

Support Building Subtotal (Net)
328.9 M2 + 540.0 M2 + 13.9 M2 = 882.8 M2(net)
(3,575 SF + 5,700 SF + 150 SF = 9,425 SF(net))

Support Building Total (Gross)
882.8 M2(net) x 1.25 = 1,103.5 M2(gross)
(9,425 SF(net) x 1.25 = 11,781 SF(gross))

Figure 11665-2. Typical Large Complex Van Pad Layout



NOT TO SCALE

121 AVIATION FUEL FACILITIES

121 10 AIRCRAFT DIRECT FUELING STATION (GM)
FAC: 1211
BFR Required: Y

Design Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
UFC 3-260-02, Pavement Design for Airfields
UFC 3-401-01, Mechanical Engineering
UFC 3-460-01, Design: Petroleum Fuel Facilities
Additional Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design

12110-1 DESCRIPTION. Aircraft direct fueling stations provided outlets where aircraft can be fueled from a closed-circuit fuel system as opposed to refueler trucks.

12110-2 POLICY. Refueler trucks are the preferred method to fuel aircraft. However, direct fueling stations may be considered for: (1) carrier aircraft, including helicopters, when the mission dictates a continuing need for rapid turnaround without shutting engines down, (2) cargo/transport aircraft with prescribed short ground times or (3) patrol aircraft which require an average refueling of 2500 gallons or more. Aircraft direct fueling stations shall be installed only when authorized by NAVFACENGCOM HQ and NAVAIRSYSCOM HQ. NAVFACENGCOM HQ (Code 04) and NAVAIRSYSCOM HQ (Code 4106) will provide technical assistance for the determination of the type and number of fueling station. See UFC 3-260-01, Chapter 6 for additional considerations.

12110-3 CRITERIA. Aircraft direct systems utilize multi-arm pantographs with closed circuit type nozzle assemblies. Cargo/transport aircraft may also be refueled from flush type direct fueling stations located in the apron in conjunction with hose/pantograph trailers or trucks. However, flush fueling stations should only be used where taxi patterns preclude the parking of aircraft in spaces which can be reached by apron edge fueling stations with fully extended (135 foot maximum reach) five arm pantographs.

The number of fueling outlets required must be determined by an engineering analysis. Where aircraft require quick turnaround, (i.e. transport aircraft with minimum ground time, tactical aircraft returning to the air without shutting down engines, or patrol aircraft on ready alert status), the number of fueling outlets required is a function of the number of aircraft that must be refueled within the specific time frame. UFC 3-460-01 "Design: Petroleum Fuel Facilities" provides guidance on the minimum number of outlets, fuel flow per outlet and total fuel flow required in the system. Systems are designed such that the flow in the system is less than the sum of the maximum outlet capacities. Three or four outlets each capable of delivering 600 gallons per minute (GPM) can be adequately served by a system with a capacity of 1200 GPM.

When determining the number of outlets required for simultaneous refueling of aircraft, the average rate at which the aircraft can receive fuel shall be used rather than the maximum GPM capacity of the outlet. For example, if the average fuel receiving rate for an aircraft is 250 GPM (the actual rate varies during filling), and the aircraft normally requires 2000 gallons of fuel, the fill-up time equals 2000/250 or 8 minutes. Allowing 7 minutes for other functions such as brake check, taxiing, hook-up, paperwork, etc., one aircraft can refuel every 15 minutes. In this case, each outlet could fuel 4 aircraft per hour. If the mission requirement is to turnaround 8 aircraft per hour, two outlets will be required. UFC 3-460-01 "Design: Petroleum Fuel Facilities" specifies a minimum of 2 outlets per fueling system.

12110-4 SITING REQUIREMENTS. The location of fueling stations at an activity depends on the aircraft mission and configuration of runways, taxiways, and aprons. The fueling stations may be located adjacent to through taxiways, parking aprons or dedicated fueling taxiways. See NAVFAC P-272, Drawing 1403986, for the layout of a fueling station with dedicated taxiways. Where direct fueling is used to hot fuel tactical aircraft, fueling stations shall be located to allow quick return to the runway. For cargo/transport aircraft, the fueling stations shall normally be located adjacent to where the aircraft are loaded/unloaded so that fueling may be done simultaneously with other logistic operations. Patrol aircraft may be fueled at their parking spaces or at some point enroute to the runway.

Direct fueling stations shall be sited outside of the runway or helipad primary surface and such that fueling equipment and the aircraft to be refueled do not penetrate the transitional surface as defined in UFC 3-260-01. Direct fueling stations shall not be sited beneath the approach-departure clearance surface. Fueling stations with dedicated access taxiways shall be located a minimum of 100 feet from the edge of a parking apron and 150 feet from the centerline of a through taxiway. The size and spacing of fueling lanes shall be in accordance with NAVFAC P-272, Definitive Drawing 1403986. Normally, when fueling stations are proposed adjacent to parking aprons or through taxiways, an airfield safety waiver from NAVAIRSYSCOM would be required prior to construction. However, in this case no formal waiver is required provided NAVFACENGCOM and NAVAIRSYSCOM have approved overall-planning for the project. Aircraft direct fueling stations shall not be sited within 200 feet of an inhabited building. Siting of fuel dispensing facilities must consider the effects of electromagnetic radiation; see UFC 3-460-01 "Design: Petroleum Fuel Facilities" for guidelines.

12110-5 ACCESS TAXIWAYS AND VEHICLE ROADS. Access taxiways (Category Code 112 10) and vehicle roads (Category Code 851 10) are programmed with the direct fueling facility as required.

121 20 AIRCRAFT TRUCK FUELING FACILITY (GM)
FAC: 1261
BFR Required: Y

12120-1 DESCRIPTION. An aircraft truck fueling facility is used to transfer fuel to aircraft refueling trucks. The fueling equipment is located on concrete islands which are designed to provide fuel from one side only. Where more than one island (one fueling outlet per island) is required, they shall be arranged parallel to each other with 15 feet between adjacent sides. The pavement between islands is sloped to a drain or catch basin which is connected to a containment area in case of a fuel spill. See NAVFAC P-272, Definitive Drawing 1403987 for a sketch of a typical refueler truck fill stand and UFC 3-460-01 "Design: Petroleum Fuel Facilities" for design criteria.

12120-2 POLICY. The use of refueler trucks is the preferred method to fuel aircraft. However, see Category Code 121 10 to determine when a direct fueling system may be considered. When direct fueling is provided, it is always in conjunction with truck fueling. An aircraft truck fueling facility supplied from a spur of the direct fueling system usually reduces non-productive truck time and is less costly than a separate truck fueling facility because the filter/separator and fuel monitor would be omitted. Also, depending upon the spurs' location in the system, a relaxation chamber may not be required. See NAVFAC definitive drawing 1403985 and UFC 3-460-01 –" Design: Petroleum Fuel Facilities". The determination of number of grades of fuel to be handled and the number of outlets required for each grade shall be made in conjunction with NAVFACENGCOM HQ (Code 04) and NAVAIRSYSCOM HQ (Code 4106).

12120-3 CRITERIA. The number of outlets required must be determined by an engineering analysis. The maximum capacity of each outlet is 600 gallons per minute (GPM). Factors to be considered in the engineering analysis include:

- **The number of grades of fuel to be provided.** Each grade requires a separate outlet.

- **The number of aircraft that must be refueled during peak periods of recovery and launch.**

- **The rate at which the fueling facility can fill refueler trucks.** Refueler trucks can accept up to 600 GPM, however, a figure of 450 GPM is more typical of rates achieved. Standard Navy refueler trucks can hold 5000 gallons of fuel. The capacity of refueler trucks in contract refueling operations vary and 8000 gallons is not uncommon.

- **The rate refueler trucks can fuel aircraft.** While refueler trucks can dispense fuel at approximately 250 GPM, only the larger and more modern jet aircraft can accept fuel at that rate and then only during the initial refueling phase. For planning purposes, the average aircraft fueling rates should be 200 GPM for large jet aircraft (Patrol/transport), 150 GPM for tactical jet aircraft and 100 GPM or less for rotary wing jets and all reciprocating engineer aircraft using aviation gasoline (AVGAS). Some larger aircraft can simultaneously take on fuel from two trucks in which case a combined average flow of 400 GPM can be used.

- **The distance the refueler trucks have to transit between the fueling stand and the aircraft.** The distance should be minimized to reduce transit times.

The analysis should consider that aircraft can be refueled overnight for morning departures. Peak demand for the truck fueling facility will normally occur at mid-morning or mid-afternoon when high rates of aircraft recovery are experienced.

12120-4 SITING. Aircraft Truck fueling facilities shall not be sited within the primary surface or under the approach/departure clearance surface of any runway or helipad. The facilities shall be sited so that no part of the fueling stand, equipment or refueler truck penetrates the imaginary surfaces specified in UFC 3-260-01 or the airfield safety clearances published in UFC 3-460-01 - Design: Petroleum Fuel Facilities (see criteria for runways, helipads, taxiways, and aprons). The fueling facility shall be at least 100 feet from any building, public road or above ground fuel storage tank. See UFC 3-460-01 – "Design: Petroleum Fuel Facilities" for additional siting restrictions with respect to electromagnetic radiation.

121 30 AIRCRAFT DEFUELING FACILITY (GM)
FAC: 1242
BFR Required: N

This Category Code shall be used for inventory of existing facilities only. Aircraft shall be defueled into tank trucks designated for that purpose.

121 50 AIRCRAFT READY FUELS STORAGE (BL)
FAC: 1241
BFR Required: Y

Note: Previously listed as Category Code 124 30 AIRCRAFT READY FUELS STORAGE

12150-1 DESCRIPTION. Aircraft ready fuel storage provides an operation and reserve supply of aviation gasoline and jet fuel. At air installations all aviation fuel storage shall be categorized as ready fuel storage as opposed to depot level storage; see 411 Category Code series. Aircraft ready fuel storage may be classified as local or remote. The remote are usually designated as the station's fuel farm and provide the majority of the storage capacity. Local storage refers to those storage tanks located close to a fuel dispensing facility. Local storage tanks (or day tanks) can be refilled overnight thereby permitting the use of a smaller diameter pipeline from the remote tanks to the local storage and dispensing area. Local storage such as day tanks should be used settlement prior to dispensing.

12150-2 CRITERIA. The fuel storage requirement must be determined by an engineering analysis. The Fleet Fuels Officer, Code N413F, within the US Fleet Forces Command in collaboration with Defense Logistics Agency's (DLA) Defense Energy Support Center (DESC) Code B (Bulk Fuels) will determine the fuel storage requirement. The requirement is a function of: the number and type of aircraft supported, aircraft fuel consumption rates, and the number of hours of flown. At CONUS installations, a ten-day supply is normally provided. At OCONUS installations, a thirty-day supply may be provided. The above days of supply requirements are guidelines and may be modified to reflect restricted or unpredictable fuel delivery schedules. When both local and remote storage are provided, the remote storage capacity requirement shall be reduced by 50% of the tank capacity provided by local storage. See Figure 12150-1 for a sample calculation.

Figure 12150-1. Example Requirement Calculation

Given: (1) CONUS 10 day requirement = 500,000 GA
(2) 50,000 GA of local storage is being provided

Remote Storage = 500,000 GA – {50% x (local storage)}
= 500,000 GA – {0.50 x (50,000 GA)}
= 500,000 GA – 25,000 GA
= 475,000 GA

Total (121 50) Requirement
= local + remote
= 50,000 GA + 475,000 GA
= 525,000 GA

12150-3 SITING. Fuels storage tanks must be separated from each other, buildings, property lines, roads, railroads lines, and power lines. The fuel farm layout, design and siting are available in the UFC 3-460-01 Design: Petroleum Fuel Facilities.

122 MARINE FUEL FACILITIES

122 10 MARINE FUELING FACILITY (GM)
FAC: 1221
BFR Required: Y

Design Criteria: UFC 3-460-01: Design: Petroleum Fuel Facilities

12210-1 DESCRIPTION. A marine fueling facility is designed for small vessels and capital ships and should be able to refuel the largest ship that can dock at the station’s waterfront. The facility may have the outlets located on a general purpose berthing pier, a combined cargo and fueling pier or on a separate fueling pier, depending on the station’s mission, logistics, and base location.

12210-2 ADDITIONAL REQUIREMENTS. In addition to the pier outlets, the facility has a piping approach trestle, a pumping station, security fencing, hose racks, access roads, fire protection and ready marine fuel storage tanks. Surge storage tanks, if required, are categorized under code 124-70 and bulk marine fuel storage tanks are categorized under code 411-10, Ship Fuel Storage. Fuel piers or wharves will vary greatly according to the services required. Some may be of the simple type having one ship berth and a minimum-size dock platform to the more elaborate pier head or finger-type having two or three ship berth all provided with the appropriate fuel bunkering connections.

12210-3 SEPARATION DISTANCES. There should be 1,800 feet between tankage and the nearest station structure or boundary fence. Consideration must be given to safe distances from other buildings and facilities.

122 20 SMALL CRAFT FUELING STATION (GM)
FAC: 1221
BFR Required: Y

Design Criteria: refer to UFC 4-150-01 “Piers and Wharves”

12220-1 DESCRIPTION. A small craft fueling station is used to refuel such small craft as crash boats and administrative boats. It shall include dispensing pedestal-type commercial pumps, piping, tanks, hoses, floodlights and grounding devices, electrical power, and fire protection.

12220-2 CAPACITY. There will be at least one separate pump for each grade of fuel used and each shall have a minimum backup storage of 5,000 gallons. The station will normally dispense a minimum of two grades of gasoline and diesel fuel and shall have sufficient capacity to service three boats simultaneously. This may be modified to conform to the type and number of small craft serviced.

12220-3 SITING. The small craft fueling station, except for the storage tanks, is a part of the Small Craft Berthing facility. The fuel storage tanks may be located in a remote area. The spacing of these tanks will be in accordance with criteria set forth in Category Code series 124.

122 30 SMALL CRAFT READY FUEL STORAGE (GA)
FAC: 1242
BFR Required: Y

Note: Previously listed as Category Code 124 40 SMALL CRAFT READY FUELS STORAGE

12230-1 DESCRIPTION. A marine ready fuel storage tank is the ready issue operation storage of a particular grade of fuel for small boats and yard craft. These boats will include small tugs, security boats, repair barges, etc. The boats may be operated by several different departments within or tenants operating at the installation including: Public Works, Base Security, Naval Coastal Warfare Command, Amphibious Group Two, Naval Special Forces Command, etc. Large ships will refuel at depot fueling piers or via fuel barges. For depot level fuel storage see Category Code 411. See Category Code 122 20 (Small Craft Fueling Station) for the fuel dispensing facility which includes commercial fuel pumps, piping from the tank to the pump, hoses, floodlights, and other equipment for dispensing the fuel.

12230-2 CRITERIA. The fuel storage requirement must be determined by an engineering analysis. The Fleet Fuels Officer, Code N413F, within the US Fleet Forces Command in collaboration with Defense Logistics Agency's (DLA) Defense Energy Support Center (DESC) Code B (Bulk Fuels) will determine the fuel storage requirement. The requirement is a function of: the number and type of boats supported, fuel consumption rates, and the number of hours of driven. At CONUS installations, a ten-day supply is normally provided. At OCONUS installations, a thirty-day supply may be provided. As minimum, the ready fuel storage will be one 5,000-gallon gasoline tank for each octane grade and one 5,000-gallon diesel fuel tank. The tanks will include the piping for fuel delivery to the tanks, pumps for pumping fuel into the tanks, tank security fencing, tank fire protection, and paving for fuel delivery, as required.

12230-3 SITING. Fuels storage tanks must be separate from each other, buildings, property lines, roads, railroads lines, and power lines. The fuel farm layout, design and siting are available in the Unified Facilities Criteria (UFC) 3-460-01 "Design: Petroleum Fuel Facilities".

123 LAND/GROUND VEHICLE FUELING/DISPENSING FACILITIES

123-1 This Category Code group is for facilities serving official government land vehicles and equipment only. If NEX operates the facility, see Category Code 740-30/31, Exchange Service and Auto Repair/Supplemental Gasoline Station. For Aviation Fueling and Dispensing, see Category Code Series 121. For Marine and Small Craft Fueling and Dispensing, see Category Code series 122. For bulk fuel storage such as tank farm installation, see Category Code series 411.

123 10 FILLING STATION (OL)
FAC: 1231
BFR Required: Y

12310-1 DESCRIPTION. A filling station is a fueling facility for official vehicles and equipment on Navy and Marine Corps installations. This Category Code applies to pump outlets including the covered islands that support the pump outlets, the concrete parking area, lighting and the access paving to the pumps/islands.

12310-2 ITEMS INCLUDED IN STATION. In the event the installation still has a filling station, the following items will be included:

- Three dispensing pumps (Outlet – OL) for each 250-gasoline engine vehicles in the official motor pool:

    1. One pump for gasoline that can dispense each of the three of standard octane grades gasoline (low, medium, high octane if required)
    2. One pump for diesel fuel
    3. One pump for other fuel if needed (i.e., leaded fuel if required, etc.)

- Allowance for associated safety and environmental equipment

12310-3 EXCLUSIONS. This Category Code excludes the fuel storage tanks and filling station building; see Category Code 123 30 for tank storage and Category Code 123 15 for shelter.

123 15 FILLING STATION BUILDING (SF)
FAC: 1444
BFR Required: Y

12315-1 DESCRIPTION. This code is used for reporting the administrative shelter associated with a filling station. If the filling station is operated by a private entity, then use the 740-30/31 Category Codes. Where credit card systems are used and operators are not needed, a shelter is not required. A shed may be provided to protect or house equipment.

12315-2 REQUIREMENT. This code should also include the following:

- Minimum size shelter is 6’x6’
- Control/monitoring room area
- Access road and 400 SF of pavement at each pump with appropriate curbing for spills and containment
- Area lighting and signage

123 16 OVERHEAD COVER, AIRFIELD (SF)
FAC: 1459
BFR Required: N

12316-1 DESCRIPTION. This category code was created for inventory purposes. It can be used for overhead covers located on the airfield (that are not classified as equipment).

123 17 OVERHEAD COVER, MISCELLANEOUS (SF)
FAC: 1459
BFR Required: N

12317-1 DESCRIPTION. This category code was created for inventory purposes. It can be used for overhead covers located at the main gates of installations, overhead covers atop gas pumps, and any other time that an overhead cover is used.

123 30 VEHICLE AND EQUIPMENT READY FUEL STORAGE (GA)
FAC: 1243
BFR Required: Y

Note: Previously listed as 124 50 VEHICLE READY FUEL STORAGE

12330-1 DESCRIPTION. This code is used for reporting the tank storage requirement associated with Category Code 123 10 and 740 30, including those tanks in remote locations that are considered Real Property.

NOTE: Tanks that are skid mounted and/or designed to be moved to various locations are considered equipment. Tanks that are provided by vendors are also considered equipment. This Category Code does not apply to equipment.

12330-2 NUMBER OF TANKS REQUIRED. One tank for each grade of fuel required (low, medium, and high-octane fuels; diesel fuel; and other fuels as required).

12330-3 STORAGE CAPACITY. The total amount of storage capacity in each station should be approximately twice the capacity of all fuel tanks of vehicles and equipment assigned to an activity.

12330-4 MINIMUM NUMBER OF GALLONS. Service station tanks should be a minimum of 5,000 gallons unless approved by Service Headquarters. For other tanks, such as heating fuel, small tanks may be used.

12330-5 ADDITIONAL REQUIREMENTS. In addition, there should be a 10-day total storage capacity for CONUS bases and a 30-day total capacity for overseas bases. This total storage should be based on high average such as winter months for heating oil. Location of base and access to fuel resources as well as current delivery schedules should be considered when developing this immediate backup fuel requirement. Don't forget to include emergency generators for buildings and utilities that may be needed in a hurricane or other base emergency. Some of these generators and equipment may have service contracts (i.e., utilities privatization, etc.) that should not be included in these calculations. A good resource for the rate of consumption information is the historical accounting and billing records. If records are not available, provide 32 gallons per vehicle for each type of fuel used at overseas bases. Equipment requirements will vary.

12330-6 ALTERNATE UNIT OF MEASURE. Barrels (BL) may be used as an alternative unit of measure.

12330-7 EXCLUSION. For fuel oil or heating fuel see Category Code 126 15 Petroleum Fuel Storage Facility.

123 40 ETHANOL READY FUEL STORAGE (GA)
FAC: 1243
BFR Required: Y

1**2340-1 DESCRIPTION.** This category is for alternative fuel facilities in support of ethanol operation of vehicles.

123 50 BIODIESEL READY FUEL STORAGE (GA)
FAC: 1243
BFR Required: Y

12350-1 DESCRIPTION. This category is for alternative fuel facilities in support of biodiesel operation of vehicles.

125 POL DISTRIBUTION / PIPELINE FACILITIES

125-1 This category is for pipelines and accessory equipment between tank farms and operating fuel storage facilities and intermediate points.

125 10 POL PIPELINE (MI)
FAC: 1251
BFR Required: N

12510-1 **DESCRIPTION.** Separate fuel lines should be used for each type of fuel stored at the activity. Underground pipelines are preferred and should be used wherever practical, therefore eliminating thermo-solar effects. In some instances, subaqueous pipelines will be required for crossing harbors or through marshy areas. Submarine pipelines have specific design requirements unique to sub refueling. This category will include in-line fuel filtering systems, censors, alarms, manifolds, area lighting for the pipeline, paving and piers. A surge tank is required for pipeline systems; see Category Code 125 30.

12510-2 **GENERAL PLANNING NOTES.** The capacity and size of the pipeline will have a direct impact on rate of flow as well as exposure to temperature changes. The design criteria are provided in the Unified Facilities Criteria Design: Petroleum Fuel Facilities (UFC 3-460-01 dated 16 Jan 2004). In distributing fuel oil, large pipelines are preferred. Whenever crossing private property be sure to include access roads and maintenance areas paralleling the pipeline. The maintenance area should not be less than 16 feet wide. Daily consumption, storage requirements, delivery schedules, length of delivery, and thermo-solar effects should all be considered when designing POL pipeline. Only the length of the POL is needed for this category requirement. Looped systems are preferred, so be sure to add this to total length of the pipeline. The loop will provide flexibility, reliability and contributes to product cleanliness as well as reduce the magnitude of hydraulic shock.

125 16 POL PIPELINE PUMP STATION - ANCILLARY EQUIPMENT (EA)
FAC: 1262
BFR Required: N

12516-1 **DESCRIPTION.** This Category Code includes pumping stations and ancillary equipment used to move the fuel through the pipes. This facility may also include controls, gauges, meter, lighting, fire protection, and ventilation. An alternative unit of measure may be cubic feet per minute (CM). Underground pump stations are preferred around runways.

125 20 SHED/SHELTER - PUMP STATION - ANCILLARY EQUIPMENT (SF)
FAC: 1459
BFR Required: N

12520-1 **DESCRIPTION.** This code is for the building or structure housing pumping stations and ancillary equipment.

12520-2 **REQUIREMENT.** Facility should be large enough to house or shelter equipment with ample space allow performance of maintenance to housed equipment. Typically, 2 - 4 feet of clearance is adequate. In lieu of net to gross factor, add in wall thickness if facility is enclosed.

125 21 POL PIPING - SINGLE SITE (LF)
FAC: 1252
BFR Required: N
125 30 SURGE STORAGE (GA)
FAC: 1244
BFR Required: N

Note: Previously listed as Category Code 124 70 SURGE STORAGE

12530-1 **DESCRIPTION.** A surge tank is used where there is a risk of hydraulic shock. Hydraulic shock can occur when the pump used to deliver fuel is greater than the pipeline capacity; unloading rate of the delivery tanker/barge exceeds the rate of the shore pumping system; or water, air or other blockage occurs in the pipeline. One surge tank is required each type of fuel. The size of the surge tank will be determined by the size of the tanker unloading at the facility and the capacity of shore booster pumps. UFC 3-460-01 suggests computer modeling to determine need and tank size.

126 OTHER LIQUID PETROLEUM PRODUCTS FACILITIES

126-1 Use this Category Code for liquid fuel or petroleum products facilities not specifically related to aviation, marine craft, or ground vehicle fuel requirements (see Category Codes series 121, 122, and 123, respectively). Use Category Code 821 60 or 821 61 for heating plant fuel storage. This Category Code includes fuel loading and unloading; drum storage, loading and maintenance; and miscellaneous fuel storage (i.e., heating fuel, kerosene, propane, fuel oil, etc.). See Category Code series 411 for depot level storage.

126 10 DRUM AND CAN LOADING FACILITY (SF)
FAC: 1261
BFR Required: Y

12610-1 **DESCRIPTION.** A drum and can loading facility is a fuel facility equipped to fill drums with fuel oil, diesel, kerosene, jet engine fuel, motor gasoline, aviation gasoline, and lubricating oils. The facility may also be provided with a drum reconditioning plant. Drum storage areas may also be needed. Drums with varying fuel may be stored in one storage area. Others may be separated; see Unified Facilities Criteria Design: Petroleum Fuel Facilities (UFC 3-460-01 dated 16 Jan 2004). There may be one storage area for empty drums and another storage area for filled drums. The drums have 55-gallon capacity. This facility should not be used for storage of contaminated fuel or waste oil ready for disposal; see hazardous waste facilities under Category Codes 831 41 and 831 42.

12610-2 **STORAGE.** Jet engine fuel and gasoline drums shall be stored outside in designated compounds. Special construction features will be required if an outside compound is not available. Drummed products with a flash point of 100 degrees Fahrenheit shall contain no more than 5,000 drums. Drummed products with a flash point above 100 °F may be stored in groups of 10,000 or less. When possible, racks and pallets should be used to reduce the footprint utilized to store drums.

12610-3 **WORK PLATFORMS.** The drum filling area shall include a work platform covered with an open shed. A separate platform shall be used for each type of fuel with individual pipelines for each of the various fuel types. The pipeline will run from the storage tank to a fuel manifold to the outlet (see Category Code 126 15 for storage tank). Each platform will have 2 outlets, spaced at 10-foot intervals. A mechanical drum conveyor system or equipment may be used to carry the drums, depending on the size of the operation.

12610-4 **SMALLER QUANTITIES.** For smaller operations where the fuel products are delivered in drums, only a small fuel/petroleum storage area may be required to hold a limited number of drums; in this case, use Category Code 441 30. For very small quantities, a hazardous material storage locker may be used.

126 15 PETROLEUM READY FUEL STORAGE FACILITY (GA)
FAC: 1244
BFR Required: Y

Note: Previously listed as Category Code 124 20 DRUM AND CAN READY FUEL STORAGE and Category Code 124 65 ACTIVITY HEATING FUEL STORAGE

12615-1 **DESCRIPTION.** This category shall be used for the storage of petroleum products used to fill drums as provided in Category Code 126 10, heating oil tanks (see Category Code 821-60 or 61 for heating plant fuel storage), lube oil tanks, grease, propane tanks, or fuel storage tanks for generators and other equipment. This Category Code should not be used for those items included in Category Code series 121,122, and 123.

12615-2 **REQUIREMENT.** The normal storage for CONUS would be a 10 day supply and for OCONUS a 30 day supply. Historical annual data may be used to determine average daily consumption, then multiply that times the number of days of supply needed to get the total storage requirement for each type of petroleum product stored. For storage tanks associated with one piece of equipment such as a building generator, sewage pump station or building heater, check equipment specifications and emergency requirements. Some facilities or activities may have specific hurricane or other emergency requirements that should be taken into consideration. If this activity has a drum loading facility, the size and number of drums should be added to the storage requirements for each type of fuel or petroleum product. Design should factor in fuel delivery schedules and availability. If emergency requirements dictate, additional storage may be required.

12615-3 **ALTERNATIVE UNIT OF MEASURE.** The alternative unit of measure is gallons, (GA).

126 30 TANK TRUCK TANK CAR LOADING FACILITY (OL)
FAC: 1261
BFR Required: Y

12630-1 **DESCRIPTION.** This Category Code applies to a tank truck loading facility (either a truck fill stand or stands) that dispense fuels other than aircraft fuels to delivery trucks. (For information on an aircraft truck fueling facility, see Category Code 121 20.) Each stand has one dual outlet, a meter, static line, platform, roadway, strainer and necessary valves, piping, pump, and electrical controls. For design criteria, see UFC 3-460-01.

12630-1.1 **Outlet Requirements**. A tank truck loading facility is required at those installations without contract refueling and automotive ready fuel storage facilities. There shall be at least one outlet for each grade of fuel, capable of dispensing fuel at the rate of 250 to 600 gallons per minute. The total number of outlets will vary with the station population, mission, and the number of fuels used. A tank truck loading island is 38 feet 9 inches long by 6 feet 0 inches wide.

12630-2 **PROVIDING FOR MULITPLE TYPES OF FUEL.** Facilities for issue of fuel by tank car shall be provided when specified by NAVFAC. The fuel normally issued will be jet engine fuel and gasoline, but diesel fuel oil and other fuel oils may be included. Separate pipe lines shall be provided from the storage tanks for each type of fuel.

12630-2.1 **Railroad Siding and Sludge Transfer Disposal.** The normal installation will provide for a railroad siding to each side of the loading island with a length to accommodate six cars on each side. A tank car issuing facility may also be used for disposal of sludge from storage tanks, and for this purpose special pipe lines to the facility shall be provided for sludge transfer.

12630-2.2 **Rate at Which Facilities Will Provide for Receipt of Fuel.** Tank cars are generally of 8,000- and 10,000-gallon capacity. However, there are some tank cars of 12,000-gallon capacity.

126 40 TANK TRUCK/TANK CAR UNLOADING FACILITY (OL)
FAC: 1261
BFR Required: Y

12640-1 **DESCRIPTION.** A tank car unloading facility unloads liquid products from tank cars. Each facility has static lines, strainer, access road, security fencing, lighting, necessary valves, piping, pump, electrical controls, and a shelter structure for use of accounting and/or control house. For design criteria, see UFC 3-460-01.

12640-2 **REQUIREMENT.** The number of cars to be accommodated at an unloading facility shall be determined by a survey. There will be one unloading connection for each car. The tank car unloading facility will provide 400- to 800-gallon fuel transfer rate between each tank car and storage.

12640-3 **QUANTITY OF TANK TRUCK UNLOADING FACILITIES.** Tank truck unloading facilities shall be determined by a survey. Facilities should be capable of handling the entire daily fuel requirements in 8 hours. Where unloading facilities by railroad tank cars are available, paved aprons should be provided adjacent to sidings so pumping facilities may serve both tank cars and tank trucks.

131 COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, COMBAT SYSTEMS, INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE, (C5ISR) BUILDINGS

131-1 **DEFINITION.** This group of shore facilities supports the reception, processing, distribution, and/or transmission of classified and unclassified voice, data, and video communications in support of the Navy and Marine Corps organizations. Table 131-1 provides a matrix identifying which types of C5ISR functions are best represented for each category code.

Table 131-1. Category Code Functional Space Matrix

Function/Command	131 15	131 24	131 35	131 40	131 50	143 65	143 80
Base Communications Office	X						
Information Technology Office	X						
Data Center or Server Center	X						
Navy Information Operations Command (NIOC)	X						
Naval Computer and Telecommunications Station (NCTS) / Naval Computer and Telecommunications Master Area Station (NCTAMS)	X						
Satellite Communications (SATCOM)		X					
Receiver/Transceiver Function			X				
Unmanned Telecommunications Distribution				X			
Transmitter Function					X		
Region/Installation Operations Center						X	
Mission Operation Command and Control							X
High Density Computing Center	X						

131-2 **REQUIREMENT PROCESS.** Unless otherwise specified, the following requirements process should be utilized when planning C5ISR buildings. C5ISR buildings are unique in that they are specifically tailored to a Navy or Marine Corps activity. As a result, engineering evaluations, manning, and equipment configurations may also be required. This information should be used with the guidance provided below to determine the basic facility requirements.

131-3 **SECURITY.** Security issues and operational efficiencies may result in the co-location of office space, equipment space, associated maintenance space, and other associated support/storage space within respective commands.

131-4 **RESILIENCY.** The design of buildings and infrastructure to withstand, absorb, or avoid damage without suffering catastrophic failure is critical to C5ISR facilities. C5ISR facilities must be planned to provide the appropriate level of continuity of operations based on the individual mission of the tenant. There are three facets to the resiliency of C5ISR facilities: Tier Classification, Survivability, and Antiterrorism/Force Protection. All three of these facets must be addressed in basic facility calculations, facility design, and project cost estimating.

131-4.1 **Tier Classification.** The Tier Classification system, as defined by the Uptime Institute, is used to identify the appropriate redundancy requirements for power, cooling, maintenance, and capability to withstand a failure. Planning criteria should address any additional space requirements based on the Tier level required. The Tier Classification system is further described in the "Tiers Standard Topology" available at the Uptime Institute website: https://uptimeinstitute.com/resources/asset/tier-standard-topology

131-4.2 **Survivability.** Survivability is the ability of the overall building to withstand failure due to natural disaster such as earthquakes, hurricanes, tornados, flooding, and sea level rise - all of which are dictated by the climate in the geographic location of the existing or proposed facility.

131-4.3 **Antiterrorism/Force Protection (AT/FP).** The facility must be planned to meet antiterrorism and force protection requirements as identified in UFC 4-010-01, DoD Minimum Antiterrorism Standards for Buildings and UFC 4-010-02 DoD Minimum Antiterrorism Standoff Distances for Buildings.

131-5 **FUNCTIONAL AREAS.** C5ISR facilities may contain the following functional areas: General Administrative Space, Special Purpose Space, C5ISR Operations Space, Maintenance Space, Training Space, Equipment Space, and IT Logistics Support Space.

131-6 **PERSONNEL LOADING.** All C5ISR BFRs should be based on an official personnel loading source, projected loading year, and associated personnel loading. The official personnel loading analysis must be provided separately to support the requirement. The personnel loading document should include all assigned billets to include: military (including reservists), civilians, students, and contractors. Each billet should be assigned a space type of: private office, cubicle, shared, or special as defined below:

131-6.1 **Private Office.** Personnel that are entitled to an office include supervisory personnel or special billets that require privacy such as a legal officer or financial manager. See section 131-7.1 for calculation criteria.

131-6.2 **Cubicle**. Personnel that require a non-operations workspace but do not require a private office as stated in section 131-6.1 are assigned cubicles. See section 131-7.2 for calculation criteria.

131-6.3 **Shared**. Personnel assigned to watch sections are assigned to shared workstations, which are provided based on the watch stations required, not the total personnel assigned. Personnel that work in the maintenance spaces are also assigned to shared areas. The quantity of workstations required is calculated using the number of positions in the Watch Center and/or the number of workstations required to support the maintenance function. See Sections 131-9.1, “Watch Center” and 131-10 “Maintenance Space” for calculation criteria.

131-6.4 **Special**. Personnel that conduct analysis or operations functions that require space greater than that allotted by a cubicle are assigned the category of “Special”, see Section 131-9.2 “Analysis Operations” for calculation criteria. This space type is also used to classify specific billets such as the Special Security Officer, which is provided a specific space allotment under Section 131-8, “Special Purpose Space”.

131-7 **GENERAL ADMINISTRATIVE SPACE.** General Administrative Space types are justified to support administrative or similar functions. They include private and open office spaces.

131-7.1 **Private Office.** Private Offices are typically provided for supervisory and other personnel based upon specific job requirements. These offices typically have full-height walls, or partitions, from finished floor to finished ceiling.

Planning factor: Allocate 120 NSF/PN requiring Private Office space.
Justification: Private Offices are justified for supervisory personnel or for those positions whose job duties require privacy such as legal or financial officers.

131-7.2 **Open Offices**. Open Offices are programmed and designed to incorporate modular workstations, which are typically occupied by general administrative and/or functional support staff. Personnel assigned as requiring a cubicle per the personnel loading are assigned to Open Office space.

Planning factor: Allocate 64 NSF/PN requiring Open Office space.

131-8 **SPECIAL PURPOSE SPACE**. Special Purpose Spaces are additive and must be individually justified in support of specific missions or functions. For C5ISR missions, the following Special Purpose Spaces may be authorized with justification.

131-8.1 **Special Purpose Space – Basic.** Basic Special Purpose Spaces include allowances for Administrative Support, Auditorium, Break Room, Break Room Kitchen, Classified Material Storage (CMS) Vault, Conference/Training Rooms, Duty/Bunk Room, Mailroom, and Technical Publications Area.

131-8.1.1 **Administrative Support Space.** This space supports the administrative functions and includes the following:

- Conference room equipment storage (e.g. AV equipment, chairs, lecterns, tables)
- Day lockers
- Group file storage (excluding individual file storage provided within modular furniture)
- Lactation room(s)
- Office equipment and supply storage
- Reception area(s)

Planning factor: Allocate 8 NSF/PN requiring Administrative Support Space.

131-8.1.2 **Auditorium.** A large area performing the function of an auditorium may be required for commands with more than 250 personnel. The size of this area is dependent on the staffing and size of the organization.

Planning factor: Allocate 150 NSF plus 10 NSF per seat based on the largest department of the command.
Justification: An Auditorium may be justified under special circumstances. Justification should address some or all of the following factors as appropriate:

- Mission or functions performed
- Size of organization is greater than 250 personnel
- Other justification

131-8.1.3 **Break Room.** A Break Room w/o Kitchen is a staff-only space, used for breaks and lunches. It typically includes some or all of the following: coffee bar, microwave oven, MWR drink/snack space, refrigerator, water cooler.

Planning factor: Allocate 2 NSF/PN assigned.

131-8.1.4 **Break Room Kitchen.** A full kitchen may be provided, with justification, if a command has 24-hour operations or if the facility is located in a remote location with no food service options available on-site or near by. A Break Room Kitchen is a staff-only space. It may include some, or all, of the following: coffee bar, cupboards, microwave, refrigerator, stove, sink and meal preparation space.

Planning factor: Allocate an additional space for a kitchen equal to one third of the total Break Room requirement, up to a maximum of 150 NSF. This area is considered an additional requirement above and beyond the total Break Room requirement.
Justification: A Break Room Kitchen may be justified for operational functions. Justification should address some or all of the following factors as appropriate:

- Mission or functions performed
- Distance from food service facilities
- Other justification

131-8.1.5 **Classified Material Storage (CMS) Vault.** A CMS Vault is a secured area for handling classified material. For C5ISR functions, this type of facility is only provided when the primary facility is unclassified and intermittent access to classified materials and networks is required. Additionally, this space is not intended to be the primary workspace for any staff. It may include a worktable at 50 NSF and up to a maximum of 5 workstations at 64 NSF each. The number of workstations required must be provided by the organization for which the space requirements (BFR) are being prepared.

Note: If a portion of an organization operates at a higher classification than the rest of the facility, the space provided for them is calculated based on the overall requirements set forth in the 131 Introductory Criteria with an additional justification provided indicating the requirement for any additional physical separation, construction requirements, and security requirements.

Planning factor: Allocate 50 NSF (for a worktable) and up to a maximum of 5 workstations at 64 NSF, each based on specific requirements of the organization.
Justification: A CMS Vault room may be justified for various organizations or functions. Justification should address some or all of the following factors as appropriate:

- Mission or functions performed
- Number of workstations required
- Number of vaults required (if more than one)
- Other justification as necessary

131-8.1.6 **Conference/Training Rooms.** Conference/Training Rooms provide space for staff meetings, briefings, and training sessions. The total allocation may be adjusted in terms of number and size of conference rooms to meet organizational needs.

Planning factor: Allocate total NSF space requirement based on the Conference Room Table 61010-1.

131-8.1.7 **Duty/Bunk Room.** A Duty/Bunk Room is required when the mission requires 24 hours a day, 7 days a week operations.

Planning factor: Allocate 130 NSF for a Duty/Bunk Room.
Justification: A Duty/Bunk Room may be justified for any C5ISR function with an overnight watch that requires overnight accommodations for the duty officer and requires approval from the Installation Commanding Officer. Justification should address some or all of the following factors as appropriate:

- Mission or functions performed
- Watch schedule
- Other justification

131-8.1.8 **Mailroom.** A Mailroom accommodates processing and distribution of the facility's incoming and outgoing mail and parcels. It may accommodate screening requirements as necessary based on security requirements. Ensure adequate storage and work space. The mail room should be adjacent, and provide direct access, to the shipping/receiving area. A mail room must be individually justified for operational, site specific or other reasons such as large size of organization.

<u>Planning Factor</u>: Allocate 40 NSF for every 50 personnel assigned.
<u>Justification:</u> Address some or all of the following factors as appropriate:

- Mission or functions performed.
- Size of organization - Is organization large enough to warrant its own mail room rather than rely on the host installation's centralized postal facility?
- Location of organization - Does geographic separation of the organization from the host installation site warrant a standalone mailroom?
- Security - Do security requirements warrant a mail room?
- Mail room hours of operation (e.g., full-time or part-time)
- Other justification

131-8.1.9 **Technical Publications Area.** A Technical Publications Library provides ready access to technical manuals, handbooks, and other guidance.

Note that the need for technical/legal/other libraries has diminished as many resources are now readily available online; however, some functions still require access to printed publications.

As a space saving measure, consider combining technical libraries with small conference/training rooms, rather than providing a separate allocation. This area may be required to store reference publications and literary data. It is configured similar to a reference library and contains bookshelves, a reference area, and a working space for a minimum of two people. This requirement must be justified based on mission operational requirements.

<u>Planning Factor:</u> Allocate 300 NSF.
<u>Justification:</u> A Technical Publications Library may be justified for technical components or divisions of an organization. Justification should address some or all of the following factors as appropriate:

- Mission or functions performed
- Function(s) supported (e.g., architecture, engineering, legal, other)
- Number and size of technical libraries required
- Other justification

131-8.2 **Special Purpose Space – Fitness, Locker, and Shower**. Fitness Rooms, Locker Rooms, and Shower Rooms may be authorized as described below:

131-8.2.1 **Fitness Room.** A Fitness Room is a space specifically designated for exercise, fitness training, and physical wellness activities. Fitness Rooms are only allowed in accordance with CNICINST 1710.1, whereby an organization has more than a 15 minute commute by vehicle to the nearest Morale Welfare and Recreation (MWR) Fitness Center or if active duty personnel are required to be on station and unable to leave for 18 hours at any given time. A fitness room must also have approval from the Installation Commanding Officer. If approved, calculate the requirement separately under Category Code 740 45 Fitness Room.

131-8.2.2 **Locker Room.** A Locker Room provides individual secured storage space for a change in clothing and other personal belongings. Lockers are authorized in support of 24-hour, multiple shift operations. Lockers may also be authorized in support of military physical training requirements at remote locations, without access to fitness centers.

- When lockers are authorized in support of 24-hour, multiple shift operations, one locker, for every 10 PN based on the largest shift, should be provided.
- When lockers are authorized in support of physical training requirements for military personnel at remote locations without access to fitness centers, one locker for every 20 military personnel assigned should be provided.
- If the locker room is required due to overseas operations, where personnel are not allowed to travel to and from the installation in uniform, 1 locker per military staff is allowed with Installation policy provided as justification.

Use the guidance above to determine the number of lockers required.

Planning Factor: Allocate 8 NSF/Locker each.
Justification: A Locker Room may be justified to support physical training requirements for military personnel, and may be applicable to certain personnel that do not occupy a dedicated workspace, such as security personnel or workstation operators working in shifts. Justification should address some or all of the following factors as appropriate:

- Mission or functions performed
- Type of operations supported (normal, shift, emergency)
- Physical Training (PT) requirements at remote locations
- Overseas Installation uniform policy
- Type of locker space required (e.g., shared, dedicated, other)
- Types of personnel that require locker space (e.g., military, civilian, or contractor personnel)

- Types of personnel that require locker space (e.g., military, civilian, or contractor personnel). Military personnel may require locker space in support of mandatory physical fitness requirements. Military, civilian and/or contractor personnel may require locker space in support of shift or emergency operations. Other (e.g. security) personnel that do not occupy a dedicated work space, may require locker space.
- Other justification

131-8.2.3 **Shower Room.** A Shower Room provides one or more shower stalls and is typically collocated with a locker room and/or bathroom. Showers are authorized in support of critical 24-hour, multiple shift operations. Showers may also be authorized in support of military physical training requirements at remote locations without access to fitness centers.

- When showers are authorized in support of 24-hour, multiple shift operations, one shower for every 10 PN, based on the largest shift, should be provided.
- When showers are authorized in support of physical training requirements for military personnel at remote locations without access to fitness centers, one shower for every 20 military personnel assigned should be provided.

In both cases, a ratio of 80/20 (male/female), should be used for planning purposes (ratio may go up as manning structure dictates, but not lower than 80/20). Use the guidance above to determine the number of showers required.

<u>Planning Factor:</u> Allocate 20 NSF/shower.
<u>Justification:</u> A Shower Room may be justified for commands with 24-hour, multiple shifts or remote operation requirements. If the organization is located on a large installation with access to fitness centers, shower rooms are generally not authorized except when 24-hour operations are required. Justification should address some or all of the following factors as appropriate:

- Mission or functions performed
- Type of operations supported (normal, shift, emergency)
- Physical Training (PT) requirements at remote locations
- Total number of showers required based on guidance above
- Military personnel may require showers in support of mandatory physical fitness requirements.
- Military, civilian and/or contractor personnel may require showers in support of shift or emergency operations.
- Other justification

131-8.3 **Special Purpose Space, Security**. Security spaces for C5ISR facilities include the Entry Control Area and the Special Security Office Suite.

131-8.3.1 Entry **Control Area.** This multifunctional area provides an assembly or holding area for visitors awaiting escort, badge and pass issue and verification, and is considered the central point for ingress and egress. For unclassified facilities, this area should consist of up to two workstations, for a two-person watch, and up to 100 NSF waiting area for personnel.

For general planning purposes, facilities that have classified spaces will require larger Entry Control Area that supports two stations for a two-person watch, a waiting area that accommodates mantraps, one unisex restroom, and a waiting area. Additionally, this area should include an additional 20 NSF per every 50 personnel assigned to the organization to accommodate the transit of personnel though the Entry Control Area.

Planning Factors: For each area within the Entry Control area, allocate as follows:

- Security Entry Control Area. Allocate 1 entry control area at 100 NSF plus 20 NSF per every 50 personnel in the command.
- Secure Visitor Waiting Area. Allocate one secure waiting area at 120 NSF.
- Security Watch Station. Allocate 64 NSF per workstation (max of 2 workstations).
- Security Unisex Bathroom. Allocate one unisex bathroom at 60 NSF, allowed only if command population exceeds 500 PN in a single facility.
- Security, Other Space. Allocated as needed for other security requirements (e.g. Security Systems Monitoring). Provide appropriate Engineering Evaluation and justification.

Justification: Justification should address some, or all, of the following factors as appropriate:

- Mission or functions performed
- Security requirements
- Other justification

Note: Refer to requirements for classified facilities requiring more stringent security requirements and specific design guidance such as: Open Storage Secret (OSS), Sensitive Compartmented Information Facility (SCIF), Special Access Program (SAP) and Top Secret/Sensitive Compartmented Information (TS/SCI).

131-8.3.2 **Special Security Officer (SSO) Suite**. The SSO Suite may be required depending on the following TS/SCI classification level:

- If SCIF or SAP facilities are present
- If personnel within the command maintain clearance levels

The SSO Suite is a multifunctional area containing, but not limited to, a reception area, indoctrination area, photography area, vault, and the SSO office space. The required area varies based on the size of the command. Large commands require additional space to handle a larger volume of personnel that

need to be processed. A minimum allowance of 350 NSF is provided for all commands up to 100 personnel. Medium and large sized commands are provided additional area as shown in Table 131-2.
Note: The SSO Suite provides office area for the SSO but does not provide office space for any additional staff. SSO staff should be provided cubicle space as a part of the open office calculation, see Section 131-6. Alternatively, since the SSO office is included in this calculation, a private office should not be included in the private office calculation for the SSO.

Table 131-2. SSO Suite Allowances

SSO Suite Command Size	Total Max NSF
Small (< 100 PN)	350
Med (100-500 PN)	450
Large (>500 PN)	600

131-9 **C5ISR OPERATIONS SPACE**. C5ISR Operations Spaces are areas that directly support the C5ISR mission. These areas are often contained within a separate secure space from the rest of the facility and may require entry control space and dedicated briefing/planning spaces to support highly classified missions. Although not every C5ISR facility will contain all the areas listed, the criteria are provided as a guide. An Engineering Evaluation should be used to determine the total quantity and type of workstations required and if briefing and/or planning rooms are required. Depending on the nature of the mission, the workstations may be calculated based on the number of systems, networks, or personnel assigned. These spaces are often configured by a Watch Center or Analysis Operations Workspace. See Table 131-3 for further clarification and application of the spaces.

131-9.1 **Watch Center.** The Watch Center generally operates on a shift system where personnel oversee multiple systems using multiple shifts to provide coverage up to 24 hours a day. This space may contain the following areas: Watch Floor (containing Kiosk Workstations, Watch Stander Workstations, and Watch Workstations), Command Viewing Area, and Briefing Rooms.

All allowances for Watch Floor components include circulation area to support unclassified and classified printers, shredders, display walls, and line of site area requirements (Watch Commander Workstations to the Watch Stander Workstations).

131-9.1.1 **Kiosk Workstations**. Kiosk Workstations are provided for standalone systems. The number of Kiosk Workstations required is based on the purpose and necessity of the workstations. This station is also presumed to be unmanned, but available to all personnel on watch for use as needed.

<u>Planning Factors</u>: Allocate 40 NSF (including circulation area) for each Kiosk Workstation that supports up to 2 networks.

Justification: Kiosk Workstations may be justified when stand-alone or separately monitored systems require separate Kiosk Workstations.

131-9.1.2 **Watch Stander Workstations.** The number of Watch Stander Workstations is based on the number of systems being monitored and the number of watch standers per shift.

Planning Factors: Allocate 60 NSF (including circulation area) for each Watch Stander Workstation that supports up to 4 networks.
Justification: Watch Stander Workstations may be provided for operational missions with watch teams.

131-9.1.3 **Watch Commander Workstation.** In addition to Watch Stander Workstations, there are also Watch Commander Workstations required for each group identified within the Watch Center. The number of Watch Commander Workstations required is based on the structure of the watch team oversight and may include a Watch Commander, Deputy Watch Commander, and under instruction Watch Commander Workstations.

Planning Factors: Allocate 100 NSF (including circulation area) for each Watch Commander Workstations that supports up to 4 networks and 4 peripherals (secure telephones and secure video conferencing systems).
Justification: Watch Commander Workstations may be provided for operations missions with watch teams.

131-9.1.4 **Command Viewing Area.** A viewing area immediately adjacent to the Watch Floor Area may be provided for the Commanding Officer and Chief of Staff, if justified. This area may be separated from the Watch Floor by a glass wall, and may be elevated to provide complete visual oversight of the Watch Floor and its associated status boards.

Planning Factors: Allocate 300 NSF for a Command Viewing Area separate from Watch Commander Workstations. This area is separated and elevated from the Watch Floor but has a direct line of site to the Watch Floor and all displays. This space must be justified based on mission requirement.
Justification: Command Viewing Area is authorized for Emergency Operations Centers (CCN 143 65) and Mission Operation Command and Control Facility (CCN 143 80). It may be provided for other category codes with additional justification to include specific mission requirement.

131-9.1.5 **Watch Center Briefing Room.** A separate briefing area with Video Teleconference (VTC) capability is also be required for planning and briefing purposes to ensure uninterrupted operations on the Watch C. This space is separate from general-purpose conferencing capabilities due to mission requirements that may require long-term utilization of the Briefing Rooms, (e.g exercises and/or crisis action response).

Planning Factors: Allocate 500 NSF for a 25-person Watch Center Briefing Room in support of watch operations. All systems and displays monitored on the Watch Floor should also be available in this space.
Justification: Watch Center Briefing Room is authorized for Emergency Operations Centers (CCN 143 65) and Mission Operation Command and Control Facility (CCN 143 80). It may be provided for other category codes with additional justification to include specific mission requirement.

131-9.2 **Analysis Operations.** Analysis Operations generally require use of multiple network systems including both unclassified and classified networks. All personnel assigned to Analysis Operations functions require a dedicated workspace that provides both privacy for independent work and teaming areas. The workstation sizing includes the workstation area and appropriate circulation areas within the Analysis Operations space to accommodate shredders, safes and a printer for each network.

131-9.2.1 Analysis **Workstations (up to 4 networks).** This workstation provides adequate space to support operations personnel that utilize up to 4 different networked systems. This workstation can accommodate multiple classified systems that require separation from both unclassified systems and other classified systems.

Planning Factors: Allocate 90 NSF (including circulation area) for each workstation required. These workstations should support up to 4 networks of which 2 or more are classified networks and require a separation of 3 feet from each other and from unclassified networks.
Justification: Analysis Workstations (up to 4 networks) may be provided when the operations mission require staff to access more than 2 networks.

131-9.2.2 **Analysis Workstations (greater than 4 networks).** This workstation provides adequate space to support operations and personnel that utilize more than 4 different networked systems. This workstation can accommodate multiple classified systems that require separation from both unclassified systems and other classified systems.

Planning Factors: Allocate 130 NSF (including circulation area) for each workstation required. These workstations should support more than 4 networks, of which 2 or more are classified networks and require a separation of 3 feet from each other and from unclassified networks.
Justification: Analysis Workstations (greater than 4 networks) may be provided when operations missions require staff to access more than 4 networks.

131-9.2.3 **Analysis Teaming Room.** An Analysis Teaming Room provides a crisis response operations area to support operations that may last multiple days and is separate from conference room allocations due to the potential long-term operations and classified requirements that are supported.

Note: This is not a substitute for a department conference room, which is already provided by the command conference room calculation and requires mission specific justification.

Planning Factors: Allocate 150 NSF for a 10 PN Analysis Teaming Room.
Justification: Justification should address some, or all, of the following factors as appropriate:

- Mission or functions performed
- Organization size if more than one Analysis Teaming Room for 10 PN is required
- Other justification

Table 131-3. Analysis and Watch Center Space Types

Workstation Type	NSF	Notes
Watch Center – Kiosk	40	This workstation is composed of a single monitor and keyboard assembly. It is generally used as a hoteling station, which supports non-resident access to systems or provides access to a network not accessible to all staff members. In a Watch Center, this Kiosk is not manned but is provided for access to systems not available at every Watch Stander's Workstation.
Watch Center – Watch Stander Workstation	60	This workstation is composed of multiple monitors and accesses up to 4 different networks or systems.
Watch Center –Watch Commander Workstation	100	This workstation has access to all networks and systems monitored by the Watch Standers and has access to at least 4 peripherals - such as secure telephones and secure video conferencing systems.
Command Viewing Area	300	The Command Viewing Area is separate from Watch Floor. This space must be justified based on mission requirement.
Watch Center - Briefing Room	500	The Watch Center Briefing Room supports planning and briefing functions and ensures uninterrupted operations on the Watch Floor.
Analysis Workstation (up to 4 networks)	90	Each workstation supports up to 4 networks of which 2 or more are classified networks and require a separation of 3 feet from each other and from unclassified networks.
Analysis Workstation (greater than 4 networks)	130	Each workstation supports greater than 4 networks of which 2 or more are classified networks and require a separation of 3 feet from each other and from unclassified networks.
Analysis Teaming Room	150	This space is separate from Conference Room allocations due to the longer-term operations that are supported. This room may be configured to host crisis response operations that may last multiple days. This space must be justified based on mission requirement. *Note: This room is not a substitute for a department conference room which is already provided by the Conference Room calculation.*

131-10 **MAINTENANCE SPACE**. Maintenance Spaces that are internal to commands providing communications and electronic equipment maintenance may be provided utilizing an Engineering Evaluation, architectural layout, or the allowances provided in Table 131-4. These areas are considered integral to the mission of the command. Communications equipment maintenance areas that support multiple commands are considered external maintenance activities and should be classified as Category Code 217 10 (Electronics and Communication Maintenance Shop). Appropriate justification should also be provided.

131-10.1. **Maintenance Area Basic Components**. Table 131-4 provides the maximum allowance for basic components found within a Maintenance Space. Quantity and composition of these components vary with mission, logistics support systems, and levels of required security; and will be determined by an on-site Engineering Evaluation.

Table 131-4. Maintenance Area Basic Component Maximum Allowances

Component	Max Allowance NSF per Component
Work Desks	60
Small Work Tables	10
Computer Tables	30
Workbenches-Full Access	96
Workbenches-Limited Access	60
Storage Lockers	18
Small Storage Lockers	10
Large Storage Shelves	40
Large Storage Cabinet	30
Parts Lockers	12
File Cabinets	10
Test Equipment Storage Cabinets	50
Test Equipment Carts	15
Bookshelves	10
Equipment Shelves	40
Equipment Staging	TBD(1)
Other (provide Description & Justification)	TBD(2)

(1) The Equipment staging allowance is provided for C5ISR missions that fabricate or maintain large C5ISR systems and require storage and staging areas. These areas are primarily associated with NIOC Fleet Electronic Support functions, but may be justified by other missions. An Engineering Evaluation and detailed justification to include the average size and quantity of equipment maintained must be provided.
(2) An "Other" allowance is provided for C5ISR missions that have a unique maintenance or storage requirement. An Engineering Evaluation and detailed justification must be provided.

131-11 **TRAINING SPACE**. Due to the nature of C5ISR functions, specialized Training Spaces are required. These activities support ongoing training for command and fleet personnel on the latest C5ISR systems, networks, or threats. Formal course programs such as those provided through Naval Education and Training Command (NETC) learning sites should be classified as Category Code 171 10 (Academic Instruction Building) or Category Code 171 20 (Applied Instruction Building), and justified accordingly. General military training is not considered valid justification for training spaces and should not be included in the analysis to provide C5ISR Training Spaces.

131-11.1. **Training Stations**. A maximum of 20 Training Stations is provided in a training room. This training space should support the training of system upgrades, the fielding of new hardware and software, and security classifications of equipment. Training rooms that require more than 20 Training Stations require specific course justification. The exact quantity and size of training areas is determined by an Engineering Evaluation aligned to internal operations requirements. Table 131-5 provides applicable classroom types and appropriate space allocations per student station.

Table 131-5. Classroom Type and Student Station Allowances

Classroom Type	Max Student Stations	Training Station NSF
General (standard chairs and desks)	20	22
Work Desk (with CPU, keyboard, monitor)	20	40
Workbench (larger work space to support maintenance training functions)	20	60

131-12 **EQUIPMENT SPACE**. This area is provided for communications and electronic equipment mounted in racks in support of the function(s) being performed by the organization. An Engineering Evaluation is required to determine the total quantity of equipment racks required to support each network or system.

Note: Allowances identified in the following sections provide guidelines for planning purposes when exact values are not available. In accordance with UFC 3-580-01 2-4.4.3 to support equipment refresh and future growth, rack calculations should provide 25 percent spare capacity in each rack, and one spare rack for every four utilized racks. This will provide a growth multiplier of 1.67 which affords adequate rack space to set up new or updated equipment prior to the decommissioning of older systems and future system growth.

131-12.1. **Data Center**. Computer systems and associated components, such as telecommunications and storage systems are housed in the Data Center. This definition excludes facilities exclusively devoted to communications and network equipment (e.g., telephone exchanges and telecommunications rooms).

Data Centers act as a centralized repository, either physical or virtual, for the storage, management, processing, and dissemination of communications and information systems. Depending on the function of the command, these spaces could be the consolidated communications and information server support for the Navy or Marine Corps activities or may support high-density legacy computing systems that are integral to an individual command and cannot be consolidated into remote Data Centers.

131-12.2. **Communications Security Material Area**. This area supports the management and storage of Communications Security (COMSEC) material such as the Electronic Key Management System (EKMS). This area must be segregated and meet security requirements for the highest level of COMSEC material stored and consists of rack mounted equipment and workstations for personnel. An Engineering Evaluation is required to determine the total quantity of equipment racks and workstations to support a Communications Security Material Area.

131-12.3. **Commercial Services Equipment**. Also referred to as the Cable Plant Area, this area is a specialized equipment area that provides a demarcation point separating the incoming commercial communications sources from the Data Center area. This area is separated to provide controlled access without encroachment on the mission operations. It requires two-layer access, racks and cabinets with telephone lines and switches. This space is only provided when Commercial Services Equipment areas are provided directly to the facility. An average allowance of 25 percent of the Data Center size is to be used for planning purposes.

131-12.4. **Network Distribution Area.** This area consists of server racks that provide cabling and switching areas that connect operations spaces to the server area. These areas are most often required for operations that maintain additional networks above and beyond the DON Mission Networks, which include but are not limited to: Next Generation Enterprise Network (NGEN), OCONUS Navy Enterprise Network (ONE-Net), Marine Corps Enterprise Network (MCEN) and Global Network Transport (PSNet); and/or include a large watch or analysis operation area where internal distribution areas may be required to provide adequate network management and flexibility. A maximum of 15 percent of the size of the Data Center should be used for planning purposes.

Planning Factors**:** Although the quantity and size of Equipment Spaces will vary depending on which specific Category Code is being evaluated, the analysis will conform to the following guidance:

- An Engineering Evaluation of the equipment systems is to be used to determine the total quantity of racks required. These racks are to be positioned on a theoretical 2 ft x 4 ft grid.
- Racks should be set up in rows with an equal number of racks.
- A continuous row, with a maximum of 25 ft in length, is allowed before a safety passage must be included between columns or racks.
- The safety passage shall be a minimum of 5 ft wide and aligned to permit direct paths through the rows of racks.

- Racks should be aligned so the front and rear of the rows face each other to create cold aisles (front) and hot aisles (rear) to maximize cooling efficiency.

- When multiple rows of racks are required, a maximum of 6 ft is to be provided between the faces of parallel rows of racks; a maximum of 5 ft is to be provided between the backs of parallel racks; and a minimum of 5 ft is established between the end of a row and a wall. An engineering evaluation and appropriate justification is required for increased distances.

- When support devices such as electrical panels, transformers; heating, ventilation, and air conditioning (HVAC) equipment; and/or large conduit runs are surface mounted to the inside of the walls of an equipment and communications areas containing racks, the clearance requirements outlined above are to be increased by the depth of the respective support device. See Figure 131-2.

- For less than 120 total racks, the recommended server room requirements are listed in Table 131-6. For a server room with less than 10 racks, multiply the total number of racks by 45 net square feet (NSF) per rack.

Table 131-6. Equipment Room Requirement by Total Racks

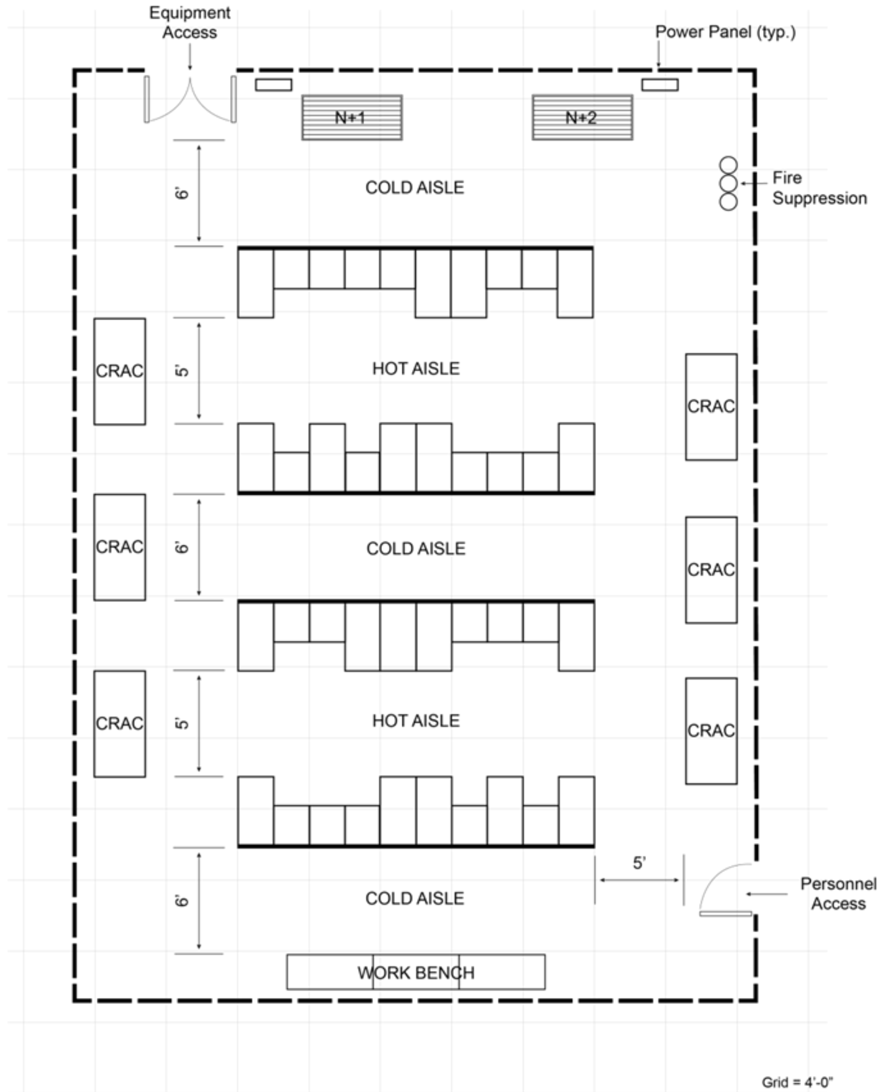
Total Racks	Total Equipment Rows	Total Columns of Equipment	Total Equipment Room (NSF)	NSF per rack
0-10	1	1	450	45
11-20	2	1	750	38
21-30	3	1	1020	34
31-40	4	1	1320	33
41-50	5	1	1590	32
51-60	6	1	1890	32
61-80	4	2	2420	30
81-100	5	2	2610	29
101-120	6	2	2915	29
>121	To be Determined by Engineering Analysis			28

- For Data Centers that have more than 120 racks, and in the absence of a specific layout, an overall maximum of 28 NSF per rack may be used which accommodates a maximum rack size of 24 inches wide by 48 inches deep.

- Depending on the type of cooling system and cable distribution system utilized in the Data Center, a false deck (also known as a raised floor) may be required. The depth of false deck shall be determined by the system design.

Figure 131-1. Typical Layout of Equipment Mounted in Racks

Note: Cooling redundancy within the Data Center is represented as N+1 and N+2; this represents



the total number of computer room air conditioner (CRAC) units required, plus one or two extra CRAC units for back up as required. The space requirement for the CRAC units is addressed within the Data Center Mechanical & Electrical Factor found in Section 131-9.

131-12.5. **C5ISR Equipment Room Factor.** To accommodate the significant electrical and mechanical requirements associated with facilities with large equipment rooms serving as a large Data Center or server space, this factor accounts for the additional spaces required to support the C5ISR equipment rooms that is above and beyond the requirement for the remainder of the facility. The type of mechanical systems used for cooling these types of rooms that support Data Centers and the level of redundancy required, as indicated by the Tier Level assigned to the Data Center, play key roles in the total footprint required. The Tier Level identified for a specific Data Center will dictate the redundancy requirements for each major system and is represented by N+1, N+2, 2N, etc. The general mechanical and electrical planning factor for Data Centers and server rooms with power densities of 5kW per rack or less, are provided in Table 131-7. Additionally, once the power requirement per Data Center rack exceeds 5 kW per rack, conventional computer room air condition (CRAC) unit based mechanical systems become ineffective to meet the demand of high-density servers. In cases where the power requirement exceeds 5kW per rack or the mission criticality of the facility requires a Tier IV facility, an Engineering Evaluation is required to determine the mechanical, electrical equipment, Uninterruptable Power Source (UPS) system, and emergency generator system requirements for the facility.

Table 131-7. C5ISR Equipment Factor

Tier Level	Data Center Factor
I	1.56
II	2.10
III	2.28

131-13 **IT LOGISTICS SUPPORT SPACE.** A dedicated shipping, receiving, laydown/IT staging, and storage areas may be provided to support the equipment and parts storage for a command. This area is in addition to any maintenance parts and consumables storage area requirements that may also exist.

Planning Factors**:** IT Logistics Support space may be provided using the following Planning Factors:

- This area should be capable of supporting a refresh rate of 18-24 months plus growth due to new systems. As a general rule, assume that the space can support at least 25 percent of the equipment room racks (volume) and 15 percent of CPUs and Monitors (volume) used within the command.

- The standard stacking height for this type of material is 6 feet. A factor of 0.327 NSF per cubic foot (CF) is applied to the volume of material to determine the required NSF for this functional area.

- To calculate the shipping, receiving, and laydown/IT staging area, multiply the total NSF of storage area by a factor of 2.

- Variance from the standard stacking height or larger storage operations should be classified as Category Code 143 77 (Operational Storage) or Category Code 217 77 (Electronics Spares and Miscellaneous Procured Items and Equipment) and justified accordingly.

131-14 **NET-TO-GROSS**. Unless otherwise noted, a net-to-gross conversion factor of 1.45 is used for all CCNs within the 131 Series. This factor applies to all spaces (including the Data Center) and is required to account for the additional electrical equipment, mechanical equipment, and architectural or structural elements required to directly support the electronic and communications systems and subsystems throughout the facility.

131-15 **ASSOCIATED INFRASTRUCTURE**. Additional power and HVAC system redundancy must be provided for Tier II and Tier III facilities. For Tier II facilities: N+1 generators, N+1 Uninterruptible Power Supply (UPS) system, and N+1 HVAC components must be provided for critical areas. For Tier III facilities: N+1 generators, 2N Uninterruptible Power Supply (UPS) systems, 2N HVAC, multiple distribution paths for critical power, multiple distribution paths for cooling, and elimination of single points of failure must be provide for critical areas. Fast action fire suppression systems that do not damage equipment are also required for critical areas in Tier III facilities.

131-16 **REQUIREMENTS SUMMARY**. The functional areas authorized by right (A), authorized with justification (J), or not authorized (N) for each the following Category Codes 131 15, 131 24, 131 35, 131 40, 131 50, 143 65, and 143 80 are shown in Table 131-8.

Table 131-8 Functional Areas Summary Matrix for Communications Buildings

Functional Area	Subspace	131 15	131 24	131 35	131 40	131 50	143 65	143 80
Administrative General Purpose	Private Office	A	A	A	J	A	J	A
	Open Office (Cubicle)	A	A	A	J	A	A	A
Special Purpose Space Basic	Admin Support	A	A	A	J	A	A	A
	Break Room	A	A	J	J	J	A	A
	Break Room Kitchen	J	J	J	N	J	N	J
	Classified Vault	J	J	J	J	J	J	J
	Conference Rooms/VTC	A	A	J	J	J	A	A
	Duty/Bunk Room	J	J	J	J	J	J	J
	Mail Room	J	J	J	J	J	N	J
	Technical Publications Area	J	J	J	J	J	J	J
Special Purpose Space Fitness/Locker/ Shower	Fitness Room[1]	J	J	J	N	J	N	J
	Locker Room	J	J	J	N	J	J	J
	Shower Room	J	J	J	N	J	J	J
Special Purpose Space Security	Quarterdeck/Entry Control	A	A	J	J	J	J	A
	Special Security Office	J	J	J	J	J	J	J
Operations Space	Watch Center	A	A	A	J	A	A	A
	Analysis Operations	A	A	J	J	J	A	A
Maintenance Space	Maintenance	J	J	J	J	J	N	J
Training Space	Training	J	J	J	N	J	N	J
IT Logistics Support Space	IT Logistics Support Space	A	A	J	J	J	N	A
Equipment Space	Data Center/Server	A	A	N	N	N	A	A
	Commercial Services Equipment	A	A	N	N	N	N	J
	Communications Security Material Area	A	A	N	N	N	J	J
	Network Distribution Area	A	A	N	N	N	N	J
	Specialized Equipment	J	J	A	A	A	N	J

Legend:
A – Approved without additional justification (based on the staffing and mission requirements)
J – Only approved with specific justification of mission requirements
N – Not approved for this category code
(1). This requirement should be captured under CCN 740 45. Fitness Rooms are only allowed in accordance with CNICINST 1710.1 where by the command is located more than a 15- minute commute by vehicle from the nearest Morale Welfare and Recreation (MWR) Fitness Center, or in cases where service members are required to be on station and unable to leave for 18 hours at any given time. The fitness room must also have approval from the Installation Commanding Officer.

131 10 CABLE HOUSE (SF)
FAC: 1311
BFR Required: Y

13110-1 **DEFINITION**. A Cable House is an unmanned facility that functions either as an external junction point for coaxial cables, or as mechanical space for support equipment associated with Extremely Low Frequency (ELF) and Very Low Frequency (VLF) antennas. As a junction point for coaxial cables, it permits significant changes of cable direction without exceeding the bending radius limit specified by the cable manufacturer and provides a physical access point for installation and maintenance of the cables that connect equipment areas and their respective antenna systems. The Cable House will be located within, or adjacent to, the antenna field containing ELF, VLF, Low Frequency (LF), and/or High Frequency (HF) antennas for shore to ship, and/or shore-to-shore communications.

13110-2 **FREQUENCIES.** For Very High Frequency (VHF) and/or Ultra High Frequency (UHF) systems in support of aircraft operations and tactical base support systems, a Cable House functions as a collection point that permits communication cables from multiple locations to be combined into a single path or trench that serves an single operational facility such as a Control Tower or Emergency Control Center.

13110-3 **ALLOWANCE.** Although no requirement calculations are associated with this category code, and requirements are based on an as needed basis, the maximum size of a Cable House should not exceed 27.87 GSM (300 NSF).

131 12 COMMUNICATIONS MAINTENANCE VAULT (EA)
FAC: 8927
BFR Required: N

13112-1 **DEFINITION.** A communications maintenance vault is a handhole, manhole, or confined space used for non-electrical splice and transport.

131 13 COMMUNICATIONS MAINTENANCE TUNNEL (LF)
FAC: 8931
BFR Required: N

13113-1 **DEFINITION.** This type of tunnel is an underground communications maintenance walkway accessible by personnel for communication line inspections, upgrades, and repairs below ground.

131 15 COMMUNICATIONS / INFORMATION / INTELLIGENCE BLDG. (SF)
FAC: 1311
BFR Required: Y

13115-1 **DEFINITION**. Communications, Information, or Intelligence Facilities are responsible for information processing, delivery of information services, and information/data storage. These facilities ultimately support the Joint Information Environment (JIE). The JIE/ identifies several different types of functional nodes: computing nodes (e.g. Data Centers), communication nodes (e.g. Network Gateways), and operations nodes (e.g. Enterprise Operation Centers). These nodes should be viewed as functional enclaves, not separate facilities; in fact, multiple nodes and node types may be present in a single physical facility. For further understanding of the different functional nodes refer to *DoD Information Enterprise Architecture, Data Center Reference Architecture Version 1.10 Final April 25, 2014 Table 1 and Table 2*.

13115-2 **FUNCTION TYPES.** Table 13115-1 provides a list of typical functions and sample commands that apply to this category code.

Table 13115-1. Function Types and Sample Organizations

Function Type	Sample Organizations
Data Center or Server Center (Only)	Any
Communications Center	Naval Computer and Telecommunications Station (NCTS), Naval Computer and Telecommunications Master Area Station (NCTAMS), etc.
Weather Center	Fleet Weather Centers (FWC), Joint Typhoon Warning Center (JTWC), etc.
Information and Intelligence Commands	NIOC, Navy Information Operations Division (NIOD), Navy Cyber Defense Operations Command (NCDOC), Navy Information Warfighting Development Center (NIWDC), Naval Network Warfare Command (NNWC), etc.

13115-2 **FUNCTION AREAS.** A Communications, Information, or Intelligence Facility may contain the functional areas shown in Table 13115-2. This facility will be supported by an Uninterruptible Power Supply (UPS) system and emergency generator system. Please refer to the guidelines provided in the introduction of 131-series Category Codes for C5ISR buildings to calculate the requirement for each functional area. Per section 131-14, the authorized **net-to-gross** factor is 1.45.

Table 13115-2. Communications, Information, or Intelligence Facility Functional Areas

Functional Area	Subspace	131 15
Administrative General Purpose	Private Office	A
	Open Office (Cubicle)	A
Special Purpose Space Basic	Admin Support	A
	Break Room	A
	Break Room Kitchen	J
	Classified Vault	J
	Conference Rooms/VTC	A
	Duty/Bunk Room	J
	Mail Room	J
	Technical Publications Area	J
Special Purpose Space Fitness/Locker/ Shower	Fitness Room[1]	J
	Locker Room	J
	Shower Room	J
Special Purpose Space Security	Quarterdeck/Entry Control	A
	Special Security Office	J
Operations Space	Watch Center	A
	Analysis Operations	A
Maintenance Space	Maintenance	J
Training Space	Training	J
IT Logistics Support Space	IT Logistics Support Space	A
Equipment Space	Data Center/Server	A
	Commercial Services Equipment	A
	Communications Security Material Area	A
	Network Distribution Area	A
	Specialized Equipment	J

Legend:
A – Approved without additional justification (based on the staffing and mission requirements)
J – Only approved with specific justification of mission requirements
(1). This requirement should be captured under CCN 740 45. Fitness Rooms are only allowed in accordance with CNICINST 1710.1 where by the command is located more than a 15- minute commute by vehicle from the nearest Morale Welfare and Recreation (MWR) Fitness Center, or in cases where service members are required to be on station and unable to leave for 18 hours at any given time. The fitness room must also have approval from the Installation Commanding Officer.

13115-4 **SPACE DISTRIBUTION.** A Communications, Information, or Intelligence Facility will generally consist of the functional space types shown in Table 13115-3: General Administrative and Special Purpose Space, C5ISR Operations (watch/analysis) Space, Maintenance Space, Training Space, Equipment Space (racked equipment area, often called a Data Center or server area), and IT Logistics Space. The percentages shown in Table 13115-3 provide a guide of the general size of these areas in relation to the overall facility. For instance, a stand-alone Data Center would likely be made up of 75 percent Equipment Space; 20 percent of General Administrative and Special Purpose Space, C5ISR Operations Space, Maintenance Space, and Training Space; and 5 percent IT Logistics Space.

Table 13115-3 Function Type and Space Type Distribution

Function Type	General Admin & Special Purpose	C5ISR Operations	Maintenance	Training	Equipment	IT Logistics
Data Center/Server Space (Only)	20%				75%	5%
Communications Center	25%	15%	5%	5%	45%	5%
Weather Center	34%	40%	n/a	1%	20%	5%
Information Analysis Center	30%	35%	n/a	5%	20%	5%

13115-4 **BUILDING BLOCKS.** Figure 13115-1 provides a diagram demonstrating a summary of the applicable spaces, appropriate allocation factors, and the special relationship for Communications, Information, and/or Intelligence Facilities.

Figure 13115-1.

131 15 Communications, Information, or Intelligence Facility

ADMINISTRATIVE & SPECIAL PURPOSE SPACE

General Admin Space

- Determine the number of private offices and cubicles based on personnel loading documents

Special Purpose Space ◆
See Section 131-8

Basic
- Determine personnel loading documents

Fitness/Locker/Shower
- Determine the military population

Security
- Determine the personnel loading
- See Table 131-2

OPERATIONS AND OPERATIONS SUPPORT SPACE

Operational Space
See Section 131-9

Watch
- Determine # of Systems Monitored
- Determine Type and # of Workstations
- See Table 131-3

Analysis Operations
- Determine # of Workstations
- See Table 131-3

Maintenance Space ◆
See Section 131-10
- Build based on Table 131-4

Training Space ◆
See Section 131-11
- Build based on Table 131-5
- Maximum of 20 positions allowed
- Greater than 20 positions requires justification

IT Logistics Support Space
See Section 131-13
- Determine shipping, receiving, laydown, and IT staging requirements
- Determine CF of storage requirement NSF = 0.327 × CF

EQUIPMENT SPACE

Communications Security Material Area
- Determine # of Racks & Workstations. See Table 131-6
- 1.67 Factor for refresh/growth

Data Center
See Section 131-12.1
- Determine # of Racks
- Multiply 1.67 refresh / growth factor
- If total racks required less than 120 refer to Table 131-6 for total NSF
- If over 120 racks, use 28 NSF / Rack
- See Figure 131-1

Commercial Services Equipment / Cable Plant
- 25% × Data Center/Server NSF

Network Distribution
- 15% × Data Center/Server NSF

Apply Equipment Factor Based on Tier Level – Table 131-7

Apply NTG Factor of 1.45 – See Section 131-14

◆ Justification Required

131 17 COMMUNICATIONS MAINTENANCE CHANNEL (LF)
FAC: 8932
BFR Required: N

13117-1 **DEFINITION.** This type of facility is an underground communications maintenance channel accessible via ground level access panels to allow inspections, upgrades, and repairs to communication lines below ground.

131 20 COMMUNICATIONS RELAY FACILITY (SF)
FAC: 1311
BFR Required: Y

13120-1 **DEFINITION**. A Communications Relay Facility is an unmanned facility or enclosure associated with the operation of Microwave (MW) communications systems. It contains rack mounted communications receiving, amplification, and transmitting equipment, along with an Uninterruptible Power Source (UPS) system and an emergency generator system. A Communications Relay Facility can be a permanent facility, but unless location and atmospheric conditions dictate otherwise, it is normally Class III Property. It is located at the base of the antenna tower that contains the associated microwave dishes. The size of the facility or enclosure is dependent on the number of microwave links be served by the antenna tower and by the quantity of commercial equipment (cell phone) systems that DON has authorized. See Table 13120-1.

Table 13120-1 Allowances

Facility Size	Description	Allowance
Small Facility	Two Microwave Links with no commercial tenants	16 GSM (172 GSF)
Medium Facility	Three or more Microwave Links with no commercial tenants	20 GSM (215 GSF)
Large Facility	Three or more Microwave Links with multiple commercial tenants	22 GSM (237 GSF)

131 22 VHF/UHF COMMUNICATIONS FACILITY (SF)
FAC: 1311
BFR Required: Y

13122-1 **DEFINITION**. A VHF/UHF Communications Facility can either be contained within a permanent facility or within Class III Property. It contains a limited amount of rack mounted communications receiving, amplification, and transmitting equipment associated with Airfield Operations, Security and Fire Operations, or a tactical Communications system integral to unique special operations. A small Uninterruptible Power Source (UPS) system and an emergency generator system support a VHF/UHF Communications Facility.

13122-2 **Allowance.** Although no requirement calculations are associated with this Category Code, and requirements are based on an as needed basis, the maximum size of a VHF/UHF Communications Facility should not exceed 41.81 GSM (450 NSF).

131 24 SATELLITE COMMUNICATIONS FACILITY (SF)
FAC: 1312
BFR Required: Y

13124-1 **DEFINITION**. Satellite Communications Facility is often referred to as a 'gateway facility' supporting Worldwide, Regional, and Area of Responsibility (AOR) communications. It contains office and support requirements, equipment and operations areas, maintenance and training areas, and limited storage areas for ready-to-issue communications systems and subsystems required for the reception, processing, routing, and dissemination of incoming and outgoing communications traffic.

13124-2 **ANTENNAS.** The receiving/transmitting antennas systems associated with this facility are directional in nature. Antennas that are in excess of 3 meters in diameter are mounted, in most cases, on a dedicated tower or support structure that is integral to the antenna. In selected instances, the functional equipment associated with a Satellite Communications Facility may be located within a Communications, Information, Or Intelligence Facility (131 15), and thus this Category Code should be used only where 'stand-alone' facilities are being evaluated.

13124-2 **FUNCTIONAL AREAS.** A Satellite Communications Facility may contain the functional areas shown in Table 13124-1. This facility will be supported by an Uninterruptible Power Support (UPS) system and emergency generator system. Please refer to the guidelines provided in the introduction of 131-series Category Codes for C5ISR buildings to calculate the requirement for each functional area. Per section 131-14, the authorized **net-to-gross** factor is 1.45.

13124-3 **BUILDING BLOCKS.** Figure 13124-1 provides a diagram demonstrating a summary of the applicable spaces, appropriate allocation factors, and the special relationship for Satellite Communications Facilities.

Table 13124-1. Satellite Communications Facility Functional Areas

Functional Area	Subspace	131 24
Administrative General Purpose	Private Office	A
	Open Office (Cubicle)	A
	Admin Support	A

Functional Area	Subspace	131 24
Special Purpose Space Basic	Break Room	A
	Break Room Kitchen	J
	Classified Vault	J
	Conference Rooms/VTC	A
	Duty/Bunk Room	J
	Mail Room	J
	Technical Publications Area	J
Special Purpose Space Fitness/Locker/ Shower	Fitness Room[1]	J
	Locker Room	J
	Shower Room	J
Special Purpose Space Security	Quarterdeck/Entry Control	A
	Special Security Office	J
Operations Space	Watch Center	A
	Analysis Operations	A
Maintenance Space	Maintenance	J
Training Space	Training	J
IT Logistics Support Space	IT Logistics Support Space	A
Equipment Space	Data Center/Server	A
	Commercial Services Equipment	A
	Communications Security Material Area	A
	Network Distribution Area	A
	Specialized Equipment	J

Legend:
A – Approved without additional justification (based on the staffing and mission requirements)
J – Only approved with specific justification of mission requirements
(1). This requirement should be captured under CCN 740 45. Fitness Rooms are only allowed in accordance with CNICINST 1710.1 where by the command is located more than a 15- minute commute by vehicle from the nearest Morale Welfare and Recreation (MWR) Fitness Center, or in cases where service members are required to be on station and unable to leave for 18 hours at any given time. The fitness room must also have approval from the Installation Commanding Officer.

Figure 13124-1. Satellite Communications Facility Building Blocks Diagram

131 24 Satellite Communications Facility

ADMINISTRATIVE & SPECIAL PURPOSE SPACE

General Admin Space

- Determine the number of private offices and cubicles based on personnel loading documents

Special Purpose Space ◆J
See Section 131-8

Basic
- Determine personnel loading documents

Fitness/Locker/Shower
- Determine the military population

Security
- Determine the personnel loading
- See Table 131-2

OPERATIONS AND OPERATIONS SUPPORT SPACE

Operational Space
See Section 131-9

Watch
- Determine # of Systems Monitored
- Determine Type and # of Workstations
- See Table 131-3

Analysis Operations
- Determine # of Workstations
- See Table 131-3

Maintenance Space ◆J
See Section 131-10
- Build based on Table 131-4

Training Space ◆J
See Section 131-11
- Build based on Table 131-5
- Maximum of 20 positions allowed
- > 20 positions requires justification

IT Logistics Support Space
See Section 131-13
- Determine shipping, receiving, laydown, and IT staging requirements
- Determine CF of storage requirement NSF = 0.327 × CF

EQUIPMENT SPACE

Communications Security Material Area
- Determine # of Racks & Workstations. See Table 131-6
- 1.67 Factor for refresh/growth

Data Center
See Section 131-12.1
- Determine # of Racks
- Multiply 1.67 refresh / growth factor
- If total racks required less than 120 refer to Table 131-6 for total NSF
- If over 120 racks, use 28 NSF / Rack
- See Figure 131-1

Commercial Services Equipment / Cable Plant
- 25% × Data Center/Server NSF

Network Distribution
- 15% × Data Center/Server NSF

Apply Equipment Factor Based on Tier Level – Table 131-7

Apply NTG Factor of 1.45 – See Section 131-14

◆J Justification Required

131 25 TELEMETRY BUILDING (SF)
FAC: 1311
BFR Required: Y

13125-1 **DEFINITION**. A Telemetry Building is an extremely specialized and unique facility specifically designed for the tracking of missiles and satellites. It can be a permanent facility or configured as a mobile asset within Class III property. As a permanent facility, it will contain equipment areas for transmitters, receivers, and recorders and personnel areas for operators and staff support elements. The size of equipment areas will be dependent upon the quantity of mission specific arrays of tracking antennas and communications interfaces. Personnel, support, maintenance, and logistics support requirements will be dependent on the infrastructure of the Shore Activity with which the Telemetry Building is collocated and will require an Engineering Analysis. If configured within Class III property, a maximum of three fifty-foot by twelve-foot vans are standard for the support of equipment, operations, and logistics spaces.

131 30 HELIX HOUSE (SF)
FAC: 1311
BFR Required: Y

13130-1 **DEFINITION**. A Helix House contains a Helical Coil and associated antenna tuning devices directly associated with, and integral to, the transmission of Low Frequency (LF), Very Low Frequency (VLF), and Extremely Low Frequency (ELF) communications.

13130-2 It is an unmanned facility, and is located within an antenna field associated with a Transmitter Building (Category Code 131 50). It is connected to a Transmitter Building by a cable trench, which contains power and signal cables. The Helix house is positioned adjacent to its respective antenna system.

13130-3 The size of a Helix House is totally dependent on the output power and operating frequency of the LF, VLF, or ELF transmitter located within the Transmitter Building. Although some AN/FRT-72 LF transmitters remain in the DON inventory, the AN/FRT-95 is the current generation of LF transmitters. An allowance of 342nsm (3,681nsf) is provided for a Helix House in support of the AN/FRT-95. VLF and ELF transmitters, which operate in the less than 30Kc range, are special manufacture units. Mission and location of the Transmitter Building, and coverage within a specific Area of Operation determine frequency and power. An allowance of 439nsm (4,725nsf) is normally provided for a Helix House in support of VLF and ELF transmitters.

131 35 RECEIVER BUILDING (SF)
FAC: 1311
BFR Required: Y

13135-1 **DEFINITION**. A Receiver Building supports a 24-hour a day, 7-day a week operations requirement for shore to shore and ship to shore administrative, tactical, and strategic High Frequency (HF) communications. This building may also be used to support transceivers, which are capable of both receiving and transmitting. *Note: if the transmitting only equipment is required, please refer to category code 131 50 Transmitter Building.*

The Receiver Building contains an equipment area with racked receivers and interface equipment, a maintenance area, and a storage area containing a small quantity of spare parts. A small personnel support space containing a toilet facility and break area is considered part of the facility. An Uninterruptible Power Source (UPS) system and an emergency generator system support a Receiver Building.

13135-2 **LOCATION.** The Receiver Building is physically located near the center of the receive antenna field, and it is connected to all antennas via direct buried coaxial cables. Location requirements for a Receiver Building and its associated antenna field with respect to possible areas of interference are provided in Table 13135-1 below.

Table 13135-1. Communications Distance Separations

From any High Frequency Antenna at a Receiver Site to:	
Navy Very Low Frequency (VLF) Transmitter Buildings	25 miles
Navy Low Frequency and High Frequency Transmitter Buildings	15 miles
Transmitting Facilities Not Under Navy Control	5 miles
Runways and Guide Paths Aeronautical Receivers	1,500 feet
General Communications Receivers	5 miles
Main Highways (hourly traffic count over 1,200 vehicles)	3,000 feet
Overhead High Tension Power Lines to include Receiver Station Feeders less than 100KV	1,000 feet
Overhead High Tension Power Lines to include Receiver Station Feeders over 100KV	2 miles
Residential Areas Not Under Navy Control	1 mile

From any High Frequency Antenna at a Receiver Site to:	
Light Industry	3 miles
Heavy Industry	5 miles
Primary Power Plants	5 miles

13135-3 **FUNCTIONAL AREAS.** A Receiver Building may contain the functional areas shown in Table 13135-2. In instances where the Receiver Building is located in an isolated location, and thus not readily supported by the staff of the associated Communications, Information, or Intelligence Facility (131 15), additional personnel support functions may be justified with appropriate documentation. These areas may include Conference Room, Break Room Kitchen, Locker Rooms, Shower Rooms, Duty/Bunk Rooms etc. This facility may also be supported by an Uninterruptible Power Support (UPS) system and emergency generator system. Please refer to the guidelines provided in the introduction of 131-series Category Codes for C5ISR buildings to calculate the requirement for each functional area. Per section 131-14, the authorized **net-to-gross** factor is 1.45.

See Table 13135-2 for additional spaces allowed with justification. In some instances, functions performed by a Receiver Building are an integral part of a Communications, Information, or Intelligence Facility (131-15), thus <u>this Category Code should be used only where 'stand-alone' facilities are being evaluated</u>.

Table 13135-2. Receiver Building Functional Areas

Functional Area	Subspace	131 35
Administrative General Purpose	Private Office	A
	Open Office (Cubicle)	A
Special Purpose Space Basic	Admin Support	A
	Break Room	A
	Break Room Kitchen	J
	Conference Rooms/VTC	J
	Duty/Bunk Room	J
Special Purpose Space Fitness/Locker/ Shower	Fitness Room[1]	J
	Locker Room	J
	Shower Room	J
Special Purpose Space Security	Quarterdeck/Entry Control	J
Operations Space	Watch Center	J
	Analysis Operations	J
Maintenance Space	Maintenance	A

Functional Area	Subspace	131 35
Training Space	Training	J
IT Logistics Support Space	IT Logistics Support Space	A
Equipment Space	Data Center/Server	A
	Specialized Equipment	A

Legend:
A – Approved without additional justification (based on the staffing and mission requirements)
J – Only approved with specific justification of mission requirements
(1). This requirement should be captured under CCN 740 45. Fitness Rooms are only allowed in accordance with CNICINST 1710.1 where by the command is located more than a 15- minute commute by vehicle from the nearest Morale Welfare and Recreation (MWR) Fitness Center, or in cases where service members are required to be on station and unable to leave for 18 hours at any given time. The fitness room must also have approval from the Installation Commanding Officer.

13135-4 **BUILDING BLOCKS.** Figure 13135-1 provides a diagram demonstrating a summary of the applicable spaces, appropriate allocation factors, and the special relationship for Receiver Buildings.

Figure 13135-1. Receiver Building
Building Blocks Diagram

131 35 Receiver Building

ADMINISTRATIVE & SPECIAL PURPOSE SPACE

General Admin Space

- Determine the number of private offices and cubicles based on personnel loading documents

Special Purpose Space ◆J
See Section 131-8

Basic
- Determine personnel loading documents

Fitness/Locker/Shower
- Determine the military population

Security
- Determine the personnel loading
- See Table 131-2

OPERATIONS AND OPERATIONS SUPPORT SPACE

Operational Space ◆J
See Section 131-9

Watch
- Determine # of Systems Monitored
- Determine Type and # of Workstations
- See Table 131-3

Analysis Operations
- Determine # of Workstations
- See Table 131-3

Maintenance Space ◆J
See Section 131-10

- Build based on Table 131-4

Training Space ◆J
See Section 131-11

- Build based on Table 131-5
- Maximum of 20 positions allowed
- Greater than 20 positions requires justification

IT Logistics Support Space ◆J
See Section 131-13

- Determine shipping, receiving, laydown, and IT staging requirements
- Determine CF of storage requirement NSF = 0.327 × CF

EQUIPMENT SPACE

Equipment Area

- Specialized Equipment - Egineering Evaluation Required

Apply Equipment Factor Based on Tier Level – Table 131-7

Apply NTG Factor of 1.45 – See Section 131-14

◆J Justification Required

131 40 TELECOMMUNICATIONS DISTRIBUTION FACILITY (SF)
FAC: 1311
BFR Required: Y

13140-1 **DEFINITION**. A Telecommunications Distribution Facility is a dedicated facility that supports the distribution of telecommunications systems across Navy Installations and Regions. This facility is often unmanned or has limited space for support staff. This type of facility contains the telecommunications switches and distribution frames. It may also contain the incoming demarcation point for commercial services or support the outside cable plant services for an installation or a special area. The facility is supported by Uninterruptible Power Source (UPS) systems and emergency generator systems, and may use a combination of hard wire, microwave, and satellite system to interface with the commercial providers. The receiving/transmitting antennas are normally commercial units and are directional in nature. The antennas are mounted on a dedicated tower or support structure immediately adjacent to the equipment they support. In many instances the telecommunications systems and their respective antennas are an integral part of a Communications, Information, or Intelligence Facility (Category Code 131 15). This Category Code (131 40) should only be used where ‘stand-alone’ facilities are being evaluated.

13140-2 **FUNCTIONAL AREAS.** A Telecommunications Distribution Facility may contain the functional areas shown in Table 13140-1. This facility may be supported by an Uninterruptible Power Supply (UPS) system and emergency generator system. Please refer to the guidelines provided in the introduction of 131-series Category Codes for C5ISR buildings to calculate the requirement for each functional area. Per section 131-14, the authorized **net-to-gross** factor is 1.45.

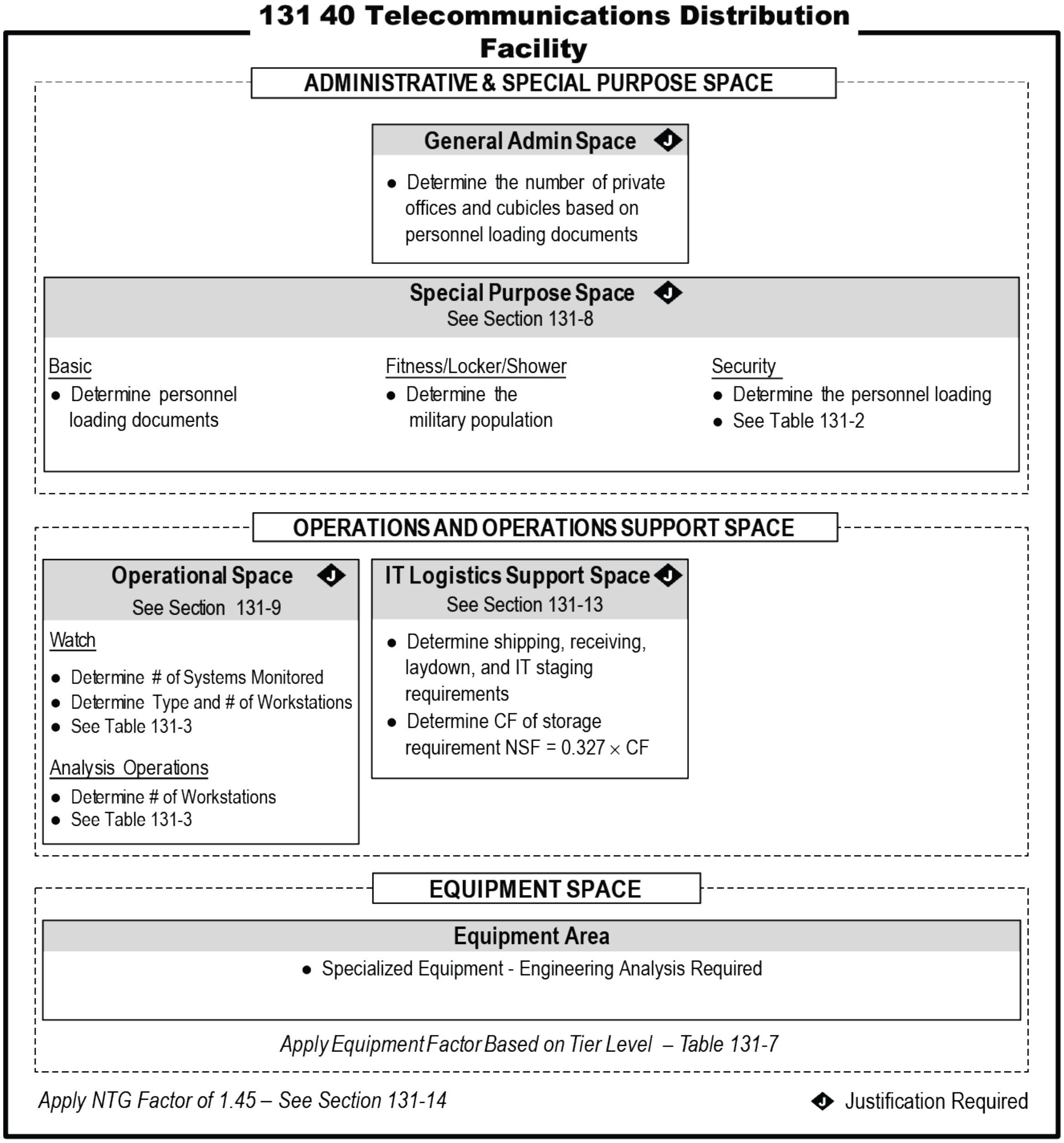
13140-3 **BUILDING BLOCKS.** Figure 13140-1 provides a diagram demonstrating a summary of the applicable spaces, appropriate allocation factors, and the special relationships for Telecommunications Distribution Facility.

Table 13140-1. Telecommunications Distribution Facility Functional Areas

Functional Area	Subspace	131 40
Administrative General Purpose	Private Office	J
	Open Office (Cubicle)	J
Special Purpose Space Basic	Admin Support	J
	Break Room	J
	Classified Vault	J
	Conference Rooms/VTC	J
	Duty/Bunk Room	J
	Mail Room	J
	Technical Publications Area	J
Special Purpose Space Security	Quarterdeck/Entry Control	J
	Special Security Office	J
Operations Space	Watch Center	J
	Analysis Operations	J
IT Logistics Support Space	IT Logistics Support Space	J
Equipment Space	Specialized Equipment	A

Legend:
A – Approved without additional justification (based on the staffing and mission requirements)
J – Only approved with specific justification of mission requirements

Figure 13140-1. Telecommunications Distribution Facility Building Blocks Diagram



131 42 AUTOMATIC COMMUNICATIONS SWITCHING CENTER (SF)
FAC: 1311
BFR Required: Y

13142-1 An Automatic-Communications Switching Center identifies a facility that contains the Telephone Switch and its immediate support infrastructure. Although it is possible that some isolated examples of this configuration may still exist, the current communications architecture for this equipment places it within a Telecommunications Distribution Facility (Category Code 131 40).

Use for Inventory Purposes only.

131 45 TERMINAL EQUIPMENT BUILDING (SF)
FAC: 1311
BFR Required: Y

13145-1 This facility originally, and currently to a minor extent, performs as a single-function building that is in direct support of High Frequency (HF) or Low Frequency (LF) communications. It provides an intermediate connection point that is required technically to support communications configuration or is required as the result of waveguide or cable loss.

13145-2 A Terminal Equipment Building is also the designation currently given to a new generation of facilities associated with satellite equipment and the selected equipment in support of the satellite antenna. It is commonly referred to as an equipment shelter and can be located within the pedestal base of the antenna or in a separate enclosure immediately adjacent to the base of the antenna. This new generation facility is Class III property in most instances. Although the antenna is classified as a structure, this Category Code is appropriate for 'stand-alone' configurations.

131 50 TRANSMITTER BUILDING (SF)
FAC: 1311
BFR Required: Y

13150-1 **DEFINITION**. A Transmitter Building supports a 24 hour a day, 7 day a week operations requirement for shore to shore, and shore to ship administrative, tactical, and strategic High Frequency (HF), Low Frequency (LF), and Very Low Frequency (VLF) communications. It contains an equipment area with stand-alone and racked transmitters, as well as their associated interface equipment, a maintenance area, and a storage area containing a small quantity of spare parts. A small personnel support space containing a toilet facility and break area is considered part of the facility. The Transmitter Building is physically located near the center of the transmit antenna field and is connected to all antennas via direct buried coaxial cables for HF applications, or by a dedicated power and signal trench for LF and VLF applications.

Due to the variable nature of transmitter equipment, an Engineering Evaluation is required to calculate the equipment and operations space requirements.

13150-2 **DISTANCE SEPARATIONS.** A specific Transmitter Building will support one of the following: HF only, HF and LF, VLF only, or ELF only operations. Location requirements for a Transmitter Building and its associated antenna field, with respect to possible areas of interference, are provided in Table 13150-1 below. An Uninterruptible Power Source (UPS) system and an emergency generator system support a Transmitter Building.

Table 13150-1. Communications Distance Separations

From the Nearest High Frequency, HF/LF/VLF/ELF Antenna Supporting a Transmitter Site to:	
Transmitting Facilities Not Under Navy Control	5 miles
Runways and Guide Paths Aeronautical Transmitters	1,500 feet
Main Highways (hourly traffic count over 1,200 vehicles)	1,000 feet
Overhead High Tension Power Lines to include transmitter station feeders	1,000 feet

13150-3 **FUNCTIONAL AREAS.** A Transmitter Building may contain the functional areas shown in Table 13150-2. This facility may be supported by an Uninterruptible Power Supply (UPS) system and emergency generator system. To calculate the area required to support the specialized equipment associated with each type of transmitter, an Engineering Evaluation is required. Specific requirements may be classified; therefore proper security clearance is required to obtain the information.

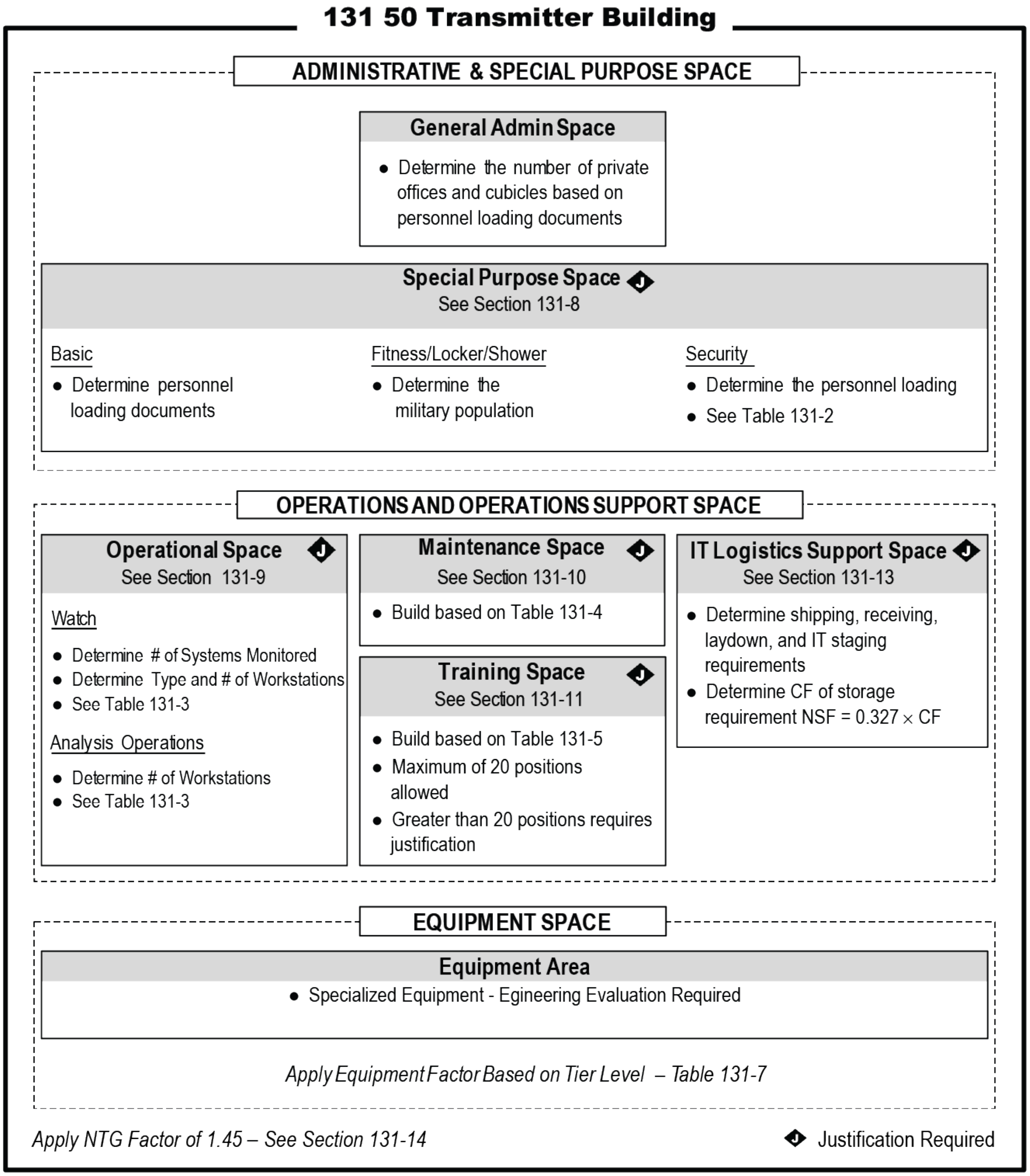
Please refer to the guidelines provided in the introduction of 131-series Category Codes for C5ISR buildings for additional information to calculate the requirement for other standard functional areas. Per section 131-14, the authorized **net-to-gross** factor is 1.45.

Table 13150-2. Transmitter Building Functional Areas

Functional Area	Subspace	131 50
Administrative General Purpose	Private Office	A
	Open Office (Cubicle)	A
Special Purpose Space Basic	Admin Support	A
	Break Room	J
	Break Room Kitchen	J
	Classified Vault	J
	Conference Rooms/VTC	J
	Duty/Bunk Room	J
	Mail Room	J
	Technical Publications Area	J
Special Purpose Space Fitness/Locker/Shower	Fitness Room[1]	J
	Locker Room	J
	Shower Room	J
Special Purpose Space Security	Quarterdeck/Entry Control	J
	Special Security Office	J
Operations	Watch Center	A
	Analysis Operations	J
Maintenance	Maintenance	J
Training	Training	J
IT Logistics Support Space	IT Logistics Support Space	J
Equipment	Specialized Equipment	A

Legend:
A – Approved without additional justification (based on the staffing and mission requirements)
J – Only approved with specific justification of mission requirements
(1). This requirement should be captured under CCN 740 45. Fitness Rooms are only allowed in accordance with CNICINST 1710.1 where by the command is located more than a 15- minute commute by vehicle from the nearest Morale Welfare and Recreation (MWR) Fitness Center, or in cases where service members are required to be on station and unable to leave for 18 hours at any given time. The fitness room must also have approval from the Installation Commanding Officer.

Figure 13150-1. Transmitter Building Building Blocks Diagram



131 55 CIRCULARLY DISPOSED ANTENNA ARRAY BUILDING (SF)
FAC: 1311
BFR Required: N

13155-1 **DEFINITION.** A Circularly Disposed Antenna Array (CDAA) Building is a High Frequency Direction Finding (HFDF) facility that contains the tuning and receiving equipment associated with the AN/FRD-10 antenna. Category Code 131 55 is specific to Naval Security Group Activity (NSGA) locations. It is a technical and operational requirement that the CDAA building be located within the center of the AN/FRD-10 array. The AN/FRD-10, commonly referred to as a Wullenweber antenna, requires specific siting criteria as outlined in NSGINST 2450.1. The CDAA building also contains staff and personnel support spaces, maintenance and training spaces, and storage spaces.

13155-2 The Department of Navy no longer maintains a HFDF mission. As a result, Circularly Disposed Antenna Array Buildings contained within inventory are in the process of being demolished, or are have been converted for use in other category codes. Category Code 131 55 is provided for information purposes only.

131 56 DIRECTION FINDER BUILDING (SF)
FAC: 1311
BFR Required: N

13156-1 **DEFINITION**. A Direction Finder Building is a High Frequency Direction Finding (HFDF) facility that contains the tuning and receiving equipment associated with the AN/FRD-13 antennas. It is associated with functions performed by various DON Communications, Intelligence, and Operational missions. Unlike the CDAA (131-55), the Direction Finder Building is not located within the center of the AN/FRD-13 array, and it contains very limited personnel support space, maintenance space, and storage space. The AN/FRD-13 requires specific siting criteria as outlined in NSGINST 2450.1.

13156-2 DON no longer maintains a HFDF mission. As a result, Direction Finder Buildings contained within inventory are in the process of being demolished, or are have been converted for use in other category codes. Category Code 131 56 is provided for information purposes only and should not be used.

131 60 MILITARY AFFILIATE RADIO STATION (MARS) (SF)
FAC: 1311
BFR Required: N

13160-1 This category code is for inventory purposes only until the function is either absorbed into Category Code 131 15 or is eliminated completely and facilities are reassigned to other functions.

131 65 COMMUNICATIONS ANALYSIS FACILITY (SF) [DELETE]
FAC: 1311
BFR Required: Y

13165-1 This category is deleted. All future requirements should be reassigned and revised to Category Code 13115 “Communications, Information, or Intelligence Analysis Facility.”

132 COMMUNICATIONS-OTHER THAN BUILDINGS

132-1 This facility group encompasses radio antennas, switching stations and public address systems. The antennas required are a function of the number and type of radio circuits to be incorporated in the communications system.

132 10 ANTENNA-COMMUNICATIONS (EA)
FAC: 1321
BFR Required: N

13210-1 Planning for communications antennas involves consideration of three basic aspects: siting, selection of types, and structures for support.

13210-2 Requirements for siting, arrangements, types of antennas, circuitry, and other aspects, are determined by the Space and Warfare Systems Command (SPAWAR) and the office having support responsibility. The antenna types and their heights are:

Uniform lattice (guyed)	to 1500 feet
Uniform lattice (self-supporting)	to 600 feet
Pole	to 220 feet

13210-3 Vertical radiators make use of the tower structure as the radiator. The SPAWAR Systems Command provides the electronic specifications for vertical radiator antennas. The Naval Facilities Engineering Command provides the structural design.

13210-4 The majority of antenna installations used at radio communications facilities are tower/pole and wire construction. These are:

- Antenna system supported between self-supporting or guyed towers, transmitting/receiving
- Vertical radiator, transmitting only
- Rhombic, transmitting/receiving

- Tilted folded doublet transmitting/receiving
- Vee, transmitting/receiving
- Horizontal LF, transmitting/receiving
- Vertical doublet transmitting/receiving
- Horizontal parasitic doublet, transmitting/receiving
- Horizontal two-wire doublet, transmitting only
- Horizontal three-wire doublet, transmitting only
- Various UHF and VHF antennas
- Rotatable log periodic, transmitting/receiving (tower supported)
- Horizontal log periodic, transmitting/receiving (tower supported)
- Vertical log periodic, transmitting/receiving (tower supported)
- Conical monopole, transmitting/receiving (tower supported)
- Discone, transmitting/receiving
- Inverted cone, transmitting/receiving
- Wire grid lens, receiving only
- Wullenweber, receiving only (Code 132 55)
- High take off angle, transmitting/receiving (tower supported)
- Hermes loop array, receiving only
- Umbrella top-loaded monopole, transmitting (tower supported)
- Inverted-L, transmitting (tower supported)
- T-antennas, transmitting (tower supported)
- Various VLF antennas, transmitting/receiving

132 50 PUBLIC ADDRESS SYSTEM - OUTDOOR (EA)
FAC: 1321
BFR Required: N

Design Criteria: UFC 4-021-01, Design and O&M: Mass Notification Systems

13250-1 Outdoor public address systems will be planned and installed to meet individual needs of a facility.

132 55 CIRCULARLY DISPOSED ANTENNA ARRAY (WULLENWEBER) (EA)
FAC: 1321
BFR Required: N

13255-1 This antenna array is generally planned in conjunction with a Circularly Disposed Antenna Array Building. See Category Code 131 55 for additional guidance.

13255-2 The Department of Navy no longer maintains a HFDF mission. As a result, Circularly Disposed Antenna Arrays contained within inventory are in the process of being demolished or have been converted for use in other category codes. Category Code 132 55 is provided for information purposes only and should not be used.

133 NAVIGATION AND TRAFFIC AIDS – BUILDINGS (NON-SHIP)

133-1 **DESCRIPTION.** Basic Category Code group 133 applies to those Air Traffic Control Facilities (ATCFs) that contain the equipment, devices, and personnel responsible for air traffic control and navigational aids. This group discusses complete air traffic control classes and systems, which are defined below. Other elements of air traffic control and navigation aids that are remotely located around the airfield can be found in the 133, 134 and 135 series of Category Codes.

133-1.1 **Air Traffic Control Facility (ATCF).** The ATCF includes personnel and equipment associated with the operation of the following:

- Control Tower
- Approach Control
- Terminal Radar
- En Route Radar
- Flight Planning
- Air Navigational Aids

The standard ATCF serves as the foundation for all other ATCF planning standards by establishing a common baseline for ACTF resource determinations. Addressed within the standard are the needs for ATCF classification, the concepts used for standard development, descriptions of the services provided by ATCFs and definitions of the resulting six ATCF classes.

133-1.2 **ATCF Classification Scheme.** The approach to standard development, by definition, is the process of arranging items into groups based on the systematic division of common traits. The underlying principle for establishing a classification scheme is that each resultant class must encompass common elements. Since Navy Air Traffic Control (ATC) is one of a large number of closely interrelated elements collectively supporting the naval aviation mission, the classification scheme must identify all elements that bear upon the performance of ATC and analyze each for commonality across the spectrum of ATCFs. The ATCF classification scheme, by segregating ATC services into groups, establishes six major classes as shown in Table 133-1.

Table 133-1 ATCF Classification Scheme

Class	Description
Class I	Flight Planning Facility
Class II	Control Tower Facility

Class	Description
Class III	Control Tower with Ground Control Approach (GCA) Facility (Class III ATCFs can be further identified by GCA pattern control authority, i.e., with or without)
Class IV	Approach Control Facility
Class V	Joint Control Facility
Class VI	Fleet Area Control and Surveillance Facility

133-1.3 **ATC Services.** ATC services include five distinct directives that are provided slightly or in combination at every ATCF:

133-1.3.1 **Flight Assistance Service.** The planning of a flight is the first element of an air operation. Safety of flight is dependent on thorough flight planning covering itinerary, times, and weather. Flight assistance services interface the flight crew with the air traffic control system and encompass work, space, personnel, equipment, and information related to:

- Planning a flight.
- Introducing the plan into the ATC system.

133-1.3.2**Airport Traffic Control Service.** Airport traffic control encompasses those services provided to aircraft operating within the airport traffic area or on the airport surface. They include:

- Issuing control instructions to provide sequencing to assure the orderly and expeditious movement of aircraft departing, landing, or approaching the airport or landing.
- Furnishing information to pilots concerning clearances to operate aircraft, weather and field conditions, and pertinent operating and procedural instructions.
- Relaying aircraft operation and control messages between pilots and other air traffic facilities.
- Notifying crash and rescue agencies during actual or potential accidents on or in the vicinity of the airport. These services are somewhat unique as they are the only services that are location sensitive; using today's technology, they also require an elevated structure and visual contact.

133-1.3.3**Low Approach and Landing Service.** This service permits aircraft to be recovered when weather ceilings and visibility are less than that prescribed for Instrument Approach Procedures (IAPs) predicated on the non-precision air navigational aids. The service encompasses:

- Issuing control instructions to provide separation to aircraft approaching for landing under marginal weather conditions.
- Providing control instructions and information to align aircraft in azimuth and altitude so an optimum touchdown point on the landing surface may be reached.

133-1.3.4**Terminal Area Control Service.** Terminal area control services provide separation and control of aircraft operating in the relatively dense air traffic environment surrounding major airports. Services are exclusive to those performed as part of airport traffic control and low approach and landing services. This service includes:

- Separation and control of departing and arriving aircraft operating under Instrument Flight Rules (IFR).
- Separation and control of transiting aircraft operating under IFR.
- Separation and control of aircraft operating under Visual Flight Rules (VFR) that desire the added margin of safety afforded by such control.

133-1.3.5 **Range Control (Air) Service.** Range control (air) services combine both ATC in the classic sense, i.e., separating aircraft from each other or obstructions, and the provisions of combat direction and/or range surveillance. Services are mission-oriented and encompass:

- Mission aircraft flight-following.
- Mission aircraft direction.
- National Airspace System Interface.

133-1.4 **ATCF Class Definitions**.

133-1.4.1**Class I**. Flight Planning Activity (also known as an Air Operations Building, Category Code 141 40). An ATCF organized, manned, and equipped to provide flight assistance services to aircrews including flight planning and flight safeguarding services. The air operations building is generally located on the edge of the airfield adjacent to the air traffic control tower and Military Terminal Radar Approach Control Facility (MTRACON), Category Code 133-72.

133-1.4.2**Class II.** Control Tower (Category Code 141 70). An ATCF organized, manned, and equipped to provide airport traffic control services including: air traffic sequencing to aircraft airborne within the airport traffic area; authority for aircraft to land or takeoff from runways, or heliports; and control of aircraft and vehicles on the surface within the movement area to ensure safe, orderly, and expeditious aircraft movement. Unless modified by letter of agreement, the air traffic control clearance authority vested in the tower is limited to that permitted operation in accordance with VFR; although IFR or special VFR air traffic control clearances, originated by other tower facilities having such authority, may be relayed by the tower. Flight assistance services may also be provided. The air traffic control tower facility is generally located on the edge of the airfield, situated to have an unobstructed line-of-sight to the aircraft approach areas, runways, taxiways, aircraft parking areas, and other operational areas over which aircraft movements are to be controlled. Provide tower location and height to result in lower cab eye level line of site intersecting airport traffic surfaces at a vertical angle of 35 minutes or greater.

133-1.4.3 **Class IIIA/IIIB**. Control Tower/Ground Control Approach (GCA) Facility (also referred to as a Radar Air Traffic Control Facility (RATCF), Category Code 133 71). An ATCF is organized, manned, and equipped to provide air traffic control and low approach and landing services, including: air traffic sequencing to aircraft airborne within the airport traffic area; authority for aircraft to land or takeoff from runways, or heliports; control of aircraft and vehicles on the surface within the movement area; and control instructions to aircraft during the intermediate and final approach segments (Class IIIA) to ensure safe, orderly, and expeditious aircraft movement. Unless modified by letter of agreement, the air traffic control clearance authority vested in the control tower is limited to that permitted for operation in accordance with VFR, although IFR and special VFR air traffic control clearances, originated by other facilities having such authority, may be relayed or issued. Likewise, GCA control authority may be extended beyond the intermediate fix when authorized by letter of agreement (Class IIIB). Flight assistance services may also be provided. This facility is generally located adjacent to the air traffic control tower.

133-1.4.4 **Class IV**. Approach Control Facility (also referred to as a Military Terminal Radar Approach Control Facility (MTRACON), Category Code 133-72). An ATCF organized, manned, and equipped to provide airport traffic control and terminal area services including separation and control to arriving, departing, and occasionally en route aircraft operating in accordance with IFR and, when appropriate, VFR within airspace assigned for the purpose by letter of agreement, to ensure safe, orderly, and expeditious aircraft movement. Service to the primary airport include air traffic sequencing to airborne aircraft within the traffic area; authority for aircraft to land or take off from runways or heliports; and control of aircraft and vehicles on the surface within the movement area. These facilities are authorized to originate IFR and special VFR air traffic control clearances for aircraft landing and departing airports within their assigned area of responsibility or transiting airspace under their control jurisdiction, including instrument approach and departure clearances. They may also provide low approach and landing and flight assistance services. This facility is generally located adjacent to the air traffic control tower and aircraft operations building where site requirements permit.

133-1.4.5 **Class V**. Joint Control Facility (JCF) (Category Code 133 74). A combined air ATCF and Range Operations Center (ROC), organized, manned, and equipped to provide Class II, IIIA/B, or IV services and range control services. ROC services may include aircraft control, separation, positioning, tracking, and target scoring. ROC operational jurisdiction is typically limited to special use airspace (restricted areas, Military Operations Areas (MOAs), or ATC Assigned Airspace (ATCAA)). The JCF is located adjacent to the air operations building when site criteria allows. An air traffic control tower may be sited with the JCF.

133-1.4.6 **Class VI**. Fleet Area Control and Surveillance (FACSFAC) (Category Code 133 73). A FACSFAC is an ATCF facility defined as an organization of personnel and equipment designated, equipped, and manned to manage offshore and inland operating areas, as required, dedicated for military use. The mission of a FACSFAC is to manage military use of Offshore Operating Areas (OPAREAS) through coordination, scheduling, and control, if applicable, of subsurface, surface, and airborne military platforms operating within and transiting to and from these areas. FACSFACs are established as an intermediate level facility between that of a Military Radar Unit (MRU) and an ATCF. Prior to being upgraded from a MRU level facility to an intermediate level ATCF, FACSFACs must comply with the following requirements:

- Possess flight check data depicting areas of radio/radar coverage.
- Possess radar/radio communication redundancy in areas routinely used for national airspace interface.
- Validate operator training programs by assuring compliance with FAA, OPNAV, and FACSFAC personnel qualification standards.
- Implement comptroller certification standards in compliance with FAA publications and the OPNAVINST 3721.1K.
- Possess auxiliary power to support the Fleet Area Control System (FACS) in the event of loss of commercial power.
- Obtain FACS interface certification with the FAA.

Each FACSFAC is tailored to meet the operational needs of a specific area in direct support of the fleet operational requirements. For purposes of identification, equipment and personnel control, each FACSFAC, at time of commissioning, is placed under the operational control of the supported command; administrative control is through the local commander; and technical support is received from Naval Electronic Systems Command (NAVELEX). Each FACSFAC is a stand-alone facility. Table 133-2 defines each of the six different types of ATCFs with their respective facility nomenclature in tabular form.

TABLE 133-2. ATCF CLASSES AND FACILITY NOMENCLATURE

Class ATC Facility	Air Operations Building	Control Tower	RATCF	MTRACON	JCF	FACSFAC
1	X					
2	X	X				
3	X	X	X			
4	X	X		X		
5	X	X			X	
6						X

133 15 RADAR WIND SOUNDING (RAWIN) BUILDING
FAC: 1331
BFR Required: Y

13315-1 **DEFINITION.** A RAWIN building (Radar Wind Sounding) is a specialized weather reporting facility. It houses tracking equipment used in conjunction with balloon-borne radiosonde transmitters.

13315-2 **GENERAL**. An engineering analysis is required to determine facility space allocations.

133 20 VERY HIGH FREQUENCY OMNI-DIRECTIONAL RANGE FACILITY (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13320-1 **DEFINITION.** The Very High Frequency (VHF) Omni-Directional Range (VOR) building houses a VHF, fixed ground-based station which continuously transmits bearing, identification, and with proper equipment, distance information to properly equipped aircraft.

13320-2 **REQUIREMENTS.** A gross area of 28 M2 (300 SF) is provided for the electronic equipment, monitoring and test equipment, and mechanical equipment. A vehicle access road is required.

13320-3 **SITE PLANNING.** Any facility located within the Airfield Safety Clearance Zone as defined by NAVFAC P-80.3 requires a criteria waiver approved by COMNAVAIRSYSCOM (Code 09Y1). Any equipment that must be located in violation of the Safety Clearance Zone criteria shall be coordinated with the In Service Engineering Agent (ISEA). The ISEA must ensure that such equipment will be sited as far as possible away from the operating surface toward the outer limits of the NAVFAC P-80.3 criteria.

133 25 TACTICAL AIR NAVIGATION (TACAN) BUILDING (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13325-1 **DEFINITION**. The Tactical Air Navigation (TACAN) Building houses UHF ground-based station which transmits bearing, identification, and distance information to properly equipped aircraft. The TACAN is primarily a military short-range 322 km (200 mile) navigational aid that is generally planned for each Navy and Marine Corps air station.

13325-2 **REQUIREMENTS**. A TACAN building is not required at those air stations which can be serviced by a TACAN or VORTAC of a nearby airfield, either military or civilian. A gross area of 28 M2 (300 SF) is provided for the electronic equipment, monitoring and test equipment, and mechanical equipment. A vehicle access road is required.

13325-3 **SITE PLANNING**. Any facility located within the Airfield Safety Clearance Zone as defined by NAVFAC P-80.3 requires a criteria waiver approved by COMNAVAIRSYSCOM (Code 09Y1). Any equipment that must be located in violation of the Safety Clearance Zone criteria shall be coordinated with the In Service Engineering Agent (ISEA). The ISEA must ensure that such equipment will be sited as far as possible away from the operating surface toward the outer limits of the NAVFAC P-80.3 criteria.

133 30 VERY HIGH FREQUENCY (VHF) OMNI-DIRECTIONAL RANGE/TACTICAL AIR NAVIGATION (VORTAC) BUILDING (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13330-1 **DEFINITION.** The Very High Frequency (VHF) Omni-Directional Range/Tactical Air Navigation (VORTAC) Building houses VHF/UHF fixed ground-based station that continuously transmits bearing, identification, and distance information to properly equipped aircraft when distance measuring equipment (DME) is installed.

13330-2 **REQUIREMENTS**. A gross area of 28 M2 (300 SF) is provided for the electronic equipment, monitoring and test equipment, and mechanical equipment. A vehicle access road is required.

13330-3 **SITE PLANNING**. Any facility located within the Airfield Safety Clearance Zone as defined by NAVFAC P-80.3 requires a criteria waiver approved by COMNAVAIRSYSCOM (Code 09Y1). Any equipment that must be located in violation of the Safety Clearance Zone criteria shall be coordinated with the In Service Engineering Agent (ISEA). The ISEA must ensure that such equipment will be sited as far as possible away from the operating surface toward the outer limits of the NAVFAC P-80.3 criteria.

133 35 NON-DIRECTIONAL BEACON (NDB) FACILITY (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: None Available.
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13335-1 **DEFINITION**. This Non-Directional Beacon (NDB) facility is an unattended facility which houses electric equipment (radio beacon) used to transmit a non-directional radio signal pattern to aircraft equipped with Automatic Radio Direction and Finding (ADF) equipment. The signal is used by the aircraft for homing and radio fix assistance. The radio beacon may be employed for voice or tone modulated transmission. The facility consists of an equipment building with adjoining or adjacent space with emergency standby power and an antenna mounted on an antenna support.

13335-2 **REQUIREMENTS.** The facility is required at all Navy and Marine Corps air stations unless other navigational aid facilities obviate the need. The NDN is located on or adjacent to the airport. Metal buildings, power lines, or metal fences should be kept a minimum of 30.5 meters (100 feet) from the NDB antenna. The building area is 11.2 M2 (120 gross SF) and requires an antenna support.

13335-3 **SITE PLANNING.** NDB may be located either on or off the station with specific siting satisfactory to NAVAIRSYSCOM and NAVELEXSYSCOM.

133 65 AIR NAVIGATION BUILDING (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: None Available.

Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13365-1 **DEFINITION**. An Air Navigation Building is a specialized facility for providing a readily available source of operational and aeronautical intelligence information; storage and issue of aeronautical maps and charts; and secure storage of classified material up to TOP SECRET documents.

13365-2 **REQUIREMENTS.** There are two types of air navigation buildings:

13365-2.1 **Type A Building.** A Type A building requires a gross area of 417 M2 (4,487 SF) and is planned for flight support air stations having an area command mission.

13365-2.2 **Type B Building.** A Type B building requires a gross area of 1,010 M2 (10,863 SF) and is planned for those stations having logistics support for a major area command such as COMNAVAIRLANT or COMNAVAIRPAC.

13365-3 **SECURE STORAGE.** Secure storage areas are provided in conformance with OPNAVINST 5510.1 (latest revision).

133 71 RADAR AIR TRAFFIC CONTROL FACILITY (RATCF) (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13371-1 **DEFINITION.** The Radar Air Traffic Control Facility (RATCF) provides housing for equipment and personnel to support Instrument Flight Rules (IFR) control of aircraft on approach to or departure from the terminal radar facility or airport. Other functions include Precision Approach Radar (PAR) for landing aircraft during inclement weather and limited visibility. It provides space for an IFR control room that contains radar display consoles and communications terminals, equipment rack storage for communications terminal equipment, a ready room for Air Traffic Control (ATC) watch standers, a training room, and office area for supervision and control.

13371-1.1 **Components.** The RATCF, a Class IIIA/IIIB activity, contains the Control Tower/Ground Controlled Approach (GCA) Facility. An Air Traffic Control Facility (ATCF) organized, manned, and equipped to provide air traffic control and low approach and landing services, including:

- Air traffic sequencing to aircraft airborne within the airport traffic area.
- Authority for aircraft to land or takeoff from runways or heliports.
- Control of aircraft and vehicles on the surface within the movement area.

- Control instructions to aircraft during the intermediate and final approach segments (Class IIIA) to ensure safe, orderly, and expeditious aircraft movement.

13371-1.2 **Control Authority.** Unless modified by letter of agreement, the air traffic control clearance authority vested in the control tower is limited to that permitted for operation in accordance with Visual Flight Rules (VFR), although IFR and special VFR air traffic control clearances, originated by other facilities having such authority, may be relayed or issued. Likewise, GCA control authority may be extended beyond the intermediate fix when authorized by letter of agreement (Class IIIB). Flight assistance services may also be provided. Consult Basic Category Code 133 information for additional ATCF class information.

13371-2 **REQUIREMENTS.** The facility space allowance is 402 M2 (4,320 SF) gross area which includes mechanical equipment room.

13371-3 **SITE PLANNING**. The facility should be sited adjacent to the air traffic control tower when site conditions permit.

133 72 MILITARY TERMINAL RADAR APPROACH CONTROL FACILITY (MTRACON) (FORMERLY RATCC CENTER) (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13372-1 **DEFINITION**. A Military Terminal Radar Approach Control (MTRACON) Facility is used to control air traffic to provide safe, expeditious, and orderly movement of aircraft under all weather conditions. Justification for a MTRACON is established by the Chief of Naval Operations.

13372-1.1 **Components**. The MTRACON is a Class IV, Approach Control, Air Traffic Control Facility (ATCF). An ATCF is organized, manned, and equipped to provide airport traffic control and terminal area services including:

- Separation and control to arriving, departing, and occasionally en route aircraft operating in accordance with Instrument Flight Rules (IFR) and, when appropriate, Visual Flight Rules (VFR) within airspace assigned for the purpose by letter of agreement, to ensure safe, orderly, and expeditious aircraft movement.

- Air traffic sequencing to aircraft airborne within the airport traffic area.

- Authority for aircraft to land or takeoff from runways or heliports.
- Control of aircraft and vehicles on the surface within the movement area.
- Control instructions to aircraft during the intermediate and final approach segments (Class IIIA) to ensure safe, orderly, and expeditious aircraft movement.

These facilities are authorized to originate IFR and special VFR air traffic control clearances for aircraft landing or departing airports within their assigned area of responsibility or transiting airspace under their control jurisdiction, including instrument approach and departure clearances. They may also provide low approach and landing and flight assistance services. Consult Basic Category 133 information for additional ATCF class information.

13372-1.2 **Operation of a MTRACON.** NAVAIR 00-80T-114 promulgates policies affecting the establishment and operation of a MTRACON and its component radar systems. The area of jurisdiction for a MTRACON facility extends beyond the area of responsibility assigned to a Radar Air Traffic Control Facility (RATCF).

13372-2. The MTRACON radar facilities may consist of the Air Surveillance Radar (ASR) facility, Category Code 133 75, the Air Route Surveillance Radar (ARSR) facility, Category Code 133 76, and the Precision Approach Radar (PAR), Category Code 134 40, located on a turntable. Video information from each of these radars is transmitted to remote monitors in the MTRACON and control tower by underground cable or microwave relay.

13372-3 **SITE PLANNING.** Wherever practicable it is highly desirable that the MTRACON, the Control Tower, Attached/Free Standing, Category Code 141 70, and the Aircraft Operations Building, Category Code 141 40, be located together as an integral unit. If site conditions dictate the separation of the Air Operations Building and the Control Tower, the MTRACON should be collocated with the control tower, creating an integrated air traffic control facility.

13372-4 **REQUIREMENTS.** The MTRACON requires a gross area of 1,230 M2 (13,200 SF). The nerve center of the MTRACON is the control room which contains the radar monitors and communications modules. A radar and communications terminal equipment room houses the audio and video tape recorders as well as the automation central (or terminal) equipment. An office for the FAA liaison officer, training classroom, a ready room for radar controllers on work breaks, a Combined radar/ training chief office, leading chief office, MTRACON equipment maintenance and office space, an air traffic control officer’s office, and a proficiency trainer room are also provided. Space is also provided in the mechanical room for an emergency generator system and Uninterruptible Power Supply (UPS) system.

133 73 FLEET AREA CONTROL SURVEILLANCE FACILITY (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13373-1 **DEFINITION.** The Fleet Area Control Surveillance Facility (FACSFAC) building houses the FACSFAC Tracking System (FACTS) and Navy Tactical Data System/Advanced Combat Direction System (NTDS/ACDS) equipment and personnel to provide a variety of services to air, surface and subsurface units. These services are provided to both military and civilian users and include radar surveillance and various forms of air traffic control in warning and other special airspace areas. Other services include:

- Surface operating area management.
- Ground controlled intercept.
- Operating area scheduling.
- Range control.

The FACSFAC normally operates continuously, 24 hours per day, and 7 days per week.

13373-1.1 **Components.** The FACSFAC is a Class VI Air Traffic Control Facility (ATCF) and is defined as an organization of personnel and equipment designated, equipped, and manned to manage offshore and inland operating areas, as required. The mission of a FACSFAC is to manage military use of Offshore Operating Areas (OPAREAS) through coordination, scheduling, and control, if applicable, of subsurface, surface, and airborne military platforms operating within and transiting to and from these areas. FACSFACs are established as an intermediate level facility between that of a Military Radar Unit (MRU) and an ATCF. Prior to being upgraded from a MRU level facility to an intermediate level ATCF, FACSFACs must comply with the following requirements:

- Possess flight check data depicting areas of radio/radar coverage.
- Possess radar/radio communication redundancy in areas routinely used for national airspace interface.
- Validate operator training programs by assuring compliance with FAA, OPNAV, and FACSFAC personnel qualification standards.
- Implement comptroller certification standards in compliance with FAA publications, the OPNAVINST 3721.1K, and the NAVAIR 00-80T-114.
- Possess auxiliary power to support the Fleet Area Control System (FACS) in the event of loss of commercial power.
- Obtain FACS interface certification with the FAA.

Consult Basic Category Code series 133 for additional ATCF information.

13373-1.2 **Operational Organization**. Each FACSFAC is tailored to meet the operational needs of a specific area in direct support of the fleet operational requirements. For purposes of identification, equipment and personnel control, each FACSFAC, at time of commissioning, is placed under the operational control of the supported command; administrative control is through the local commander; technical support is received from Naval Electronic Systems Command (NAVELEX).

13373-1.3 **Functions.** The FACSFAC functions include:

- Radar Air Traffic Control and Area Management.
- Communications Monitoring and Control.
- Command Administration.
- Equipment Maintenance.
- Training and Briefings
- Computer Systems Management and Engineering.

13373-2 **SITE PLANNING.** Facility normally stands alone and can be sited either on or off Station.

13373-3 **REQUIREMENTS.** The standard size of the FACSFAC building is 2,570 M2 (27,650 SF) gross area. The mechanical space should include sufficient room for as emergency generator system and an Uninterruptible Power Supply (UPS) system. The size of the facility should be adjusted in accordance with the specific mission and number of personnel assigned.

133 74 JOINT CONTROL FACILITY (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13374-1 **DEFINITION.** The Joint Control Facility (JCF) is an air traffic control facility, a Radar Air Traffic Control Facility (RATCF), and a Range Operations Center (ROC) under one roof.

13374-1.1 **Components.** The JCF is a Class V Air Traffic Control Facility (ATCF). It is a combined air ATCF and ROC, organized, manned, and equipped to provide Class II, IIIA/B, or IV services and range control services. ROC services may include aircraft control, separation, positioning, tracking, and target scoring. ROC operational jurisdiction is typically limited to special use airspace (restricted areas, Military Operations Areas (MOAs), or ATC Assigned Airspace (ATCAA). The JCF is located adjacent to the air operations building when siting criteria allows. An air traffic control tower may be sited with the JCF. Consult Basic Category Code group 133 for additional ATCF class information.

13374-2 **REQUIREMENTS.** The specific functional areas to be provided include a main operations room where air traffic control radar display monitors and communications terminals are located; adjacent equipment spaces for communications devices, recorders and navigational aids; maintenance spaces for Ground Electronics Maintenance Division (GEMD) support personnel; and administrative spaces for command functions, training and personnel administration. The mechanical spaces should include sufficient space for an emergency generator system and Uninterruptible Power Supply (UPS) system. See Table 13374-1 for space allowances for the JCF facility.

Table 13374-1. Joint Control Facility Space Allowances

Type of Facility	Gross Area	
	M2	SF
Medium Density	3,156	33,970
High Density	3,670	39,500

13374-3 **SITE PLANNING.** The JCF should be located adjacent to the Air Operations Building when site conditions permit. The Air Traffic Control Tower, Category Code 141 70, should be sited with the JCF.

133 75 AIR SURVEILLANCE RADAR (ASR) FACILITY (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13375-1 **DEFINITION.** The Air Surveillance Radar (ASR) facility is an unattended facility which serves as a major component of the Radar Air Traffic Control Facility (RATCF), Category Code 133 71; the Military Terminal Approach Control Facility (MTRACON), Category Code 133 72; and the Joint Control Facility (JCF), Category Code 133 74. It provides detection and identification for control of aircraft operating in a line-of-sight range and altitudes determined by system design. The system also provides azimuth and range data and is remotely controlled by the air traffic control personnel via underground cables or microwave link. It consists of a rotating radar antenna mounted on a supporting tower, a transportable building which houses the electronic equipment, and a standby power plant installed in a separate transportable shelter. The facility and its antenna are located under the direction of Naval Electronics Systems Command (NAVELEX) and defined in the Base Electronic Systems Engineering Plan (BESEP).

13375-2 **SITE PLANNING.** The ASR is the standard terminal air traffic control surveillance radar for the Navy, Air Force, and FAA. It is a separate facility, housing radar transmitting, receiving, and monitoring equipment and maintenance personnel to provide detection and identification of aircraft transiting the area or executing and instrument approach or departure. The building and its associated antenna tower are located in a remote area of the airfield and an access road and emergency generator are required. Information derived from the ASR is transmitted to the MTRACON, RATCF, or JCF by underground cable or microwave link, and the ASR is remotely controlled from the MTRACON, RATCF, or JCF.

13375-3 **REQUIREMENTS.** The ASR facility has a gross area of 130 M2 (1,400 SF) including mechanical equipment room.

133 76 AIR ROUTE SURVEILLANCE RADAR (ARSR) FACILITY (M2/SF)
FAC: 1331
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13376-1 **DEFINITION.** The Air Route Surveillance Radar (ARSR) facility houses the electronic long range radar system used to obtain the range and azimuth of an aircraft. When equipped with an Air Traffic Control Radar Beacon System (ATCRBS), the Air Route Surveillance Radar System (ARSR) obtains altitude and identification of the aircraft. The ARSR has a range greater than that of an ASR, and as such, is used primarily for Fleet Area Control and Surveillance Facility (FACSFAC), Category Code 133 73 or Joint Control Facility (JCF), Category Code 133 74 functions. This facility is similar to the Air Surveillance Radar (ASR) facility, Category Code 133 75; the difference being that an ARSR is used to monitor a larger piece of airspace than an ASR. An ASR only controls overflight, approach, and departure flight paths at a terminal facility.

13376-2 **SITE PLANNING.** The ARSR building should be located adjacent to the radar facility antenna tower.

13376-3 **REQUIREMENTS.** The facility provides space primarily for the radar equipment systems, a small work bench for maintenance of system equipment, storage areas for spare parts and restroom if required. The ARSR facility has an gross area of 174 M2 (1,876 SF), including mechanical equipment room.

133 80 WHEELS WATCH SHELTER (EA)
FAC: 1331
BFR Required: Y

Design Criteria: Not Available

Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13380-1 **DESCRIPTION.** A portable wheels watch booth is provided with the runway Wheels-Up/Wave-Off Lighting system, Category Code 136 45. The shelter is located approximately 302 meters (990 feet) short of the runway threshold near the wheels-up/wave-off lighting system. The facility may be either a trailer or truck. Due to its location and access road and pad may be required and the shelter is an obstruction to airfield safety criteria, therefore a waiver is required from Naval Air Systems Command (NAVAIRSYSCOM) prior to its installation. Normally this requirement will be satisfied by portable equipment, Class III Property. However, this code may be used for planning purposes.

134 NAVIGATION AND TRAFFIC AIDS - OTHER (NON - SHIP)

134-1 **DEFINITION.** Basic Category Code group 134 applies to structures which function as aircraft navigation/ traffic aids.

134 10 ANTENNA - NAVIGATION (EA)
FAC: 1341
BFR Required: N

Design Criteria: Not Available
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13410-1 **DESCRIPTION.** An antenna system for navigation aid will vary with the type and purpose of the navigational aid. This Category Code shall be used to indicate entire antenna systems.

13410-2 **REQUIREMENT.** No specific planning factors are applicable.

134 20 AIRPORT AND/OR HELIPORT BEACON (EA)
FAC: 1341
BFR Required: N

Design Criteria: FAA AC 150/5345-12C; NAVAIR 51-50AAA-12
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13420-1 **DEFINITION.** An airport and/or heliport beacon is an internationally recognized rotating or flashing illuminated beacon operated as a visual aid to air navigation to assist aircrews in locating and identifying airports and/or heliports. Basic criteria on usage of airport and/or heliport beacons may be found in Federal Aviation Administration Advisory Circular 150/5345-12 (L-801H), (L-802A), and (L-803A) Specifications for Airport and Heliport Beacons.

13420-2 **REQUIREMENTS**. Three functional types of airport and/or heliport beacons are: airport rotating, identification or code, and heliport beacons. Requirements for each type are as follows:

13420-2.1 **Airport Rotating Beacon.** This is required for each airfield; with exception that two adjacent airfields may have a common beacon. A lighted military airport is identified by a beacon showing alternate flashes of two white and one green light. An unlighted military airport is identified by white flashes only.

13420-2.2 **Identification or Code Beacon.** This is required when the airport beacon is more than 1,520 meters (5,000 feet) from the nearest point of the usable landing area or where two or more adjacent airfields use one common airport beacon. The identification or code beacon is non-rotating and flashes a signal, the code and color of which identify the field. Where a heliport is not part of an airfield and an operational requirement has been established, an identification beacon is required.

13420-2.3 **Heliport Beacon.** This is a rotating beacon that provides identification for a lighted heliport when it is not clearly associated with an airfield. The beacon should alternately flash white, green, and yellow. It is not to be installed within one mile of an existing airfield beacon or runway.

13420-2.4 **Hazard Beacon.** A hazard or obstruction beacon is a non-rotating beacon with a flashing red light used where special warning is required to identify a hazard to air navigation and is incorporated in Category Code 134 50, Obstruction Lighting, Aircraft.

134 40 GROUND CONTROL APPROACH SYSTEM (EA)
FAC: 1341
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13440-1 **DEFINITION.** A Ground Control Approach (GCA) System is a radar approach system operated from the ground by air traffic control personnel transmitting instructions to the pilot by radio. The approach may be conducted with surveillance radar (ASR), Category Code 133 75, only or with both surveillance and precision approach radar (PAR), Category Code 134 41.

13440-1.1 **Components**. A GCA system is part of a Class IIIA Air Traffic Control Facility (ATCF), see Basic Category 133. An ATCF is organized, manned, and equipped to provide air traffic control and low approach and landing services, including: air traffic sequencing to aircraft airborne within the airport traffic area; authority for aircraft to land or takeoff from runways, or heliports; control of aircraft and vehicles on the surface within the movement area; and control instructions to aircraft during the intermediate and final approach segments to ensure safe, orderly, and expeditious aircraft movement. Unless modified by letter of agreement, the air traffic control clearance authority vested in the control tower is limited to that permitted for operation in accordance with Visual Flight Rules (VFR), although Instrument Flight Rules (IFR) and special VFR air traffic control clearances, originated by other facilities having such authority, may be relayed or issued. Likewise, GCA control authority may be extended beyond the intermediate fix when authorized by letter of agreement (Class IIIB). Flight assistance services may also be provided. The GCA system is generic in terms of name; therefore, the two components should be identified separately by their respective Category Codes.

134 41 PRECISION APPROACH RADAR (PAR) (EA)
FAC: 1341
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13441-1 **DEFINITION.** The Precision Approach Radar (PAR) is an unattended self-contained radar system. The PAR detects azimuth, elevation, and range information of aircraft on final landing approach to PAR instrumented runways. The information is displayed in the Military Terminal Radar Approach Control (MTRACON) Facility. The controller uses the information to direct the aircraft along the glide path to the visual portion of an instrument approach. A PAR is a self-contained transportable unit mounted either on a turntable or on fixed base.

13441-2 **REQUIREMENTS**. A reinforced concrete platform is provided for fixed mounted PAR. Reinforced concrete foundations are provided to support the turntable mounted PAR frame.

134 42 PRECISION APPROACH LANDING SYSTEM (PALS) (EA)
FAC: 1341
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13442-1 **DEFINITION**. The Precision Approach Landing System (PALS) is an unattended, self-contained radar system. The PALS detects azimuth, elevation, and range information of aircraft on final approach to PALS instrumented runways. This information is displayed in the Military Terminal Radar Approach Control (MTRACON)

Facility. The controller uses the information to direct the aircraft along the glide path to the visual portion of an instrument approach.

13442-2 **REQUIREMENTS**. Reinforced concrete foundations are required for the PALS antenna tower.

134 43 INSTRUMENT LANDING SYSTEM (ILS) (EA)
FAC: 1341
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13443-1 **DEFINITION**. The Instrument Landing System (ILS) provides azimuth, distance, elevation, and glide path position to aircraft on a precision approach to the ILS instrumented runway. The ILS operates in the VHF and UHF radio bands.

13443-2 **REQUIREMENTS**. The ILS consists of two stations, a localizer and antenna station, and a glide slope equipment station. The localizer station requires a 5.49 meter by 6.1 meter (18 foot by 20 foot) concrete pad for the building housing the localizer equipment and a 3.66 meter by 5.49 meter (12 foot by 18 foot) concrete pad for the glide slope equipment building.

13443-3 **SITE PLANNING**. Both stations are located near the ends of the runway and require access roads and a pull-off area for maintenance personnel.

134 44 MICROWAVE LANDING SYSTEM (MLS) (EA)
FAC: 1341
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13444-1 **DEFINITION**. The Microwave Landing System (MLS) provides azimuth, distance, elevation, and glide path position to aircraft on a precision approach to the MLS instrumented runway. The MLS operates in a narrow band microwave frequency.

13444-2 **REQUIREMENTS**. The MLS consists of two stations, an azimuth station and an elevation station. Each station requires a concrete foundation pad for the respective types of equipment. The azimuth station requires a 1.52 meter by 6.1 meter (5 foot by 20 foot) pad and the elevation station requires a 1.21 meter by 1.83 meter (4 foot by 6 foot) pad for the instrumentation device.

13444-3 **SITE PLANNING**. Both stations are located near the ends of the runway and require access roads and a pull-off area for maintenance personnel.

s

134 45 SHORE BASED AUTOMATIC CARRIER LANDING SYSTEM (EA)
FAC: 1341
BFR Required: Y

Design Criteria: None Available
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13445-1 **DEFINITION**. The Shore-based Automatic Carrier Landing System (ACLS) is an unattended, self-contained radar system. The ACLS consists of precision tracking radar coupled to a computer data link to provide continuous information to the aircraft, monitoring capability to the pilot, and a backup approach system. Four modes of approach are available, depending on aircraft equipment. In Mode 1 approaches, data-link-transmitted ACLS signals are coupled to the autopilot after ACLS radar lock-on and control the aircraft until touchdown. Mode 1A approaches differ from Mode 1 approaches in that data-link ACLS signals are uncoupled at ½ mile (approximately 61 meters (200 feet) altitude) from touchdown. Mode 2 approaches the pilot-controlled using data-link needles information displayed in the aircraft allowing the pilot to fly the aircraft to the minimums in effect. A Mode 3 approach is a controller talk-down approach using no special equipment on the aircraft.

13445-2 **REQUIREMENTS**. Reinforced concrete foundations are required for the Shore-based ACLS antenna tower.

134 50 OBSTRUCTION LIGHTING AND MARKINGS (EA)
FAC: 1341
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13450-1 **DEFINITION OF OBSTRUCTION**. An airfield obstruction is an object that extends above the air safety clearance surfaces established for the airfield. Any object that violates the clearance zone will be removed, if practical; reduced in height to below the hazard level; or marked as an obstruction. Standards for determining obstructions to air navigation have been established by U.S. Code and are published in Federal Aviation Regulations, Part 77, which covers "Objects Affecting Navigable Airspace."

13450-2 **OBSTRUCTION LIGHTING**. Obstruction lighting provides visual identification of objects at night, or in some cases in day times, that are potentially hazardous to air navigation.

13450-2.1 **Definition**. Obstruction lighting is a system of lights that define the vertical and horizontal limits of a hazard to aircraft operations. Hazardous conditions exist when any obstruction encroaches on the standard airfield clearance surfaces or an unsafe condition, such as construction, on the airfield exists. Obstruction lighting includes flashing beacons and steady burning lights, both of which are aviation red in color.

13450-2.2 **Requirements**. The configuration, type, and number of lights depend upon the height and type of obstruction to be identified and on its surroundings. For objects less than 45.7 meters (150 feet) in height only steady burning lights mounted at the top are used. For objects more than 45.7 meters (150 feet) in height a combination of one or more beacons and one or more levels of steady burning lights are used. For each required lighting level not less than one beacon or two lights will be visible at any azimuth angle and at all approach angles. Some obstructions may require several lights or beacons at each light level. Consult NAVAIR 51-50AAA-2 for additional lighting types that may be used.

In some instances, obstructions require higher intensity lighting to provide identification and adequate clearance of the object in restricted visibility, especially during daylight hours. These objects are typically tall antenna towers, transmission lines, and tall stacks or chimneys. It is recommended to use flashing higher intensity obstruction lighting systems that may be more effective and more economical to install and maintain where permitted. These lighting systems include high intensity white obstruction lights; medium intensity obstruction lights; and dual red and higher intensity white lights. Consult NAVAIR 51-50AAA-2 for the necessary lighting type. It is necessary to provide lighting on all obstructions so that visibility of the lighting is assured from any normal angle of approach and from any direction.

13450-3 **OBSTRUCTION MARKINGS.** Obstruction markings provide visual identification of objects that are potentially hazardous to safe air navigation and to warn aircrews of their presence during daytime flight operations. The markings for different types of obstructions vary depending on the nature of the object and its location. The types of markings or markers used for obstructions include painted markings; markers; and vehicle markings.

13450-3.1 **Painted Markings**. Painted markings are the most common form of obstruction marking. Most obstructions are marked by painting the surface. Obstruction marking colors are aviation orange and aviation white. Other colors sometimes used include yellow, black, red, and aluminum. Painted surfaces will change color with time by fading, cracking, and/or peeling. Repainting is a must. The size and shape of the obstruction determines the type of painting pattern used. Painting patterns include solid patterns, alternate color bands, checkerboard patterns, and teardrop patterns. Consult NAVAIR 51-50AAA-2 for additional pattern information.

13450-3.2 **Markers**. Markers are used where it is impractical to mark an obstruction by painting. Markers may also be used in addition to painted markings if such markers may improve the conspicuity of the obstruction. These markers are displayed in conspicuous positions on or adjacent to the obstructions so as to retain the general definition of the obstruction. Markers should not increase the hazard that they mark. The two types of markers used include spherical markers and flag markers. Consult NAVAIR 51-50AAA-2 for marker usage.

13450-3.3 **Vehicle Markings**. Vehicle markings exist on vehicles used in the aircraft operational areas of the airfield and are marked according to NAVAIR 51-50AAA-2.

134 55 VISUAL APPROACH SLOPE INDICATOR (VASI) SYSTEM (EA)
FAC: 1341
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13455-1 **DEFINITION.** The Visual Approach Slope Indicator (VASI) System is an unattended system that provides visual glide slope guidance to pilots of aircraft during the final landing approach. The VASI is helpful during day and night operations and for Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) operations. These requirements apply only for existing VASI installations. For complete replacement use Precision Approach Path Indicator (PAPI) System, Category Code 134 56.

13455-2 **CONFIGURATIONS**. The VASI system consists of several light units arranged in two and three bars near the edges of the runway in the touchdown zone. Each light unit projects a beam, fan-shaped in azimuth and split vertically with a white sector above and a red sector below. The light units are arranged in rows or bars on one or both sides of the runway. Each bar consists of two or three light units. If the bars are on both sides of the runway, the opposite bars shall be in the same line. The bar nearest the runway threshold is referred to as the downwind bar. The bar farthest from the threshold is the upwind bar. If the system has three bars, the bar between the others is the middle bar. A pilot making an approach and observing a two-bar VASI system will see one of the following configurations:

- On the established approach path angle, the downwind bar will be white and the upward bar will be red.

- Below the established approach path angle, both bars will be red.

- Above the established approach path angle, both bars will be white. In the transition sector where the light changes color, a narrow sector of the beam may appear to be pink. For a three-bar VASI system, which creates two approach path angles, the pilot uses the approach path angle established for his type of aircraft, and the third bar, although visible, is not part of the guidance system.

13455-3 **TYPES OF VASI SYSTEMS**. There are three types of VASI systems:

13455-3.1 **VASI-4 System.** This is a two-bar, four light unit system. There are two light units in each bar and are located only on one side, usually the left, of the runway. Some Navy airfields may have this system.

13455-3.2 **VASI-12 System**. This is a two-bar, twelve light unit system. There are three light units in each bar located on both sides of the runway. This is the system for joint use airfields with international civilian airline operations and some existing VASI installations at Navy airfields use this system.

13455-3.3 **VASI-16 System**. This is a three-bar, sixteen light unit system. There are three light units in each bar located on both sides of the runway for the downwind and middle bars and two lights on each side of the runway for the upwind bar. This system is used for airfields qualified for international civilian operations using large aircraft.

13455-4 **CRITERIA**. Conditions that may justify the requirement for a VASI installation are:

- The runway is used by aircraft with such characteristics that the approach angle must be maintained within close limits including speed and rate of descent.
- The runway is situation in an area where the pilots of some aircraft may have difficulty in judging the proper approach angle for any of the following reasons: 1) The approach is over water or featureless terrain that does not provide adequate visual cues; 2) Absence of sufficient extraneous lights in the approach area at night; or 3) Visual information is misleading, e.g., deceptive terrain or sloping runways may cause false impressions.
- Objects in the approach area that may be a serious hazard if an aircraft descends below the normal approach path.
- Conditions at the runway ends may present special hazards to aircraft undershooting or overrunning the runway.
- Terrain or meteorological conditions create severe or unusual turbulence along the approach path.

All light units are elevated lights and shall be installed on stable concrete pads or bases. Each leg support of the unit shall be mounted on a frangible coupling.

13455-5 **LOCATION OF VASI BARS.** The preferred locations are 184 meters (600 feet) from threshold to the downwind bar and at 213 meter (700 foot) intervals for the other one or two bars. The Runway Reference Point (RRP) is normally located midway between the downwind and upwind bars of two-bar VASIs or downwind and middle bar of three-bar VASIs installations. VASI bars may be placed at other than preferred locations, but the downwind bar shall not be less than 152 meters (500 feet) or more the 244 meters (800 feet) from runway threshold. The other bar or bars shall not be less than 152 meters (500 feet) or more than 274 meters (900 feet) from the adjacent bar.

13455-6 **LOCATION OF THE LIGHT UNITS**. The centerline of the innermost light unit of each bar shall be not less than 15.2 meters (50 feet) and not more than 18.3 meters (60 feet) from the runway edge and not less than 22.9 meters (75 feet) from the edge of any other runway, taxiway, or apron area. The innermost light units of all bars of the system shall be the same distance from the runway edge. The light units for each bar shall be equally spaced at 4.88 meters (16 feet) on center starting from the innermost light units. The elevation of the horizontal apertures of the light units shall be within 0.31 meters (12 inches) of the crown of the runway, except in areas with deep snow accumulations. There the light unit may be installed with the apertures not to exceed 1.22 meters (48 inches) above the ground surface. For installations with light units on both sides of the runway, the elevations of the lights on opposite sides shall not differ by more than 0.31 meters (12 inches). The apertures of the light units in a bar may have a tolerance of 0.03 meters (1 inch) horizontally and vertically from the line of the bar.

134 56 PRECISION APPROACH PATH INDICATOR (PAPI) SYSTEM (EA)
FAC: 1341
BFR Required: Y

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13456-1 **DEFINITION**. The Precision Approach Path Indicator (PAPI) System is an unattended system which provides visual glide slope guidance to pilots of aircraft during the final landing approach. The PAPI system provides this information during the day and night for Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) operations as low as Category I conditions.

13456-2 **REQUIREMENTS**. The PAPI system consists of four light source units arranged in a wing bar near the edges of the runway in the touchdown area. Each light unit consists of two or more lamps and projects a beam of light, fan-shaped in azimuth and split vertically with a white sector above and a red sector below the transition zone. Each light unit is aimed at a slightly different elevation angle to present a different color pattern to a pilot on final approach depending on his/her position relative to the established approach slope. When observed from the ideal approach slope the two inboard light units are seen as red and the two outboard units as white. If more light units are red, the pilot is too low, and if more are white, he/she is too high. The lights also provide information on how much too high or too low the pilot is. The four light units are operated simultaneously whenever this runway approach is active.

13456-3 **CRITERIA.** Conditions that may justify the requirement for a VASI installation are:

- The runway is used by aircraft with such characteristics that the approach angle must be maintained within close limits including speed and rate of descent.

- The runway is situation in an area where the pilots of some aircraft may have difficulty in judging the proper approach angle for any of the following reasons: 1) The approach is over water or featureless terrain that does not provide adequate visual cues; 2) Absence of sufficient extraneous lights in the approach area at night; or 3) Visual information is misleading, e.g., deceptive terrain or sloping runways may cause false impressions.

- Objects in the approach area that may be a serious hazard if an aircraft descends below the normal approach path.

- Conditions at the runway ends may present special hazards to aircraft undershooting or overrunning the runway.

- Terrain or meteorological conditions create severe or unusual turbulence along the approach path.

- The runway length is short and there is serious danger of overrun if the touchdown is long.

All light units shall be installed on stable concrete bases and mounted on a frangible coupling.

13456-4 **LOCATION OF PAPI SYSTEM**. The wing bar shall be in a horizontal line at 90 +/-1 degrees to the runway centerline and should be on the left hand side of the runway as observed from the approach zone. To avoid intersecting runways or taxiways or other major installation problems, the PAPI may be located on the right side of the runway. The individual light units shall not be more than 0.08 meters (3 inches) longitudinally or in elevation from the line for the wing bar. The elevation of the line of the wing bar at the exit lenses or windows should be not more with 15.2 meters (50 feet) preferred. The other units shall be equally spaced at 9.2 +/- 0.6 meters (30 +/-2 feet). The preferred distance of the wing bar upwind from the runway threshold should be 305 +/- 30.5 meters (1,000 +/-100 feet). The actual location of this wing bar may be affected by the following conditions:

- The preferred distance of the wing bar shall be such as to have the visual approach slope coincide with the established glide path angle of the Precision Approach Radar (PAR), the Instrument Landing System (ILS), or other precision electronic approach aid.
- No light source unit shall be less than 22.9 meters (75 feet) from the edge of any other runway or any taxiway.

- The preferred distance of the wing bar shall ensure the minimum wheel clearance at threshold, usually 9.2 meters (30 feet), of the most critical aircraft normally using the runway or of obstacle clearance when the pilot is at or above the transition sector from red to white for the light source unit with lowest vertical aiming angle.

- The preferred distance of the wing bar shall be adjusted to compensate for the differences in elevation between the light exit windows and the runway threshold for sloping runways or for extra high installations to clear snow accumulations.

- The preferred distance of the wing bar shall provide adequate landing distance for stopping the most critical aircraft using this approach.

134 60 OPTICAL LANDING AIDS (EA)
FAC: 1341
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13460-1 **DEFINITION.** Optical Landing Aids (OLA) provides the pilot approaching for a landing with a visual signal to assist in intercepting and maintaining the correct approach glide slope. The OLA is a required visual aid for landings on aircraft carriers, but on shore-based airfields the OLA is primarily an aid for training or practice. The OLA may be used during day or night operations and in all weather conditions.

13460-2 **REQUIREMENTS**. The OLA systems are located near the touchdown point on the runway and consist of the following lighting components:

13460-2.1 **Source Lights**. The source lights are a yellow line of lights or images often referred to as the “meatball”. Some systems present a red signal when the aircraft is too low. The source lights may be formed by reflections in a special mirror or a vertical stack of lens cells or closely spaced lights.

13460-2.2 **Datum Lights**. The datum lights are a horizontal bar of green lights that provide a visual reference for determining the aircraft’s position in relation to the ideal approach glide path. The datum lights bar is in two groups of lights with a group on each side of the source lights. The visual signals presented to a pilot making an approach for landing are the same as his/her position relative to the glide slope path. If the source light appears to be above the datum lights he/she is too high, or if the source light appears to be below the datum lights he/she is too low and should adjust his/her approach path angle to obtain the correct on glide path signal with the source light in line with the datum lights.

13460-2.3 **Wave-off Lights**. The wave-off lights are flashing red lights along each side of the source lights. The wave-off lights are activated only to inform the pilot that he must execute a missed approach procedure.

13460-2.4 **Cut Lights**. Some optical landing systems have flashing green lights located above the source lights which are activated to instruct the pilot of propeller-driven aircraft to cut engine power.

13460-2.5 **Mounting Pad**. The height of the mounting pad shall be at ground level to preclude the creation of an obstruction when the OLA system is relocated from the site. During the calibration process the optimum height of the OLA system can be achieved by placing blocks under the equipment trailer cart and/or the addition of load leveling jacks to the cart.

13460-3 **TYPES OF OLA SYSTEMS**. There are four types of OLA Systems. The FLOLS, MOLS and IFLOLS are fixed signal systems that automatically indicate to the pilot his/her position in relation to the established glide path. The MOVLAS is a temporary replacement system for which the LSO controls the position of the source ("meatball") light. The specifications for each of these systems are listed below.

13460-3.1 **Fresnel Lens Optical Landing System (FLOLS).** The FLOLS consists of five yellow source light cell assemblies arranged vertically, 12 green datum lights, 10 red wave-off lights, and some models have 4 green cut lights. The stack of lens cells are all lighted but usually only one cell is visible to the pilot. The relation of this cell to the datum lights indicates the pilot's position relative to the proper glide slope. These lights are trailer-mounted for portability to move from one site to another.

13460-3.2 **Mirror Optical Landing System (MOLS).** The MOLS consists of a special mirror, 8 yellow source lights, 12 green datum lights, 10 red wave-off lights, and may have two green cut lights and double obstruction lights. The mirror reflects the image of the source lights to provide the "meatball". The position of the "meatball" in relation to the line of datum lights indicates the pilot's position relative to the proper glide slope.

13460-3.3 **Manually Operated Visual Landing Aid System (MOVLAS).** The MOVLAS is an emergency system to be used when the FLOLS or MOLS is inoperable. The MOVLAS source light is operated by the Landing Signal Officer (LSO) using a special controller. The source lights are 23 lights arranged in two closely spaced vertical rows. The six lowest lights are red and the other 17 are yellow. Three lights at adjacent heights are operated to form the source lights. As the controller handle is moved upward, the source lights are switched on progressively towards the top in clusters of three. This gives an approaching pilot the signal to increase his elevation as directed by the LSO. The LSO therefore guides the pilot by signaling to raise or lower his/her altitude to achieve the proper glide slope. The MOVLAS is provided with 10 green datum lights, 8 red wave-off lights, and 2 green cut lights.

13460-3.4 **Improved Fresnel Lens Optical Landing System (IFLOLS).** The land-based MK 14 MOD 0 IFLOLS is the replacement system for the FLOLS MK 8 MOD 0 and MK 8 MOD 1 land-based systems. The IFLOLS consists of 12 cells which provide greater sensitivity and resolution to the light in the cell seen by the pilot ("meatball") than the FLOLS. The position of the "meatball" relative to the datum lights indicates to the pilot where he/she is relative to proper glide slope. The IFLOFS system also has greater acquisition distance than the FLOLS. The land-based IFLOLS is also trailer-mounted for easy portability.

13460-4 **CRITERIA FOR JUSTIFYING OLA EQUIPMENT**. Each runway landing area with or programmed for a simulated carrier deck lighting installation shall be provided with a site installation and OLA equipment. Most OLA systems are portable and may be moved to different sites as the approach runway is changed. The use of OLA is intended for runway ends with simulated carrier deck lighting. Airfields without simulated carrier deck lights may have a need for proficiency that justifies the installation of OLA sites and equipment.

13460-5 **LOCATION OF OLA EQUIPMENT**. The OLA site shall be located on the left hand side of the runway as viewed by the approaching pilots. If the OLA is associated with a simulated carrier deck installation, the face of the lens cells or mirror shall be located 131.1 meters (430 feet) forward of the ramp athwartship lights. If the OLA is an independent installation for a three degree glide slope, the preferred location of the face of the lens cells or mirror is 228.7 +/- 3.05 meters (750 +/-10 feet) forward of the runway threshold but may be influenced by the following factors:

- The glide path angle for the primary electronic approach system.
- Special threshold crossing height requirements.
- Special ground point intercept for the runway or instrument approach system.
- Approach zone obstruction clearance requirements.
- Intersecting runways or taxiways.

The mounting pad shall be located so that the centerline of the lens cells is not less than 35.1 meters (115 feet) from the runway centerline and not less than 3.05 meters (10 feet) from the runway edge. To preclude the mounting pad from becoming an airfield obstruction when the OLA is relocated, the height of the pad should be no higher than 0.05 – 0.08 meters (2-3 inches) above terrain level (almost at ground level). The required height of the OLA should then be achieved by the use of concrete blocks on the pad and/or jacking screws attached to the OLA. The mounting pad shall be 3.4 meters x 5.2 meters (11 feet x 17 feet), level, and have a permanent survey marker for correct location and alignment of the centerline of the FLOLS cells. At 45.7 meters (150 feet) toward the runway threshold from the position for the face of the cells on a line parallel to the runway centerline, a survey monument for the siting mirror station for the FLOLS shall be installed. This monument or pad shall have a permanent survey marker for correct location of this equipment and should be at the same elevation as the mounting pad.

NOTE: Any new OLA pads installed at simulated carrier deck lighting installations or proficiency installations shall be made to accommodate an IFLOLS configuration. Pad size 3.4 meters x 5.2 meters (11 feet x 17 feet), perpendicular to the simulated carrier deck centerline, with an elevation at terrain level.

134 62 WIND DIRECTION INDICATOR (EA)
FAC: 1341
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13462-1 **DEFINITION**. A Wind Direction Indicator provides visual information of the surface wind direction and general indication of the wind speed to the aircrew. This wind information is most useful during takeoff, for orientation to make an approach, and in the final phase of approach prior to touchdown.

Wind cones/socks are the most common type of wind direction indicators; however, wind tees do still exist and remain in this Category Code for inventory purposes. The "wind tee" is a "T" shaped rotating structure used at Navy and Marine Corps air installations as a navigational aid. It is positioned on the ground where it will be visible from all directions of approach and centrally located for identification and orientation from the air. The "wind tee" is outlined with green lights which, when lit, give it the appearance of a single green "T" when viewed from above. When the lights are not lit, it appears as a single stroke yellow "T". A background of crushed stone, gravel, or similar material that will retard the growth of vegetation and provide sharp contrast to the "wind tee" colors is provided.

13462-2 **REQUIREMENTS**. The standard wind direction indicator used on Navy and Marine Corps airfields is the 3.66 meter (12 foot) wind cone and is often called a wind sock. This wind cone is a fabric, truncated cone 3.66 meters (12 feet) long. The throat, or entrance for air into the cone is 0.91 meters (3 feet) in diameter to fit over the framework 1.37 meters (54 inches) long to hold the cone open. The color of the cone is orange or white and provides good contrast with its background when viewed from an altitude of 305 meters (1,000 feet). The support for the wind vane and illumination and obstruction lights, if used, is pivoted for lowering the cone and lights for maintenance. If the airfield or runways have lighted facilities for flight operations at night, the cone must be illuminated.

A 2.44 meter (8 foot) wind cone can be used for smaller, secondary airfields, heliports, or if necessary to locate the wind indicator closer than the standard runway. These wind cones are proportionately smaller than the larger size, be in contrast to their surroundings, have the same maintenance issues, and must be illuminated at night for visibility.

13462-3 **SITE PLANNING**. The location of the 3.66 meter (12 foot) wind cone is near the runway threshold not less than 122 meters (400 feet) from the centerline, preferably between 152 meters (500 feet) and 457 meters (1,500 feet) down the runway from the threshold. One wind cone may serve the ends of two runways if the distance from either runway centerline is not more than 305 meters (1,000 feet).

The location of the 2.44 meter (8 foot) wind cone is not less than 45.7 meters (150 feet) from the runway edge where clearance space or wind disturbances are not suitable for the 3.66 meter (12 foot) wind cone. If the wind cone is less than 91.4 meters (300 feet) from the runway edge, the support shall be low-mass or light-weight type.

134 64 RUNWAY DISTANCE MARKERS (EA)
FAC: 1341
BFR Required: N

> **Design Criteria:** NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Landbased Installations
> **Planning Criteria:** P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13464-1 **DEFINITION**. The purpose of Runway Distance Markers (RDMs) is to indicate to aircrews the distance remaining to the end of the runway during takeoff and landing. The RDM provide this information for day and night operations in all weather conditions. The RDM should be provided for all runways where fixed wing jet aircraft operations are conducted and are recommended for runways intended for operations of propeller type aircraft. If the runway is used for nighttime or low visibility Instrument Flight Rule (IFR) operations, the RDM must be internally illuminated. If the runway is only used for daytime operations, the RDM may have unlighted markers.

13464-2 **REQUIREMENTS**. The RDM consists of a row of vertical markers (signs) spaced along each side of the runway longitudinally. The faces of the markers are vertical. Each face of the marker indicates the distance in thousands of feet remaining to each end of the runway. The color scheme used is white numerals on a black background.

13464-3 **SITE PLANNING**. The rows of RDM are parallel to and equidistant from the runway centerline. A pair of markers on opposite sides of the runway is located at each 305 meter (1,000 foot) spacing. The lines connecting the pairs of markers are perpendicular to the runway centerline. The apex or edges of the markers nearest the runway in each row shall form a line not less than 15.2 meters (50 feet) and not more than 22.9 meters (75 feet) from the full strength runway edge. The 22.9 meter (75 foot) distance is preferred. The marker cannot be less than 15.2 meters (50 feet) from the edge of any intersecting runway or taxiway. Where the 305 meter (1,000 foot) positions do not provide clearance from an intersecting runway or taxiway, the position of the pair of markers may be moved a maximum of 30.5 meters (100 feet) to obtain the clearance.

For runways that are not exact multiples of 305 meters (1,000 feet), the extra distance is apportioned at the runway ends by the following equation:

$$E = (D - M)/2$$

E = the excess distance in feet to be added to the intervals at the runway ends.
D = the length of the runway in feet.
M = the distance in feet of the maximum number of 305 meter (1,000 foot) intervals.

Consult NAVAIR 51-50AAA-2 for additional information of marker siting and special site conditions. The markers are internally illuminated. Runway distance markers are planned for all Navy and Marine Corps installation.

134 66 VOR/TACAN CHECK SIGN (EA)
FAC: 1341
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13466-1 **DEFINITION**. A VOR/TACAN Check Sign provides information for the pilot when verifying the operation of the navigational aid in the aircraft before taking off. This check sign is a visual identification marker erected in the area adjacent to the aircraft holding point at the taxiway access to runway ends. The sign includes the type of navigational aid, identification code, radio channel, magnetic bearing, and the distance in nautical miles to the transmitting antenna from the checkpoint marking. It provides aircrew members with operational check information on the navigation equipment of the aircraft.

13466-2 **REQUIREMENTS**. The character height shall not be less than 0.18 meters (7 inches) or more than 0.20 meters (8 inches) high and the stroke width of not less than 0.03 meters (1 inch). The sign should have black characters on a yellow background and be similar in shape and color when lighted at night and unlighted during the daytime.

13466-3 **SITE PLANNING**. Check signs are planned for all runway ends at each air installation equipped with a tactical air navigation (TACAN), visual omni-directional range (VOR), or combined (VORTAC) installation.

134 70 RADAR TOWER (EA)
FAC: 1341
BFR Required: N

Design Criteria: None Available.
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13470-1 **REQUIREMENT.** Radar towers must be planned on an individual basis.

134 71 AVIATION METEOROLOGICAL FACILITY (EA)
FAC: 1341
BFR Required: Y

13471-1 **DEFINITION**. An AVI meteorological facility is a weather forecasting facility that supports air operations.

13471-2 **GENERAL.** . An engineering analysis is required to determine facility space allocations.

135 COMMUNICATION LINES

135 10 COMMUNICATION LINES OTHER THAN TELEPHONE (MI)
FAC: 1351
BFR Required: N

13510-1 Communication lines provide circuits between the various activities on or off the station. The communications net may include trunk line service cable, feeder lines, and direct circuits depending on the complexity of the system.

135 11 FIBER OPTIC COMMUNICATIONS LINES, UNDERGROUND IN CONDUIT (MI)
FAC: 1351
BFR Required: N

13511-1 **DEFINITION.** The communications lines are non-armored OM-2 Single mode Fiber Optic cables installed inside an underground duct.

135 12 FIBER OPTIC COMMUNICATIONS LINES, NON-CONDUCTIVE RISER RATED (EA)
FAC: 1351
BFR Required: N

13512-1 **DEFINITION.** The communications lines are non-armored OM-3 multimode Fiber Optic cables installed inside and underground duct.

135 13 FIBER OPTIC COMMUNICATIONS LINES, OUTSIDE PLANT, ARMORED (MI)
FAC: 1351
BFR Required: N

13513-1 **DEFINITION.** These communications lines are single mode, or multimode or mixed mode fiber rated for indoor and outdoor use for campus and/or building backbone installed in riser, conduit, and ducts or direct buried.

135 15 OPTICAL GROUND WIRE (MI)
FAC: 1351
BFR Required: N

13515-1 **DEFINITION.** Optical ground wire is for electrical power and optical communication between power substations in support of relay interconnects.

135 20 TELEPHONE LINES (MI)
FAC: 1351
BFR Required: N

13520-1 No specific criteria are available.

135 21 FIBER OPTIC COMMUNICATIONS LINES, OUTSIDE PLANT, MARINIZED (UNDERWATER / WETLAND) (MI)
FAC: 1351
BFR Required: N

13521-1 **DEFINITION.** The communication lines are underwater grade reinforced composite fiber cable used in aquatic conditions.

135 31 COPPER COMMUNICATIONS LINES, OUTSIDE PLANT, GEL FILLED (MI)
FAC: 1351
BFR Required: N

13531-1 **DEFINITION.** These types of communications lines are for indoor and outdoor use for campus and/or building backbone copper cable installed in riser, conduit, and ducts or direct buried.

135 32 COPPER COMMUNICATIONS LINES, OUTSIDE PLANT, AIR CORE (MI)
FAC: 1351
BFR Required: N

13532-1 **DEFINITION.** These types of communications lines are annealed reinforced composite copper cable used with air compressors to support continual drying.

135 33 COPPER COMMUNICATIONS LINES, OUTSIDE PLANT, MARINIZED (UNDERWATER / WETLAND) (MI)
FAC: 1351
BFR Required: N

13533-1 **DEFINITION.** These types of communications lines are underwater grade reinforced composite copper cable used in aquatic conditions.

135 34 COPPER COMMUNICATIONS LINES, OUTSIDE PLANT, ARMORED (MI)
FAC: 1351
BFR Required: N

13534-1 **DEFINITION.** These communications lines are bulk copper cable designed for direct burial condition installed directly in or above ground without conduit.

136 AIRFIELD PAVEMENT LIGHTING

136-1 **DEFINITION**. Airfield pavement lighting includes facilities for lighting all airfield pavements and approaches thereto. The purpose of this section is to provide the general requirements for airfield Visual Landing Aids for approaches, landings, takeoffs, taxiing, and surface maneuvering of aircraft on Navy and Marine Corps airfields. The visual landing aids include lighting and markings. The various lighting systems are planned with regard to other airfield related facilities so that integrated control is achieved, and the resultant overall lighting system is compatible with the operational mission of the air installation.

136-2 **CONDITIONS**. Based on missions assigned by CNO, lighting facilities are developed to meet Visual Flight Rules (VFR) or Instrument Flight Rules (IFR) conditions as defined in NAVAIR 51-50AAA-2 as follows:

136-2.1 **Visual Flight Rules (VFR).** These are rules which govern the procedures for conducting flights under visual conditions. The minimum conditions in which VFR operations are permitted is a minimum cloud ceiling height of 304.8 meters (1,000 feet) and ground visibility of 4.83 km (3 miles).

136-2.2 **Instrument Flight Rules (IFR).** These are rules governing procedures for conducting instrument flight. IFR flight operations are dependent upon pilots' use of instrument guidance. As a ceiling becomes lower or the visibility more restrictive, the more precise the electronic ad visual guidance must be as required for the following categories:

(1) Non-precision IFR: IFR operations that use non-precision electronic aids (TACAN, VORTAC, etc.) to provide directional guidance for straight-in approaches to a Minimum Decent Altitude (MDA) as low as 79.2 meters (260 feet) and 1.61 km (1 mile) visibility or 1,250 meters (5,000 feet) Runway Visual Range (RVR).

(2) Precision IFR, Category I: Requires precision electronic aids (ILS, PAR, or MLS) and visual aids for approach minimums of 60.9 meters (200 feet) Decision Height (DH) and 732 meters (2,400 feet) (some cases 488 meters (1,600 feet)) RVR.

(3) Precision IFR, Category II: Requires precision electronic aids (precision ILS or MLS) and visual aids for approach minimums of 30.5 meters (100 feet) DH and 366 meters (1,200 feet) RVR.

(4) Precision IFR, Category IIIA: Requires precision electronic aids (precision ILS or MLS) and visual aids for approach minimums of 0 meters (0 feet) DH and 213 meters (700 feet) RVR.

(5) Precision IFR, Category IIIB: Requires precision electronic aids (precision ILS or MLS) and visual aids for approach minimums of 0 meters (0 feet) DH and 45.7 meters (150 feet) RVR.

(6) Precision IFR, Category IIIC: Requires precision electronic aids (precision ILS or MLS) and visual aids for approach minimums of 0 meters (0 feet) DH and 0 meters (0 feet) RVR.

136-3 **REQUIREMENTS.** The types of approach visual aids required for an airfield depend on the kind of flight operations that will be performed. Flight operations are separated into VFR and IFR. Major airfields usually have both types of operations.

136-3.1 **Approach Visual Aids**. Approach visual aids associated with the different flight rules are indicated in Table 136-1.

Table 136-1. Approach Visual Aids Requirements

Visual Aids System		Authorized Operations						
		VFR	IFR Category					
			Non-Prec	I	II	IIIA	IIIB	IIIC
136-10	ALSF-1	NR	NR	R	NR	NR	NR	NR
136-10	ALSF-2	NR	NR	NR	R	R	R	R
136-10	MALSR	RS	RS	-	-	-	-	-
136-10	SALS	NR	RS	NR	NR	NR	NR	NR
136-30	Circling Guidance Lights	RS	RS	NR	NR	NR	NR	NR
136-60	REIL	C	C	-	NR	NR	NR	NR

C = Recommended
= Required. These visual aids are required for operating in the IFR Category, but other factors may negate approval for installation.
RS = Required under special conditions.
NR = Not required.

136-3.2 **Runway Approach Visual Aids.** The runway visual aids consist of markings and lighting installed near the runway. The runway lights include basic edge lights, low-intensity runway lights, and supplemental runway lights. The basic runway lights define the limits of the runway surface. These are edge lights, threshold lights, and runway end lights. Some runways may have displaced threshold lights and markings. The low-visibility runway lights are the centerline and touchdown zone lights. The supplemental runway lights may be runway exit lights, runway distance markers, and arresting gear markers. The configuration of the markings differs for the class of runway. The marking and types of lights may be different for runways on the same airfield. Runway visual aids associated with different flight rules are shown in Table 136-2.

Table 136-2. Runway Approach Visual Aids Requirements

Visual Aids System		Authorized Operations						
		VFR	IFR Category					
			Non-Prec	I	II	IIIA	IIIB	IIIC
	Runway Markings	R	R	R	R	R	R	IN
136-30	Runway Edge Lights (HIRL)	R	R	R	R	R	R	IN
136-30	Runway Edge Lights	R	R	R	R	R	R	IN
136-35	Runway Centerline Lights	NR	C	C	R	R	R	IN
136-55	Touchdown Zone Lights (TDZL)	NR	NR	OPT	R	R	R	IN
136-60	Displaced Threshold Lights and Markings	RS	RS	RS	RS	RS	RS	IN
136-60	Runway Threshold Lights and Markings	R	R	R	R	R	R	IN

C = Recommended
= Required. These visual aids are required for operating in the IFR Category, but other factors may negate approval for installation.
RS = Required under special conditions.
OPT = Option as recommended by Air Station Commander and approved by NAVAIRSYSCOM.
IN = Installation necessary.
NR = Not required.

136-3.3 **Taxiway Visual Aids**. The taxiway lights and markings identify the area as a taxiway, define its limits, and provide directional guidance for maneuvering aircraft. The signs provide information on routes to taxi destinations and identify areas along the taxi route. Taxiway markings are painted on the paved surfaces and include centerline, edge, holding position, and checkpoint markings. The taxiway lights include either edge lights, centerline lights, or a combination of both lights, and in some cases holding position lights. Taxiway guidance signs provide mandatory information that the pilot must recognize because of the existence of potential hazards. Also, general information is provided that assists the pilot in proceeding along the proper taxi route. Special signs may provide checkpoint information or routing information at complex intersections. The locations, types, and information on the signs vary for each taxiway. Taxiway visual aids associated with different flight rules are shown in Table 136-3.

Table 136-3.Taxiway Visual Aids Requirements

Visual Aids System	Authorized Operations						
	VFR	IFR Category					
		Non-Prec	I	II	IIIA	IIIB	IIIC
Taxiway Markings	R	R	R	R	R	R	R
Taxiway Edge Lights	R	R	R	R	C	C	C
Taxiway Centerline Lights, Intersections	NR	OPT	C	C	R	R	R
Taxiway Centerline Lights, Continuous	NR	NR	OPT	C	R	R	R
Taxiway Guidance Signs	RS	C	R	R	R	R	R
Special Signs (TACAN)	RS	RS	RS	RS	RS	RS	RS
Special Signs, Billboards	RS	RS	RS	RS	RS	RS	RS
Holding Position Signs	C	R	R	R	R	R	R
Holding Position Lights	RS	RS	RS	RS	RS	RS	RS
Taxiway Lights for Runways Used as Taxiways	RS	RS	RS	RS	RS	RS	RS

C =	Recommended
R =	Required.
RS =	Required under special conditions.
OPT =	Option as recommended by Air Station Commander and approved by NAVAIRSYSCOM.
NR =	Not required.

136-3.4 **Special Considerations**. The following airfield lighting requirements are determined by individual airfield needs as described under the referenced Category Code:

Approach Lighting	136 10
Apron and Parking Area Lighting and Markings	136 20
Runway Edge Lighting and Markings and Circling Guidance Lights	136 30
Runway Centerline Lighting and Markings	136 35
Simulated Carrier Deck Lighting and Markings	136 36
Wheels-Up/Wave-Off Lighting	136 45
Taxiway Lighting and Markings	136 50
Touchdown Zone Lighting and Markings	136 55
Threshold Lighting and Markings	136 60
Heliport Lighting and Marking Systems	136 65

Obstruction lighting, beacons, and other visual navigation and traffic aids are discussed under basic Category Code series 134. For airfield perimeter lighting, street lighting, and other general illumination, see Basic Category Code series 812, Electric Power – Transmission and Distribution Lines.

136 10 APPROACH LIGHTING (M/LF)
FAC: 1361
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13610-1 **DEFINITION.** Approach lighting enhances the aircrew's ability to acquire the runway environment visually when making an approach for landing during periods of reduced visibility. Visual cues for directional and roll guidance are provided to the aircrew for operations at night and in marginal weather conditions by day. The system includes both approach lights and sequenced flashers.

Approach lighting is provided for primary instrument approach runways. Planning of Category I, Category II, or Category III approach lighting systems is accomplished in accordance with mission requirements as listed in Basic Category 136. With sufficient justification approach lighting may also be authorized for other runways.

13610-2 **CONSIDERATIONS**. Factors to be considered in the justification of any approach lighting system include, but are not limited to:

- Existing and desired precision approach minimums.
- Number of actual instrument approaches.
- Climatology.
- Surface features, obstructions and feasibility of construction.

13610-3 **REQUIREMENTS**. Approach lights fall into three categories:

13610-3.1 **High Intensity Approach Lighting System (ALSF-1)**. The High Intensity Approach Lighting System, ALSF-1, is a system of light bars and barrettes in the approach zone immediately ahead of the runway threshold. The standard length of an ALSF-1 is 914 meters (3,000 feet) unless terrain or other local conditions prevent a full length installation. Then the length may be shortened to not less than 732 meters (2,400 feet). This shorter system can impact landing minimums. Approval from NAVAIRSYSCOM is required for systems shorter than 914 meters (3,000 feet). Systems that are between 427 meters (1,400 feet) and 701 meters (2,300 feet) are called Short Approach Lighting Systems (SALS). The ALSF-1 consists of centerline lighting barrettes, sequencing flashing lights, 305 meters (1,000 foot) crossbar, terminating bar, pre-threshold wing bars, and threshold lights (Category Code 136 60). The standard system extends from the threshold 914 meters (3,000 feet) into the approach area of the runway. A barrette is three or more lights closely spaced in a transverse line so that from a distance they appear as a single short illuminating bar. For the ALSF-1, the length of the barrette shall not exceed 4.57 meters (15 feet) and the center-to-center spacing of the lights shall not exceed 1.52 meter (5 feet).

13610-3.2 **High Intensity Approach Lighting System (ALSF-2).** The High Intensity Approach Lighting System, ALSF-2, is a system of light bars and barrettes in the approach zone immediately ahead of the runway threshold. This approach lighting system is intended for use where operation during Category II instrument flight conditions or lower weather minimums are required. The standard length of an ALSF-2 is 914 meters (3,000 feet) unless terrain or other local conditions prevent a full length installation. Then the length may be shortened to not less than 732 meters (2,400 feet). The plan for the ALSF-2 consists of centerline lighting barrettes, sequencing flashing lights, 305 meters (1,000 foot) crossbar, 152 meter (500 foot) crossbar, side row barrettes, and threshold lights (Category Code 136 60). A barrette is three or more lights closely spaced in a transverse line so that from a distance they appear as a short illuminating bar. For the ALSF-2, the length of the barrette shall not exceed 4.57 meters (15 feet) and the center-to-center spacing of the lights shall not exceed 1.52 meter (5 feet).

13610-3.3 **Medium Intensity Approach Lights (MALSR).** The MALSR is a medium intensity approach lighting system with runway alignment indicator lights. It is intended for installation at Naval airfields only in support of Visual Flight Rules (VFR) or non-precision instrument approaches where installation costs are a factor. The standard system consists of centerline lights, a 305 meters (1,000 foot) crossbar, and sequenced flashing lights. The centerline is coincident with the extended runway centerline. The overall system is 732 meters (2,400 feet) long, but may be shortened to as little as 427 meters (1,400 feet) where space or construction problems arise. Where systems are shortened to less than 610 meters (2,000 feet), flashers will be added to steady burning light stations to provide a minimum of three flashing lights.

136 20 APRON AND PARKING AREA LIGHTING AND MARKINGS (M/LF)
FAC: 1361
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13620-1 **DEFINITION**. Apron and parking area lighting enables the aircrew to guide their aircraft into position for loading, servicing, or parking and provides illumination to perform such functions as fueling, maintenance, loading, unloading, and security.

13620-2 **APRON MARKINGS**. Apron markings are the basic visual aid for taxiing in the apron area during daylight and to supplement the lights during night operations and for all meteorological conditions. The markings provide visual cues to aircrews for taxiing through a complex or congested area between the end of the taxiway and the final position for parking the aircraft. This area includes terminals, hangars, service areas, and taxiways. The apron markings include taxiway centerline and edge markings, shoulder or deceptive area markings for paved areas not intended for aircraft traffic, parking area markings, and special markings to identify destinations or to provide specific information.

13620-3 **APRON LIGHTING.** Lighting of apron and parking areas is accomplished by a combination of high and surface mounted floodlights and roadway luminaries. Apron and parking area lighting is provided at all air installations where night or all weather operations are conducted. The overall lighting scheme is developed after a study of the functions to be performed and the physical layout of pavements and structures of the particular airfield.

136 30 RUNWAY EDGE LIGHTING AND MARKINGS AND CIRCLING GUIDANCE LIGHTING (M/LF)
FAC: 1361
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13630-1 **DEFINITION**. This Category Code includes two groups of lights, Runway Edge Lights, which define the lateral limits of the pavement, and Circling Guidance Lights (CGLs), which enable an airborne aircrew to locate the runway while off to the side of the runway and establish the proper traffic pattern.

13630-2 **RUNWAY EDGE LIGHTING SYSTEM**. Runway edge lighting consists of three types of lights including: Low Intensity Runway Edge Lights (LIRL); Medium Intensity Runway Edge Lighting (MIRL); and High Intensity Runway Edge Lighting (HIRL). Runway edge lights are installed parallel to the runway centerline for the length of the runway. The intensity of edge lighting used depends upon dominant weather conditions over the airfield. Each type of runway edge lights defines the lateral limits of the usable runway surface for landings and takeoffs during nighttime operations and in reduced visibility. The runway edge lighting is a basic airfield lighting system. With its associated Threshold Lighting, Category Code 136 60, and runway end lighting, it can function without other lighting support. All runways intended for use at night or during Instrument Flight Rules (IFR) operations require edge lighting.

Edge lighting systems consists of two straight lines of lights with one line of lights located along each edge of the runway. The lights are equally spaced along the edge of the runway, bi-directional, and the emitted color shall be aviation white. For runways with displaced thresholds, edge lighting is installed at the edges of the displaced area if this area is used for rollouts and takeoffs. Edge lighting located in the displaced threshold area the color of the emitted light towards the approach zone shall be aviation red.

13630-2.1 **Edge Lights**. Runway edge lights are white lights equally spaced on each side of the runway with a maximum interval of 61 meters (200 feet). Runway edge lights are installed to provide visual guidance during takeoff and landing operations at night and under low visibility conditions. Requirements are expressed in terms of runway length; that is, runway lights programmed for a runway 3,200 meters (10,500 feet) long will be shown as 3,200 meters (10,500 feet) of runway lights. Consult NAVAIR 51-50AAA-2 for layout and spacing requirements.

13630-2.2 **Edge Markings**. Runway edge markings are continuous lines near each edge of the runway parallel to the runway centerline. The stripes are 0.914 meters (3 feet) wide. For runways 61 meters (200 feet) or less in width, the outer edge of these stripes shall be 0.61 meters (2 feet) from the nominal or designated edge of the runway. For runways more than 61 meters (200 feet) wide, the inner edges of the markings are 58 meters (190 feet) apart and symmetrical about the runway centerline. If the runway has a displaced threshold, the side stripes continue through the displaced section. Preferably, the edge markings extend to the runway ends but may terminate with the beginning of the threshold markings except where the threshold is displaced from the runway end. The color of the edge markings is retro-reflective white. Consult NAVAIR 51-50AAA-2 for layout and spacing requirements.

13630-3 **CIRCLING GUIDANCE LIGHTS**. Circling Guidance Lights (CGLs) are two straight lines of white lights with one line on each side of the runway with the beam emitted perpendicular to and away from the runway centerline. GCLs have a nominal 305 meter (l,000 foot) spacing and are placed outboard of the runway edge in line with the Runway Distance Markers, Category Code 134 64. They are used only for visual flight operations where conditions around the air installation, such as a metropolitan area or smog, confuse or obscure the runway when viewed from a circling aircraft. The need for circling guidance lights at a given air installation is determined by the particular airfield environment. Circling guidance lights requirements are also expressed in feet of runway length. Consult NAVAIR 51-50AAA-2 for layout and spacing requirements.

136 35 RUNWAY CENTERLINE LIGHTING AND MARKINGS (M/LF)
FAC: 1361
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13635-1 **RUNWAY CENTERLINE LIGHTING**. Runway centerline lighting provides visual aid to assist the aircrew in keeping the aircraft centered on the runway during take-off and after landing at night or in condition of reduced visibility. It is a supplement to Runway Edge Lighting and Markings and Circling Guidance Lighting, Category Code 136 30. White in-pavement lights are placed along the runway centerline at either 7.62 meter (25 foot) spacing of “tailhook resistant” lights or 15.2 meter (50 foot) spacing of standard duty lights. Lights are white when viewed from the landing threshold until the last 914 meters (3,000 feet) of the runway. The white lights alternate with red for the next 610 meters (2,000 feet), and are all red the final 305 meters (1,000 feet) in order to distinguish the runway’s end.

13635-2 **REQUIREMENTS**. Runway centerline lighting is planned in accordance with mission requirements as listed in Basic Category Code series 136. Requirements are expressed in meters (feet) of runway length vice the length of the lighting circuit. Consult NAVAIR 51-50AAA-2 for layout and spacing requirements.

13635-3 **RUNWAY CENTERLINE MARKING**. Runway centerline markings are centered on the runway centerline. The markings are a broken line of 36.6 meters (120 foot) long stripes separated by blank spaces of 24.4 meters (80 feet) +/- 3.05 meters (10 feet). The first stripe from each end is 12.2 meters (40 feet) from the top of the designation number. The minimum width of stripes is 0.305 meters (1 foot) wide for basic runways and a minimum of 0.914 meters (3 feet) wide from other runways. The color of these markings is retro-reflective white.

136 36 SIMULATED CARRIER DECK LIGHTING (EA)
FAC: 1362
BFR Required: Y

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13636-1 **DEFINITION**. A simulated carrier deck is used to train pilots ashore for landing aircraft under simulated conditions of a carrier at sea. Simulated carrier deck lighting and markings permits training during the day, night, and adverse visibility conditions.

13636-1.1 **Lighting**. The carrier deck lighting consists of centerline lights, edge lights, and athwartship lights. The edge and athwartship lights form a 21.3 meter by 228 meter (70 foot by 748 foot) rectangle outlining the simulated carrier deck that is on the left side of the runway, as seen from the landing aircraft, and approximately 98 meters (320 feet) beyond the runway threshold. An Optical Landing Aid, Category Code 134-60, and Landing Signal Officer (LSO) station is also required. Consult NAVAIR 51-50AAA-2 for layout and spacing requirements.

13636-1.2 **Markings**. The simulated carrier deck markings supersede the standard runway markings, including the unpainted areas within the deck boundaries and are symmetrical about the designated deck centerline. The markings are painted on the runway surface. If the contrast of the markings against the runway is poor, the markings may be outlined with a lusterless black border. The markings shall consist of centerline markings, edge markings, and ramp athwartship markings. There is no athwartship line at the forward end of the deck. Consult NAVAIR 51-50AAA-2 for layout and spacing requirements.

13636-2 **REQUIREMENTS.** Simulated carrier deck lighting is required at all air installations designed by the Chief of Naval Operations (CNO) for Fleet Carrier Landing Practice (FCLP). Normally two sets are installed per runway, one at each end of the runway selected for FCLP.

136 45 WHEELS-UP/WAVE-OFF LIGHTING (M/LF)
FAC: 1362
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13645-1 **DEFINITION**. Wheels-Up and Wave-Off Lights are provided to allow either the Wheel Watch, the Landing Signal Officer (LSO), or Control Tower personnel to determine if a landing aircraft has its landing gear fully extended and/or to signal to an aircrew to abort or "wave-off" a landing attempt.

13645-2 **REQUIREMENTS**. Wheels-up lights are a bar of 20 white lights installed under the approach path that are aimed upward and toward the threshold. They are intended to illuminate the underside of landing aircraft to permit observers to determine that the landing gear is fully lowered. The system also includes a pad for siting a portable Wheels Watch Shelter, Category Code 133-80. The light bar is placed 264 meters (980 feet) +/- 1.54 meters (5 feet), from the threshold under the approach path and on the same side of the extended runway centerline as the Control Tower.

Wave-off lights are used to signal to the aircrew to abort or "wave off" a landing attempt. Six pairs of flashing red lights, three pairs on each side of the runway, spotted 3.05 meters (10 feet) outboard of the runway edge at 270 meters, 510 meters, and 750 meters (900 feet, 1,700 feet, and 2,500 feet) from the runway threshold that are activated by either the Wheels Watch or Control Tower personnel. The lights flash when activated.

136 50 TAXIWAY LIGHTING AND MARKINGS (M/LF)
FAC: 1361
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13650-1 **DEFINITION**. Taxiway lighting and markings define the lateral limits and direction of a Taxiway, Category Code 112-10, to guide aircraft movement between the runway operational area and the aircraft parking area during night operations or conditions of poor visibility.

13650-2 **TAXIWAY LIGHTING SYSTEM REQUIREMENTS**. Taxiway lighting requirements are expressed in meters/feet of lighted taxiway length, not in length of lighting circuit. The total length of taxiway lighting is dependent upon the length of the taxiway itself, its turn radii, and its number of intersections and holding positions. The amount of taxiway lighting is expressed in meters (linear feet). Included in this category are taxiway edge lights, taxiway centerline lights, hold lights and guidance signs.

13650-2.1 **Taxiway Edge Lights**. Taxiway edge lights are elevated or semi-flush blue lights located on each side of the taxiway at intervals delineated in NAVAIR 51-50AAA-2. This interval varies based on the length and turn radii of the taxiway. Therefore, the number of lights cannot be determined without first knowing the geometry of the taxiway and airfield. Consult NAVAIR 51-50AAA-2 for layout information. Taxiway edge lighting is planned for all air installations conducting all-weather or night operations.

13650-2.2 **Taxiway Centerline Lights**. Taxiway centerline lights are semi-flush green lights placed in the pavement on the centerline of the taxiway. They are used to add the directional guidance required at high speed taxiway exits. They are also used to supplement edge lights wherever more positive guidance of aircraft is necessary, such as at complex taxiway intersections or large ramp areas where pilot confusion might occur. Again, the number of taxiway lights cannot be determined without knowing the geometry of the airfield. Consult NAVAIR 51-50AAA-2 for layout and spacing requirements.

13650-2.3 **Hold Lights**. Hold lights are a group of three semi-flush lights centered about the taxiway centerline at the holding position marker. For wide taxiways, five lights may be used. If the taxiway has centerline lighting in the area where the holding position lights are to be installed, the holding position lights shall be the same type as the centerline lights except with yellow filters. For intersections without centerline lights, three yellow lights, located in the center of the taxiway, perpendicular to the aircraft's direction of travel, shall be aimed towards the holding position. Holding position yellow lights are used for night marking of the painted hold positions. Their position and location are based on operational requirements. Consult NAVAIR 51-50AAA-2 for layout information.

13650-2.4 **Guidance Signs**. Taxiway guidance signs are internally lighted signs used to supplement taxiway lighting systems. They are placed at intersections of runways, taxiways with runways, taxiways with aprons, taxiways with taxiways, at refueling stations, and generally where direction or location information is required. The number of signs is based on the particular airfield requirements and is kept to a minimum. Consult NAVAIR 51-50AAA-2 for sign height limitations and letter text size.

13650-3 **TAXIWAY MARKINGS REQUIREMENTS.** Taxiway markings consist of a system of markings identified by the functions which they serve. The elements of taxiway markings include: taxiway centerline markings (required); holding position markings (standard and Category II, required); runway entrance and exit markings (required); TACAN checkpoint markings (required, if established); edge markings (optional); shoulder markings (optional); hazardous area markings (optional); and closed taxiway markings (optional). The markings shall be painted of the specified color applied to the taxiway surface except temporary hazardous area markings may use flags or barrier markings. Also, temporary closed taxiway markings may be of materials such as tape of that color that can be easily removed.

Taxiway centerline markings are a contiguous retro-reflective yellow stripe not less than 0.152 meters (6 inches) wide located along the taxiway axis. If taxiway centerline lights are installed, the axis of the centerline stripe may be offset no more than 0.305 meters (1 foot) from the taxiway centerline to avoid painting over the lights. These marking provide identification of a taxiway and longitudinal guidance for steering the aircraft. The markings continue across the intersecting taxiways or curve into the intersecting taxiway to indicate turns that are frequently used in taxiing. On curves or curved sections the markings are smooth curves and the minimum distance from the edge of the taxiway is not less than one-half the width of the taxiway. Consult NAVAIR 51-50AAA-2 for layout information.

13650-4 **SPECIAL SITUATIONS**. The use of runways as taxiways should be avoided; however, where the existing airfield layout requires the use of the runway as a taxi path, separate taxiway fixtures and circuits, in addition to the runway lighting system, are used. Consult NAVAIR 51-50AAA-2 for lamp layout and spacing.

136 55 TOUCHDOWN ZONE LIGHTING AND MARKING (M/LF)
FAC: 1362
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13655-1 **LIGHTING REQUIREMENTS**. Touchdown zone lighting delineates the touchdown zone on the runway and provides directional and roll guidance for aircraft approaching the threshold. It provides visual cues for more accurately centering the aircraft on the runway, adjusting attitude for touchdown, and determining the touchdown position. The lighting consists of bars of white lights in the pavement on each side of the runway centerline. Thirty pairs of bars are spaced along the runway at 30.5 meters (100 foot) intervals for a total distance of 914 meters (3,000 feet). Touchdown zone lighting is planned in accordance with mission requirements as listed in Basic Category Code group 136. A set of lights is required only on the end of the runway with approach lighting.

13655-2 **MARKING REQUIREMENTS**. Touchdown zone markings consist of groups of three, two, and one rectangular bars symmetrically arranged impairs about the runway centerline. Each bar is 1.83 meters (6 feet) wide and 23.4 meters (75 feet) long. The bars within a group are spaced 1.52 meters (5 feet) apart. The second group of bars from the threshold shall be fixed distance markings as single bars 9.14 meters (30 feet) wide and 45.7 meters (150 feet) in length. For runways less than 45.7 meters (150 feet) wide, the width of the bars and spaces is reduced proportionately. The inner edges of the bars in a pair are 22 meters (72 feet) apart. The first pair of bars begins 152 meters (500 feet) down the runway from the beginning of the threshold markings (159 meters (520 feet) from the runway end).

On shorter runways, these pairs of bars that would extend to within 274 meters (900 feet) of the midpoint of the runway are eliminated. The color of touchdown zone markings is retro-reflective white. Consult NAVAIR 51-50AAA-2 for layout and spacing requirements.

136 60 THRESHOLD LIGHTING AND MARKINGS (EA)
FAC: 1362
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13660-1 **THRESHOLD LIGHTING**. Threshold lighting is a system of lights defining the ends of the usable runway surface. They include threshold lights, displaced threshold lights, Runway End Identification Lights (REIL) and runway end lights. The threshold lights are displaced from the extremity of the runway when a portion is unavailable for normal operations. REIL and runway end lights enable a pilot to positively identify the ends of the runway from a distance during night-non-precision approach operations.

13660-1.1 **Threshold Lights**. Threshold lights are installed to provide positive identification of the beginning of the operational runway surface for approaching aircraft at night or under Instrument Flight Rules (IFR) conditions. Threshold lighting consists of two groups of lights located symmetrically about and perpendicular to the runway centerline at each end of the runway, both inboard and outboard of the line of the runway edge lights. The lights show green toward the approach zone and, if at an extremity, red toward the runway. Threshold lights are planned for all lighted runways, but more lights are required where an approach lighting system is used as displayed in NAVAIR 51-50AAA-2.

13660-1.2 **Displaced Threshold Lights**. Displaced threshold lighting is used only if a portion of the end of the runway is unusable for landing but is available for rollout and takeoff. When this condition exists because of obstructions or other reasons, the lighting is modified to delineate the extent of runway which is available to aircraft approaching from either direction. This is accomplished by displacing and changing the threshold lights to indicate the new threshold location for landing aircraft and equipping the intervening runway edge lights with filters.

13660-1.3 **Runway End Identification Lights (REIL).** REIL consist of two synchronized flashing lights near the runway threshold to provide rapid and positive identification of the approach end of a runway. These lights have been adopted to replace the obsolete runway identification lights formerly employed as the standard.

13660-1.4 **Runway End Lights**. Runway end lights are installed to define the end of the operational runway for aircraft on landing rollout and takeoff. A minimum of ten red lights are arranged in two groups symmetrical about and perpendicular to the runway centerline pointing toward the runway side of the threshold at each end of the runway. Intervals between lights in each group are not to exceed 3.05 meters (10 feet). They are to be positioned not more than 1.52 meters (5 feet) beyond the length of usable pavement and the outboard most light in each group will be in the line of the runway edge lights. Where runway end lights and threshold lights are to be installed in the same location, bi-directional red/green lights may be used with the appropriate color lens. If located at the end of usable pavement in displaced threshold areas, they are bi-directional red.

13660-2 **THRESHOLD MARKING.** Threshold markings consist of ten stripes, five on each side, parallel and symmetrical about the runway centerline. The color of these markings is retro-reflective white. If the runway is less than 61 meters (200 feet) wide, the overall width of the threshold markings is 6.1 meters (20 feet) less than the runway width. The width of the stripes and spaces between the stripes is reduced proportionately. Consult NAVAIR 51-50AAA-2 for layout and spacing requirements.

136 65 HELIPORT LIGHTING AND MARKING (M/LF)
FAC: 1361
BFR Required: N

Design Criteria: NAVAIR 51-50AAA-2, Visual Landing Aids Design Standards, Land-based Installations
Planning Criteria: P-80.3, Airfield Safety Clearances (Facility Planning Factor Criteria for Navy and Marine Corps Shore Installations, Appendix E)

13665-1 **DEFINITION**. Heliport lighting is a system of lights arranged to clearly define the helicopter landing pad for operations at night and during periods of poor visibility. Heliport lighting includes all visual reference aspects of the approach and landing of rotary wing aircraft. This includes visual aids, markings, perimeter and approach lights, and runway and taxiway lights.

13665-2 **REQUIREMENTS**. The basic heliport lighting requirement is perimeter lighting and landing direction lights. Approach direction lights and depth perception lighting may also be required. Perimeter lighting and landing direction lights are planned for all helicopter pads designated for night or all-weather operations and when authorized as an operational requirement at a specific location. Landing direction lights are used to indicate a preferred landing direction and to give side orientation as wing bars. Approach direction lights are added if additional approach guidance is required. The need for depth perception lighting (pad inset lights and/or flood lights) is determined by heliport location, steepness of approach, and prevailing environmental conditions.

Heliport lighting and marking systems are comprised of numerous types of pavement markings and lighting systems. They include:

13665-2.1 **Helipad Identification Markings**. Included in this category are identification markings and perimeter markings. Helipad identification marking for a paved helipad shall be a capital letter “H”. The “H” marking shall be located in the center of the landing area, and oriented with the preferred approach direction. The dimensions shall vary with size of the landing and takeoff area. The color of the “H” is aviation white, and must be reflective if the pad is used at night. If the paved surface is a light color and improved contrast is needed, the identification marker shall be outlined with a lusterless black border. Perimeter markings define the safe landing area and are oriented with the sides of the parallel square to the letter “H”. The perimeter markings consist of the corners and edge bars. The corners form right angles and the edge bars are located midway between the corner markings. The outer edges of the markings are the designated limits of the landing and takeoff area. These markings are aviation white and if the helipad is used at night shall be reflective. Again, if contrast is needed, these markings will be outlined with a black border.

13665-2.2 **Helipad Perimeter Lights**. Helipad perimeter lights consist of a row of lights along or near the four sides of a helipad. Typically, these lights are elevated although semi-flush lights may be used in areas where helicopters with wheels may be taxiing on the surface between the helipad and parking or service areas. Both type of fixtures emit omni-directional yellow light.

13665-2.3 **Helipad Approach Lights**. Helipad approach lights consist of a row of landing direction lights perpendicular to the centerline of the perimeter lights, beginning approximately 7.62 meters (25 feet) from the midpoint of the perimeter light centerline. These lights are usually elevated although semi-flush lights may be use in areas where helicopters with wheels may be taxiing on the surface. These lights emit omni-directional beams. The helipad approach light system entails two types of lights. The first are Landing Directional Lights. These consist of a single row of six yellow lights outward from the helipad perimeter lights centered on the helipad in the established direction for the approach. The second type of light is the Approach Direction Lights. This system is comprised of two parallel rows of lights extending outward from the last landing direction light. Each row shall have five pairs of white lights.

13665-2.4 **Heliport Runway Lights**. Heliport runway lights are required for runways doing night operations. Yellow lights define the limits of the runway and are spaced at 4.57 meter (15 foot) intervals at the line of perimeter lights and extend outward in the direction of the preferred approach/takeoff path. These lights are an optional feature that is installed when it is necessary to provide directional guidance.

13665-2.5 **Heliport Taxiway Lights.** Heliport taxiways are defined while flush mounted green lights along the taxiway centerline. Blue omni-directional lights define taxiway route edges. The lights are spaced at 7.62 meter (25 foot) intervals on straight sections. On curves, this distance should remain the same; however, there must be at least four lights defining the turn.

137 SHIP NAVIGATION AND TRAFFIC AIDS-BUILDINGS

137-1 This code group applies to buildings for housing sea traffic control, navigation aids and navigation services.

137 10 METEOROLOGY AND OCEANOGRAPHY BUILDING (SF)
FAC: 1371
BFR Required: Y

13710-1 This category is deleted. All future requirements should be reassigned, revised, and calculated as a Category Code 13115 “Communications, Information, or Intelligence Analysis Facility”.

137 20 LIGHTHOUSE (M2/SF)
FAC: 1371
BFR Required: Y

13720-1 **DEFINITION.** A lighthouse is a structure that houses a navigation beacon that may emit light, sound, radio, radar, or a combination thereof. It may be onshore or offshore. Construction is done overseas when appropriate by the Naval Facilities Engineering Command.

13720-2 **REQUIREMENTS**. Criteria are supplied by the U.S. Coast Guard. See UFC 4-141-10N for details.

138 SHIP NAVIGATION AND TRAFFIC AIDS-OTHER THAN BUILDINGS

138-1 This code group applies to structures which function as sea traffic navigation/traffic aids.

138 10 BEACON - SHIP (EA)
FAC: 1381
BFR Required: N

13810-1 **DEFINITION**. The U.S. Coast Guard has specific jurisdiction over all aids to navigation (day beacons, buoys, foghorns, etc.,) in the continental United States and in all outlying territories and possessions. Day beacons are unlighted structures used to mark isolated dangers or channels, edges, or alignment. They are painted white, black, green, or red, either separately or in combination. Day beacons also have reflectors for night use. See Harbor and Coastal Facilities, UFC 4-150-06, for technical information, and International Rules of Road and Inland Waterways, U.S. Coast Guard, for regulations.

138 20 NAVIGATION AID TARGET (EA)
FAC: 1381
BFR Required: N

13820-1 **DEFINITION**. This Category Code is to be used for navigational aid targets which are a part of maritime navigational aids.

13820-2 **REQUIREMENTS**. These facilities are planned on an individual basis.

138 25 ANTENNA-NAVIGATION (EA)
FAC: 1381
BFR Required: N

13825-1 **DEFINITION.** This Category Code is to be used for antennas or antenna systems which are a part of maritime navigational aids.

13825-2 **REQUIREMENTS.** These facilities are planned on an individual basis.

140 LAND OPERATIONAL BUILDINGS

141 OPERATIONAL - BUILDINGS

141 11 AIR PASSENGER TERMINAL (SF)
FAC: 1412
BFR Required: Y

14111-1 **DEFINITION.** The air passenger terminal provides facilities for processing authorized passengers and their baggage and for processing incidental freight. Space is provided in the terminal for the following functional areas: administrative space, baggage claim room, check-in counter, minor freight storage, information counter, and waiting lounge with food concessions. (For air cargo terminal, see Category Code 141 12.) The space to be planned is based on an analysis of the passenger traffic anticipated. A terminal is planned for those air stations where passenger traffic is projected to exceed 30 passengers during a typical peak hour.

14111-2 Due to the irregular and often unpredictable passenger flow in military air terminals, the facility requirements must be justified in each individual case where a terminal is warranted. Supporting data must include historic passenger flow figures and mode in sufficient detail to permit validation of facility scope.

141 12 AIR CARGO TERMINAL (SF)
FAC: 1412
BFR Required: Y

14112-1 **DEFINITION.** An air cargo terminal is planned for air stations where cargo and freight handling exceeds 10,000 pounds per day. The air cargo terminal is separate from the air passenger terminal (Code 141 11) where only incidental freight is handled. Air cargo terminal functions include receipt of packages, control documentation, palletization, and holding for shipment, aircraft loading and unloading, package sorting, and loading on trucks.

14112-2 Space required for air cargo terminal operations is based on the weight of cargo to be handled as determined by station survey. Terminals are planned using the space allowances in Table 14112-1.

Table 14112-1 Space Allowances - Air Cargo Terminal

Average Daily Load (pounds) (1)	Air Cargo Terminal Type	Gross SF Area
10,000 - 20,000	Small, non-mechanical	7,720
20,000 - 40,000	Small, mechanical	32,500
40,000 - 100,000	Medium, mechanical	44,500
100,000 - 160,000	Large, mechanical	54,500

(1) Average Daily Load includes cargo originating, terminating, and being re-handled through the terminal.

14112-3 Air cargo terminal facilities must be adjacent to the transient aircraft apron area, but siting shall not violate aircraft pavement clearance criteria. Exterior pavement requirements include road access, access to aircraft apron, and non-organizational vehicle parking area (see Category Code 852 10).

141 20 AIRCRAFT FIRE AND RESCUE STATION (SF)
FAC: 1411
BFR Required: Y

Refer to Design Criteria, UFC 4-730-10 Fire Stations, for technical requirements at https://www.wbdg.org/dod/ufc/ufc-4-730-10.

The Space Planning Spreadsheet is at located at: https://www.wbdg.org/dod/unified-facilities-space-program-sustainability-spreadsheets.

14120-1 **DEFINITION.** This space criteria applies to Installation fire and rescue facilities which provide fire protection and emergency rescue services for pilots and aircraft.

14120-1.1 When feasible, the aircraft fire and rescue station is combined with the structural fire station (Category Code 730 10) to develop the total space allocation for one complete emergency facility, Category Code 141 25 “Combined Structural / Aircraft Fire / Rescue Station”.

14120-2 **REQUIREMENT.** The number of fire stations required on an Installation will be determined by the necessary response time for the type and function of facilities requiring fire protection. This analysis will be provided by Commander Navy Installations Command (CNIC) N30 or Marine Corps Installations Command (MCICOM) G3.

14120-3 **SCOPE.** Refer to CCN 730 10 for explanation of the scope, types, classes and function of the fire station facility.

14120-4.1 The total space allocation is based on the number of fire and rescue vehicles assigned to the aircraft fire and rescue function, at both the parent and outlying fields.

14120-2.2 Covered space, either building or shed, is provided for all assigned fire and rescue vehicles and equipment. Generally, the building element houses the active vehicles required to protect the parent Installation. The shed element houses: (1) the active foamer and crane, (2) the active vehicles to support the outlying fields, and (3) the spare vehicles for maintenance and reserve for both parent and outlying fields.

14120-4 **FUNCTIONAL AREAS.** Aircraft Fire and Rescue Stations consist of apparatus bays and support areas, equipment and gear storage areas (for fire extinguishers, self-contained breathing apparatus (SCBA), protective clothing, hoses, firefighting agents, etc.), dispatch office, administrative offices, training facilities, living quarters, recreation and dining facilities, and possibly an emergency operations center and/or apparatus and equipment maintenance areas (if required by Installation mission requirements).

14120-3 **SPACE ALLOWANCE.** The Total Gross Building area is determined using the space planning spreadsheet. This area will be the sum of the building and shed space allowance at both the parent and outlying field locations. The planner must account for all fire and rescue vehicles at the location and determine how many will be housed in the building and how many will be housed under sheds. The planner will reflect the following on the BFR: (1) the total shed area equals the number of vehicles housed in sheds times the area of the vehicle bays, and (2) the total building area is the Total Gross Building area minus the total shed area.

14120-3.1 Pavement is provided adjacent to the station for 25 percent of the vehicles and for one vehicle wash rack.

14120-3.2 The Fire and Rescue Vehicles Alert Pad is computed separately under Category Code 116 60.

Figure 141-20 Sample Computation - Aircraft Fire and Rescue Station

Assume an Air Station operates with outlying fields. The space planning spreadsheet has indicated that the Total Gross Building area is 11,700 GSF. The planner has determined that 40% of the fire and rescue vehicles will be housed in sheds, both at the parent and the outlying fields. The total shed requirement is 4,752 GSF, which is split into 2,160 GSF at the parent station and 2,592 GSF at the outlying fields. The building area will be 6,948 GSF. The total building and shed space sum up as follows:

	Building Area - GSF	Shed Area - GSF
Parent Station	6,948	2,160
Outlying Fields	0	2,592
Total	6,948	4,752
Total Gross Building Area	11,700 GSF	

The total space to show on the BFRL is 6,948 + 4,752 = 11,700 SF gross for the parent air station. No space to house the vehicles is required at any of the outlying fields.

141 25 COMBINED STRUCTURAL / AIRCRAFT FIRE / RESCUE STATION (SF)

FAC: 1411
BFR Required: Y

14125-1 **DEFINITION.** A combined structural/aircraft fire/rescue station is planned under certain conditions to serve the function of a structural fire station (Category Code 730 10) and an aircraft fire and rescue station (Category Code 141 20). The combined facility is planned for a location that satisfies the response time and distance requirements for both the structural fire and the aircraft fire and rescue stations.

14125-2 The station must provide adequate support of airfield activities and protection for all buildings and structures. The size of the building is planned to house the aircraft fire and rescue vehicles required plus the structural fire vehicles required. The computations are done as indicated in Category Codes 141 20, Aircraft Fire and Rescue Station, and 730 10, Fire Station. The sum of the areas required for the structural fire station and the aircraft fire and rescue station is the total building area for the combined station.

14125-3 Protection against structural fires may be provided in part or completely by community resources. The method for development of reciprocal agreements between Navy and a municipality for mutual fire protection may be found in NAVMATINST 11320.10.

141 30 AIRCRAFT LINE OPERATIONS BUILDING (SF)
FAC: 1412
BFR Required: Y

14130-1 **DEFINITION.** The aircraft line operations building is a structure used to centralize ground operations of the flight line. The building is utilized in keeping of squadron daily flight books, aircraft status boards, and bulletin boards and as support for line operations personnel by providing shelter, a water cooler, and a chemical toilet. The aircraft line operations building is a standard 12- by 20-foot portable building with a building area of 240 square feet gross.

14130-2 One line operations building may be planned for each hangar module when the distance between the squadron's parked aircraft and the hangar is greater than 1,000 feet.

NOTE: Criteria for this facility indicates that it is to be portable and therefore carried as collateral equipment, when acquired. Collateral equipment is not Class II real property and cannot be included in the real property inventory. However, this category code is being retained for real property inventory purposes since many of the existing facilities are not portable and accordingly must be reported in the RPI.

141 40 AIRCRAFT OPERATIONS BUILDING (SF)
FAC: 1412
BFR Required: Y

14140-1 **DEFINITION.** An aircraft operations building is planned for all Navy air stations, auxiliary air stations, and air facilities. The building houses the administration of flight operational activities with all supporting functions including flight control, communications, and weather services. The operations building adjoins the airfield control tower and the radar air traffic control center where siting requirements permit. See Table 14140-1 for space allowances.

Table 14140-1
Aircraft Operations Building

Installation	Gross Area Sq. Ft.
Air Station	12,637
Air Facility	9,760

141 41 MARINE AIR TRAFFIC CONTROL UNIT (MATCU) OPERATIONS BUILDING (SF)
FAC: 1412
BFR Required: Y

14141-1 **DEFINITION.** The MATCU performs a combined function similar to that accomplished in Category Codes 134 40, Ground Control Approach (GCA) System; 133 25, TACAN Building; and 133 75, Air Surveillance Radar (ASR) Building. Depending on the level of aircraft operations, the MATCU operations building may provide the sole GCA support at an air installation or may supplement and be in addition to permanent ASR, TACAN, and GCA facilities. A MATCU operations building should not be planned without prior coordination with and approval of the Commandant of the Marine Corps (LFF-1).

14141-2 When authorized, the MATCU operations building shall not exceed 9,130 gross square feet.

141 42 AIR INTELLIGENCE SUPPORT CENTER (SF)
FAC: 1444
BFR Required: Y

14142-1 **DEFINITION.** This facility, also known as a Joint Intelligence Center (JIC), is used to store and disseminate classified material for mission planning, pilot training and briefings in support of attack aircraft operations. The design and size of the center will be determined by the type and amount of equipment to be installed and the number of standard attack squadrons assigned to a station. Typical spaces include: administrative, library/chart storage, classroom, special security office, planning rooms, briefing rooms, photo intelligence interpretation room and storage. No specific planning criteria are currently available for this facility. Inquiries regarding space allocations should be forwarded to OPNAV N2.

141 60 VISUAL INFORMATION (VI) FACILITY (SF)
FAC: 1441
BFR Required: Y

14160-1 **DEFINITION.** This category code was previously referred to as a "Photographic Building". Navy visual information (VI) is a professional visual communication capability closely associated with Navy public affairs (PA). The role of Navy VI is to support the following activity missions and functions:

- VI documentation (VIDOC), which includes combat camera (COMCAM) documentation, operational documentation (OPDOC), technical documentation (TECDOC) and sub functions using graphic arts, motion media, still photographic, audio and other VI systems
- VI production in support of Navy operations, training, and other functions.
- Support of DoD records centers

- Ship/shore VI activities which include motion media production, still photographic production, graphic arts production, and other VI services needed at ship/base level

A VI Facility is a building or a space within a building that houses an authorized VI activity, which is a function within an organization whose principal responsibility is to provide VI products and/or services and must meet specific requirements as described in OPNAVINST 3104.1A, Chapter 0201. All VI Activities must first be approved by CNO Office of the Assistant for Visual Information N09C2 and assigned a Defense Activity number (DVIAN) prior to establishing a VI facility. Requests for establishing or modifying Navy VI activities must correspond with the guidance for activity establishment or modification prescribed in OPNAVINST 5400.44 (5440.169D); and, must meet CA requirements prescribed in OPNAVINST 4860.7D.

14160-2 **ALLOWANCE.** The size of a VI Facility will be determined by an engineering analysis of the space required to support the VI activity mission, functions, and systems. Basic Facility Requirements (BFR) creation/revision must be validated through the Commanding Officer and Public Affairs Officer of an installation.

141 65 FLEET RECONNAISSANCE PHOTOGRAPHIC LABORATORY (SF)
FAC: 1441
BFR Required: Y

14165-1 **DEFINITION.** These facilities are no longer programmed and are for inventory purposes only. All new Visual Information (VI) facilities should be captured under either CCN 14142 Air Intelligence Support Center or CCN 14160 Visual Information (VI) Facility.

141 70 CONTROL TOWER (SF)
FAC: 1413
BFR Required: Y

Planning Criteria: UFC 3-260-01, Airfield and Heliport Planning and Design
Design Criteria: UFC 4-133-01, Air Traffic Control and Air Operations Facilities

14170-1 **DEFINITION.** A control tower provides space for equipment and personnel to control aircraft traffic. It is an elevated structure having an unobstructed line-of sight to the airfield approach areas, runways, taxiways, aircraft parking areas, and all other operational areas over which aircraft movements must be controlled. This category code is used for the control tower in all cases even though the tower may be an independent structure or combined with a RATCC or an aircraft operations building. If at all possible, the control tower should be an integral unit with the RATCC (Category Code 133 71, thus providing a complete, integrated air traffic control facility. A control tower is planned for each installation where aircraft are based. It is not planned for outlying fields and auxiliary landing fields unless specifically authorized by competent authority. The minimum installation is the basic tower containing an entrance level, intermediate levels, and the control tower cab. The area of floor space for a control tower of standard design with six floors plus the control room is 2,956 square feet gross. Towers of increased height can be provided by adding incremental levels.

141 81 GROUND CONTROL APPROACH CREW FACILITY (SF)
FAC: 1412
BFR Required: Y

14181-1 **DEFINITION.** The ground control approach (GCA) crew facility provides a ready room for on duty personnel assigned to the GCA van. The facility consists of two (2) standard design skid-mounted shelters (each 12 feet by 20 feet). The crew facility is authorized whenever the mobile GCA unit is furnished.

NOTE: Criteria for this facility indicates that it is to be portable and therefore carried as collateral equipment, when acquired. Collateral equipment is not Class II real property and cannot be included in the real property inventory. However, this category code is being retained for real property inventory purposes since many of the existing facilities are not portable and accordingly must be reported in the RPI.

141V 82 FULL PRESSURE SUIT FACILITY (SF)
FAC: 1412
BFR Required: Y

14182-1 **DEFINITION.** Pressure suit maintenance is normally performed in the Aviation Life Support Systems Shop (Non-Navair Depot), Category Code 211 75. Special justification is required to provide a separate facility for this purpose.

141 87 LIQUID OXYGEN/NITROGEN FACILITY (SF)
FAC: 4122
BFR Required: Y

14187-1 **DEFINITION.** A liquid oxygen/nitrogen facility is required at each Navy and Marine Corps air station where 50 or more attack and fighter-type aircraft are assigned. Smaller numbers of aircraft are provided with these gases by bottled gas from commercial suppliers. The facility provides for storage, vaporization, and transfer of non-industrial oxygen and nitrogen and for test and repair of cryogenic equipment associated with aviator and aircraft support. Liquid and gaseous forms of both oxygen and nitrogen, as well as hot nitrogen gas for purging equipment, are handled. The facility includes liquid storage tanks, vaporizing units, transfer areas, cart and tank filling and storage areas, repair shops, and office space. Port land cement concrete driveways, loading ramps, and cart parking areas are required. A building with a gross area of 2,704 SF is adequate for all needs. The facility has a storage capacity of 4,000 gallons each of bulk liquid oxygen and nitrogen and 150 cylinders of each gas. The size of the transfer areas may be reduced if a station survey indicates a lesser requirement for cylinder storage.

14187-3 MARINE CORPS CRYOGENICS FACILITY. A Marine Corps cryogenics facility provides for operational support of a Marine Aircraft Group and accommodates in garrison the expeditionary liquid oxygen/nitrogen generating equipment assigned. A Marine Corps cryogenics facility does not supplant the liquid oxygen/nitrogen facility at a Marine Corps air station. Generally, two generators are assigned to each Group. The exceedingly high noise level of the turbine-powered expeditionary liquid oxygen/nitrogen generator necessitates locating the facility in a remote area. The facility consists of a generator area, a cylinder fill area, cylinder and cart storage shelter, and main building. The generator area has a concrete pad, an underground fuel tank, exterior lighting, electric power, water, and an outbuilding with a gross area of 246 square feet. Five hundred and ten square yards of concrete and 5,000 gallons of fuel storage are provided for a single generator. One thousand feet from the nearest generator is a shelter of 1,258 square feet gross area where gas cylinders are filled, and converters and liquid oxygen and liquid nitrogen carts and cylinders are stored.

14187-4 The main building of the Marine Corps cryogenics facility has a gross area of 3,570 square feet and is located no closer than 100 feet from the shelter. The main building contains offices, toilets, classroom, maintenance shop, and repair parts storage. Because of the training mission conducted at this facility, normally only one generator is in production at a time. Hence, the storage shelter and the main building usually may be shared by all Groups utilizing this facility. The size of either the storage shelter or the main building may be modified if a survey indicates a different requirement.

141 88 HARDENED AIRCRAFT SHELTER (SF)
FAC: 1465
BFR Required: Y

14188-1 No criteria is currently available for this Category Code.

142 OPERATIONAL – HELIUM PLANTS

142 10 HELIUM PROCESSING PLANT BUILDING (SF)
FAC: 1421
BFR Required: Y

14210-1 No criteria is currently available for this Category Code.

142 19 HELIUM STORAGE BUILDING (SF)
FAC: 1421
BFR Required: Y

14219-1 No criteria is currently available for this Category Code.

142 20 HELIUM STORAGE FACILITY (EA)
FAC: 1422
BFR Required: Y

14220-1 No criteria is currently available for this Category Code.

143 SHIP AND OTHER OPERATIONAL-BUILDINGS

143 08 EXPEDITIONARY OPS BOAT MAINTENANCE REPAIR FACILITY (SF)
FAC: 2133
BFR Required: Y

14308-1 **DEFINITION.** An Expeditionary Operations Boat Maintenance Facility provides spaces for expeditionary units to perform continuous maintenance on boats. The facility will provide maintenance bays, a tool room, parts room, oily water separator system, overhead crane, and administrative support space.

14308-2 **REQUIREMENT CALCULATIONS.** Criteria is currently being developed for this category code. In the interim, please contact NAVFAC Atlantic AM2 for space allowance information.

143 09 EXPEDITIONARY OPS SUPPORT FACILITY (SF)
FAC: 1444
BFR Required: Y

14309-1 **DEFINITION.** An Expeditionary Operations Support Module (EOSM) provides the organic components of an expeditionary command and guidelines for associated CCNs to be used to support them. The EOSM would define the following attributes: Expeditionary Administration, (at a 80% of standard space allowance), Medical (A Contingency Aid Station provides medical care at the local level for the Expeditionary commands), Sensitive Compartmented Information Facility (SCIF), Mission Planning Cell (may or may not be part of SCIF), Training Classrooms (not NETC associated training), Armory (at a reduced footprint from the CCN 143-45), and Locker and Shower spaces to support the physical training requirement of an Expeditionary Combat Command.

14309-2 **ALLOWANCE.** Space allowances are being developed. Questions regarding criteria can be directed to the NAVFAC Atlantic Expeditionary Operations criteria manager.

143 10 EMERGENCY VEHICLE GARAGE (SF)
FAC: 5307
BFR Required: Y

14310-1 **DEFINITION.** This is a building for official emergency and alert vehicles, such as an ambulance. It is justified in instances when immediate response required by special waterfront operational vehicle. The building protects these vehicles from extreme weather to improve operational availability. The building is not used for vehicle services nor housing personnel. This category code excludes shelters used for aircraft and community fire and rescue vehicles, see Category Codes 141 20, 141 25, and 730 10.

The size of the garage is determined by the vehicle area plus nominal clearances surrounding the vehicle.

A. Typically, three feet of clearance on each side is sufficient plus a gross to net factor of 1.05.
B. In cases where vehicle side doors or access panels' clearances are greater than three feet, larger clearances may be justified.
C. The distance between two vehicles should be the same as the side vehicle clearance.
D. The front-end clearance should be no more than one foot.
E. The rear clearance would vary the same as side clearances and depend on loading and accessibility. Three feet should be sufficient in most cases.
F. A carport type shelter may be provided where the air conditioning design temperature on a 10% basis exceeds 87°F dry bulb.
G. A garage may be provided where the heating design temperature on a 97.5% basis is less than 11°F dry bulb.

143 11 OPERATIONAL VEHICLE GARAGE (SF)
FAC: 1444
BFR Required: Y

14311-1 **DEFINITION.** An operational vehicle garage is used for the storage of vehicles which are not utilized on a daily basis, and which are exposed to adverse weather conditions that would have a detrimental effect upon them if stored out in the open. Accordingly, the type of vehicle stored, frequency of use and climatic conditions, will determine whether this type of facility is warranted.

14311-2 **INCLUSIONS/EXCLUSIONS.** This category code excludes 216 45 Line Vehicle Parking for airfield equipment, 214 40 Holding Shed for Public Works Transportation vehicles awaiting maintenance, 218 65 Equipment Holding Shed for Public Works Transportation construction vehicles and equipment, and 219 20 Pavement and Grounds Equipment Shed. This category code also excludes vehicles and equipment maintained and operated by the Public Works Transportation Department. This category code includes operational vehicles maintained by Naval

Special Warfare Groups, Naval Construction Battalions, and other groups that are responsible for the maintenance and upkeep of their company vehicles. Some of the vehicles that may require environmental protection include MK V boats and Ridged Hulled Inflatable Boats (RHIBs). These types of boats have rubber hulls that can deteriorate more quickly when exposed to sun and extreme temperatures creating a significant increase in maintenance expense of these vehicles. A Construction Battalion may have all sorts of heavy construction equipment like pavers and backhoes, etc.

14311-3 **REQUIREMENT CALCULATIONS.** To calculate the total gross are for this facility, first tally the quantity for each type of vehicle. Assign a "type code" per the Type Code and NSF Table 14311-1, based on the length of the item. Next, develop the Civil Engineering Support Equipment (CESE)/Service Craft & Boat Support System (SABAR) NSF requirements in accordance with Tables 14311-1 and 14311-2, to determine the total NSF required to store the command's equipment. Add 250 SF for a Mechanical Room for the fire suppressant system. Sum the total NSF and the 250 SF (mech. room) to determine the total NSF that is required. Based on the Net to Gross (NTG) Table 14311-3, multiply the total NSF times the correct NTG factor to determine the Gross Square Feet (GSF). For the final GSF, round up to nearest whole number. A ratio of between 1.5 and 3 (length to width) of the overall facility is desired, if possible. If an existing facility is converted to this use, an increase of fifteen percent may be added to the total area in order compensate for incompatible column spacing, wall, etc.

Table 14311-1: Type Code and NSF Table

Size	Gen Description	Type Code	NSF
0 - 5 FT	Non-mechanized CESE and SABAR (ex: Generators, Air Conditioner/Heating Units)	1A	108
5 - 10 FT	Non-mechanized CESE and SABAR (ex: Fuel Water SIXCON, Motors, Pumps, Generators, TRICONS)	A	168
10 - 15 FT	Vehicles and non-mechanized CESE and SABAR (ex: Trailers, Forklifts, Small Zodiac Boats)	1B	228
15 - 20 FT	Vehicles and non-mechanized CESE and SABAR (ex: Passenger Vehicles, HMMWV, Light Plant, Fork Lifts, Small Zodiac Boats)	B	288
20 - 30 FT	Large CESE and SABAR (ex: MTVR, Fuel Trucks, Boats < 30FT)	C	408
30 - 40 FT	Extra Large CESE and SABAR (ex: Boats > 30FT, MTVRs, Scrapers, Water Well, Semi-Trailers)	D	528
40 - 50 FT	Extra Large CESE and SABAR (ex: Boats > 40FT, Crane, Scrapers, Water Well, Semi-Trailers)	E	648
50 - 60 FT	Extra Large CESE and SABAR (ex: Boats > 50FT, Semi-Trailers, lowboy 55T)	F	768
60 - 70 FT	Extra Large CESE and SABAR (ex: Prime Mover and Boats > 60FT (11M w/ Prime Mover))	G	888

NSF: storage lanes are 12' wide (which includes side to side clearance for Inspection X length of component plus 2' front/back. The addition of the side to side and front/back is to provide space for minor Preventive Maintenance.

Example Table 14311-2:
CESE/SABAR NSF Calculation Table

Description	Type Code	Total Qty	NSF/Item	Total NSF
Assembly:10178-AIR CONDITIONER / HEATING UNIT (IECU)	1A	3	108	324
Assembly:04250; SHORT DESC: COMPRESSOR,RECIPROCATING	1A	5	108	540
Assembly: 52680; SHORT DESC: MK18 56KW GENERATOR	A	8	168	1344
Assembly:088002; SHORT DESC: TRLR 400G TANK POTABLE WATER	1B	3	228	684
Assembly:06700; SHORT DESC: JLTV HEAVY GUN CARRIER W/ OPTION KITS	B	12	288	3456

Description	Type Code	Total Qty	NSF/Item	Total NSF
Assembly:036091; SHORT DESC: HMMWV M1151A1B1 A-KIT	B	12	288	3456
Assembly:036371; SHORT DESC: LSSV MAINT UTILITY CREW CAB W/ A-KIT	C	5	408	2040
Assembly: 70005; SHORT DESC: MEDIUM SERVICE SUPPORT VEHICLE (MSSV)	C	3	408	1224
Assembly:058867; SHORT DESC: TRK CARG 7T MIL	D	3	528	1584
Assembly:082655; SHORT DESC: TRLR 55T SEMI LOWBED DED HYDRAULIC REMOVABLE GOOSE	E	3	648	1944
		57		16,596

Table 14311-3:
Net to Gross Table

FROM	TO	NTG
0 SF	20,000 SF	1.35
20,000 SF	50,000 SF	1.2
50,000 SF	150,000 SF	1.15
150,000 SF	above	1.1

NTG: includes 2’ perimeter lane along all walls and a 20’ access lane.

Total SF 16,596 SF
Add 250 SF for Mechanical Room 250 SF
(Fire sprinkler system)

NTG: 1.35
Total: 22,742.10 GSF
Say: 22,743 GSF

143 12 OPERATIONAL VEHICLE LAYDOWN AREA (SY)
FAC: 8523
BFR Required: Y

14312-1 **GENERAL.** Many Navy and Marine Corps operational commands have missions that require the acquisition, operation, and maintenance of various types of vehicles and equipment. Examples of these include Civil Engineering Support Equipment (CESE) and Service craft and Boat Accounting Report (SABAR) equipment.

These items are typically acquired based on information shown in each command's Tables of Allowance and Equipment (TOA & E; Navy) or Table of Equipment (TE; Marine Corps) and are usually associated with an operational maintenance shop or motor pool. As a result, these commands have requirements for secure paved areas for storing these vehicles and equipment. These areas are typically different from standard parking areas in that they require more robust parking surfaces, and they are sized to accommodate vehicles and equipment that are infrequently used. This CCN is intended for long term storage of specialized vehicles and equipment only, and normal command staff parking should continue to be captured under CCN 85210 or similar.

14312-2 **DEFINITION.** An operational vehicle parking and/or laydown area consists of an asphalt or concrete paved area large enough to store and provide circulation for the vehicles and equipment for which the command is responsible. Vehicles can range from a typical passenger vehicle to a large prime mover such as an MTVR truck. The equipment requiring storage can range from towable generator sets or light packs to large flatbed trailers. It also includes operational small craft such as the in-shore fast boats and their trailers. These parking/laydown areas require perimeter fencing and in some case will require site lighting adequate enough to perform vehicle or small craft outfitting or minor repairs during nighttime hours. This category code should also be used to capture parking and maneuvering areas associated with CCN 15522 Small Craft Boat Ramp facilities (where the parking/laydown requirements are captured as a CCN14312 utilization on the associated boat ramp property record card).

14312-3 **ALLOWANCE.** Space allowances are based on engineering evaluations that summarize the size and quantity of each vehicle shown on the requesting command's TOA. The process for determining overall requirements is as follows:

1. Using the "General Description" column in Table 14312-1 (see below), planners must determine the type code for each vehicle/equipment type being used by the command. In cases where the general description is unclear or doesn't match that which is listed, use the actual item length and compare it to the "Size" column in the table to determine the type code.

Table 14312-1 Engineered Surface Laydown

Size	General Description	Type Code	GSY	GSF	*Net to Gross Factor
Small (<10FT)	Non-mechanized CESE and SABAR (ex: Fuel Water SIXCON, Motors, Pumps, Generators, TRICONS)	A	19	168	1.50
Medium (10FT-20FT)	Vehicles and non-mechanized CESE and SABAR (ex: Passenger Vehicles, HMMWV, Light Plant, Fork Lifts, Small Zodiac Boats)	B	32	288	1.75
Large (20FT-30FT)	Large CESE and SABAR (ex: MTVR, Fuel Trucks, Boats < 30FT)	C	46	408	1.75

Size	General Description	Type Code	GSY	GSF	*Net to Gross Factor
Extra Large (30FT-40FT)	Extra Large CESE and SABAR (ex: Boats > 30FT, Scrapers, Water Well, Semi Trailers)	D	59	528	2.00
Extra Large (40FT-50FT)	Extra Large CESE and SABAR (ex: Boats > 40FT, Scrapers, Water Well, Semi Trailers)	E	72	648	2.00
Extra Large (50FT-60FT)	Extra Large CESE and SABAR (ex: Boats > 50 FT, Semi Trailers, lowboy 55T)	F	86	768	2.25
Extra Large (60FT-70FT)	Extra Large CESE and SABAR (ex: 11M Rib with Prime Mover; 40PB with Prime Mover)	G	99	888	2.25

* Net to gross factor includes drive lanes/maneuvering areas, and circulation space around each item.

2. When requirement is for covered laydown engineered surface, use the Covered Laydown (Table 14312-2). The area is determined by: Component length (based on table's Type Code) x NUMBER OF CESE for each item.

Table 14312-2 Covered Laydown

Type Code	Length (FT)
1A	5
A	10
1B	15
B	20
C	30
D	40
E	50
F	60

3. Once the type codes are assigned for each item in the command’s TO&A/TE, multiply the area allowances per each type (A though G) by the quantity of each type needed. The sum of the total areas for each type code is then the total area requirement for the parking/laydown area for the command’s operational vehicles and equipment. This area includes circulation and maneuvering space.

NOTE: For parking/laydown areas associated with CCN 15522 Operational Boat Ramp facilities only: Determine the required area based on the average number of boat trailers, prime movers, and support vehicles/equipment to be parked on site during a typical training mission and use Table 14312-1 to determine a total gross area (same process as shown above). Add an additional 5% to this gross area to account for the prime mover/trailer combination maneuvering apron located adjacent to the boat ramp.

143 13 OPERATIONAL VEHICLE/EQUIPMENT CANOPY (SF)
FAC: 1459
BFR Required: Y

14313-1 **DEFINITION**. An operational vehicle/equipment canopy is used by the Navy and Marine Corps expeditionary units to protect vehicles and equipment from the weather. These canopies are usually associated with operational vehicle laydown areas or similar.

14313-2 **ALLOWANCE.** Sizing of these canopies is accomplished via an engineering analysis and is based upon the total area occupied by vehicles and/or equipment plus any related circulation between them. Note that canopies are measured by the drip line projected from the roof eaves down to ground level.

143 15 RANGE OPERATIONS CENTER (SF)
FAC: 1731
BFR Required: Y

14315-1 **DEFINITION**. A range operations center is the control point for testing torpedoes, calibrating ships' firing systems, and training pilots and testing aircraft on gunnery and bombing ranges. The center will vary with the equipment and control areas required. Standard planning factors for a center are not available. Its size must be planned to support the equipment and control areas to be housed.

143 17 SPACE SURVEILLANCE FACILITY (SF)
FAC: 1444
BFR Required: Y

14317-1 **DEFINITION.** Requirements are determined by Naval Network and Space Operations Command. Facilities typically support global space surveillance network which detects, tracks, identifies, and catalogs man-made objects in space and provides position information on these objects.

143 20 ORDNANCE OPERATIONS BUILDING (SF)
FAC: 1444
BFR Required: Y

14320-1 **DEFINITION**. An ordnance operations building is authorized where there is a need to control an ordnance operation. Ordnance operations are those involving ammunition storage, handling or disposal and organizational level maintenance. The facilities whose primary function is ordnance maintenance, intermediate level and above, are addressed in the 200 series Category Codes.

14320-1.1 **Installation Ordnance Operations Building**. At an ammunition storage or handling installation the authorized building space are 150 gross SF per person for administrative personnel and 50 gross SF per person for operating personnel (ammunition handlers, etc.). This provides space for an office (s), assembly and briefing room for ammunition handlers, locker room, and storage space for ammunition handling tools and equipment. Space requirements may increase as handling and support equipment changes dictate larger work and storage areas. Sufficient justification should support the increased space requirements. Air installations with bomb build-up requirements can plan for a weapons build-up facility. This facility serves as an ordnance assembly area for bombs, missiles and the like prior to going to the flight line for loading on aircraft. An overhead hoist, worktables and several roll up doors are minimal requirements to promote the buildup process. This facility can also serve to perform basic ordnance maintenance. Planning criteria is not available because of the potential multi-functions that may be served in this facility. Recommend a space analysis starting with a process flow and identifying functions to be performed.

14320-1.2 **Explosive Ordnance Disposal Facilities.** The EOD facilities have been moved to Category Codes 143 22, 143 23 and 143 24.

143 21 AMMUNITION SEGREGATION FACILITY (SF)
FAC: 1443
BFR Required: Y

14321-1 **DEFINITION.** A segregation facility is a building or series of buildings where fleet return explosive and inert material are screened and grouped by type and physical condition.

14321-1.1 Definition from NAVSEA OP-5 Vol. 1: Typically, these functions are located at Naval Weapons Station or Naval Magazine installations. For these larger installations, there may be multiple segregation facilities for bomb-type ammunition, general ammunition and propellant powder buildings. At smaller ammunition installations there would be just one segregation facility. For additional information see the NAVSEA OP-5 Manual.

14321-1.2 No planning criteria exist for the segregation function; recommend an engineering evaluation be completed. Functional examples might be: Shipping /receiving, inspection area, banding area and a technical documents area, etc. Some questions that might be asked of the facility user interviews: What is approx. ordnance throughput (amount/time period) average? Peak? What types of ordnance? Containerized precision guided munitions may require large amounts of space versus palletized ordnance. Will explosives be left in facility overnight? NAVSEA OP-5 safety criteria will dictate requirements.

143 22 NAVY EXPLOSIVE ORDNANCE DISPOSAL SHORE DETACHMENT FACILITY (SF)

FAC: 1444
BFR Required: Y

14322-1 **DEFINITION**. the nature and scale of the EOD operations involved, billets will be assigned for a "shore detachment" (1 officer, 1 – Leading Chief Petty Officer (LCPO), and 7 enlisted personnel). The facilities defined below are sized to support an EOD Shore Detachment (DET) and includes the following: Operational Space – built to "Open Secret", armory – built to meet **OPNAVINST 5530.13C, Physical Security Instruction for Conventional Arms, Ammunition, and Explosives, Armory**, latest revision. Lobby/Quarter Deck, Operational Space, Locker/Shower room, and drying cages (climate controlled) will be in environmentally controlled spaces. Open Bay spaces will include: 1) Workshop/Maintenance spaces, equipment storage, 2) exterior fresh water wash down area with deep sink, 3) drying area, and 4) four-bay High Bay Area Vehicle/ Boat Storage/miscellaneous emergency response equipment area. High Bay area must be provided with exhaust ventilation system and 16' x 16' roll-up doors. One bay, minimum, will be a "drive-through" to support the Multi-Mission Expeditionary Response Truck (MERT) and the trailer. To ensure correct line-up into the MERT bay, provide a straight approach lane, 58 feet x 16 feet, in front of and behind (for drive through lane) the facility for access.

Description	NSF	Climate Control	Net to Gross
Lobby/Quarter Deck			
Lobby and Sign In Area	165	Yes	1.35 to 1
Bunk Room	100	Yes	1.35 to 1
Male/Female Restroom for EOD Shore DET personnel	48	Yes	1.35 to 1
Provide a male/female restroom for lobby area	48	Yes	1.35 to 1
CONSTRUCT TO OPEN SECRET			
OPS (admin)	948	Yes	1.35 to 1
private offices - 2 ea: 200 SF, general office space – 7 ea: 448 SF Planning and Briefing Cell: 150 SF SIPER Room: 1 ea: 150 SF			
Male Restroom for EOD Shore DET personnel within the Open Secret Spaces	62	Yes	1.35 to 1
Female Restroom for EOD Shore DET personnel within the Open Secret Spaces	46	Yes	1.35 to 1
Shore DET PGI Cages			
9 ea @ 112 SF/cage	1,008	Yes	1.35 to 1

Description	NSF	Climate Control	Net to Gross
Shore DET Changing Room			
Male Bathroom/Shower/Locker Area	194.5	Yes	1.35 to 1
Female Bathroom/Shower/Locker Area	95	Yes	1.35 to 1
Drying Cages Area			
9 ea at 36 SF/cage (Drying Cages to be Climate & Humidity Controlled)	324	Yes	1.35 to 1
Armory			
(Armory must meet OPNAVINST 5530.13C, Physical Security Instruction for Conventional Arms, Ammunition, and Explosives, Armory requirements)			
General Armory Space for maintenance parts storage, safe, HazMat Locker, workbench, etc.	433	Yes	1.35 to 1
Weapons and Case Storage	180	Yes	1.35 to 1
Communications Gear Storage			
Shelving (4 In ft x 2 ft deep and 4 In ft x 4 feet deep) for communications gear storage	65	Yes	1.35 to 1
OPEN BAY AREA			
Operational Storage			
Shore DET Operational Storage Cage Space (Section 10 material), 10' x 10'. Size based on 8' max stack height	100	No	1.35 to 1
TOA stored on shelving units - Section 47: 32 sf plus 2.25 clearance factor(BDY ARMR EOD/LG)	72	No	1.35 to 1
Open floor space for items too heavy to store on shelving	538	No	1.35 to 1
TOA Storage (items not in Cage, on shelves, or on floor), Total Cubic Foot	975	No	1.0 to 1
Note: Net to Gross built into the GSF calculation for TOA storage			
Miscellaneous Work Areas			
Maintenance Work Benches, 2 ea	108	No	1.15 to 1
Wet Charging Stations, 2 ea - 2' x 6'	54	No	1.15 to 1
2 ea dip tanks located near exterior wall to be connected to Shore DET Air Compressor located near exterior wall under cover)			
Shore DET Open Area for Misc functions			

Description	NSF	Climate Control	Net to Gross
12 sf/EOD Tech	96	No	1.15 to 1
CESE/SABAR Storage			
Four Bays; Bays to be 68' deep X 16' wide with a 16' x 16' bay opening	4,352	No	1.15 to 1
Note: Provide at least One bay with drive through capability			
EXTERIOR SPACES/FUNCTIONS			
Exterior Rinsing Station			
Outside showers and wash sink is required. Provide 4 Showers, 1 stainless steel sink, 8' W x 4' deep and appropriate screening for outdoor gear washing.	108	No	1.10 to 1
Equipment Wash Tank, 2 ea, 6' L x 2' W	27	No	1.10 to 1
Temp exterior drying cage area (equipment/material staging/drying racks/shelving), 6 each, 3' x 4', cage spaces	162	No	1.10 to 1
Covered area outside of DET facility High Bay area for the DET's air compressor. Area to include cover from weather and piping, certifiable to Breathing Air standards and routed into the DET's Wet Charging station inside the High Bay space.	25	No	1.10 to 1

14322-2 In addition to the EOD shore detachment building proper, there are supporting facilities, which are located separately to meet safety requirements. This square footage is not part of this CCN and, therefore a separate BFR must be submitted for this requirement. The EOD Shore DET will require either a Golan or Ready Service Locker, both equipment, to house small quantiles of explosives. This equipment must be mounted on an Explosive Storage Site Pad, CCN 425-11, and the Explosive Storage Site Pad will be sited In Accordance With Naval Ordnance Safety and Security Activity (NOSSA) Instruction 8020.22 (latest revision). The Shore DET will need an Ordnance Demolition Area for destroying explosives and explosives-loaded devices, see CCN 148-20. Include an Observation Tower/Bunker for the protection of the EOD Shore DET personnel, CCN 173-40, to support the Ordnance Demolition Area. The Shore DET will need space for a generator to support Intrusion Detection System (IDS) requirements for AA&E/Classified Storage. Provide a Miscellaneous Open Storage Pad, CCN 852-40. Size the pad in accordance with the size of the backup generator plus a clearance area of 3 foot minimum on all sides of the generator to accommodate facility maintenance. The generator is equipment and therefore must be provided by the command. In situations where the Shore DET requires a boat ramp and pier space, add CCNs 143-12, 155-20 and 155-22.

14322-3 **EOD Shore Detachment Facility:**

EOD Shore DET Building	CCN 143-22: 12,032 GSF
Additional Requirements:	
Operational Vehicle Parking/ Laydown Area	CCN 143-12: 338 GSY
Explosive Storage Site Pad	CCN 425-11: Sized to requirement
Ordnance Demolition Area	CCN 148-20: Sized to requirement
Observation Tower/Bunker	CCN 173-40: Sized to requirement
Backup Generator	CCN 852-40: Sized to requirement
Boat Ramp	CCN 155-22: 1 ea
Small Craft Berthing	CCN 155-20: 89 FB, 2,250 SF
POV Parking	CCN 852-10: Sized for 9 personnel plus 2 visitor parking spaces

143 23 NAVY EXPLOSIVE ORDNANCE DISPOSAL MOBILE UNIT (EODMU) FACILITY (SF)
FAC: 1444
BFR Required: Y

14323-1 **DEFINITION.** EODMUs are responsible for manning, equipping and training of any number of deployable EOD detachments: Mobile Detachments, Area Search Detachments, Ordnance Clearance Detachments, Mobile Communications Detachments, Combat Service Support Detachments, Fly Away Recompression Chamber Detachments, Mine Counter Measures Detachments and Marine Mammal System Detachments. Facilities are required for administrative activities, equipment maintenance and storage, training and operations. Manning levels vary by MU, so square foot requirements for a given installation is based on the following criteria, all SF are net (NSF):

14323-1.1 **Net to gross markups by functions:**

- Administration through bath/showers functions below: 1.25
- Training Spaces: 1.33
- Supply/Storage: 2.38
- Remainder, operational spaces: 1.33

14323-1.2 **Administrative spaces**: 120 SF per administrative worker (includes CO, XO, CMC, MAA and all administrative department personnel).

14323-1.3 **Classified equipment and documents area**: 300 SF plus an additional 25 SF for each detachment assigned for the storage and maintenance of classified documents and equipment.

14323-1.4 **Quarterdeck:** Allow 150 SF for security screening area.

14323-1.5 **Bunkroom:** Allow 72 SF for each member of the watch. Separate male and female bunkrooms required.

14323-1.6 **Bathrooms/Showers**: Allow 15 SF/water closet, 20 SF/shower, 6 SF/urinal and 6 SF/lavatory with the number of fixtures appropriate for the maximum number of personnel using the facility at one time.

14323-1.7 **Multi-purpose Training/Conference Room**: Use Category Code 171-10, General academic. Loading is based upon an all-hands function, the mobile unit and all assigned detachments.

14323-1.8 **Academic Instruction Space**: Use Cat Code 171-10, General academic. Allow for instructor(s) space.

14323-1.9 **Supply/Storage**: Allow 2,100 SF for spare parts storage and 450 SF of administrative area for supply functions. The administration area should use the admin. net to gross markup above.

14323-1.10 **Magnetometer Room**: Allow 360 SF for testing of special purpose low magnetic signature tools.

14323-1.11 **Compressor Room**: Allow 300 SF for divers fixed high-pressure compressor and flasks.

14323-1.12 **Hydro Room:** Allow 300 SF for hydro test equipment.

14323-1.13 **MK 16 Locker**: Allow 800 SF for maintenance and preparation of MK 16 diving equipment. This needs to be an O_2 clean room.

14323-1.14 **Communal Staging Area**. Allow 1,000 SF for a communal outdoor staging area for assigned mobile detachments. Used prior to deployment for gear inspection and preventive maintenance.

14323-1.15 **Electronics Shop**. Allow 400 SF for maintenance of communications and navigation equipment.

14323-1.16 **Personnel Lockers**. Allow 12 SF for each diver and 6 SF for each additional support person assigned.

14323-1.17 **Medical Area**. Allow 150 SF for a doctor or independent duty corpsman (if both, 150 each), 200 SF for an examining room and 150 SF for a waiting area/medical records office.

14323-1.18 **Scuba Locker**: Allow 1350 SF for maintenance and preparation of scuba diving equipment.

14323-2 **Spaces**. The unique detachment missions may dictate additional spaces. The different type of EOD detachments and their space requirements that may be assigned to the Mobile Units are listed below. The typical manning levels are provided; should additional space be required; it must be individually justified.

14323-3 **Area Search Detachment (ASD):** Allow 450 SF for equipment storage and maintenance and 150 SF of administrative area for each ASD assigned. Manning: 1 Off/ 7 Enl.

14323-4 **Combat Service Support Detachment (CSSD):** Allow 1,200 SF for administrative, 6,000 SF warehouse for material and equipment storage and 3,968 SY controlled outside equipment lay down storage. Manning: 1 Off/ 16 Enl.

14323-5 **Fly Away Recompression Chamber Detachment (FARC):** Allow 1,204 SF for administrative, supply and equipment storage and 90 SY lay down compound for (1) FARC, (1) Generator set and (1) 8' x 8' x 10' Milvan. Manning: 1 Off/ 5 Enl.

14323-6 **Marine Mammal System Detachment (MMS):** Allow 1000 SF for each Mark shop assigned (e.g. Mk 5). Allow 432 SF for veterinarian. Allow 800 SF for food preparation. The Marine Mammal Systems Managers will determine space requirements for holding pens, staging areas and Marine Mammal Management Facilities. These spaces are regulated by Federal regulations and standards. Manning: 1 Off/ 15 Enl.

14323-7 **Mine Counter Measures Detachment (MCM):** Allow 1700 SF for equipment storage and maintenance and 150 SF for administrative area for each MCM detachment assigned. Manning 1 Off / 7 Enl.

14323-8 **Mobile Communications Detachments (MCD):** Allow 1,850 SF for equipment storage and maintenance and 150 SF of administrative area for each MCD assigned. Manning: 1 Off/ 7 Enl.

14323-9 **Mobile Detachments (MOB):** Allow 800 SF for equipment storage and maintenance and 150 SF for administrative area each mobile detachment assigned. Manning: 1 Off/ 7 Enl.

14323-10 **Ordnance Clearance Detachments (OCD):** Allow 480 SF for equipment storage and maintenance. Allow 150 SF of administrative area for each OCD's assigned to the mobile unit. Manning: 1 Off/ 7 Enl.

14323-11 **Additional Functions.** Additional functions associated with EOD units/detachments are mission driven and must be individually justified. The following Category Codes are some applicable selections:

- Parachute Survival Equipment Shop: use Category Code 211 75.
- Small Craft Fuel Station: use Category Code 122 20.
- Small Craft Fuel Storage Area: use Category Code 122 30.
- Emergency Vehicle Garage: use Category Code 143 10.
- Operational Vehicle Garage: use Category Code 143 11.
- Operational Storage: use Category Code 143 77.
- Armory: use Category Code 143 45.
- Hazardous Material/Flammable Storage: use Category Code 143 78.
- Ordnance Demolition Area: use Category 148 20.
- Small Craft Berthing: use Category Code 155 20.
- Landing Craft (boat) Ramp: allow one EA under Category Code 159 66.
- Light Demolition Range: use Category 178 30.
- Boat Shop: use Category Code 213 58.
- Vehicle Holding Shed: use Category Code 214 40.
- Vehicle Shop: use Category Code 214 20.
- Ready Magazine: use Category Code 421 35.
- Open Storage Area: use Category Code 451 10.
- Parking Area: use Category Code 852 10.

143 24 MARINE CORPS EXPLOSIVE ORDNANCE DISPOSAL FACILITY (SF)
FAC: 1444
BFR Required: Y

14324-1 **DEFINITION.** These facilities provide support for Marine Corps EOD shore teams and platoons permanently assigned to Marine Corps installations. The manning structure for EOD teams and platoons has increased and is reflected below in category codes 143 24 and 143 26.

14324-2 This facility provides support for EOD operations on Marine Corps Bases, Marine Corps Air Stations, and Marine Corps Air Wing Support Squadrons. The facility defined below is scaled to match the EOD Team (1 Officer, 8 Enlisted) and include administrative spaces, classified publication vault, quick response ready lockers, workshop/maintenance space, classroom, equipment storage, locker room, and ordnance training aids library space. The facility will be equipped with an Intrusion Detection System (IDS). In addition, the facility will house all the emergency response vehicles, trailers (including total containment vessels), and other emergency response equipment.

14324-3 In addition to the EOD team facility proper, there are supporting facilities, which are located separately to meet safety requirements. The hazardous/flammable storage building, category code 143 78, stores petroleum products, petroleum operated equipment, corrosives, and paints. Typically, these building are 12’x17’, but larger sizes may be justified depending on the team’s operational mission. This building should be located as close the EOD building as safety standards permit. The other facilities are the ready service magazines and are described under category code 421 35 as “Ready Magazines”. Refer to category code 421 series to understand the unique storage requirements of ordnance. These are sited in accordance with safety criteria published in NAVSEA OP 5, Volume 1, “Ammunition and Explosives Ashore” (abbrev. Title).

14324-4 When multiple EOD teams are assigned to the same installation and when collocating teams is viable, the gross square below should be multiplied by the number of teams assigned. Overall square footage may be reduced for common use spaces.

Table 14324-1
Overall Square Footage Requirements
For EOD Teams

EOD Building	7000 GSF
EOD Haz/Flam Building	204 GSF or sized to requirement
EOD Ready Service Magazine	Sized to requirement

14324-5 Submitted basic facility requirement (BFR)s shall include the EOD Table of Organization for the installation supported and facility component breakdowns of the overall requirement (i.e. admin, vehicle/trailer housing, storage, publication vault, locker area, etc.

143 25 SEAL TEAM BUILDING (SF)
FAC: 1444
BFR Required: Y

Note: This Category Code contains assets that were previously classified under 143 28.

14325-1 **DEFINITION.** The requirements for these facilities are developed by an industrial analysis for the specific facility. See category code 610 10 for administrative space guidelines and category code 159 64 for Waterfront Operations Building guidelines.

143 26 MARINE CORPS EXPLOSIVE ORDNANCE DISPOSAL PLATOON FACILITY (SF)
FAC: 1444
BFR Required: Y

14326-1 This facility is responsible for manning, equipping, and training for EOD operations in support of Fleet Marine Forces. The facility defined below is scaled to match the EOD Platoon (9 Officers, 97 Enlisted). Facilities are required for administration, equipment maintenance and storage, training and operations. All SF criteria are Net Square Feet (NSF), net to gross conversion = 1.33.

14326-2 **Administrative space:** Allow 1520 SF for administrative functions this includes Platoon commander, assistant platoon commander, SNCOIC, and all administrative department personnel.

14326-3 **Classified publications vault:** Allow 811 SF for storage of classified material and administrative space. This space requires IDS.

14326-4 **Combat Service Support Team Room:** Allow for 1200 SF administration area and 1000 SF for material, equipment, and maintenance area for each EOD team. Team manning level: 1 Officer, 8 enlisted.

14326-5 **Bathrooms/showers:** Allow 15 SF/water closet, 20 SF/shower, 6 SF/urinal and 6 SF/lavatory with the number of fixtures appropriate for the maximum number of personnel using the facility at one time. Allow 200 SF for female bathroom/Shower area.

14326-6 **Multi-purpose/Conference room:** Use category 171 10, General academic. Loading is based upon an all-hands function, or a maximum of 100 students.

14326-7 **Communal staging area:** Allow 1000 SF for a communal outdoor staging area for assigned detachments. Used prior to deployment for gear inspections and preventative maintenance. This should be at a minimum a paved surface.

14326-8 **Personnel Lockers:** Allow 18 SF for the maximum number of personnel using the facility at one time. This is sized to accommodate all the necessary combat equipment every platoon member is assigned.

14326-9 **Training aids library:** Allow 2000 SF. This area is used to store/display inert training aids.

14326-10 **Break area:** Allow 811 SF.

14326-11 **Material and equipment work area:** Allow 2000 SF for table of equipment storage and maintenance.

14326-12 Submitted basic facility requirements (BFR)s shall include the EOD Table of Organization for the installation supported and facility component breakdowns of the overall requirement (i.e. admin, vehicle/trailer housing, storage, publication vault, locker area, etc.

14326-13 Additional functions associated with EOD teams/platoons are mission driven and must be individually justified. The following category codes are some applicable selections:

- Small Craft Fuel Station: use Category Code 122 20.
- Small Craft Fuel Storage Area: use Category Code 122 30.
- Emergency Vehicle Garage: use Category Code 143 10.
- Operational Vehicle Garage: use Category Code 143 11.
- Armory: use Category Code 143 45.
- Operational Storage: use Category Code 143 77.
- Hazardous Material/Flammable Storage: use Category Code 143 78.
- Ordnance Demolition Area: use Category 148 20.
- Small Craft Berthing: use Category Code 155 20.
- Landing Craft (boat) Ramp: allow one EA under Category Code 159 66.
- Light Demolition Range: use Category 178 30.
- Parachute Survival Equipment Shop: use Category Code 211 75.
- Boat Shop: use Category Code 213 58.
- Vehicle Shop: use Category Code 214 20.
- Vehicle Holding Shed: use Category Code 214 40.
- Ready Magazine: use Category Code 421 35.
- Open Storage Area: use Category Code 451 10.
- Parking Area: use Category Code 852 10.

143 35 REGISTERED PUBLICATIONS ISSUING OFFICE (SF)
FAC: 1444
BFR Required: Y

14335-1 **DEFINITION.** A Registered Publications Issuing Office (RPIO) has a primary mission of supporting communications operations of the Fleet, Naval Aviation, U.S. Marine Corps, and the U.S. Coast Guard. RPIO's receive, store, issue, account for, and-officiate during the destruction of highly classified cryptological publications, equipment, and devices circulating in the Registered Publications System (RPS). An RPIO has three major space areas: Storage, Receive/ Issue, and Administration. The storage area of the RPIO must be constructed to meet the criteria of a Class A vault as defined in KAG-1D. The size of an RPIO can generally be related to the number of RPS items handled yearly. RPS items are such things as publications, magnetic tapes, films, crypto equipment, spare parts, cards, and other key material. See Table 14335-1 for planning factors.

Table 14335-1. Space Allowances
Registered Publications Issuing Office

RPS Items Handled Per Year (Thousands)	Gross Area (SF) Admin, Receive/Issue, Vault
100 - 500	7,500
501 - 750	12,500

RPS Items Handled Per Year (Thousands)	Gross Area (SF) Admin, Receive/Issue, Vault
751 - 1,250	14,000
1,251 - 2,500	16,000

143 40 COMPUTER PROGRAMMING OPERATIONS CENTER (SF)
FAC: 6104
BFR Required: Y

14340-1 This category is deleted. All future requirements should be reassigned and revised to Category Code 13115 "Communications, Information, or Intelligence Analysis Facility".

143 41 AMPHIBIOUS OPERATIONS BUILDING (SF)
FAC: 1431
BFR Required: Y

14341-1 The requirements for these facilities are developed by an industrial analysis for the specific facility. See category code 610 10 for administrative space guidelines and category code 159 64 for Waterfront Operations Building guidelines.

143 45 ARMORY (SF)
FAC: 4427
BFR Required: Y

14345-1 **DEFINITION.** A Navy installation armory provides space for storage and routing maintenance of small arms and emergency gear. The materials stored will provide for emergencies and for training of selected personnel in the handling of station emergencies, civil disorders, and area disasters. See Table14345-1 for space allowance.

Table 14345-1. Armory

Installation Military Strength	Building Gross Area
up to 2,000	576
2,001 - 4,000	880
4,001 - 7,500	1,200
7,501 - 10,000	1,508

Over 10,000	Add 0.1 sq ft per person

14345-2 The space above provides for an armory and small arms shop supporting only the weapons and personnel assigned to that installation. See Category Code 215 10 for Small Arms Shop in support of multiple installations.

14345-3 An additional method is to build the space requirements by weapon and ammunition count. The weapons/equipment within the armory is typically stored within cabinets, gun racks, shelving, boxes, or wall boards. In most cases, this method of storage allows some stacking of the weapons/equipment which can reduce floor space requirements. Requirements are listed on the Marine Force Armory website. Go to the “input” worksheets for: terms, definitions, weapon storage dimensions and basic algorithms for different types of weapons and equipment. Use this information to calculate space requirements.

14345-4 Armory design specifications can be found in MIL-HDBK-1013/1A and additional policy and guidance in OPNAVINST 5530.13 Series, Fleet Marine Force Armory (SF).

14345-5 An armory for Fleet Marine Force air and ground units provides a humidity controlled, air conditioned and secure space for storing and maintaining weapons assigned to personnel. Consolidation of unit armories should be emphasized provided such action is compatible with mission requirements, responsiveness and accessibility.

14345-6 The SF allocation for the Marine Force armory can be determined by locating the P-80 on the NAVFAC portal. The criteria algorithm is an EXCEL spreadsheet with the instructions provided in the first worksheet. Once the spreadsheet is opened go to the “instructions” worksheet.

14345-7 If you intend on using the spreadsheet to calculate facility requirements, it is suggested you perform a “save as” function to operate the spreadsheet from your computer vice via the Internet.

Click here to go to the spreadsheet.

143 46 MARINE BARRACKS - GENERAL PURPOSE BUILDING (SF)
FAC: 1446
BFR Required: Y

14346-1 **DEFINITION.** The criteria contained herein are applicable to CNO commanded Marine Barracks. The purpose of the Marine Barracks is to provide such security as approved by the Chief of Naval Operations, in coordination with the Commandant of the Marine Corps, and to perform such additional functions as directed by CMC.

14346-2 The criteria for Marine Barracks cover general-purpose functions only (for example, administration/operational, general instruction, armory and supply). Requirements for specific functions such as shop space, specialized storage, etc., should be developed from criteria of the Category Code for the specific function. This criterion does not include BEQ or community support facility requirements. Planning factor criteria for BEQ and community support facilities necessary to support the Marine Barracks personnel are contained in the Category Codes series 700. However, under normal conditions, the host activity would be expected to provide all community type support.

14346-3 The following shall be utilized for broad planning purposes when there is an absence of a detailed analysis of functional requirements. Provisions for parking (Category Code 852 10) and small arms pyrotechnic magazine (Category Code 421 48) should utilize the appropriate Category Code.

Table 14346-1 Marine Barracks

Military Strength	Gross SF/MN
1-50	75
51-100	65
101-150	55
151-200	45
201 -	For every man over 200, add 30 gross square feet per man

143 47 ALERT FORCE BUILDING (SF)
FAC: 1446
BFR Required: Y

14347-1 **DEFINITION**. An Alert Force Building is programmed in conjunction with an Air/Underwater Weapons Shop, Category Code 216 55, when required to meet the Alert Force response times established for the shop. The Alert Force Building provides barracks facilities, including limited messing facilities necessary to accommodate the guard of the day for an AUW Shop. It also contains a duty office, provision for weapons storage and an alarm repeater panel. Space requirements should be generated by an engineering space analysis.

143 55 TRANSIT SHED (SF)
FAC: 1444
BFR Required: Y

14355-1 **DEFINITION.** A transit shed is planned to support the rapid and orderly transfer of truck and rail freight in shipment from one carrier to another with minimum storage. For a waterfront transit shed, see Category Code 156 10. The transit shed is of the minimum design that will protect the freight from the weather and provide any security necessary. It may be a roofed shed with open sides or completely enclosed space built to the minimum specifications to provide the required protection. Plan at the rate of 1500 SF per 64 measurement tons (MT) of throughput per day for a peak (assumes 4 FT high stacking, 12 FT aisles for equipment maneuvering)

143 60 EXPLOSIVES, SHIPPING/TRANSFER DEPOT (SF)
FAC: 1431
BFR Required: Y

14360-1 **DEFINITION**. An explosives transfer depot is a facility used to transfer break-bulk ammunition and explosives between automotive vehicles and railcars for further shipment, or for delivery to a storage magazine, loading building, waterfront or airfield. The transfer depot may be in close proximity to a loading platform, a flight line, or a truck or rail center. This facility is typically required only at installations which expend or transship the ordnance materials in large quantities, e.g. NAVWPNSTAs and NAVMAGs. No planning factors are available; however, consider using industry metrics like peak daily throughput in sf/ton per unit of time. This code is not to be used for containerized ordnance; for ordnance moved in ISO (International Standards Organization) containers, use Category Code 148 40, Container Transfer Facility (Ordnance) should be used.

143 65 REGION/INSTALLATION OPERATIONS CENTER (SF)
FAC: 1431
BFR Required: Y

14365-1 **DEFINITION.** A Region/Installation Operations Facility is a shore mission specific Command, Control, and Coordination (C3) area in direct support of the operations mission of a Region/Installation Navy or Marine Corps Activity. This facility can also be designated as a Regional Operations Center (ROC), Emergency Control Center (ECC), or Emergency Action Center (EAC).

14365-2 **FUNCTIONAL AREAS.** This facility may contain the following functional areas:

- Equipment areas for both classified and unclassified server spaces to support tactical and operational communications systems and networks
- Operations areas to include a Watch Center and a Command Viewing Area
- Operations Analysis Workstations and Special Access Programs (SAP) area

Additional space may be provided to support Special Purpose Spaces such as: Break Room, Conference Room, and a Duty/Bunk Room, as well as Private and Open Office areas to support the small day-to-day operating staff. Additionally, adequate facilities are required to accommodate all operations staff that man the facility during emergency operations. Additionally, due to the nature of the mission of these facilities, an Uninterruptible Power Supply (UPS) system and emergency generator system may be required. See Table 14365-1 for authorized functional areas. An Engineering Evaluation will be used to determine the quantity and type of functional areas required. Please refer to the guidelines provided in the introduction of 131-series Category Codes for C5ISR buildings to calculate the requirement for each functional area. Per section 131-14, the authorized **net-to-gross** factor is 1.45.

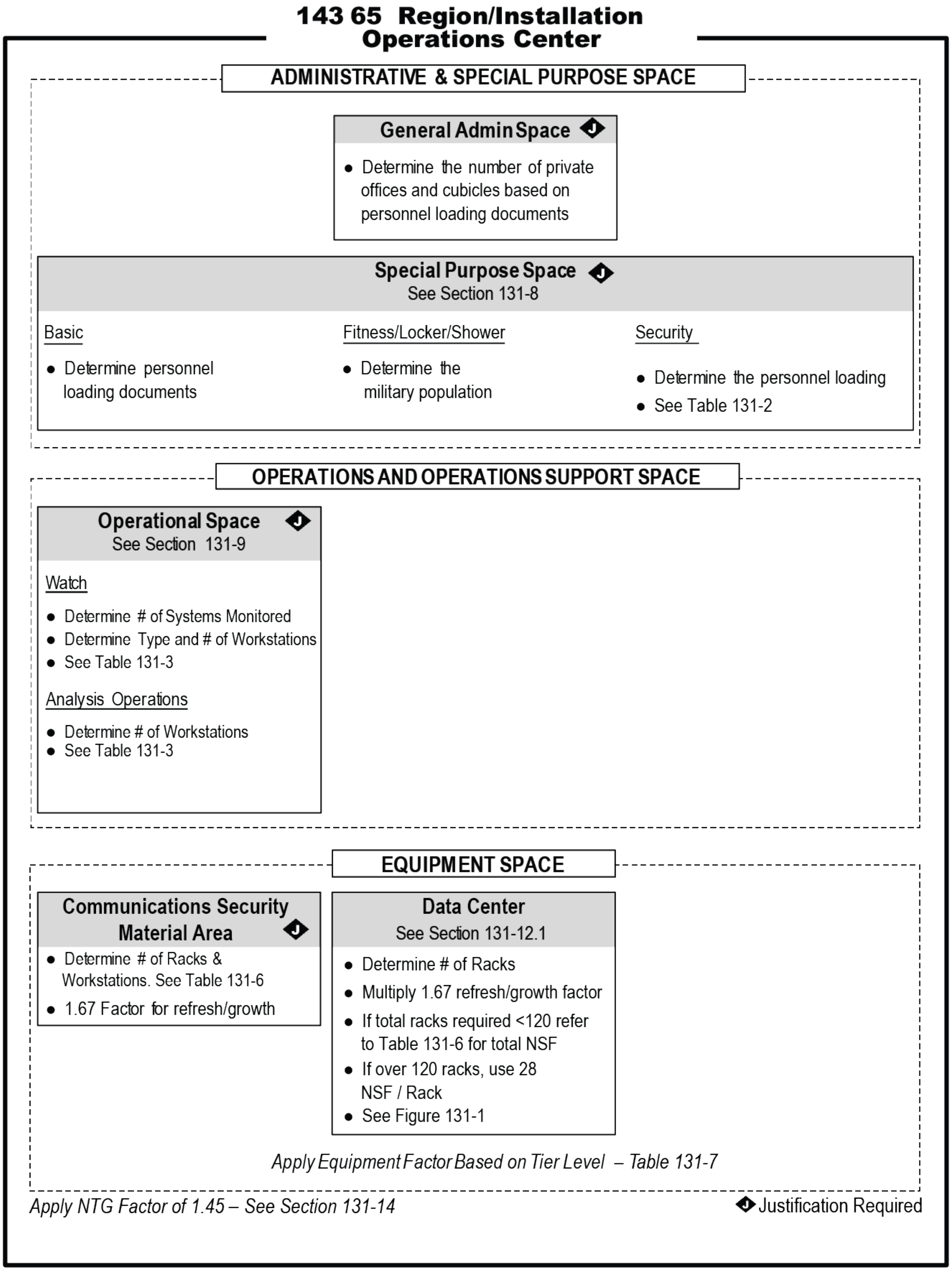
14365-3 **BUILDING BLOCKS.** Figure 14365-1 provides a diagram demonstrating a summary of the applicable spaces, appropriate allocation factors, and the special relationship for Region/Installation Emergency Operations Facilities.

Table 14365-1. Region/Installation Operations Facility Functional Areas

Functional Area	Sub-space	143 65
Administrative General Purpose	Private Office	J
	Open Office (Cubicle)	A
Special Purpose Space Basic	Admin Support	A
	Break Room	A
	Classified Vault	J
	Conference Rooms/VTC	A
	Duty/Bunk Room	J
	Technical Publications Area	J
Special Purpose Space Fitness/Locker/ Shower	Locker Room	J
	Shower Room	J
Special Purpose Space Security	Quarterdeck/Entry Control	J
	Special Security Office	J
Operations Space	Watch Center	A
	Analysis Operations	A
Equipment Space	Data Center/Server	A
	Communications Security Material Area	J

Legend:
A – Approved without additional justification (based on the staffing and mission requirements)
J – Only approved with specific justification of mission requirements

Figure 14365 -1. Region/Installation Operations Facility Building Blocks Diagram



143 70 RADIATION INSTRUMENT CALIBRATION FACILITY (SF)
FAC: 1442
BFR Required: Y

14370-1 **MONITORING DEVICES.** A health physics calibration building contains facilities required for calibration of health physics survey instruments and area monitoring devices. These devices are used to protect personnel against ionizing radiation from x-rays and atomic particles. The size of the building will depend upon the type and number of instruments being calibrated. Requirements typically include the following:

14370-2 **ADMINISTRATIVE OFFICES.** Refer to Category Code 610 10 guidance to determine the space requirements based on the number of offices needed.

14370-3 **CALIBRATION LAB.** Space consists of electrical and non-electrical workbenches, tool cabinets, and library of technical manuals, safety equipment, and storage of equipment waiting for calibration, storage for repair parts, and file storage for record keeping. The number of workbenches and cabinets must be determined based on the number of instruments being calibrated and number of personnel assigned to this function.

Table 14370-1. Calibration Lab

Items	NSF
Workbench (each)	125
Tool cabinet (each)	15
Library for manuals	50
Safety equipment	20
Equipment waiting calibration	80
Replacement parts	200
File storage cabinet (each)	7

14370-4 **Range.** Space consists of area to safely test the survey and monitoring equipment. The requirements will be determined by an engineering evaluation. The number of instruments, frequency of testing, and specific instrument testing requirements will dictate the space required for the range.

143 75 POL OPERATIONS/SAMPLING/TESTING BUILDING (SF)
FAC: 1442
BFR Required: Y

14375-1 **DEFINITION.** The POL operation building provides space required for quality control and administration of fuel activity. Space is provided in the building for an administrative office, control/gauge monitoring center, and fuels testing laboratory. Physical operation and control of the fuel system will be accomplished elsewhere (such as the pump house). Each person not working in the lab should be assigned desk space not to exceed 162.5 NSF. This net area allows for wall thickness, corridors and other general circulation, mechanical rooms, and rest rooms. Supervisor may be provided with private offices. The lab area and control monitoring center requirements will be based on engineering field analysis of the spaces. For the lab and control center only, a gross to net multiplier of 1.45 may be used. This multiplier will account for wall thickness, corridors, and circulation around equipment, mechanical rooms, and rest rooms.

143 77 OPERATIONAL STORAGE (SF)
FAC: 1443
BFR Required: Y

14377-1 **DEFINITION.** Operational Storage supports multiple Departments/Divisions within a command. It is under the control of the Logistics and Supply Department. This Category Code is used to identify areas used for bulk storage areas of major end items, and operational material. Storage of material under the control of the Communications Department should be classified within Category Code 217 77.

14377-2 Storage facilities for equipment related to operational facilities will be provided only where it can be individually justified. There are no criteria for this type of facility. General information on normal stacking heights, SF per measurement ton requirements, and other parameters are provided in Category Code 440 series.

143 78 OPERATIONAL HAZARDOUS/FLAMMABLE STORAGE (SF)
FAC: 1443
BFR Required: Y

14378-1 **DEFINITION.** This category will be used to provide a facility for the storage of materials used in daily operations that require special environmental separation. These materials such as paint, acetone, oil, etc. are considered to be hazardous and/or flammable. Personnel or storekeeper that may be assigned to this facility should be provided with a separate office space not to exceed 162.5 NSF. An engineering field analysis will be required to determine the warehouse space based on quantity of materials stored. Racks or shelves will be used to reduce footprint. Some materials may not be mix or must be divided by berms or firewalls and this separation space should be added to calculations. These facilities may require some environmental controls and ventilation. If quantity is palletized allow for forklifts in aisle ways or access through overhead doors. Reference the 440 series for assistance on converting CF to NSF.

14378-2 Facility should be close to or an extension of other warehouse space, therefore other personnel support spaces (i.e., restrooms, break area, lockers, etc.) are not required. Operational commands store small quantities of materials and small facilities under 1000 NSF are typical. For hazardous waste, see category codes 831 41/42.

143 80 MISSION OPERATION COMMAND AND CONTROL FACILITY (SF)
FAC: 1404
BFR Required: Y

14380-1 **DEFINITION**. A Mission Operation Command and Control Facility is a specialized facility that is only required in select locations to support the operations of Force Commanders and Fleet Commanders (e.g. US Fleet Forces Commander, Pacific Fleet) and selected others as established by DoD. A Mission Operation Command and Control Facility may also contain facility requirements for Type Commands (e.g. AIRLANT, SUBPAC), Operational Support Commands (e.g. CTF and CTG) and a Maritime Operations Center (MOC).

14380-2 **SPECIALIZED REQUIREMENTS**. A Mission Operation Command and Control Facility contains the total requirements for office space, special purpose space, operations spaces, maintenance spaces, training spaces, equipment space, and limited IT logistics support space. The technical and operational mission of this facility may require that it contain: Secure Compartmented Information Facility (SCIF) areas, an Uninterruptible Power System (UPS), emergency generator system and in select cases, TEMPEST countermeasures may be required such as Radio Frequency (RF) shielding, Protected Distribution Systems (PDS), and signal/power line isolation and filters. Although a Communications, Information, Intelligence Facility (Category Code 131 15) and/or a Satellite Communications Facility (Category Code 131 24) may be collocated on station with a Mission Operation Command and Control Facility, the Mission Operation Command and Control Facility may contain dedicated communication architecture and operational systems that require it to have its own connectivity via direct satellite systems.

14380-3 **FUNCTIONAL AREAS.** This facility may contain the functional areas outlined in Table 14380-1. In instances where Type Commands (e.g. AIRLANT, SUBPAC) and Operational Support Commands (e.g. CTF or CTG) are collocated with the operating force within the Mission Operation Command and Control Facility, a separate analysis shall be calculated for each respective command to determine their specific requirements. An Engineering Evaluation will be used to determine the quantity and type of functional areas required. Please refer to the guidelines provided in the introduction of 131-series Category Codes for C5ISR buildings to calculate the requirement for each functional area. Per section 131-14, the authorized **net-to-gross** factor is 1.45.

14380-4 **BUILDING BLOCKS.** Figure 14380-1 provides a diagram demonstrating a summary of the applicable spaces, appropriate allocation factors, and the special relationship for Mission Operation Command and Control Facilities.

Table 14380-1. Mission Operation Command and Control Facility Functional Areas

Functional Area	Subspace	143 80
Administrative General Purpose	Private Office	A
	Open Office (Cubicle)	A
Special Purpose Space Basic	Admin Support	A
	Break Room	A
	Break Room Kitchen	J
	Classified Vault	J
	Conference Rooms/VTC	A
	Duty/Bunk Room	J
	Mail Room	J
	Technical Publications Area	J
Special Purpose Space Fitness/Locker/ Shower	Fitness Room[1]	J
	Locker Room	J
	Shower Room	J
Special Purpose Space Security	Quarterdeck/Entry Control	A
	Special Security Office	J
Operations Space	Watch Center	A
	Analysis Operations	A
Maintenance Space	Maintenance	J
Training Space	Training	J
IT Logistics Support Space	IT Logistics Support Space	A
Equipment Space	Data Center/Server	A
	Commercial Services Equipment	J
	Communications Security Material Area	J
	Network Distribution Area	J
	Specialized Equipment	J

Legend:
A – Approved without additional justification (based on the staffing and mission requirements)
J – Only approved with specific justification of mission requirements
(1). This requirement should be captured under CCN 740 45. Fitness Rooms are only allowed in accordance with CNICINST 1710.1 where by the command is located more than a 15- minute commute by vehicle from the nearest Morale Welfare and Recreation (MWR) Fitness Center, or in cases where service members are required to be on station and unable to leave for 18 hours at any given time. The fitness room must also have approval from the Installation Commanding Officer.

Figure 14380-1. Mission Operation Command and Control Facility Building Blocks Diagram

143 80 Mission Operation Command & Control Facility

ADMINISTRATIVE & SPECIAL PURPOSE SPACE

General Admin Space

- Determine the number of private offices and cubicles based on personnel loading documents

Special Purpose Space ◆J
See Section 131-8

Basic
- Determine personnel loading documents

Fitness/Locker/Shower
- Determine the military population

Security
- Determine the personnel loading
- See Table 131-2

OPERATIONS AND OPERATIONS SUPPORT SPACE

Operational Space
See Section 131-9

Watch
- Determine # of Systems Monitored
- Determine Type and # of Workstations
- See Table 131-3

Analysis Operations
- Determine # of Workstations
- See Table 131-3

Maintenance Space ◆J
See Section 131-10
- Build based on Table 131-4

Training Space ◆J
See Section 131-11
- Build based on Table 131-5
- Maximum of 20 positions allowed
- Greater than 20 positions requires justification

IT Logistics Support Space
See Section 131-13
- Determine shipping, receiving, laydown, and IT staging requirements
- Determine CF of storage requirement NSF = 0.327 × CF

EQUIPMENT SPACE

Communications Security Material Area ◆J
- Determine # of Racks & Workstations. See Table 131-6
- 1.67 Factor for refresh/growth

Data Center
See Section 131-12.1
- Determine # of Racks
- Multiply 1.67 refresh / growth factor
- If total racks required <120 refer to Table 131-6 for total NSF
- If over 120 racks, use 28 NSF / Rack
- See Figure 131-1

Commercial Services Equipment / Cable Plant ◆J
- 25% × Data Center/Server NSF

Network Distribution ◆J
- 15% × Data Center/Server NSF

Apply Equipment Factor Based on Tier Level – Table 131-7

Apply NTG Factor of 1.45 – See Section 131-14

◆J Justification Required

143 85 JOINT RESERVE INTELLIGENCE CENTER (JRIC) (SF)
FAC: 1444
BFR Required: Y

14385-1 **DEFINITION**. Joint Reserve Intelligence Center (JRIC). A JRIC is a joint intelligence production and training activity that uses information networks to link reservist intelligence personnel, active duty units and contractors with the combatant commands, Services, and/or combat support agencies. A JRIC is located within a Service-owned and managed sensitive compartmented information (SCI) facility and may also include surrounding collateral and unclassified areas involved in the performance and direct management of intelligence production work that uses Joint Reserve Intelligence Program infrastructure and connectivity. The JRICs located around the country are equipped to effectively serve as satellite elements to combatant command Joint Intelligence Operations Centers (JIOCs), however they are shared facilities that serve multiple customers and missions.

14385-2 A JRIC contains the total requirements for office space, intelligence production space, support space, equipment and communications spaces, maintenance and training spaces, and limited storage space. The technical and operational mission of a JRIC will require that it contain, Secure Compartmented Information Facility (SCIF) areas, an Uninterruptible Power System (UPS), emergency generator system(s), and in selected cases, Radio Frequency Interference (RFI) shielding, Electromagnetic Interference (EMI) shielding, and Telecommunications Electronics Material Protected from Emanating Spurious Transmissions (TEMPEST) protection. It may contain dedicated communications architecture and operational systems that require it to have its own connectivity via direct satellite systems. The JRIC uses DIA / DoDIIS / DS-OGT for infrastructure and connectivity in “state of the art” Data Centers located within the SCIF.

14385-3 A JRIC may contain the functional areas outlined below.

14385-3.1 **Office Area**. Areas are provided for, but not limited to, the Site Manager (Officer in Charge), Administrative Staff, JRIC Operations Officer and JRIC Site Systems Administrator. Additional office space may be required to support the (Reserve Intelligence Area) Commander, Deputy, Chief of Staff, Command Support Staff (N-00), Special Staff (N-01/02), DCOS Manpower and Personnel (N-1), DCOS Intelligence and immediate Support Staff (N-2), DCOS Operations and immediate Support Staff (N-3), DCOS Logistics/Supply/Material and immediate Support Staff (N-4), DCOS Plans and Policy and immediate Support Staff (N-5), DCOS & Combat Systems and immediate Support Staff (N-6), DCOS Tactics and immediate Support Staff (N-7), DCOS Requirements, Readiness, and Assessment and immediate Support Staff (N-8).

14385-3.2 **Support Area**. The following support areas are normally required.

• **Reception Area**. A reception area, normally shared by the Commander, Deputy Commander, and Chief of Staff is required. This area should be capable of accommodating a minimum of eight (8) personnel. This is essentially a screening area for un-cleared personnel. This includes receptionist and visitors.

• **Commanders Conference Room**. A Conference Room normally shared by the Commander, Deputy Commander, and Chief of Staff capable of supporting a minimum of eight (8) personnel may be required.

• **Conference/Classroom Room.** Requirement is predicated on Base Loading/Stationing plan of supported units/activities.

• **Command VTC/Conference Room**. A large area performing the function of an Auditorium/Conference Room may be required. The size of this area is dependent on the stationing/base loading plan, staffing and size of the JRIC.

• **Break/Lounge/Galley Area**. As a result of the operational hours maintained within this facility, a small break/lounge/galley (kitchenette) area is required.

• **Quarterdeck Area**. This multifunctional area provides an assembly or holding area for visitors awaiting escort, badge and pass issue and verification, and is considered the central point for ingress/egress. The quarterdeck will normally contain a maximum of two workstations requiring approximately 200 nsf.

• **Technical Publications Area**. This area may be required to store reference publications and literary data. It is configured similarly to a reference library in that it contains bookshelves, a reference area, and a working space for a minimum of two people requiring approximately 190 nsf.

14385-3.3 **Operational Area**. Not every JRIC will contain all of the areas listed, and there may be slight differences in terminology of the areas referenced below as a result of geographic specialization required at each respective location. In addition, although intended as a guide, the specific size of the areas provided below may vary as a result of the stationing/base loading plan and mission of the respective JRIC. An Engineering Evaluation will be used to determine the quantity and type of space required. Guidance provided within the Category Code series applied will be used * (see notes below).

• **Intelligence Operations Center**. This operational area is typically configured as a two to three room suite. The first area supports Operational Intelligence Production/Evaluation. This area will be configured based on mission essential tasks/functional requirements, be comprised of a certain number of A, B and C type workstations and include a conference area/collaborative multi-disciplinary workspace with a table capable of seating eight (8). The second area supports Strike/Targeting production. This area will be configured based on mission essential tasks/functional requirements, be comprised of a certain number of A, B and C type workstations and include a conference area/ collaborative multi-disciplinary workspace with a table capable of seating eight (8). The third area supports Special Warfare intelligence production. This area will be configured based on mission essential tasks/functional requirements, be comprised of a certain number of A, B and C type workstations and include a conference area/ collaborative multi-disciplinary workspace with a table capable of seating eight (8). Within the center there may be areas designated as Special Access Programs (SAP) areas (see below), which may contain a conference area with a table capable of seating eight (8), one type A workstation, video displays and wall maps, and support equipment (scanners, printers, copiers, et cetera).

A workstation = Connectivity to three (3) systems
(JWICS/SIPRNet/DNI-U)

B workstation = Connectivity to two (2) systems
(JWICS/ SIPRNet/DNI-U)

C workstation = Connectivity to one (1) system
(JWICS/ SIPRNet/DNI-U)
• **Imagery Exploitation/Production Area**. The Imagery Production Area may contain up to three (3) separate areas as follows:

a. **Imagery Analysis Area**. This area may be divided into separate rooms each of which supports up to twenty (20) personnel and contains imagery technician workstations, plotters and printers. The governing reference for design of these spaces is the National Geospatial-Intelligence Agency (NGA) Exploitation Facility Design Guidelines, version 2.1 dated 21 December 2006.

b. **Production Area.** This area contains one type A workstation, large format plotter, layout tables, light tables and imagery processor equipment.

c. **Administrative, Reference and Storage Area**. This area contains one type A workstation, bookshelves & map flats for imagery materials & supplies and administrative support equipment.

d. **Collaborative multi-disciplinary work space.** This area will include a conference area with a table capable of seating eight (8) and may be co-located with the imagery production area.

The minimum imagery exploitation space allocation for any JRIC will be a four (4) workstation room.

14385-3.4 **Operational Support Area**

JRIC Support Suite. The JRIC Support Suite may contain up to four (4) areas as outlined below.

- **Data Center**. This area typically contains one Type C workstation and a single row of six to ten racks of servers. An Uninterruptible Power Source (UPS) system and emergency generator system supporting this equipment is required for continuous operations capability. This area is also supported with a remote environmental monitoring system and a gas fire suppression system.

- **JRIC Operations Officer Area**. This area typically contains one unique conference table configuration capable of seating up to eight (8) personnel, a Type A workstation, and large wall mounted video display and maps.

- **JRIC Site System Administrator (JSSA) Area**. This area typically contains one Type A workstation and administrative support equipment (scanners, printers, copiers et cetera).

- **Secure Storage**. This area will contain secure storage containers as approved by the supporting Special security office (SSO).

DIA/DoDIIS-DS/OGT Support Area. An area is required for DIA/DODIIS-DS/OGT servers associated with the JWICS, SIPRNet and DNI-U. This area functions as the technical control and monitoring point for DIA/DODIIS-DS/OGT connectivity. This area may be co-located with the Data Center.

Minimum connectivity requirements: Each JRIC will receive connectivity based on unit/activity/agency mission requirements. The minimum JRIC standard is:

System	Circuit Size	Quantity
JWICS	OC-3 line	1
SIPRNet	DS-3 line	1
DNI-U	DS-3 line	1

In addition each line will have a “back-up” or redundant circuit which will be sized in order to meet minimum mission requirements.

Special Security Officer (SSO) Suite. The SSO Suite associated with a JRIC Facility is a multifunctional area containing, but not limited to, a Reception Area, Indoctrination Area, Photography Area, and Vault requiring approximately 280 nsf. Office space for the SSO and associated support staff are located within the SSO Suite, but special requirements for them should also be contained within the Office Area above. The SSO Suite is considered a secure area and must meet Sensitive Compartmented Information Facility (SCIF) criteria.

Secure VTC/Briefing Area. This area will normally be configured for a minimum of fourteen (14) personnel. It will contain video monitors, cameras, conference room seating, a computer workstation, Smart/white boards, briefing boards for large charts and video displays. A rear screen projection room may also be required in this area.

Mission Critical Communications Equipment Area. The Mission Critical Communications Equipment Area is unmanned. It may contain IEMATS consoles and processors, SATCOM terminals, UHF voice consoles and equipment, an EMATS fiber optic interface, WWMCCS, JWICS, and other applicable information data base terminals. An Uninterruptible Power Source (UPS) system supporting this equipment is required to sustain continuous operations. Secure telecommunications is a standard requirement (e.g., Standard Telephone Units (STU) analog systems and/or Standard Telephone Equipment (STE) digital systems), to be located as mission dictates.

Mission (Operations) Cells. In addition to the Operations and Operational Support Areas addressed above, selected JRIC's may require specialized Mission Cells. These cells may include but are not limited to unique mission requirements or mission requirements incompatible with the supported units, activities or agencies (e.g., Force Cryptology Area, Fleet Support/Collection Management Area, Crisis Management Cell Area, et cetera). Each respective cell is arranged in a specific configuration, which will include a mix of rack mounted, and PC based systems. An Engineering Evaluation is to be used to determine the total number of cells required, quantity of racks and workstations associated with each respective cell.

Agency Support Area. The Agency Support Area is based on staffing. Agency personnel may be addressed under Office Area and will only be contained within the Equipment and Operational Area if required by unique security issues.

Special Access Programs (SAP), Compartmented Area (CA). In accordance with Intelligence Community Policy Memorandum, Number 2006-700-7, dated 12 JUL 2006, Subject: Intelligence Community Modifications to DCID 6/9 Physical Security Standards for Sensitive Compartmented Information Facilities (SCIF's). A CA is a room, or set of rooms, located within a SCIF designed to enforce need-to-know. A CA is required when different compartment programs are sharing the same SCIF and not all SCIF personnel are cross-briefed. CA areas are mission specific and require an Engineering Evaluation.

14385-3.5 **Maintenance and Training Area**. Although not every JRIC Facility will contain all the areas listed, they are provided below as a guide. In instances where the respective allowances for the systems do not reflect configurations at the site, an Engineering Evaluation will be used to determine the quantity and type of spaces required and guidance provided within the Category Code series will be applied.

System/Task Training Areas. Individual JRIC's may require dedicated 'modified academic' training areas. Training covers instruction and hands-on applications with operational equipment to provide Activity/Agency personnel, as well as Fleet personnel, with operator skills on existing and recently deployed systems. As CNO/CNI/DIA directives and operational requirements determine these classes, no formal yearly class schedule is established. Historical data shall be obtained on class sizes and the planning factor outlined in Category Code series 171 of UFC/NAVFAC P-80 of 45 nsf/pn applied.

Command Training Area. This academic training area is required to satisfy general training requirements for all of the RIA and JRIC units/activity/agency personnel. Training requirements cover general topics, which include but are not limited to, Quality of Life, Career Enhancement, Administrative, Educational Services, and Command Initiative Programs.

System/Task Maintenance Areas. Individual units and/or agencies may require dedicated systems/tasks maintenance areas. These maintenance areas may be configured with equipment racks and PC based workstations. An Engineering Evaluation and/or historical data shall be used to determine the quantity and configuration required for mission support, and guidance provided within the Category Code series section applied.

Flexible Secure Working Area (FlexSWA). To accommodate a broad range of system/ task training and command training requirements, where there is limited space availability for the JRIC, or greater space flexibility is required, it is possible to design and develop a Flexible Secure Working Area that is built to SCIF standards (DCID 6/9 requirements), but is configured to accommodate multiple functions and all levels of work, from unclassified up to TS/SCI, as required.

14385-3.6 **Storage Area**. A dedicated storage area may be provided for each unit/activity within the JRIC Facility. Allowance is based on Tables of Allowances/Modified Table of Organization and Equipment or equivalent.

Common Support Space Requirements. Note: Restrooms are required in both the SCIF and unclassified spaces. The restrooms in the unclassified spaces should have showers to support the full-time staff.

General. A JRIC is a remote joint service intelligence production and training activity that uses information networks to link reservists, active duty units and contractors with the Combatant Commands, Services, and/or Combat Support Agencies (C/S/A). A JRIC is located within a DoD-owned and managed Sensitive Compartmented Information Facility (SCIF) and surrounding collateral/unclassified areas involved in the performance and direct management of intelligence production work that uses JRIP (Joint Reserve Intelligence Program) infrastructure and connectivity. JRIC's provide interoperable intelligence support systems on which reserve elements simultaneously fulfill their intelligence support missions/production requirements and train on their Mission Essential Tasks. Reference: DoD Directive 3305.7, "Joint Reserve Intelligence Program (JRIP). For specific design information, please contact NAVFAC Atlantic Asset Management division.

144 40 SCALE HOUSE (SF)
FAC: 1444
BFR Required: N

14440-1 **DEFINITION.** A building that provides a protective enclosure for the operator of a vehicle/railcar weighing station. Sizing will be on a case-by-case basis and no criteria is available.

148 SHIP AND OTHER OPERATIONAL FACILITIES OTHER THAN BUILDINGS

148-1 **GENERAL.** This category group contains facilities and structures which support tactical or organizational ship and other land operations in which do not fall readily into another category. For facilities supporting aircraft operations, use category group 149.

148 10 SHIP PROPULSION SUPPORT FACILITY (EA)
FAC: 1481
BFR Required: Y

14810-1 **DEFINITION.** Planning and programming for this facility requires concurrence and planning guidance by NAVSEA Code 08.

148 15 SHIP WEAPONS HANDLING FACILITY (EA)
FAC: 1491
BFR Required: Y

14815-1 **DEFINITION.** No planning factors are available. Each facility requires individual justification and space requirements; please contact Director, Strategic Systems Program (SSP) Office.

148 17 SPACE SURVEILLANCE ANTENNA (EA)
FAC: 1456
BFR Required: N

14817-1 **DEFINITION.** Requirements are determined by Naval Network and Space Operations Command. Facilities typically support global space surveillance network which detects, tracks, identifies, and catalogs man-made objects in space and provides position information on these objects.

148 20 ORDNANCE DEMOLITION AREA (EA)
FAC: 1783
BFR Required: Y

14820-1 **DEFINITION.** An ordnance demolition (treatment) area is a location specifically designated and reserved for destroying explosives and explosives-loaded devices. The function typically means burning or detonating explosives in a bermed open burn/open detonation (OB/OD) area. Coordinate justification for this area with the EOD units or other users. Planning and scoping this facility should consider governing environmental federal and state regulations, user requirements and explosive safety criteria. This area must meet the requirements of NAVSEA OP-5 Vol.1 and OPNAVINST 3770.2 (series) for FAA clearance requirements. All ordnance demolition (treatment) areas located in the United States and U.S. territories are required to have a Resource Conservation and Recovery Act (RCRA) permit. The shelter/bunker for the demolition area will be captured under CCN 173-40 Observation Tower/Bunker. Use Category Code 178 30 for a demolition training range.

148 25 EXPLOSIVE TRUCK HOLDING YARD (SY)
FAC: 8526
BFR Required: Y

14825-1 **DEFINITION.** This yard is where trucks containing ammunition and/or explosives are held for interim periods of time prior to storage or shipment. Safe havens and wharf yards near piers and wharves should be categorized under this function. Each facility requires individual justification. Depending on land constraints and explosive safety criteria these facilities may or may not be barricaded. For containerized ordnance, use Category Code 148 35, Container Holding Yard.

148 30 EXPLOSIVES RAILROAD CAR HOLDING YARD (EA)
FAC: 1493
BFR Required: Y

14830-1 **DEFINITION.** This is a temporary holding area for railcars containing ordnance prior to storage or shipment. Each facility requires individual justification. Depending on land constraints and explosive safety criteria these facilities may or may not be barricaded. For containerized ordnance use Category Code 148 35, Container Holding Yard.

148 35 CONTAINER HOLDING YARD (SY)
FAC: 8526
BFR Required: Y

14835-1 **DEFINITION**. This is an open area that provides a temporary holding or staging area for containers loaded with explosive ordnance. Wharf yards near piers and wharves are also described by this function. Containers with explosive ordnance class/ Division 1.1 and 1.2 may or may not be in a bermed/barricaded area. Loaded containers can be stacked two high or singly on chassis or flatbed trailers. No planning criteria are provided because of the multiple container handling equipment possibilities and container configurations. A simple layout sketch of the proposed container holding

area, allowing for safe maneuvering of the container handling equipment, will generate the required space requirements.

14835-2 Minimum holding capacity of all holding yards should approximate one shipload of containers or the equivalent of 24 hours of sustained out-loading for the particular terminal operation.

148 40 CONTAINER TRANSFER FACILITY (ORDNANCE) (SY)
FAC: 8526
BFR Required: Y

14840-1 **DEFINITION.** A container transfer facility is used to transfer containers between rail flatcars and truck flatbeds or chassis, on a paved hardstand area, by means of a bridge crane or container handling equipment. Scale equipment should be expected to a part of this function. The area may be barricaded or unbarricaded. The size of the facility should be capable of handling a sustained maximum out-loading for the number of container throughput served in a 24-hour period. Determine the standard transfer rates given the type of container handling equipment. The mix of arrivals and departures of containers on rail or truck requiring transfer determines the how much material handling equipment is necessary to sustain the maximum out-loading. The area of paved hardstand and parking is dictated by the rate of container arrivals and departures. The control and service building of 204 SF provides office space, toilet facilities, etc. for employees. See Figure 14840-1 for a notional transfer facility using a bridge crane.

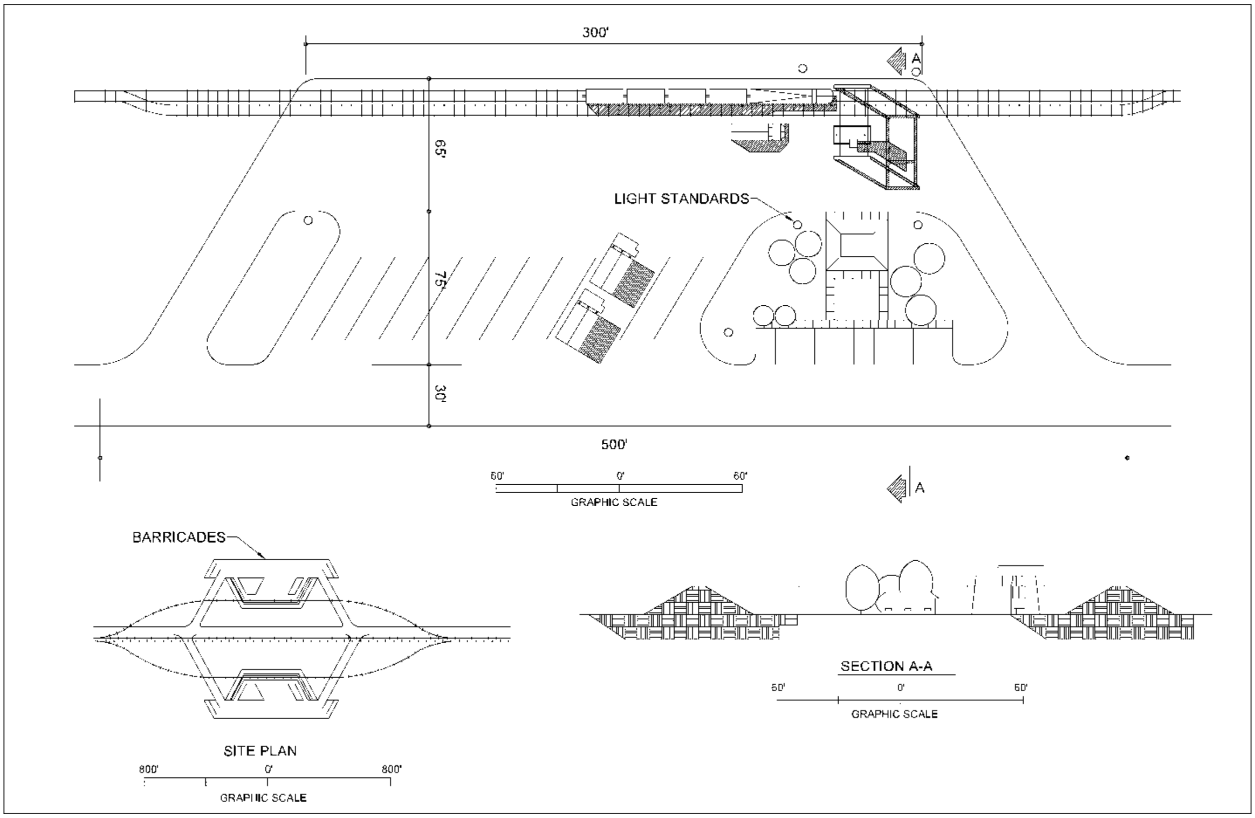


Figure 14840-1 Container Transfer Facility (Ordnance)

148 45 RAIL/TRUCK RECEIVING STATION (ORDNANCE) (SY)
FAC: 8526
BFR Required: Y

14845-1 **DEFINITION.** A rail/truck receiving station weighs and inspects all incoming shipments of break-bulk and containerized ordnance arriving by rail or truck and also a percentage of the outgoing shipments. Also, this station can be used as a short term storage facility limited to overnight and weekend periods and as an interchange storage facility limited to overnight and weekend periods and as an interchange yard between common carrier and station. The capacity of the receiving, inspecting, and weighing facility is based on expected maximum truck and rail arrivals and departures during a sustained out-loading. Figure 14845-1 provides a notional layout for a high volume ordnance receiving and inspection station. This notional facility can process 20 rail cars per hour and 20 trucks per hour and provide for a 40-truck parking area and 100 rail car siding. It contains two rail inspection pits and two truck inspection pits, scales, lighting, and 2,432 SF of administrative space.

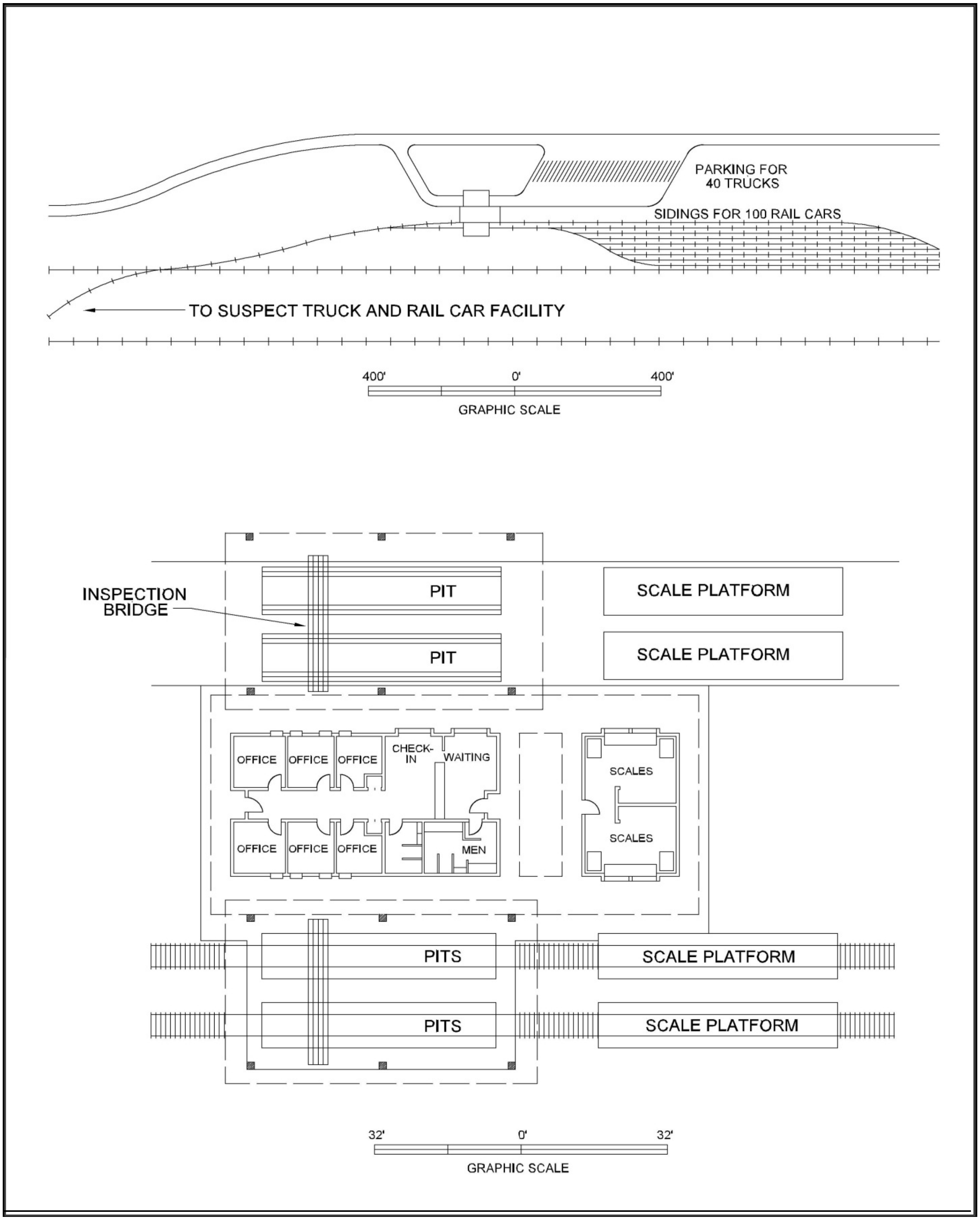


Figure 14845-1 Rail / Truck Receiving Station (Ordnance)

149 OPERATIONAL FACILITIES- OTHER THAN BUILDINGS

149-1 **GENERAL.** This category group contains facilities such as towers and structures which support tactical or organizational aircraft related operations, and which do not fall readily into another category. It includes protective construction.

149 10 AIRCRAFT REVETMENT (EA)
FAC: 1495
BFR Required: N

Design Criteria: None Available

14910-1 **DEFINITION.** Protective Barricades (also known as revetments) are constructed at locations where explosive safety dictates the need, such as in magazine areas, combat aircraft loading areas, etc. They can be either steel structures or man-made earthen berms.

Aircraft revetments are constructed only for emergencies or in combat zones for the protection of aircraft against fire, blast, or enemy action. Aircraft revetments will be sized according to the aircraft that it is to protect. Specific criteria for this requirement will be determined by field conditions and will be planned only on specific instructions of the Fleet or Area Commander. For planning purposes, the unit of measure is each (ea); that is, the number of protected aircraft sites.

Explosive barricades for suspect truck or rail cars are captured under CCN 860 20, Explosive Barricade for Suspect Trucks and Railroad Cars.

14910-1 **DEFINITION.** Aircraft revetments are constructed only for emergencies or in combat zones for the protection of aircraft against fire, blast, or enemy action. Aircraft revetments will be sized according to the aircraft that it is to protect. Specific criteria for this requirement will be determined by field conditions and will be planned only on specific instructions of the Fleet or Area Commander. For planning purposes, the unit of measure is each (ea.); that is, the number of protected aircraft sites.

149 15 FIXED POINT UTILITIES SYSTEM (EA)
FAC: 1467
BFR Required: Y

Design Criteria: UFC 4-121-10N, Aircraft Fixed Point Utility Systems
Planning Criteria: P-80.3, Aviation Operation and Support Facilities; UFC 3-260-01, Airfield and Heliport Planning and Design

14915-1 **DEFINITION.** Fixed Point Utilities Systems (FPUS) supply utilities to aircraft parking apron service points and aircraft maintenance hangar service point. The

FPUS can provide compressed air, preconditioned air for hangared aircraft, and/or electrical power. The system can consist of an enclosed pump house and storage tanks, an in-ground distribution system and service points in aircraft parking aprons or aircraft maintenance hangars. There are typically four types of systems:

1. Air Start System. Provides compressed air at the parking apron. Aircraft cooling is provided by mobile ground carts. Electrical power is provided by separate, dedicated service panels.
2. Environmental Control System. Provides compressed air for engine starting and environmentally controlled compressed air for aircraft cooling from a central source. Electrical power is provided by separate, dedicated service panels.
3. Flight Line Electrical Distribution System (FLEDS). Provides electrical power to aircraft parked on the aircraft parking apron.
4. Point of Use Frequency Converter System (Super Flight Line Electrical Distribution System (SFLEDS)). Provides conditioned (filtered and compensated) electrical power to aircraft parked on the aircraft parking apron.

Layout of FPUS shall be subject to the correlated siting of maintenance hangars, parking apron and taxiways. Aircraft parking and FPUS layout is prescribed under Aircraft Parking Apron, Category Code 113 20 and UFC 3-260-01, Airfield and Heliport Planning and Design.

149 20 AIRCRAFT CATAPULT (EA) (DELETED)

This CCN has been deleted because it is non-RP (the catapult system is equipment). However, the support building(s), which can be above or below ground, are now captured under CCN 319 10 MISCELLANEOUS EQUIPMENT AND ITEMS LABORATORY.

149 30 AIRCRAFT ARRESTING GEAR (EA)
FAC: 1461
BFR Required: N

> **Design Criteria:** AFI 32-1043, Managing, Operating, and Maintaining Aircraft Arresting Systems, FAA AC 150/5220-22B, Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns
> **Planning Criteria:** UFC 3-260-01, Airfield and Heliport Planning and Design

14930-1 **DEFINITION.** Aircraft arresting gear is designed to bring an aircraft to a stop in case of an aborted takeoff or an emergency landing.

Aircraft arresting systems consist of engaging devices and energy absorbers. Engaging devices are net barriers, disc supported pendants (hook cables), and cable support systems that allow the pendant to be raised to the battery position or retracted below the runway surface. Energy absorbing devices are ships anchor chains, rotary friction brakes, such as BAK-9 and BAK-12, or rotary hydraulic systems such as the BAK-13 and E-28. The systems designated "Barrier, Arresting Kit" (BAK) are numbered in the sequence of procurement of the system design. There is no connection between the Air Force designations of these systems and their function. Other designations such as E-5, E-28 and M-21 are U.S. Navy designations. The U.S. Air Force systems in use today are MA-1A; E-5; BAK-9; BAK-12; BAK-13; BAK-14; 61QSII (BAK-15); E-28; and Textile Brake. Other types of systems include the Mobile Aircraft Arresting System (MAAS) and Soft-Ground Type Aircraft Arresting System/Engineered Material Arresting System (EMAS).

14930-1.1 **E-5.** This unidirectional emergency arresting system is a U.S. Navy design and designation. Much like the MA-1A, this system uses several shots of ships' anchor chain as the energy absorber, but these systems are never connected with a barrier (net). These systems can have from 1 to 4 disc-supported hook cables, with designations of E-5 and E-5 Mod 1 through E-5 Mod 3.

14930-1.2 **E-28.** The E-28 aircraft arresting system is a rotary hydraulic arresting gear that will accommodate a maximum aircraft weight of 35,400 kg (78,000 lbs.) and a maximum aircraft engaging speed of 293 km/hr. (160 knots). Aircraft engaging the E-28 arresting gear are stopped within a runout distance of approximately 305 meters (1,000 feet). Engagement can be made from either runway direction and at points up to 12.1 meters (40 feet) on either side of the runway centerline. The high performance (Model E-28) type of arresting gear is planned for both primary and secondary (crosswind) runways. Normally, two sets of arresting gear are required for each operative runway: one at each end between 274 meters (900 feet) and 457 meters (1,500 feet) inboard from the runway threshold. Midpoint arresting gear may be included on the station BFR when justified by runway or operational conditions and when approved through appropriate channels.

14930-1.3 **M-21.** The M-21 aircraft arresting system is a lightweight high-capacity arresting system for the recovery of aircraft. The arresting engines utilize the vortex principle of energy absorbing in a hydrodynamic braking system.

14930-1.4 **MA-1A.** The MA-1A emergency arresting system consists of a net barrier and cable system designed to engage the main landing gear of an aircraft. Because it is a unidirectional system, it must always be installed in the overrun area. Most MA-1A systems employ ships' anchor chains as the energy absorber. These systems require a runout area of at least 259 meters (850 feet) plus the length of the aircraft. The chains lie on either side of the runway overrun, beginning at the barrier location and running in the direction of aircraft travel; however, some MA-1A systems use a BAK-9 instead of a ships' anchor chain as the energy absorber. These systems require a runout area of at least 290 meters (950 feet) plus the length of the aircraft. *The MA-1A is not currently in production as a system.*

14930-1.5 **BAK-9.** The BAK-9 is an obsolete bi-directional emergency arresting system. It consisted of 1 energy absorber that employed 2 rotary friction brakes and purchase-tape reels mounted on a common shaft. The reels were mechanically connected at the midpoint by a third brake that acted as a clutch. This allowed each reel to turn at different speeds during off-center engagements and helped steer the aircraft toward the center of the runway. The energy absorber for these systems was installed below grade on 1 side of the runway and the purchase tape was routed to the opposite side of the runway through deflector sheaves and duct. The other purchase tape was routed to a turnaround sheave located in a pit sited to allow both purchase tapes to be of equal length. *The BAK-9 is not currently in production as a system and should not be considered as a suitable system for a new requirement.*

14930-1.6 **BAK-12.** The BAK-12 is the standard U.S. Air Force operational aircraft arresting system. This bi-directional system employs 2 energy absorbers. Each absorber consists of 2 multi-disc rotary friction brakes mounted on either side of the purchase-tape reel on a common shaft. The energy absorbers are located on opposite sides of the runway, connected to a 32 millimeter (1.25 inch) disc-supported pendant by the purchase tape. Ideally, the energy absorbers should be in a below-grade pit with a minimum split distance of 15.24 meters (50 feet). (Split distance is a measurement taken between the lead-on sheave of the fairlead beam or deck sheave, and the energy absorber.) Split distances of up to 91 meters (300 feet) are acceptable for all BAK-12 installations. You may also install BAK-12 systems above ground in one of two configurations, the selection depending upon site conditions and operational requirements. These are the expeditionary installation for periods of up to 1 year, and the semi-permanent installation, well-suited for long term use and typically selected when site conditions will allow a pit-type installation.

Originally, BAK-12 energy absorbers were fitted with a 60-inch purchase-tape storage reel. This design allowed the maximum energy expected to be imparted during an aircraft engagement to dissipate within a runout of 290 meters (950 feet) plus the length of the aircraft. Designers have since improved the BAK-12 to meet increased demands of heavier and faster aircraft. They retrofitted the energy absorbers with larger 66-inch or 72-inch tape storage reels to accommodate increased runout, thus increasing the total energy capacity of the system. Although some BAK-12 systems have 60-inch tape storage reels, new and upgraded BAK-12 systems have 66-inch reels. These systems require 366 meters (1,200 feet) plus the length of the aircraft for maximum runout. The 72-inch reel systems are special-purpose systems configured for 610 meters (2,000 feet) of runout.

The standard BAK-12 is configured for cross-runway separations of up to 61 meters (200 feet) (distance between fairlead beams or deck sheaves). For installations with cross-runway spans exceeding 61 meters (200 feet), replace the BAK-12 control valve cam to accommodate full runout of the system.

Dual BAK-12 systems are special-purpose installations configured to accommodate high-energy engagements of aircraft ranging from 27,200 to 63,500 kilograms (60,000 to 140,000 pounds). These configurations consist of 4 BAK-12 energy absorbers arranged in pairs on either side of the runway. The energy absorbers may be standard BAK-12s or be equipped with 72-inch diameter tape storage reels to accommodate 610 meters (2,000 feet) of runout. You need special tape connectors and edge sheaves for these installations.

14930-1.7 **BAK-13.** The BAK-13 is a bi-directional aircraft arresting system. It employs 2 velocity-sensitive energy absorbers installed on opposite sides of the runway, interconnected by nylon purchase tapes and a 32 millimeter (1.25 inch) disc-supported pendant. The energy absorbers are made from a steel weldment base that incorporates a tape-storage reel mounted on a vertical shaft and a vaned rotor assembly enclosed within a vaned stator assembly (also called a tub) that contains a water and glycol mixture. A rewind engine, transmission assembly, and an operator control panel are also included along with necessary hydraulic system components.

The energy imparted during an aircraft arrestment converts heat through the turbulence developed by rotation of the vaned rotor within the vaned stator. An external cooling reservoir permits rapid cycle of this system.

The site requirements are essentially the same as for the BAK-12; however, the low-profile units maybe located as close as 46 meters (150 feet) from the runway edge if installed in a semi-permanent configuration. These systems require 290 meters (950 feet) plus the length of the aircraft for maximum runout. *The BAK-13 is not currently in production as a system. I should not be considered as a suitable system for a new requirement due to the potentially high hook load generated during engagement.*

14930-1.8 **BAK-14 and Type H Hook cable Support Systems.** The BAK-14 hook cable system is a bi-directional hook cable (pendant) support system used in conjunction with the BAK-12, BAK-13, or a comparable arresting system to engage and safely stop a hook-equipped aircraft. It provides the means to support the pendant at least 2 inches above the runway surface while giving ATC the means to lower the pendant below the surface of the runway to prevent damage to low-undercarriage aircraft, the pendant, and the pavement below the pendant during trampling. These systems can accommodate 46, 60, and 90 meters (150, 200, and 300 foot)-wide runways, but you order the system to suit the specific application. The control side BAK-12 pit or protective shelter and foundation must be expanded to house the compressed air and control systems needed to operate this supplemental system.

The Type H hook cable support system is a bi-directional hook cable support system that can be used in conjunction with any type of energy-absorbing device. It provides a means to raise a cable at least 2 inches above a runway surface or lower it below the runway surface in less than 1.5 seconds. It can be supplied to accommodate runway widths of 46, 60, and 90 meters (150, 200, and 300 feet). A radio remote control system provides ATC the means to operate the system and to monitor its operational status. It mainly consists of Retraction Modules (from 14 to 18 depending on runway width) installed into pre-cast concrete blocks across the runway, and connected together by metallic rods, to form a rigid loop. This loop is actuated by an electro-hydraulic motor that is located in a concrete pit on one side of the runway.

14930-1.9 **BAK-15.** The BAK-15 aircraft arresting barrier consists of a pair of electro-hydraulically powered steel masts that provide support and remote-controlled movement for a unidirectional nylon net barrier. The masts are installed on opposite sides of the runway overrun on concrete foundations. The ATC tower contains a remote control panel, which can be hard-wired but the most common is radio controlled.

The barrier must be augmented with an energy-absorbing device such as a ship's anchor chain, BAK-12, or Textile Brake. During an aircraft engagement, shear links in the net suspension straps separate by the force of the aircraft engaging the net. The net then envelops the aircraft and seats on the leading edge of the wings, transferring forward momentum of the aircraft to the energy-absorbing device.

You can complement the system with a standard disc-supported pendant to accommodate tail hook engagements through interconnect configuration hardware similar to that used for the MA-1A Modified. The hook cable interconnect kit is designated as the 62 NI (net interconnect).

14930-1.10 **Textile Brake.** This modular arresting system is primarily intended as an emergency backup system for standard operational systems. It is comprised of multiple modules arranged in equal numbers on both sides of the overrun that contain specially woven textile tearing straps to absorb the kinetic energy generated during an engagement. One end of each module is anchored to the ground and the other end is connected to a tensioned cable positioned across the runway. The system is available in a 2-stage unidirectional configuration (MB 60.9.9.C) or as a single stage bi-directional system (MB 100.10.C).

The advantages of the 2-stage system (MB 60.9.9.C) over the bi-directional system (MB 100.10.C) are higher system capacity and lower costs for reconfiguration after low energy engagements. The modules in a stage (breaking lines) are expended upon aircraft engagement and must be replaced; however, a life cycle analysis indicates system costs are approximately 50 percent of the life cycle cost for a BAK-12 installed in the overrun area of a runway due to the low number of engagements that occur there. These systems are designed for tail-hook equipped fighter aircraft, but can also be complemented with a net barrier such as the BAK-15 or a net/cable interconnect system. They may also be configured for expeditionary or temporary installations.

If the bi-directional version of the Textile Brake arresting system is installed on the operational runway surface due to a non-standard length overrun, the Arresting Gear Marker (AGM) signs should be blanked when viewed from the approach. This is because the system is a low energy capacity system (compared with BAK-12 or BAK-13) and is no intended for approach end engagements.

14930-1.11 **Mobile Aircraft Arresting System (MAAS).** The MAAS is essentially a BAK-12 aircraft arresting system mobilized through installation on a specially developed trailer. It is configured for a maximum aircraft runout of 302 meters (990 feet). This system was initially developed and tested to accommodate recovery of fighter aircraft returning to a battle-damaged airfield. Such cases require rapid deployment and installation and may require that only the minimum essential anchoring hardware be installed to accommodate the above scenario. When installed for this purpose, the MAAS is installed using a 19-stake anchoring scheme. This configuration is limited to unidirectional engagement capability with a maximum aircraft weight and speed of 18,144 kilograms (40,000 pounds) at 150 knots.

The MAAS can be upgraded to accommodate bi-directional engagements with the full capacity of a standard BAK-12 aircraft arresting system. This is accomplished by increasing the total number of cruciform stakes used to anchor the system from 19 to 31, extending the runout to 366 meters (1,200 feet), and synchronizing the system for higher brake pressure. The system may also be installed in a set-back configuration to accommodate wide body aircraft operations through use of a fairlead beam.

14930-1.12 **Soft-Ground Type Aircraft Arresting System.** The Engineered Material Arresting System (EMAS) is an FAA-approved soft-ground system normally used for civil airports to mitigate short safety areas (less than 305 meters (1,000 feet) long) at runway ends. The system is constructed of cellular foam concrete of specific strengths and thickness to decelerate an aircraft that overruns the runway through rolling resistance. The design for each system is aircraft specific, based upon the type of aircraft that will use the runway. It is intended for use where it is impractical to obtain the standard 305 meter (1,000 foot) safety area and other alternatives are not feasible. For purposes of design, the soft ground arrestor system can be considered fixed by function and frangible since it is designed to fail at a specific load; therefore, a soft ground system is not considered an obstruction to navigation. Soft ground systems are located beyond the end of the runway, centered on the extended runway centerline. They will usually begin at some distance from the end of the runway to avoid damage due to jet blast or short landings. This distance will vary depending on the available area and the specific system design.

149 45 MISSILE LAUNCH FACILITY (EA)
FAC: 3901
BFR Required: N

14945-1 **DEFINITION.** This Category Code is provided for inventory purposes of missile and drone launch pads. See NAVSEA OP-5 for Explosive Safety Siting criteria of energetic liquids associated with launch pads.

149 50 BLAST DEFLECTOR FENCE (EA)
FAC: 1464
BFR Required: N

Design Criteria: None Available

14950-1 **DEFINITION.** Blast deflector fences are structures that direct the exhaust from jet engines upward. They are used in congested areas and parking and maintenance areas to protect personnel, equipment, structures, aircraft, and other vehicles from the blast effect of jet engine exhaust. Blast fences are also used to prevent erosion of paved and unpaved areas and to provide protection from flying debris. Their siting and length must be based on the study of individual station requirements. Blast deflector fences may be purchased or constructed in sections to permit moving them from one position to another as protection requirements change. Careful selection of location is necessary to prevent creating an obstacle to taxiing aircraft.

149 62 TACTICAL VEHICLE WASH FACILITY (SF)
FAC: 1496
BFR Required: Y

14962-1 **DEFINITION.** A wash structure is located to support maneuver/training areas and provide prewash mud removal and washing of military vehicles. Structure typically provides water-soaking capability for tactical tracked and wheeled vehicles, high and low pressure cleaning capability, water cannons, wash water containment and drains, sediment basins, and sludge removal. Prep and prewash areas, wash stations, water treatment, water supply, basins and controls/equipment are included as components of the facility. The facility that houses the controls/equipment is captured under CCN 89009 Miscellaneous Utility Building.

14962-2 **REQUIREMENTS**. Sizing requires an engineering analysis on a case-by-case basis. No criteria is available for this category code.

149 85 EXPEDITIONARY AIR CONTROL SITE – MACS AND MASS (EA)
FAC: 1467
BFR Required: Y

Design Criteria: UFC 4-141-10N, Aviation Operation and Support Facilities

14985-1 **DEFINITION.** These are Marine Corps facilities required to accommodate, in-garrison, the equipment used for expeditionary aircraft command and control. These facilities are assigned to specialized Marine Corps squadrons, and the expeditionary equipment used in conjunction with these facilities is normally squadron property. The Marine Air Control Squadron (MACS) and the Marine Air Support Squadron (MASS) are squadrons within the Marine Air Control Group (MACG) and Marine Aircraft Wing (MAW) that are directly responsible for air defense and air control. Each MACS contains two Air Traffic Control (ATC) Detachments and one Air Defense Detachment. The ATC Detachments were formerly the Marine Air Traffic Control Unit (MATCU). Both the MACS and MASS are squadrons in the MAW and are directly responsible for air defense and air control.

149 86 OPERATIONS SUPPORT SHED (EA)
FAC: 1499
BFR Required: Y

14986-1 No criteria currently exist for this category code.

151 PIER FACILITIES

151-1 DEFINITION. A pier is a structure that extends out from shore into navigable water and is designed for the homeport or temporary berthing of vessels. Services available at pier side include, but are not limited to, ship repair, fueling, training and other essential services, such as potable water, electric power, compressed air, waste disposal and communications facilities. A pier is oriented either perpendicular to or at an angle with the shore and normally accommodates berthing on both sides for its entire length although there are instances where only one side is used because of site conditions or because there is no need for additional berthing space. Code 151 includes all piers regardless of function served, protective dolphins at pier heads, fendering systems, and mooring fixtures, original dredging performed specifically for the purpose of providing the pier facility, all trackage on the pier, and all supporting utilities and services.

Piers provide a transfer point for cargoes and/or passengers between water carriers and land transport. Separate facilities should be maintained where service involves large volumes of both cargo and passengers. Joint service use of piers should be considered when at all possible.

In countries outside the United States, a pier is often referred to as a jetty, or a mole when of solid fill construction, and a wharf is referred to as a quay or a jetty. In the United States, the term jetty refers to a solid fill structure, located on an open seacoast at the mouth of a river or tidal inlet, designed to prevent shoaling of a channel by littoral materials and to direct and confine stream or tidal flow.

For data on channel and turning basin dredging, see UFC 4-150-06, Military Harborts and Coastal Facilities. For utilities and services landward of the inboard end of the pier, see UFC 4-150-02, Dockside Utilities for Ship Service. For crane and railroad trackage on shore, see Civil Engineering and Utilities, MIL-HDBK-1005/6. For transit sheds on piers, see category code 156 10; and for fixed crane structures, see category code 213 40.

Piers are classified according to their primary function and are described under their respective category codes.

151-2 BERTHING. Piers are used to provide either multipurpose berths or special purpose berths. Piers providing multipurpose berthing are used to service several classes of vessels so that ships will have the option of utilizing any one of several berthing facilities at a port. Berth selection depends upon the need to match available space, utilities and support services with the requirements of an incoming ship. It is not economically feasible to develop a single facility to accommodate and service all classes of vessels. Special berths are provided when berthing arrangements and/or locations are required for fueling vessels, berthing vessels carrying explosives, and for repairing vessels.

151-3 FEATURES. The following list gives appurtenances and facilities generally provided at or near piers. The facilities to be provided depend on functional requirements, which often determine the classification of the pier. The location of support facilities will be dependent upon the existence of weapons handling Explosive Safety Quantity Distance (ESQD) Arcs.

Located on the pier:

1. Berths having sufficient depths and widths to allow for efficient servicing of ship and safe vessel approach and departure.

2. Sufficient mooring devices (bollards, bitts, cleats) to safely secure vessel.

3. Hotel and ship service facilities.

4. Fender systems, oil containment booms and floating/fixed AT/FP barriers

5. Camels or struts.

6. Brows and stands for ship access to the pier

7. Access facilities for railroad cars, trucks and emergency vehicles.

8. Cranes and trackage.

9. Privately Owned Vehicle (POV) parking

Provided by the host activity in the general area of the pier:

1. Cargo handling equipment.

2. Firefighting equipment.

3. Covered and open storage space for cargoes; fenced where required, for control of pilferage.

4. Office space.

5. Sanitary facilities.

6. Ship support and repair facilities.

7. Medical facilities.

151-4 LOCATION AND ALIGNMENT. The location and alignment of piers in a harbor should consider factors such as ease of entering and leaving berth, required quayage, harbor line restrictions, adjacent navigational channels, foundation conditions and isolation requirements. For further information and criteria, see Military Harbors and Coastal Facilities, UFC 4-150-06.

151-5 PIER DIMENSIONS AND CLEARANCES. The dimensions of a pier are based primarily on the lengths of the vessels, present or contemplated, that it is to accommodate. The length of the pier is dependent upon the type of ship, and the width is dependent upon the type of service to be provided. Pier measurements and allowances for single-length and multiple-length berths are based upon either accommodating known vessels or known types of vessels, where types but not specific ships are known. The dimensions for both types are determined as follows:

1. **Pier Length.**

   a. Single-Length Berth shall equal the overall length of the largest vessel to be accommodated, plus an allowance of 50 feet at each end of the vessel. For aircraft carriers, the allowance at each end of the vessel is 100 feet. See Figure 151-10 for berthing diagram. Reference the following ship characteristics data in UFC 4-152-01 Piers and Wharves as follows:

   Table 2-1 Ship Characteristics for Selected Ships (Fully Loaded)
   Table 2-2 Ship Characteristics for Selected Ships (Lightly Loaded)

   b. Multiple-Length Berths shall equal the total overall length of the largest vessels simultaneously accommodated, plus allowances of 100 feet between vessels, 50 feet between the shore and the inshore ship and 50 feet beyond outermost moored vessels. See Figure 151-10 for berthing diagram.

2. **Pier and Wharf Width.** The width of a pier or wharf is determined on the basis of functional requirements, space availability and site conditions such as water depths, subsurface conditions and clearances. The widths of piers and wharves, as discussed hereinafter, refer to the dimensions determined for specific function classifications. These dimensions should not be less than the widths determined by geotechnical and structural considerations. Factors to be considered in the determination of pier and wharf widths are as follows:

    - <u>Berths Provided on Outboard Face of Pier</u>. Because pier widths are determined on the basis of the requirements of the main berths, the outboard face, or the end of a pier may be used only for vessels whose overall length does not exceed the width of pier and where bow and stern clearances conform to established criteria. The proximity to shipping lanes and high-energy wave environments may prohibit the use of this portion of the pier.

    - <u>Berths Provided Alongside Pier or Wharf.</u> Total structure width depends upon the size of the transit shed, if any, type of crane service provided, number of railroad tracks, firefighting equipment and truck lanes furnished and requirements for work space and open storage areas. At wharf facilities, open storage areas are often contiguous to the apron and shed, but at pier facilities open storage areas are generally located off the pier and thus do not affect the determination of total pier width. Table 15111-1, indicating minimum pier widths, is furnished as a guide.

    - <u>Berths for Carriers</u>. Camels specifically designed to breast off aircraft carriers should be provided at designated carrier berths. Alternatively, the provision of additional pier width may be considered to provide clearances for overhangs of flight decks and elevators.

    - <u>Services Requiring Additional Width</u>. Adequate width should be provided to accommodate railroad tracks, truck lanes, crane ways, emergency response equipment and fuel handling equipment when furnished.

3. **Slip width.**
    - <u>General Considerations</u>. The clear distance between piers, or slip width, should be adequate to permit the safe docking and undocking of the maximum size vessels that are to be accommodated in the slip. The size of slip should also permit the safe maneuvering and working of tugboats, barges, lighters and floating cranes. At multiple berth piers, where vessels are docked either one per berth, two abreast per berth, sufficient clearance should be available to permit the docking and undocking of vessels at the inshore berth without interfering with

vessels at the offshore berth. Because the size of a slip is affected by docking and undocking maneuvers, consideration should be given to the advice of local pilots who are familiar with the ships to be handled and with prevailing environmental conditions such as winds, waves, swells and currents. The slip width should be reviewed with specific functional requirements of the individual installation before a final determination is made.

- Minimum Width of Slip for Active Berthing. Minimum widths should be as shown on Figure 151-10. Widths are defined as a factor times the beam of the largest vessel to be accommodated. The minimum width should not be less than 300 feet. The recommended criteria are applicable only if vessels are turned outside the slip area.

Reference the following ship characteristics data in UFC 4-152-01 Piers and Wharves for the beam of typical vessel types as follows:

Table 2-1 Ship Characteristics for Selected Ships (Fully Loaded)
Table 2-2 Ship Characteristics for Selected Ships (Lightly Loaded)
At submarine slips, width requirements should be increased by at least four vessels beam and more, as required, to account for camels and separators, to provide for ships' vulnerability if their safety is involved, to provide for special maneuvering requirements of other ships during berthing or passing and to provide for special environmental conditions such as currents, waves and winds.

- The requirements discussed above apply where vessels are berthed on both sides of a slip. Where vessels are berthed on only one side of a slip, the width may be reduced.

- Referring to Figure 151-10, when more than 2 abreast berthing is employed, the width of slip should be increased by one ship beam for each additional ship added in order to maintain adequate clearances between moored ships during berthing and un-berthing maneuvers. Thus, for 2 abreast berthing on both sides of a slip, the slip width for single berth piers would be equal to 8 times ship beam and the slip width for multiple berth piers would be equal to 9 times ship beam.

- Minimum Width of Slip for Active Berthing. At slips containing inactive berths where vessels are stored for long periods of time on inactive status, in nests of two, three or more, clear distances between moored vessels and slip width may be reduced by one or two vessels beam to reflect the reduction in the frequency of berthing maneuvers and the decrease in activities of small boats and floating equipment.

4. **Water Depth in Slips.**

Minimum Depth of Water. In a sheltered harbor and where the harbor bottom consists of soft material, water depth in a slip, measured from Mean Lower Low Water (MLLW) should be equal to the maximum loaded draft of the vessels to be accommodated plus a minimum clearance of 4 feet which includes an allowance of 1 foot for vessel trim in loading, 2 feet for under keel clearance and an allowance of 1 foot for tidal variations. For the loaded draft of typical vessel types, refer to UFC 4-152-01 Piers and Wharves as follows:

Table 2-1 Ship Characteristics for Selected Ships (Fully Loaded)
Table 2-2 Ship Characteristics for Selected Ships (Lightly Loaded)

Additional information is available in UFC 4-150-06 Military Harbors and Coastal Facilities at https://www.wbdg.org/dod/ufc/ufc-4-150-06. Specified water depths should be maintained as close to the fender line of the structure as is practicable considering the accessibility of dredging equipment used during maintenance dredging operations.

a. Other Considerations. Minimum keel clearance of 4 feet should be increased if any of the following conditions prevail:

- Harbor bottom consists of a hard material such as rock.
- Excessive silting (one foot per year or more) occurs.
- Slip area is exposed to waves, swells and winds.
- Extreme low water (one foot or more) occurs.
- Investigation indicates probable fouling of condensers.

Aircraft carriers have had situations where they suck up bottom sediments and marine organisms through their intakes, clog up condenser coils and cause undue wear on machinery. In model tests it has been determined that one part of the solution to these situations is to increase the depth below the keel. Therefore, the water depth at carrier berths and anchorages shall be 50 ft. from MLLW datum for new construction. Water depth at existing facilities shall be increased to 50 ft. where feasible. Depths for AOE's may be increased for similar reasons. However, special studies at specific locations are required.

For Vessel Characteristics, refer to UFC 4-152-01 Piers and Wharves as follows:

Table 2-1 Ship Characteristics for Selected Ships (Fully Loaded)
Table 2-2 Ship Characteristics for Selected Ships (Lightly Loaded)

These tables provide a comprehensive listing of pertinent data for vessels in the naval fleet. The following is a list of footnotes which applies to the tables:

- Ordinarily, extreme breadth is the maximum width of vessel. For submarines, the value given is the maximum diameter or width of the hull structure and is not necessarily the maximum width which may occur at the horizontal stabilizer planes and is so noted. Canted aircraft carrier flight decks may not be dimensionally symmetrical about the longitudinal centerline of the vessel, marking the extreme breadth value for aircraft carriers unsuitable for determining berthing camel width at piers and wharves with gantry crane service.

- Maximum navigational draft is the minimum depth of water required to prevent grounding of a vessel due to appendages projecting below the vessel's base line or keel. Such appendages may be sonar domes, propellers, rudders, hydrofoils, vertical submarine control planes, etc. Many vessels also possess a decided trim to the bow or stern in fully loaded condition or in the case of submarines, a trim to the stern in surfaced condition.

- Water depth at carrier berths and anchorages is 50 ft. from MLLW datum for new construction. Water depth at existing facilities will be increased to 50 ft. where feasible. Depths for AOE's may also be increased if justified.

Table 15111-1
Typical Pier and Wharf Widths

Function Classification	Vessel Type	Minimum Pier Width (feet)	Minimum Wharf Apron Width (feet)	Railroad Tracks (standard gage)	Rail-Mounted Cranes
1. Ammunition	Ammunition	100	100	-	-
2. Berthing	Aircraft Carrier	100	-	-	-
3. Berthing	Cruiser	80	-	-	-
	Destroyer	80	-	-	-
	Frigate	80	-	-	-
	Submarine	60	-	-	-
	Auxiliary	80	-	-	-
4. Fitting-out	Destroyer	100	-	2 tracks; 1 each side	2-30 ft. Gage; 1 each side
5. Repair	Cruiser	125	-	4 tracks; 2 each side	2-30 ft. Gage; 1 each side
	Auxiliary	125	-	4 tracks; 2 each side	2-30 ft. Gage; 1 each side
6. Fueling	Auxiliary	50	-	-	-
7. Supply (General Cargo)	Auxiliary	125 plus shed width	60	2 tracks	-
8. Supply (Container Cargo)	Auxiliary	80	80	Up to 3 tracks	1 50 ft. Gage

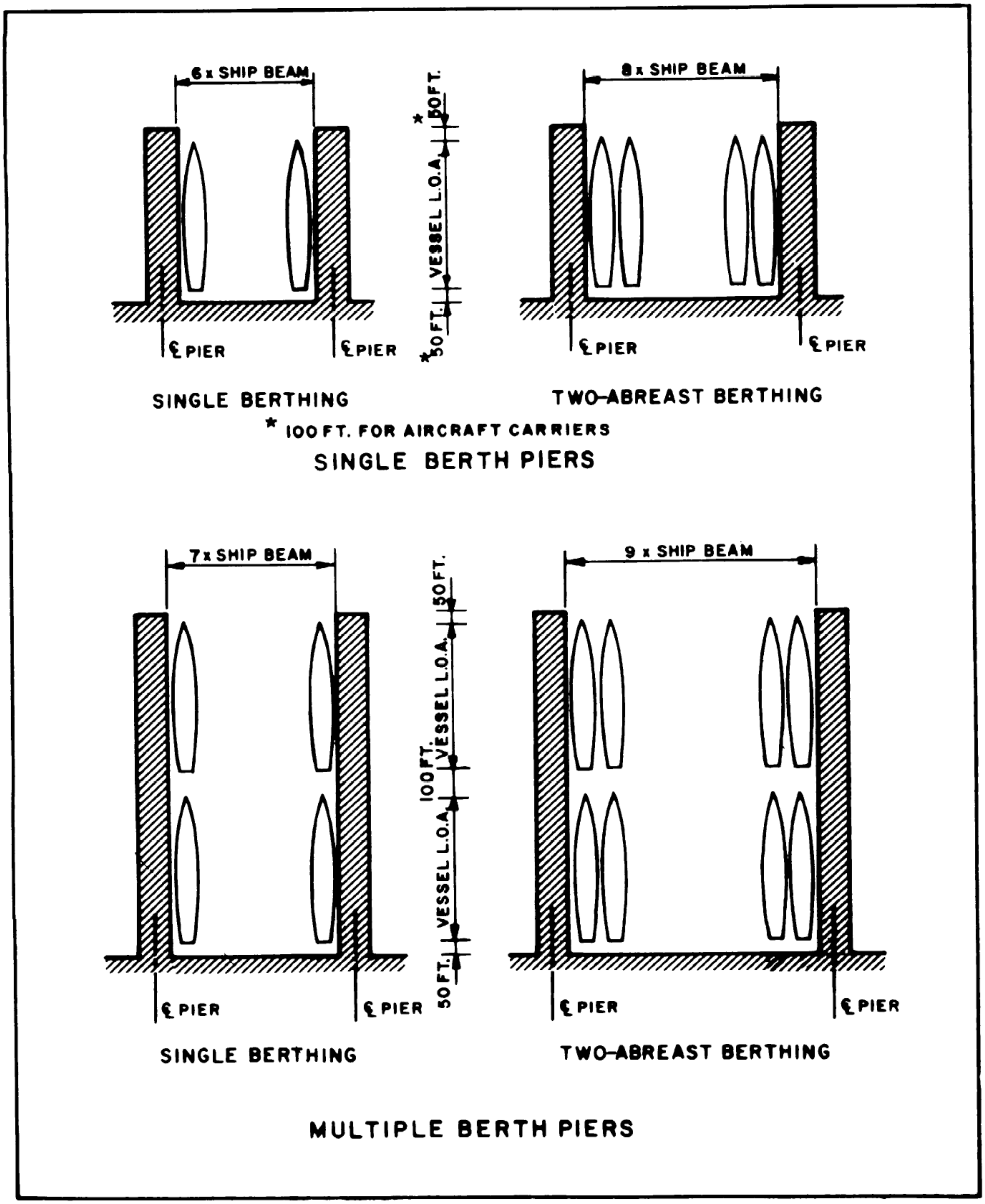


FIGURE 151-10
Slip Widths

151 10 AMMUNITION PIER (FB)
FAC: 1511
BFR Required: Y

15110-1 DEFINITION. Ammunition piers are designed for use in the receipt of ammunition for storage and for the offloading of ammunition onto barges and ships. In some cases outgoing ammunition is first loaded from the ammunition pier onto barges for transfer to ships moored offshore or in a roadstead. The services and facilities provided for ammunition piers include lighting, telephone and fire alarm systems, and salt water for firefighting. Railroad tracks are normally provided unless the established method of handling ammunition is by truck. Freshwater is provided if a supply is readily available. For dimensional and other pertinent information, see Code 151. For quantity-distant standards for pier and wharf facilities handling explosives and ammunition, see NAVSEA OP-5, Volume 1. This pier is for break bulk load/off-load of ammunition. For containerized load/off-load of ammunition, use Category Code 151 70, Ordnance Container Handling Pier.

151 20 GENERAL PURPOSE BERTHING PIER (FB)
FAC: 1511
BFR Required: Y

Design criteria: see Piers and Wharves, UFC 4-150-01

15120-1 DEFINITION. General Purpose Berthing Piers are used primarily for mooring home ported and transient ships that do not require piers equipped with shipyard facilities. Berthing piers are classified as active or inactive. The active berthing piers are used when ships are berthed for a relatively short time; the inactive classes are used when ships are to be tied up for long periods in a decommissioned status.

When berthing for carriers is to be provided on one side only or on both sides of a berthing pier the width of the structure shall be adequate to provide clearance for the overhang of the flight decks and sponsors. Alternatively, camels or other separators may be provided to fend off carriers.

All piers regardless of their function, will include such appurtenances as protective dolphins, fender systems, and dredging in connection with the facility. Supporting utilities, crane/railroad trackage, fixed cranes, and transit sheds on piers will carry their appropriate category codes. For other pertinent information, see Code 151 (general notes).

151 40 FUELING PIER (FB)
FAC: 1511
BFR Required: Y

Design criteria: see Piers and Wharves, UFC 4-150-01

15140-1 DEFINITION. Facilities for berthing ships while discharging fuel to storage or receiving fuel from storage are provided at fueling piers. Such piers will provide salt water for firefighting, telephone and fire alarm facilities and may provide freshwater, steam in cold climates, electric power. In addition, a fuel main and special protective hose racks and small derricks for handling fuel hoses are necessary. They shall also be equipped with pipelines for each type of fuel to be stored at the site, including bilge and ballast lines. Stripper pumps for emptying lines are also necessary. A fueling pier may be justified for those stations where bulk quantities of liquid fuel can be economically handled by water transportation. These piers vary according to the service required, the local exposure to wind and water, and the geologic formation of the site.

For dimensional and other pertinent information, see Code 151.

151 50 REPAIR PIER (FB)
FAC: 1511
BFR Required: Y

Design criteria: see Piers and Wharves, UFC 4-150-01

15150-1 DEFINITION. Repair piers are constructed and equipped to permit overhaul of those portions of a vessel above the waterline. These structures will normally be equipped with a gantry crane and standard-gage railroad tracks and have facilities to provide salt and freshwater, steam, compressed air, telephone and fire alarm service, and electric power for ship service, lighting and welding. In some cases industrial gases may be provided.

For dimensional and other pertinent information see Code 151.

151 60 SUPPLY PIER (FB)
FAC: 1511
BFR Required: Y

Design criteria: see Piers and Wharves, UFC 4-150-01; Supply Facilities, UFC 4-442-01N and MIL-HDBK 1032/2.

15160-1 DEFINITION. Supply piers accommodate berthing for the transfer of materials between ship and shore. A large building or transit shed normally occupies the central portion of a supply pier. The pier width will be in direct ratio to the width of the shed or sheds, placed longitudinally down the center of the pier. For example, the shed for a ship needing 600 feet of berthing space is 150 feet wide. Transit sheds are normally placed side by side parallel with the long axis of the pier when both sides of a pier are used for shipments. The pier width should then be from 380 to 420 feet because the pier deck or apron should be from 40 to 60 feet wide to accommodate railroad track, dock truck trains and allow proper cargo handling. Space restrictions at some seacoast installations will undoubtedly dictate the construction of piers of lesser width. In such cases, transit sheds must be designed with these restrictions. Planning for supply piers at installations will usually be restricted to industrial seaport locations having a primary stock point mission. For dimensional and other pertinent information relative to supply piers other than that in the preceding paragraph, see Code 151.

151 70 ORDNANCE CONTAINER HANDLING PIER (FB)
FAC: 1511
BFR Required: Y

15170-1 DEFINITION. An ordnance container handling pier is used primarily for the offloading and receiving of explosive ordnance in containers from non-self-sustaining container ships. This does not preclude use of the pier by conventional break-bulk or self-sustaining container ships. The pier should be sited in accordance with NAVSEA OP-5, Volume I. The services and facilities provided on the pier are lighting, telephones, fire alarms, and salt water for firefighting. Railroad tracks are provided where the normal method of drilling containers to the pier is by Trailer on Flat Car or Container on Flat Car (TOFC/COFC). Rails are flush with pier deck surface for ease of operations when moving containers by trucks on the pier.

For dimensional and other pertinent data, see Category Code 151Series (general notes) and UFC 4-150-01 Piers and Wharves.

151 71 DEGAUSSING PIER (FB)
FAC: 1511
BFR Required: Y

15171-1 DEFINITION. Sizing for this Category Code is based on the type of vessels to be serviced and is driven by the NAVSEA specified equipment. Special studies are required on a case by case basis.

151 80 DEPERMING PIER (FB)
FAC: 1511
BFR Required: Y

15180-1 DEFINITION. Sizing for this Category Code is based on the type of vessels to be serviced and is driven by the NAVSEA specified equipment. Special studies are required on a case by case basis.

151 90 ACCESS TRESTLE TO PIERS AND WHARVES (SF)
FAC: 1513
BFR Required: Y

No criterion currently exists for this category code.

152 WHARVES

152-1 GENERAL. A wharf is an open type marginal structure for the berthing of vessels; it is usually connected to the shore at more than one point. In most cases it will accommodate berthing along the outer face only, although a portion of the inner face may provide berthing space at a shallower draft. A wharf does not necessarily have continuous access to the shore. In general, the planning criteria that apply to piers are also applicable to wharves. Either may serve the same practicable purpose, however, since their physical design and layout will be much different, their capacities for berthing and cargo handling will vary. Piers are generally preferable structures; however, certain locations will dictate the use of a wharf rather than a pier because of the marginal fairway and topography involved.

For general planning information pertinent to wharves listed under Category Code 152 10 through Code 152 80, see the same pier designation listed under Category Code 151 10 through 151 80. The corresponding category codes for wharves are as follows:

152 10 AMMUNITION WHARF (FB)
152 20 GENERAL PURPOSE/BERTHING WHARF (FB)
152 30 FITTING OUT WHARF (FB)
152 40 FUELING WHARF (FB)
152 50 REPAIR WHARF (FB)
152 60 SUPPLY WHARF (FB)
152 70 ORDNANCE CONTAINER HANDLING WHARF (FB)
152 71 DEGAUSSING WHARF (FB)
152 80 DEPERMING WHARF (FB)

153 CARGO HANDLING OR STAGING AREAS

153 10 CARGO STAGING AREA (SY)
FAC: 8526
BFR Required: Y

15310-1 DESCRIPTION. A cargo staging area is an open hardstand for temporary storage of cargo awaiting further transshipment. For Open Storage, approximately 30,000 square feet of open storage area is required for each 431 short tons, or 385 long tons, or 1,000 measurement tons of cargo on hand per month based on a conversion factor of 2.32 measurement tons per short ton. For conversion factors for different commodities see page TBD. Average stacking height should be six feet. The square footage requirement should be established at 10% more than the space needed at peak times unless there is a wide discrepancy between the average amount of cargo on hand per month and the largest amount of cargo on hand at any one month during the last year. The square footage requirement should be established at 15% more than the average space needed in peak times if the discrepancy is recurring in nature. Average amount of receipts compared to issues per month as well as average hold time of cargo per month may be useful in developing data to support the facility requirement.

154 SEAWALLS, BULKHEADS, QUAYWALLS

154-1 **GENERAL.** Seawalls, bulkheads, and quay walls are shore protective structures not intended primarily for berthing vessels. Bulkheads and quay walls have the principal advantage of affording accessibility for their entire length along the foreshore. In addition, a much greater working area normally is available at each berth for storage, laydown, and repair operations than at berths alongside piers and wharves. The ratio of berthing space to a given length of waterfront, however, is much less for bulkheads and quay walls. The relative cost per berth is much greater for quay walls, especially for those in deep water or at sites with poor foundation conditions. Maneuverability into a berth at a long quay wall occupied by ships in adjoining berths is more difficult than entry into a single-length pier berth. In spite of these drawbacks, a quay wall may prove to be the only choice at a site located along a river or other relatively narrow channels if the natural terrain is high along the shore, making dredging of a recessed basin for piers very expensive, or if there is insufficient width of waterway for safe navigation into finger piers projecting out at an angle from the natural shoreline.

154 10 SHALLOW WATER BULKHEAD AND QUAYWALL WITHOUT A RELIEVING PLATFORM (LF)

FAC: 1541
BFR Required: N

15410-1 **DESCRIPTION.** This type of bulkhead or quay wall is a structure to retain earth along a shoreline in shallow water. The depth of water is typically limited to a 25 feet and the structure has no relieving platform. This structure does not provide ship berthing (151 Piers and 152 Wharves should be used for any ship berthing requirement). Typically, these structures are found between piers or wharves and are often used for Small Craft Berthing. It should be noted that this is a functional definition independent of the design type. Using today's technology bulkheads and quay walls have many useful design alternatives and the most economical construction should dictate the design based on local conditions.

15410-2 The linear footage and type of bulkhead required at any one installation would be determined by site location, the availability of real estate, topography, currents and wave action.

154 20 DEEP WATER BULKHEAD AND QUAYWALL WITH A RELIEVING PLATFORM (LF)
FAC: 1512
BFR Required: Y

15420-1 **DESCRIPTION.** This type of bulkhead or quay wall is a structure to retain earth along a shoreline in deep water. Typically, with a water depth exceeding 25 feet and includes a relieving platform to support heavy logistics operations. This structure does not provide ship berthing (151 Piers and 152 Wharves should be used for any ship berthing requirement). Typically, these structures are found between piers or wharves and are often used for Small Craft Berthing. Using today's technology bulkheads and quaywalls have many useful design alternatives and the most economical construction should dictate the design based on local conditions.

15420-2 The linear footage and type of bulkhead required at any one installation would be determined by site location, the availability of real estate, topography, currents and wave action.

154 30 SEAWALLS AND RIP RAP (LF)
FAC: 1541
BFR Required: N

15430-1 **DESCRIPTION.** These are structures built along and parallel to a shoreline (river or coast line) protecting and stabilizing the shore against erosion resulting from wave and current action. This is a functional definition, and various types of construction can be used to support this function. The most economical and efficient structure for a particular location can be determined only after a thorough study of local hydrographic and meteorological conditions, the amount and type of protection desired, and the characteristics of the property to be protected. This type of structure is often used in conjunction with a Category Code 871 35 Retaining Wall.

155 SMALL CRAFT BERTHING

This basic category group provides facilities supporting small craft operations. Included in this category are, but not limited to, yard craft, tug boats, security and service craft.

155 10 FLEET LANDING (FB)
FAC: 1551
BFR Required: Y

15510-1 **DESCRIPTION.** A fleet landing is a fixed or floating pier designed for the loading and/or unloading of a ship's personnel onto or from a personnel boat or ferry.

This facility must be in quiet water, carefully sheltered against disturbances. Water depth must be adequate for the type of ferry or service craft used. Requirements are developed based on the site specific conditions including tide range, available real estate and the types of crafts that will be using the facility. Category Code 155 20 can be used for general guidelines.

155 11 FLEET LANDING BUILDING (SF)
FAC: 1552
BFR Required: Y

15511-1 **DESCRIPTION.** A fleet landing building is a structure used to accommodate ship's personnel being loaded or unloaded from a personnel boat or ferry. The size and type of structure is dependent upon the average number of personnel being transferred at any one time and the type of climate in which the structure is located. In the absence of specific criteria, the quantitative requirements for the facility should be determined on an individual basis based on the experience and knowledge of the activity involved and the appropriate Systems Commands. Category Codes 155 21 and 159 64 can be used for general guidelines.

155 20 SMALL CRAFT BERTHING (FB)
FAC: 1551
BFR Required: Y

15520-1 **DESCRIPTION.** Berthing plans at waterfront facilities will provide space for all small craft authorized by CNO/CMC. Access and maintenance mooring arrangements should include facilities for harbor and pilot launches, survey boats, work boats, special service craft, rescue boats, and other small craft. If necessary, breakwaters will be provided for shelter against wind and wave action. Small boat piers and boathouses may be planned if several craft of medium and large size are to be accommodated. For medium and larger craft, water depth must be a minimum of 6 feet and preferably 8 feet at mean lower low water (MLLW). The pier may be designed to handle vehicles and provide turning space at the ell end of the pier. Water and electricity are required, as well as boat-fueling dispensers appropriately located on the pier. The utility services (800 series) and fueling for small craft (Category Code 122 30) are provided as secondary code items.

15520-2 **REQUIREMENT.** The requirement for Small Craft Berthing can be calculated using the following algorithm:

The following information should be obtained from Port Ops: CNO and other Small Craft loading, small craft dimensions, and the end-to-end spacing per type of small craft. If the end-to-end spacing varies between small craft types, then use the average spacing.

With the aforementioned information, the feet of berthing (FB) or meters of berthing (MB) necessary can be calculated using:

> [Number of each type of craft x length (or width depending on orientation of the crafts)] + [end-to-end spacing required x total number of crafts]

In addition to the FB/MB necessary there are secondary factors to consider:

- Draft - Medium and large craft = minimum of 6 ft (1.83 m), preferably 8 ft (2.44 m) at mean lower low water (MLLW)
- Breakwater required (yes/no)?
    - If yes, then determine the required length (see Category Code 16410)
- Boathouse required (yes/no)?
    - If yes, then see Category Code 155 21
- Vehicle access required (yes/no)?
    - If yes, add FB/MB depending on the vehicle type
- Vehicle turning space required (yes/no)?
    - If yes, add FB/MB depending on the vehicle type

155 21 SMALL CRAFT BOATHOUSE (SF)
FAC: 1552
BFR Required: Y

15521-1 **DESCRIPTION.** A boathouse is necessary where an alert crew is required, where a boat facility is remote from the supporting activity, or where boat repair facilities are essential. Boat crew quarters or a boathouse may be programmed for those locations that justify an alert crew for the aviation rescue boats, where the boat facility is remotely located from the supporting facility, and where boat repair facilities (either Code 213 56 or 213 58 as appropriate) are required. The boathouse is programmed on the following basis:

Alert crew quarters	85 square feet per person
Office and shop space	85 square feet per person
	170 square feet per person (Includes toilet and custodial space)

A boat shelter is often included as part of this facility and is sized by a study of the vessels required to meet the specific mission.

The following facilities should be provided for: repair shops and working platforms, crew bunkhouse, toilets, mechanical equipment room, a small office, boat machine and carpenter shops, marine railway hoist or crane, covered storage, paint shop, battery shop, fuel storage tanks with pumping apparatus, water, electricity, and sail loft, if necessary. At mean lower low water (MLLW), the depths in a boathouse shall not be less than 5 to 6 feet. The ceiling clearances will conform to the requirements of the various craft accommodated, but they should not be less than 16 feet. Working platforms should be about 3 feet above mean higher high (MHHW) water. A boathouse roof should provide cover over walkways and berths for emergency craft.

155 22 SMALL CRAFT BOAT RAMP FACILITY (EA)
FAC: 1591
BFR Required: Y

15522-1 **GENERAL.** Both the Navy and Marine Corps have in-shore boat teams that patrol inland waterways in support of various missions such as providing military escorts; securing inland waterways; carrying out “presence patrols”, and performing peacekeeping missions. These “brown water” functions require the use of fast boats that can be launched in shallow water and are capable of negotiating inland waterways. These capabilities require shore facilities such as boat ramps and piers or bulk heads that allow for launch and retrieval of these boats from towable trailers. This category code should be used for both home-ported and forward deployed operational or security forces requiring small boat launch ramps for the purposes of conducting in-shore training maneuvers or security patrols.

15522-2 **DEFINITION.** Small Craft Boat Ramp Facilities will provide a finished boat ramp that allows for launching operational boats from trailers and will be sloped to allow for proper approach, launch, and retrieval of the tow vehicle and boat/ trailer combination. This facility also includes an associated launch pier (per lane), parking (secure, if needed), and any bulkhead or shoreline erosion control measures (i.e., riprap or quarry rock) deemed necessary. Where mission requirements dictate, the launch pier should be based on criteria under Small Craft Berthing, CCN 15520 and captured in iNFADS as a sub category on the ramp Property Record Card (PRC).

The parking areas and approach apron are constructed of concrete or asphalt and are required for all Small Craft Boat Ramp facilities. These areas should be sized according to the criteria for Operational Vehicle Parking, CCN 14312 and shown as a separate utilization on the Boat Ramp property record card. All areas of the ramp, associated parking, and maneuvering areas must include adequate site lighting to allow for night time operations. In some cases, these areas might also be required to be secured via fencing and access gates. The boat ramp final design is based on many factors but for initial planning purposes, these guidelines and Figure 15522-1 dictate the parameters for a single lane small craft boat ramp facility. Note: this CCN provides requirements for a single lane ramp and uses a unit of measure of “EA”. Where ramps are required to be more than one lane, increase the quantity on the property record card based on the number of lanes needed. For example, a four lane boat ramp facility will have a quantity of “4” on the associated property record card.

15522-3 **PLANNING CRITERIA.** Small Craft Boat Ramp Facilities should be coordinated for use with the various training and operational schedules of different tenant commands at an installation. Tenant commands requiring boat ramp facilities should work together to determine how many lanes are necessary based on the op-tempo of their training cycles. The information included here should be used as a guide for planning operational boat ramps and their support spaces, but further detailed information can be found in the UFC 4-152-07 Design: Small Craft Berthing Facilities.

15522-4 **BOAT RAMP/LAUNCH PIER REQUIREMENTS (refer to Figure 15522-1)**

General guidelines:

1. Ramps will be planned at 20’ wide (clear width) and be constructed of reinforced concrete. The concrete surface will be grooved to provide both traction and proper drainage. Ramp slope will typically be set at 8 degrees (approximately 14%) wherever possible. Overall ramp length will be predicated on the local site grade elevation with respect to the Mean Lower Low Water (MLLW) mark.
2. The launch pier can be either fixed or floating but must maintain a clear minimum width of 6’. Pier length from the MLLW will be 50’ minimum.

Section (A) Approach:

1. Ramp approach transition from the shoreline to the ramp must be gradual to accommodate long prime-mover and trailer combinations. If the adjacent site terrain is relatively flat and does not have a natural slope towards the ramp, the approach apron must be vertically curved approximately 20’ from the parking/circulation area elevation to the boat ramp (see Fig. 15522-1). This area is accounted for in the parking allowances determined under the associated Operational Vehicle Parking/Laydown Area CCN 14312.
2. Any pedestrian ramps along the pier length will have a max slope (up or down) of 4 degrees (approximately 7%) to transition between various tide levels.

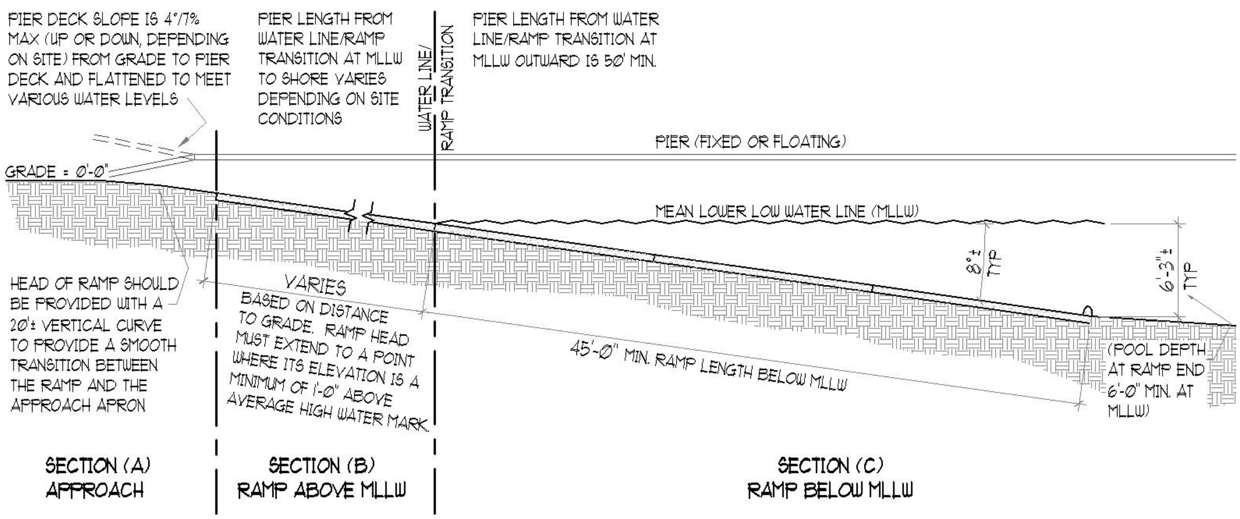
Section (B) Ramp Above MLLW:

1. Ramp length from the water line/ramp transition at MLLW is based on the shore elevation above the MLLW (see Figure 15522-1.) This distance must be determined in the field.
2. Pier length from the water line/ramp transition at MLLW is also based on the shore elevation above the MLLW. Note that the pier deck can be sloped up to 4 degrees (up or down) at any point along its length to shorten the required distance between the pier and shoreline. This determination will be made in the field.

Section (C) Ramp Below MLLW:

1. Ramp length below the MLLW is approximately 45'. At the designated 8 degree slope, this provides for a 6' deep pool at the foot of the ramp. The pool must be a minimum of 6' below the MLLW in all cases.
2. The pier length is not to exceed 75' in length from the water line/ramp transition at MLLW out into the water (see Figure 15522-1.)

Figure 15522-1



15522-5 **ASSOCIATED WATERWAY AND SMALL CRAFT BERTHING.** The basin (adjacent waterway) should be dredged to provide a minimum of 4' depth at MLLW. Bottom width at the ramp should be greater than the combined width of the launch ramp and boarding pier(s). Where required, small craft berthing should be planned and located in such a manner that it does not interfere with the actual launch procedures at the ramp or boat traffic within the basin. Any small craft berthing associated with this boat ramp facility should be captured under CCN 15520 Small Craft Berthing as a separate utilization on the boat ramp property record card.

15522-6 **PARKING AND CIRCULATION.** Small Craft Boat Ramp Facilities will require parking for prime mover and trailer combinations as well as any associated operational vehicles such as Humvees, pickup trucks, and passenger vans. Space allowances for parking, circulation, and apron areas at the boat ramp should be based on the criteria for CCN 14312 Operational Vehicle Parking/Laydown Area and captured in iNFADS under that category code. Note that this area under 14312 does not negate the need for parking allowances for the same vehicles at their permanent locations, usually operational facilities elsewhere at an installation.

156 CARGO HANDLING FACILITIES – BUILDINGS

156 10 WATERFRONT TRANSIT SHED (SF)
FAC: 1443
BFR Required: Y

15610-1 **DESCRIPTION.** A waterfront transit shed is a building or shed for storage of cargo awaiting further transshipment and requiring protection. For Covered Storage, approximately 8,000 square feet of covered storage area is required for each 560 short tons, or 500 long tons, or 1000 measurement tons of cargo based on a conversion factor of 2.32 measurement tons per short ton. For conversion factors for determining storage requirements, see Section 440-2 General Supply Requirements in Category Code 440 Series. Average stacking height should be twelve feet.

The actual space assigned to an activity must be developed taking cognizance of many factors such as planned organization and mission changes, packaging and labeling requirements, commodity mix, local fire control procedures, MHE aisle space, etc. Therefore, the best approach to use for planning purposes is to develop a general square footage figure and then adjust that figure based on other quantitative/qualitative information available. It is recommended that the following criteria be used to develop a general square footage requirement:

a. Average amount of cargo on hand per month.
b. Average amount of receipts compared to issues per month.
c. Largest amount of cargo on hand at any one month during the last year.
d. Average hold time of cargo per month.

Basically, there are three situations that are taken into consideration for calculating the space requirements for the storage of cargo awaiting further transshipment and requiring protection. These situations are as follows:

Situation (1) A relatively uniform amount of cargo is stored each month throughout the year. Since there is relatively little discrepancy between the data obtained from a and c; the square footage requirements should be established at 10% more than the space needed at peak times.

Situation (2) A relatively uniform amount of cargo is stored each month throughout the year with the exception that there is a large discrepancy that results from a one-time situation as indicated from the data in c. The square footage requirement is established as 10% more than the average actual space used per month.

Situation (3) A relatively uniform amount of cargo is stored each month throughout the year with the exception that there is a discrepancy, which is recurring in nature and is predictable. The square footage requirement is established at 15% more than the average space needed during the peak times brought about by the discrepancies.

Data developed from b and d may be useful in explaining/factoring the developed requirements.

The same criteria should be used in determining space requirements for label cargo. It should be noted, however, that since quantities of label cargo on hand are usually small, modifications to existing facilities (firewalls, secure area, etc.) should be considered prior to initiating construction of new facilities.

156 20 CONTAINER OPERATIONS BUILDING (SY)
FAC: 1443
BFR Required: Y

15620-1 **DESCRIPTION.** A container operations building is essential for safe direction and control of container operations to promote efficient and continuous flow to, within, and from the handling area. It is located to provide visual sighting of and two-way communication with handling operating facilities, such as shiploading, rail track and truck corridors serving and penetrating the handling area. The building contains muster areas, locker space, toilets, lunch room facilities, and an administrative area for container operations. A 50-foot tower contains two rooms at 30-foot and 40-foot levels for visual observation of ship, rail, and truck corridors and operational facilities.

A total gross area of approximately 6,000 square feet will house 15 employees in the administration area, 100 employees in the locker room, and 125 employees in the lunch room. The tower will accommodate 12 employees in approximately 700 gross square feet. The usual remoteness of this facility may necessitate the provision of parking spaces for all employees.

159 OTHER WATERFRONT OPERATIONAL FACILITIES

This basic category group provides for facilities which cannot be coded in basic groups 151 through 156.

159 10 AIRCRAFT DOCKING FACILITY (EA)
FAC: 1591

BFR Required: N

15910-1 This category code is for inventory purposes only. It is intended for waterfront facilities that were originally created to support seaplanes such as PBY Catalinas and similar from the WWII era and later. It is not associated with any airfield criteria and new facilities will not be planned under this CCN.

159 20 DEGAUSSING BUILDING (SF)
FAC: 1431
BFR Required: Y

15920-1 **DESCRIPTION.** Degaussing is the science dealing with the methods and techniques of reducing a ship's magnetic field so that the possibility of detection by magnetic mines and other magnetic influence detection devices is minimized. It consists of two functionally interdependent installations: An underwater Degaussing Range installation (Category Code 159 21) and this facility, which serves as an instrument station. The degaussing facility records a ship's magnetic field as it passes over the Degaussing Range and notifies the ship as to what adjustments must be made to the degaussing coils on board the ship (with the exception of submarines which have none) in order to reduce the ship's magnetic field to a safe operational level. If the vessel's magnetic field cannot be sufficiently reduced because of excessive permanent magnetization, the ship is scheduled to report for deperming (the process of reduction of permanent magnetism). See Category Code 159 30 for criteria relating to a deperming facility.

The sizing of this facility is determined by a study for the specific location and is directed by the equipment specified by NAVSEA.

159 21 DEGAUSSING RANGE (EA)
FAC: 1591
BFR Required: N

15921-1 **DESCRIPTION.** A degaussing range is an area set aside in a channel or harbor that contains submerged instruments, connected to the computer in the degaussing building (Category Code 159 20), which registers a ship's magnetic signature as it passes through the range. The test equipment in the degaussing building indicates whether the internal degaussing system on board the ship is calibrated properly. If shipboard equipment is not within tolerance new calibration settings will be provided to the ship to neutralize the fields to within an acceptable tolerances. Shipboard equipment that is not operating properly will also be identified and if necessary the ship may be scheduled for deperming.

Range Location. The range site for the degaussing facility should be carefully selected because the type of range to be installed and the method of installation depend mainly on the depth of water. The water depth will vary in accordance with the size of vessel to be ranged. The shallow range is located in 15 to 30 feet mean water depth and is used to range minesweepers and other vessels of comparable size. The medium range, which is generally 45 to 60 feet below the surface, is used for surface combatants, auxillary and amphibious warfare ships. The deep range, used for heavy carriers and the like, is located in 75 to 100 feet of water. The variation in water depth should not be greater than 10 feet for a particular range (shallow, medium, and deep). The range location should be based on the following considerations:

(1) Depth of water.
(2) Types of sea bottom.
(3) Tides and currents.
(4) Position of range relative to range house.
(5) Navigational hazards.
(6) Heading of range (generally on a north-south magnetic heading).

The selection of a range site must be approved by local naval port authorities. Continental sites and installations must be approved by the U.S. Army Corps of Engineers. See Category Codes 159 20 Degaussing Building and 159 30 Deperming Building for additional information.

159 30 DEPERMING BUILDING (SF)
FAC: 1431
BFR Required: Y

15930-1 **DESCRIPTION.** A Deperming Building is a facility that contains electrical instruments used to regulate and monitor the deperming operation. Deperming, the second phase of degaussing, is the process by which a ship's permanent longitudinal and athwartship magnetism is removed and its permanent vertical magnetism stabilized at a low level. The deperming facility consists of a Deperming Building, which serves as an instrumentation building, a Deperming Wharf, Category Code 151 80, and, if required, a generator house. The Deperming Building floor area is determined by the amount of equipment and the number of personnel determined by NAVSEA. Pier size must accommodate any size ship that requires deperming. Plans must include electrical facilities capable of meeting the power requirements determined by NAVSEA.

159 50 FERRY SLIP (EA)
FAC: 1591
BFR Required: N

15950-1 **DESCRIPTION.** A ferry slip provides the anchorage for ferries while loading or unloading. It consists of water areas directly in front of transfer bridges and is usually bordered by fender racks. The offshore waters must provide maneuvering area for the largest ferry to be accommodated. Depth of water depends on the ferries accommodated. For design criteria, see Waterfront Operational Facilities, MIL-HDBK-1025/1.

159 64 WATERFRONT OPERATIONS BUILDING (SF)
FAC: 1431
BFR Required: Y

15964-1 **DESCRIPTION.** A Waterfront Operations Building provides administrative space for the functions associated with the management of a naval port, and support for all ship berthing and small craft maintenance including related electronics systems. It may provide space for functions such as a duty crew bunk room, crew's lounge, boatswain’s locker, berthing for small boats if an integral part of the building, space for storage of boat gear and paint, oil spill equipment and a battery charging room.

This facility, which is under the cognizance of the officer in charge of port operations, is also staffed by personnel such as the dispatcher, dock master and harbormaster. Several functions performed are coordinating logistic support and harbor services, coordinating all movement of ships within the port as well as those entering and leaving, assigning ship berthing spaces, and providing pilots, operating tugs, service craft and small boats. The space for the office proper is based on the number of administrative people assigned. (See Category Code 610 10 for space allowances). Duty crew space shall be 85 net sf per person as detailed in Category Code 155 21. Space for the maintenance and boatswain’s functions are determined by an industrial analysis for the specific functions at each location. The industrial analysis shall include factors including the size of the port serviced, the size of the ships utilizing the port-and the frequency of movement of ships within the port and entrance channel(s).

In conjunction with the office space, a control tower with an unobstructed view of the entrance channel and berthing area may be provided. The tower space requirements should not exceed 600 gross square feet.

159 66 LANDING CRAFT RAMP (EA)
FAC: 1591
BFR Required: Y

15966-1 No criteria currently exists for this category code.

159 70 DREDGE CONTROL/PUMPING FACILITY (GM)
FAC: 1591
BFR Required: N

15970-1 **GENERAL.** The requirement for this facility is sized based on an engineering analysis for the conditions of the specific location.

160 HARBOR AND COASTAL FACILITIES

160-1 This category group includes all special facilities which may be required for protecting the harbor or coast against military action. This category also includes special facilities for mooring vessels and marine improvements for protecting the harbor land area or coastline from current or wave action and from flood conditions.

161 HARBOR PROTECTION FACILITIES

161-1 This basic category provides facilities for protecting the harbor against military action.

161 20 FIXED NET ANCHORAGE (EA)
FAC: 1611
BFR Required: N

16120-1 **DESCRIPTION.** This Category Code includes such functions as pile clusters and platforms used to support Anti-Terrorism/Force Protection (AT/FP) floating barriers. If a traditional submerged harbor net is used, this type of feature would also be required.
Typically, a Fixed Net Anchorage will require a means to connect and disconnect the floating barrier to allow for ships and other vessels to pass between the piers and wharves and the navigational channel. Barrier handling is typically done by service craft under the control of the Port Operations Department.

161 30 WINCH HOUSE (EA)
FAC: 1611
BFR Required: N

16130-1 **DESCRIPTION**. A winch house is a structure used in control of harbor nets, floating barriers and oil booms.

162 COASTAL PROTECTION FACILITIES

162-1 This basic category provides facilities for protecting the coast against military action.

162 10 GUN EMPLACEMENTS (EA)
FAC: 1499
BFR Required: N

16210-1 **DESCRIPTION**. Space in strategic sites is provided on base for the installation of gun emplacements, including anti-aircraft guns, for use in harbor defense.

163 MOORINGS

163-1 This basic category provides fixed structures for mooring vessels.

163 10 MOORING DOLPHIN (EA)
FAC: 1631
BFR Required: N

16310-1 **DESCRIPTION**. Mooring dolphins consist of clusters of timber, steel and concrete piles in planned patterns and spacing or can be closed structures such as sheet pile, steel or concrete caissons. Mooring dolphins are independent structures that are often placed at the outboard ends of piers or wharves to provide a mooring point that permits tying mooring lines at favorable angles without having to extend the entire pier or wharf structure. Mooring dolphins may have steel or concrete platforms used as pile cap structures and for mounting of mooring fittings. The timber piles are bound and secured by wire rope, shearing blocks, and bolts. Mooring dolphins are often connected to the main berthing pier or wharf by catwalks. Turning dolphins are used to deflect ships and assist in their alignment as the ships approach and enter a slip. Naval installations with harbor or waterfront facility requirements for mooring of small craft and ships, up to carriers, may plan for mooring dolphins to insure the safety and protection of the vessels. The number, size, and type of dolphins are dependent upon the type of vessels involved, the complexity of the approach to the slip and the requirements for mooring the vessel under prevalent environmental loads.

16310-2 **DESIGN CRITERIA**. For typical dolphin arrangements and design requirements, see Piers and Wharves, UFC 4-152-01. For other technical design information, see Military Harbors and Coastal Facilities, UFC 4-150-06.
+
163 20 MOORING PLATFORM (EA)
FAC: 1631
BFR Required: N

16320-1 **DESCRIPTION**. A mooring platform is an isolated structure consisting of a timber, steel or concrete deck supported on piling or can be a steel pile, sheet pile or concrete type caisson. Two or more platforms are provided in line for berthing of one or more vessels alongside. Mooring platforms provide facilities beyond those points where wharves or piers cease to function effectively as service or loading areas. Mooring platforms may include catwalks between each platform structure and the wharf. Mooring platforms are also referred to as breasting dolphins and allow a full length berth for large ships without the need for a full length wharf or pier. A berthing camel may be used between fender piles and the moored vessel.

16320-2 **DESIGN CRITERIA**. The mooring platform is shown in general plan and detail in Piers and Wharves, UFC 4-152-01.

163 30 STAKE PILE MOORING (EA)
FAC: 1631
BFR Required: N

16330-1 **DESCRIPTION**. A stake pile mooring consists of a stake pile driven below the surface of the firm bottom of the ocean floor. A chain attached to the stake is used to moor the vessel. The advantages of using stake piles instead of anchors for moorings are that they are fixed anchorage points. The disadvantages are that the mooring lines do not equalize the pulls in a spread mooring; the stake pile, because it is fixed, does not absorb shock energy as well as an anchor; and finally, approval from the authority in charge of channel dredging is necessary before driving stake piles into a bottom. When dredging is required in an area where stake piles are located, there is some hazard of damaging dredge cutters. The holding capacity, size, and other design details of stake piles can only be accurately determined by an analysis of bottom soil borings and field investigations at the site.

16330-2 **BUOY, CHAIN AND ANCHOR TYPE MOORINGS**. Moorings used to tie off bow and stern lines for ships can also be buoy, chain and anchor type of designs. These systems are equipment (personal property); they are not real property facilities and should not be categorized as stake pile moorings.

164 MARINE IMPROVEMENTS

164-1 This basic category provides structures for protecting the harbor, land area, or coastline from current or wave action and from flood conditions.

164 10 BREAKWATER (LF)
FAC: 1641
BFR Required: N

16410-1 **DESCRIPTION.** A breakwater is a freestanding barrier designed to break up and disperse heavy seas and to shield the waters of a harbor from wave action. Breakwaters are planned where primary protection is necessary to create or shelter a harbor or a basin for vessels from wave action. The type and quantity of breakwater is determined by local design considerations.

16410-2 **DESIGN CRITERIA**. Types of breakwater structures are shown in Piers and Wharves, UFC 4-152-01. For technical design information, see Military Harbors and Coastal Facilities, UFC 4-150-06.

164 20 GROINS AND JETTIES (LF)
FAC: 1641
BFR Required: N

16420-1 **DESCRIPTION**. Groins and jetties are structures built to intercept and deflect currents to control littoral drift and deposit of sand and silt.

16420-1.1 **Definition of Groins.** Groins are generally classified according to the principal construction materials used; that is, steel sheet piling, timber, stone, or concrete. A series of groins extending at right angles or parallel to the shoreline will protect the beaches from erosion. A groin serves to intercept currents that cause littoral drift of sand along a beach and under favorable conditions causes the deposition of sand, so as to reduce shore erosion.

16420-1.2 **Definition of Jetties**. Jetties are planned at harbor entrances and channels to control unstable conditions of silting and deposit of sand caused by river flow or tidal or wave action. A properly located jetty system will encourage scouring and maintain channel depth with a minimum of maintenance dredging. Jetties are similar in design to breakwaters, but are smaller.

16420-2 **DESIGN CRITERIA**. The types and lengths of groins and jetties will vary with local design considerations. Types and applications of groins and jetties are shown in Piers and Wharves, UFC 4-152-01 and design details are shown in Military Harbors and Coastal Facilities, UFC 4-150-06.

164 30 LEVEES (LF)
FAC: 8714
BFR Required: N

16430-1 **DESCRIPTION**. Levees are earthen embankments designed to protect property from water damage during the flood stage of rivers and/or other high water. The size and length of a levee will vary with local design considerations. Levees may be justified at air installations and at other naval installation where usable property must be protected from water damage.

169 OTHER HARBOR AND COASTAL FACILITIES

169-1 This basic category provides for harbor and entrance control points and signal towers.

169 10 HARBOR ENTRANCE CONTROL FACILITY (EA)
FAC: 1611
BFR Required: N

16910-1 **NET DEPOT**. Permanent installations from military control of a harbor entrance are not planned for peacetime, except that a large, paved area may be planned, where appropriate, as a site for layout and assembly of harbor nets and allied equipment. The layout area should be near the waterfront and accessible to mobile cranes for net and equipment handling. The area is known as the net depot and is used for net maintenance and for training in net handling.

16910-2 **FLOATING BARRIERS**. Current AT/FP measures utilize a variety of floating barriers that are considered equipment installations. Specific requirements are determined for each location based on geography, wave action and the types of assets to be protected. See Category Code series 161 and 163 for information related to the installation of floating barriers. The Naval Facilities Engineering Services Center (NFESC) has conducted a number of floating barrier studies and can serve as a valuable planning resource.

170 TRAINING FACILITIES

170-1 This category group covers facilities designated for the service career and reserve training of Navy and Marine Corps personnel. There are two basic categories under this code:

171 TRAINING BUILDINGS and
179 TRAINING FACILITIES OTHER THAN BUILDINGS

171/179-1 There are several specialized facility types such as auditoriums, drill halls, and others. Training facilities for general advancement of Navy/Marine Corps personnel, i.e., educational studies, which are conducted on an individual's own initiative and time, are planned under Category Code 740 88 (Educational Services Office).

171 TRAINING BUILDINGS

171-1 **General.** Facilities in this basic category are identified according to the nature of instruction provided. The major building types are:

171-1.1 **Academic Instruction Building** (Category Code 171 10). This facility provides accommodations for classroom lecture instruction, using chairs with fixed table arms, tables, desks or other similar working surfaces.

171-1.2 **Reserve Training Building** (Category Code 171 15). This facility is utilized for training Navy and Marine Corps Reserves.

171-1.3 **Applied Instruction Building** (Category Code 171 20). This facility is used to accommodate training through the use of equipment and tools such as drafting tables, workbenches, machinery, equipment or functional systems.

171-1.4 **Operational Trainer Space** (Category Code 171 35). This space is required to accommodate highly specialized real-life simulation training that needs specifically designed space within a building or a separate building. The size and configuration of these specialized spaces differ considerably from a typical applied instruction classroom.

171-2 **Space Type**. Training Buildings generally consist of three different types of spaces, classrooms, support and circulation, and service areas. The following is a description of the spaces and their components. See Table 171-1 for space allowances.

171-2.1 **Classroom Spaces**

171-2.1.1 **General Academic Space**. These classrooms devoted to lecture space are academic instruction classrooms defined under Category Code 171 10. Use Table 17110-1 for space allowances.

171-2.1.2 **Modified Academic Space**. This space consists of a lecture/laboratory combination classroom and is used for both lectures and practical exercises involving hands-on disassembly and assembly of small training aids applicable to the subject matter. A class that requires standard office desks is included in this category. Area includes workspace, circulation, teaching station and book storage. These classrooms are identified under Category Code 171 10.

171-2.1.3 **Workbench Lecture Space.** This space is for an instructional laboratory, the size of which may be only determined on an individual basis. The facility planners have to take into consideration the student/equipment/ instructor ratio which determines the numbers of instructional or test equipment per student station and consequently the space requirements, For example, electronics-related training requires approximately 6 linear feet of workbench resulting in approximately 50 to 55 net SF classroom space per student station, including circulation. Individual justification must accompany EWR submittals.

171-2.1.4 **Space for Hands-on Mockups**. This space is for a classroom in which instruction is given to individual or groups of students on stationary training devices representing all or part of an operating system. The size of this type classroom is generally determined not by the number of students, but by the physical size of the equipment. Figure

17120-1 under Category Code 171 20 provides a formula, which may be used to determine the required net floor space. A single line layout drawing indicating major dimensions should accompany BFR submittals.

171-2.1.5 **Learning Centers**. The learning center is a classroom utilized by students for individual study where training is conducted on a self-paced basis. It is space equipped with study carrels either designed for reading only or equipped with audio-visual training media. Since the self-paced training system has an unstructured time frame (i.e., students may use the facility whenever they have time available), the number of study carrels must be determined individually, the BFR submittal must show these calculations which should be based on the overall number of students requiring such facilities and the estimated number of students which are anticipated to use a learning center at a given time.

171-2.1.6 **Modified Academic Classroom**. This room is equipped with desks or other working surfaces in lieu of standard chairs with fixed tablet arms. Space requirements are 45 net SF per student station, including circulation. Larger areas require justification. These spaces are identified under Category Code 171 10.

171-2.2 **Support Spaces**

171-2.2.1 **Instructor's Work Space**. Facilities should be provided for each instructor to perform his administrative and preparatory duties.

171-2.2.2 **Instructor's Lounge**. The fixed allowance shown in Table 171 A assumes that no more than 10 instructors will be present at one time' Reduce this area proportionally if smaller use is anticipated. An increase in space above the amount indicated requires specific justification.

171-2.2.3 **Student Break Area**. This space should accommodate the average number of students scheduled to have a class recess at any given time. It can be provided at one location or dispersed in several locations throughout the school building.

171-2.2.4 **Library**. Due to the relative complexity of library operations, required space is broken down as follows:

- **Reading Area**. To estimate the number of persons utilizing this facility, use 20% of the average on board student load.

- **Stack Area**. Allowance given in Table 171-1 is based on 100 volumes per 3 linear feet section, 7.5 feet high, or 15 volumes per net square feet of floor area.

- **Media Storage**. Allowance given in Table 171-1 is based on storage of 424 DVDs or 260 VHS tapes in a section of shelving 3 feet long by 6 feet high in a space 3 feet wide. The width of this floor space provides for the cabinet depth plus half the width of an access aisle.

- **Staff Area**. Includes files, administration, reproduction space and material preparation area.

171-2.2.5 **Administrative Space**. This is space required for functions related to overall administration of the training facility in question and the allowances are governed by the number of administrative personnel. Planning procedures and net space allowances are the same as for Category Code 610 10 (Administrative Office), planning method 2 (detailed planning factors). The broad planning factor of 162.5 gross SF per occupant, under Category Code 610 10, may not be used because it would duplicate some of the support space allowances already provided for under this Category Code series 171.

171-2.2.6 **Training Aid Storage**. The space allowance is shown on Table 171-1.

171-2.2.7 **Other Support Spaces** not listed above must be identified separately and specific justification should accompany BFR submittals.

171-2.3 **Service Areas and Circulation.** These areas represents all spaces not in direct support of the training function, including walls, rest rooms, mechanical equipment, halls and corridors.

171-3 PLANNING PROCEDURES

Choose one of the following three methods to compute classroom net square feet space requirements.

171-3.1 **Average On Board.** This method is straightforward in the calculation of classroom space requirements. The formula requires a minimum amount of information as follows:

171-3.1.1 **Number of Students**. Total number of students per year for each course.

171-3.1.2 **Number of Days**. Total number of days (duration) to complete the course.

171-3.1.3 **Square Feet**. The proper choice of square feet per student from Table 171-1 based on the type of classroom instruction.

171-3.2 **Classroom Scheduling Method** The method that is preferred sometimes because it's easier to picture classrooms with a set number of students and a drawn schedule. The schedule shows an overall view of the student loading per month and gaps in classroom scheduling. The following minimum information is needed:

171-3.2.1 **Number of Students.** The number of students planned for each classroom.

171-3.2.2 **Course Time**. The duration of each course and the number of times taught throughout the year.

171-3.2.3 **Classroom Uses**. A decision on whether or not the classroom can be used for other courses.

171-3.3 **Student Time Distribution Method.** This method uses a more involved accounting system to estimate time expenditures for different types of course instruction. The method shows a detail study and breakdown of planned time distribution in labs, lectures and special applications classes. More information is required than in the other two methods.

In addition to computing classroom space requirements, develop the requirements for Support Spaces separately. Convert final totals to gross square feet.

SPECIAL NOTES FOR PLANNING PROCEDURES

1. Any construction project, regardless of funding source, submitted for authorization must be accompanied by detailed supporting documentation (broad planning factors cannot be used in lieu of detailed analysis).

2. Planning for training buildings shall be based on maximum utilization of available classrooms. To this end, the number and sizes of classrooms shall be determined on the basis of a detailed study encompassing curricula, group sizes, schedules, security and proximity requirements, and/or any other pertinent aspects. It is recognized that a number of subjects, especially in the applied instruction field, require extensive training aids or special classroom configurations. Every attempt must be made, however, to minimize the number of such single subject or "dedicated" classrooms, especially in those cases where their use would be relatively infrequent. Cross-scheduling of classroom use must be considered on an installation-wide basis, crossing organizational boundaries if necessary.

3. As a general rule, most training buildings will consist of a mixture of different types of instructional space (normally a combination of academic and applied instruction). For buildings of this type, the specific applicable criteria must be utilized to plan the facility in question even though a resulting project may carry only a single Category Code (171 10 or 171 20). For example, an applied instruction building (Category

Code 171 20) contains academic classrooms utilized to teach basic or familiarization aspects of an applied instruction curriculum. In such case, academic classrooms are sized using code 171 10 criteria, although on planning documentation, this space will eventually be combined with the figures for the applied instruction (Category Code 171 20) portions of the facility.

171-4 COMPUTATION METHODS FOR COMPUTING CLASSROOM SPACE

171-4.1 Average On Board

171-4.1.1 Use Figure 171-1 and list the courses of instruction conducted by the Activity. List the requirements in separate categories (e.g. general academic, lab-lecture, etc.).

171-4.1.2 Show the Course Data Processing Code (CDPC), course title, and other requested information. The columns of information are defined at the bottom of the table. Information is available in the Master Course Reference File (MCRF) of the Navy Integrated Training Resources and Administrative System (NITRAS) and other sources.

171-4.1.3 Use the AOB formula to calculate the number of students per class.

171-4.1.4 Based on the type of instruction, select the proper square feet per student from Table 171-1.

171-4.1.5 Calculate the Required NSF for each course.

171-4.1.6 Add the Required NSF column to obtain the total requirements.

171-4.2 Classroom Scheduling Method

171-4.2.1 Use Figure 171-2 and list each course.

171-4.2.2 Assume the courses meet all day. If a course meets during the AM hours in a room and a different course can meet in the same room during PM hours, assume one room requirement.

171-4.2.3 Draw a line through the number of weeks the course is held each time during the year.

171-4.2.4 Show the week the course begins and ends each time. Show the number of students planned for each course above the course duration line.

171-4.2.5 After the class scheduling is drawn, use Figure 171-3 to organize the requirements. List each course, type of class space, number of students for each classroom and the square feet used to calculate requirements obtained from Table 171-1.

171-4.2.6 Determine whether or not the classroom requirement should be dedicated strictly for the course or if other courses can be scheduled in the same room.

171-4.2.7 Use one of the following formulas to calculate space requirements and show the calculation in Figure 171-3 Column E or F.

171-4.2.8 Total Classroom requirement is the sum of Columns E and F. Separate the totals into classifications (e.g., total general academic, lab-class, etc., space).

Dedicated Classroom - This classroom has permanently installed demonstrations, mock-ups, laboratory equipment, or special teaching aids. The room is usually not conveniently set-up for teaching other courses.

Dedicated Classroom Requirement NSF	=	No. Pupils per Course in Classroom	X	Table 171-1 Type Class

Partial Classroom Requirement - This condition applies to courses that can meet in general classroom areas or courses that meet less than 60% of a 250-day school year.

Partial Classroom Requirement NSF	=	No. Pupils per Course in Classroom	X	Table 171-1 Type Class Sq. Ft.	X	Total Course Days per Year

School Year = 250 class days per year.

171-4.3 **Student Time Distribution Method**

171-4.3.1 Use Figure 171-4 to enter information.

171-4.3.2 Organize the list of planned courses according to the anticipated number of students in each classroom.

171-4.3.3 Group the courses in descending class sizes (e.g. classes with 40, 30, 20, students etc.) in Columns A and B.

171-4.3.4 Show the course duration in number of weeks. Use fractional weeks as necessary.

171-4.3.5 In Columns E, G, I, and K show the estimated percentage of time spent in each type of class (e.g., 50% lecture, 50% lab).

171-4.3.6 In Columns F, H, J, and L, show the equivalent weeks per year for the types of instruction (e.g., Col F = (C) x (D) x (E)

171-4.3.7 Total the weeks in Columns F, H, J, and L.

171-4.3.8 Organize the data according to types of instruction and class sizes as shown in the example Figure 171-4.

171-4.3.9 Calculate the classroom sizes from the square feet allowances per student shown in Table 171-1. For example, to calculate a general academic classroom for 8 students, use 22 sq ft from Table 171-1, which refers user to Table 17110-1.

171-4.3.10 Therefore, 8 x 22 = 176 sq ft. Use the same calculation method for labs and the other types of classroom spaces.

171-4.3.11 The totals in the Classroom Computation Schedule show the number of classrooms and net square feet.

Figure 171-1. Classroom Space Requirement Computation

Course CDP	Course Short Title	Duration in Days (DD)	Annual Frequency (AF)	Pupils Per CL (S)	Annual Input (AI)	Student AOB *	NSF Per Student (NSF)	Requirement Ne Area **

Total Student AOB and Total Requirement in Net SQ. FT.								

*	**Student Average on Board (AOB)**	=	Duration (DD)	X	Annual Input (AI)	/	250 (Classroom Days Per Year)
**	**Required NSF Area**	=	AOB	X	NSF	X	1.5

Round all Fractions to the next highest whole number
School year = 250 class days

NSF = Select proper square feet per student from Table 171-1 according to type of installation
CDP = Course Data Processing Code
DD = Duration of course in actual classroom days
AF = Number of times course is taught per year
AI = Number of students trained annually AI = (AF) x (S)
1.5 = A utilization factor required to compensate for the inability to completely schedule classes and fully use classroom capacity.

Figure 171-2. Classroom Scheduling Method Type of Training Space: Various

Course Title	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Remark
AN/xyz	15		15		15		15		15		15		
3B Applied	10		10		10		10		10		10		
CD Lab		6		6		6		6		6		6	
Total Student oading/Month	25	16	25	16	25	16	25	16	25	16	15	6	

Figure 171-3. Calculation Summary – Scheduling Method

(A) Course Desc.	(B) Type of Class	(C) No. of pupils per class	(D) Sq. Ft. Used Table 171-1	(E) Dedicated Room Sq. Ft.	(F) Partial or Gen Class Sq. Ft.
AN/xyz	Lecture	15	22		330
BB Applied	Mod Lec	10	30		300
CD Lab	Lab	6	45	270	
			Totals	270	630

Figure 171-4. Course Data and Student Time Distribution

Course Title (arranged by decreasing size)	Class Size	Frequency of Class per Year	Duration of Class in Weeks	% Time in General Academic classroom or Lecture Space	Weeks per Year (F=CxDxG)	% Time in Modified Academic Classroom or Modified Lecture Space	Weeks per Year (H=CxDxG)	% Time in Work-Bench Type Space	Weeks per Year (J=CxDxI)	% Time in Hans-On-Mockups	Weeks per Year (L=CxDxK)	% Time Elsewhere
A	B	C	D	E	F	G	H	I	J	K	L	M

Explanation:

Column B - Projected student loading for the designated class
Column C - Number of times per years course is offered
Column D - Individual course duration in weeks
Column E G I K - Percentage of actual student's instructional time spent in the various classroom types.
Column F H J L - Requirements of that particular class room size and type by number of weeks.

Example Figure 171-4. Course Data and Student Time Distribution

ourse Title *(Arranged decreasing class size)*	*(NOTE: Same column headings as Figure 171-4)*											
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
AA-OOOO	40	25	-4	100%	10							
BC-XXXX	40	10	2	100%	20							
) PN Totals					30							
DEF-XXXX	20	6	2	50%	6	50%	6					
GHI-YYYY	20	3	10	100%	36							
JKL-1234	20	5	10	50%	25	20%	10			30%	15	
MNO-6250	20	2	5	25%	3	50%	5	25%	3			
PQR-1111	20	50	0.6	100%	30							
9 PN Totals					100		21		3		15	
ABD-0001	10	5	10	100%	50							
ABD-0002	10	2	20	50%	20	50%	20					
ABD-0003	10	25	1	100%	25							
ABD-0004	10	50	0.4	100%	20							
PN Totals					115		20					

Explanation:

Column B - Projected student loading for the designated class
Column C - Number of times per year course is offered
Column D- Individual course duration in weeks
Columns E G I K - Percentage of actual student's instructional time spent in the various classroom types
Columns F H J L - Requirements of that particular classroom size and type by number of weeks

Classroom Computations
Refer to Figure 171-4

Class Size	Total Weeks Per Year Required	/	50 Weeks Per Year	=	Computed Classroom Requirement *	Actual Classrooms Required **		Size ***		Net
								Square Feet		
General Academic Classroom or Lecture Space										
40 PN	30	/	50	=	0.6	1 Each	X	800 NSF	=	800
20 PN	100	/	50	=	2.0	2 Each	X	440 NSF	=	880
10 PN	115	/	50	=	2.3	3 Each	X	220 NSF	=	660
Total					4.9	6 Each				
Modified Academic Classroom or Modified Lecture Space										
20 PN	21	/	50	=	0.4	1 Each	X	20 PN x 45 NSF	=	900
10 PN	20	/	50	=	0.4	0				
Total					0.8	1 Each				3240 NSF

- Workbench type space (Use Individual Justification)
- Hands-on-Mock-ups (Use Formula in Figure 17120-1)

* Allows for Holiday stand downs and scheduling flexibility

** Actual classroom required must equal or exceed computed classroom requirement. Number of required classroom must take into account the excess time available in larger size rooms, i.e., smaller classes can use available excess time in larger rooms.

*** Size data follows Table 171-1

Table 171-1. Space Allowances for Instruction Facilities

Type of Space	Maximum Allowances
1. CLASSROOM SPACE	
a. General Academic	Use Table 17110-1 allowances
b. Modified Academic Space	30 net SF per student station
c. Lecture-Lab Space	45 net SF per student station
d. Modified Academic with office desks	45 net SF per student station
c. Workbench Type Space	Individual justification required
d. Hands-On Mockup Space	Use formula given in Fig. 17120-1
e. Learning Centers	40 net SF fixed allowance
2. SUPPORT SPACE	
a. Instructor's Work Space	60 net SF per instructor
b. Instructor's Lounge	450 net SF fixed allowance
c. Student Break Area	6 net per student
d. Library	
(1) Reading Area	25 net SF per person
(2) Stack Area	6.6 net SF per 100 volumes
(3) Media Storage	9 net SF per 424 DVDs or 260 VHS tapes
(4) Media Viewing Room	100 net SF fixed allowance
(5) Staff Area	10% of sum of reading stack, film storage and viewing areas
e. Administrative Space	Use category code 610 10 detailed criteria
f. Training Aid Storage	1.5 net SF per student station
g. Other Support Spaces	Individual justification required
3. CIRCULATION AND SERVICE AREAS	
(Net to Gross Conversion)	Multiply NSF by 1.33

Note: Student station is defined as a classroom seat or shop workbench area designated to accommodate one student.

171 10 ACADEMIC INSTRUCTION BUILDING (SF)
FAC: 1711
BFR Required: Y

17110-1 A facility dedicated entirely to academic instruction will seldom be planned. In most cases, instruction of this type will be part of another training function, such as at a Service School or conducted in some other type of applied instruction building. The criteria for this type facility are based on net classroom square feet per student seat.

For planning purposes, academic classrooms can be divided into two general categories:

17110-1.1 **General Academic Classroom** - is one which supports approved training programs and provides accommodations for classroom lecture instruction, using standard chairs with fixed tablet arms or a similar seating configuration providing the student a writing surface and book depository. An instructor station is provided, with space for the use of portable training aids. The individual general academic classroom sizes in net square feet (i.e., within the interior walls of the room), as dictated by the required number of seats, shall not exceed the figures given in Table 17110-1.

17110-1.2 **Modified Academic Classroom** - is one which is equipped with desks or other working surfaces in lieu of standard chairs with fixed tablet arms.

17110-2 **Planning Steps**

17110-2.1 The number and size of individual classrooms must be determined in accordance with the general guidelines given under the topic Planning Procedures in the preceding general section for Basic Category 171.

17110-2.1.1 **Gross Square Feet - Broad Planning**

The space allowances for general and modified academic classrooms represent net classroom space only. The requirements for supporting spaces must be calculated separately in order to obtain gross SF building area. This may be done by either one of the two alternate methods:

- In the absence of detailed data during early stages of planning, the gross SF building area (including all necessary support space) shall be computed as follows:
    - In cases where the training building is composed entirely of general academic classrooms, use the broad planning factor of 45 gross SF per student station for the entire building.

- In cases where some or all of the classrooms are of the modified academic classroom type, by using the broad planning factor of 75 gross SF per student station for the entire building.

- In cases where, within an academic training facility, a number of classrooms must be modified to accommodate working surfaces different than standard chairs, the net area for such modified academic classrooms may be increased. For instance, modified academic classrooms (with standard office desks) will require approximately 45 net SF per student station, including circulation. Larger increases will require specific justification.

  - Maximum consideration must be given to provide a variety of classroom sizes in order to optimize space utilization.

Table 17110-1
Space Criteria for General Academic Classrooms

No. of Seats	Sq. Ft. per Seat
20	22
30	21
40	20
50	19.5
60	19
70	18.5
80	18
81 to 90	17
91 to 100	16
101 to 120	15.5
121 to 140	15
141 to 160	14.5
161 to 180	14
over 180	14

171 15 NAVY AND MARINE CORPS RESERVE TRAINING (SF)
FAC: 1714
BFR Required: Y
NOSC Space Program spreadsheet, located at: https://www.wbdg.org/dod/unified-facilities-space-program-sustainability-spreadsheets

Design Criteria: FC 4-171-06N "Navy Operational Support Center" https://www.wbdg.org/dod/ufc/fc-4-171-06n

17115-1 **DEFINITION.** Navy and Marine Corps Reserve Centers provide training, organizational and administrative support to Reserve units and their supporting functions. This category code refers to the Reserve Training center only. Criteria for other facilities which support the Reserve unit personnel (e.g., Bachelor Housing, Dining, Aircraft Maintenance Hangars, etc.) are not included in this section and follow the same criteria as active duty counterparts. Refer to Appendix A of this UFC for a function / category code cross-reference.

17115-2 **LOCATION:** In many instances, the Reserve Center may be located outside of the perimeter of a formal DoD Installation. In these cases, it is important to refer to UFC 4-010-01 "DoD Minimum Antiterrorism Standards for Buildings" for guidance relative to the necessary Force Protection elements to consider while planning new Reserve unit facilities and renovation of existing facilities.

17115-3 **NAVY OPERATIONAL SUPPORT CENTER (NOSC)**: A facility for use by Naval Reserve Units for training and organizational requirements.

17115-3.1 **Capacity.** The space allowances for a Naval Operational Support Center shall be determined on the basis of the **maximum weekend drill population**, not total drill population numbers. Other important factors determining capacity include the number of Full Time Staff (FTS) and the total number of Reserve Units utilizing the drill site.

17115-3.2 **Joint Space Allowance.** When two or more Services are combined into a single joint reserve facility, 50% of the smallest individual Service requirements for medical, janitorial, and male and female toilet areas shall be added to the largest individual Service's requirement for each respective area.

17115-3.2 **Space Criteria.** The gross square footage allowance for Administrative, Medical, Unit Area and Drill Hall spaces in the NOSC are obtained from the NOSC Space Program spreadsheet which can be found at https://www.wbdg.org/ffc/dod/unified-facilities-space-program-sustainability-spreadsheets.

Optional additive spaces for specific Unit requirements are provided in Tables 17115-1 through 17115-6, which should be added to the net results provided by the space program spreadsheet (if applicable) and increased by the 35% NTG factor for circulation, etc. (For Marine Corps Reserve Centers, refer to paragraph 17115-5. The space program spreadsheet does not apply to the Marine Corps Reserve Centers).

17115-4 **NOSC OPTIONAL ADDITIVE SPACES:** In specific cases, Reserve units are authorized additional space for applied training, simulators, or maintenance when authorized equipment is present at reserve centers. The following tables are provided as examples of additional requirements.

Table 17115-1 Additive Space Criteria for Cargo Handling Battalion (NRCHB)

Cargo Handling Battalion (NRCHB):		
Administrative/Training Facility	**@ Reserve Readiness Sites (RSS)**	**@ NOSC**
Classrooms	1600 NSF	
Toilets/Showers	700 NSF	
Administrative	2800 NSF	230 NSF
Locker Room	735 NSF	
Storage	1500 NSF	700 NSF
Rigging Shop	325 NSF	325 NSF
Total for Admin./Training Facility (net)	7660 NSF	1255 NSF
Vehicle Maintenance Facility (GSF)		2910 GSF
Vehicle Storage (GSF)		1820 GSF
Total for Vehicle Maint.functions (gross)		4730 GSF
Ship mock-up (1 each) (see note 1)	3700 SF	3700 SF
Simulated Pier (0.25 Acre) (see note 1)	1172 SY	1172 SY
Organizational Vehicle Parking	680 SY	680 SY
Staging Area (paved)	1 ac	1 ac
Lay down Area (paved)	556 SY	556 SY
Training Site (see note 2)	5 ac	5 ac

NOTES

1 The ship mock-up and simulated pier are authorized only when there are no Maritime Administration (MARAD) ship or other ships available for training.

2 Five (5) acres of constructible land are required only if a MARAD ship is not available and the mock-up trainer is constructed. Actual requirements will be developed as a result of Master Planning and site layout.

Table 17115-2 Additive Space Criteria for Mobile Mine Assembly Group (MOMAG)

Mobile Mine Assembly Group (MOMAG):		
	@ RSS	@ NOSC
Vault	-	18 SF
Shop	-	400 SF
TOTAL (net)		418 SF

Table 17115-3 Additive Space Criteria for Expeditionary Logistics Support Force (NRELSF)

Expeditionary Logistics Support Force (NRELSF):		
	@ RSS	@ NOSC
Administration/Training	8100 SF	-
TOTAL (gross)	8100 SF	-
POV parking	980 SY	-
TOTAL	980 SY	-

Table 17115-4 Additive Space Criteria for Sea-Air-Land (SEAL) Unit

Sea-Air-Land (SEAL) Unit:		
Diving Equipment Maintenance and Storage	-	390 SF
Boat Storage	-	250 SF
Locker Room	-	300 SF
TOTAL (net)	-	940 SF

Table 17115-5 Additive Space Criteria for Inshore Boat Unit (NRIBU)

Inshore Boat Unit (NRIBU):		
	@ RSS	**@ Reserve Centers**
Classroom (Only if not co-located at a Center)	726 SF	
Administration/Training Support	1521 SF	345 SF
Shower (2 each for male and female @ 20 SF each)	80 SF	
Locker (120 SF male plus 60 SF female)	180 SF	180 SF
Storage	800 SF	800 SF
Armory	45 SF	45 SF
TOTAL (net)	3352 SF	1370 SF
Boat Storage Area	1205 SF	1205 SF
TOTAL (gross)	1205 SF	1205 SF
Organizational Vehicle Parking	250 SY	250 SF
Private Owned Vehicle Parking (POV)	1008 SY	1008 SY
TOTAL	1258 SY	1258 SY

Mobile Diving and Salvage Unit (NRMDSU):		
Interior Storage	860 SF	860 SF
SCUBA Locker	240 SF	240 SF
Shop	400 SF	400 SF
Diver Personnel Lockers	225 SF	225 SF
Showers/Heads (Do not include if co-located at a Center)	225 SF	
Multipurpose Area (Do not include if co-located at a Center)	280 SF	
Admin/Office (Do not include if co-located at a Center)	540 SF	
Flammable Storage (56 SF portable bldg)	0 SF	0 SF
TOTAL (net)	2800 SF	1725 SF

17115-5 **MARINE CORPS RESERVE CENTER**: Space allowances for these facilities will accommodate the range of personnel listed as column headings shown in Table 17115-7 (e.g. 50 to 150 persons, etc.). Square footages for each range are based upon the design capacity listed at the top of the column. To determine the facility requirement, choose the range in Table 17115-7 that corresponds to the units projected personnel loading (found in the USMC Table of Organization). Units with loading outside of the range of Table 17115-7 require special justification, and the user should consult the Naval Facilities Engineering Command or Headquarters, USMC for planning assistance.

Tables 17115-7, 17115-8, and 17115-9 are to be used only as a guide. Changes to individual functions are acceptable given adequate justification. Tables 17115-7, 17115-8, and 17115-9 Special Requirements, are not intended for all centers and require approval from Headquarters, USMC and Commander, Marine Forces. For further assistance, see other category codes, Architectural Design Standards or contact Naval Facilities Engineering Command or Headquarters, USMC.

Table 17115-7 Space Criteria For Marine Corps Reserve Centers Training and Administrative Building
(All Numbers are Net Square Feet Unless Noted)

Functional Area	**Drill Strength 50 to 150**	**Drill Strength 151 to 250**	**Drill Strength 251 to 350**	**Drill Strength 351 to 450**
A) JOINT USE SPACE *(See Table 17115-7(a) for space derivation data)*				
Drill Hall	5,850	5,850	6,300	6,750
Classrooms	1,500	2,500	3,500	4,500
Medical Examination	650	650	650	650
Conference Room	225	375	525	675
Janitorial Space	200	200	200	200
Toilets/Showers: Male	400	500	600	700
Toilets/Showers: Female	250	300	350	450
Day Locker Room (Marines)	200	350	475	600
Lounge	200	300	400	500
Mechanical Equipment	400	500	600	700
Subtotal of Part A: Joint Use Space	9,875	11,525	13,600	15,725

Table 17115-7 Space Criteria For Marine Corps Reserve Centers
Training and Administrative Building
(All Numbers are Net Square Feet Unless Noted)

Functional Area	Drill Strength 50 to 150	Drill Strength 151 to 250	Drill Strength 251 to 350	Drill Strength 351 to 450
B) EXCLUSIVE USE SPACE *(See Table 17115-7(a) for space derivation data)*				
Administrative Offices	2,500	3,100	3,900	4,700
Conference Room	350	450	550	650
Recruiting	400	400	400	400
Training Aids (Training Storage/Storage)	100	100	100	100
Multi-Media Center/LAN Control Center	25	25	25	25
IMST Trainer	1,050	1,050	1,050	1,050
Armory/Security Vault	800	800	800	800
Shops-Comm. Maintenance	700	700	700	700
Lockers (Double Size)	1,575	2,625	3,675	4,725
Supply Storage	3,500	4,000	4,500	5,000
Exercise / Fitness Center	900	1,500	2,025	2,600
Subtotal of Part B: Exclusive Use Space	11,900	14,750	17,725	20,750

Table 17115-7 Space Criteria For Marine Corps Reserve Centers
Training and Administrative Building
(All Numbers are Net Square Feet Unless Noted)

C) SPECIAL REQUIREMENTS

Special requirements are not included in all Reserve Centers. Each function is justified by a unit's particular mission. These functions are to be part of the Reserve Center interior floor plan (should have 25% added for walls and circulation accordingly). Each function must be approved by Headquarters, USMC and Commander, Marine Forces Reserve. (See Table 17115-7(a) for space derivation data)

Functional Area				All drill strengths
Food Service Galley				400
Photo Unit (Dark Room)				100
Mobilization Station				500
Food Service Storage				700
Classified Material Storage				200
Communications/Electronics Shop				700
Medical Logistics Storage				5,000
Embark Storage				800
Dental Officer Office				180
Medical Officer Office				180
Subtotal Part C. Special Requirements Space				

Total of Parts A, B, & C	
Net to Gross Factor for Walls, Circulation, & Common Areas (25%)	
Total GSF Requirement for Reserve Center	

Table 17115-7(a) Derivation of Space Allowances for Table 17115-7

A. JOINT USE SPACE	
Assembly Hall (Navy)/Drill Hall (Marine)	Minimum space is based upon full size basketball court. Space should accommodate 100% of the drill population for all hands events: equipment staging area, unit formations and physical fitness.
Classrooms	Size based upon 50% of drill population being in class at any given time, to include space for computers and audio/visual equipment (use 20 SF per student).
Medical Examination	Fixed size.
Conference Room	Size based upon 10% of drill population (use 15 SF per person)
Janitorial Space	Fixed size consistent with architectural standards.
Heads/Showers, Male	Size based upon OSHA standards of 1 toilet for each 10 personnel (with the appropriate mixture of toilets/urinals) and 1 shower head for each personnel (up to a maximum of 35 shower heads)
Heads/Showers, Female	Size based on minimum of 5% of drill population is female (1 toilet for each 10 personnel).
Lounge	Fixed size.
Day Locker Room (Marine)	Size based on 50% of drill population requirement for 1 day locker with lockers double stacked (each locker and bench is 5.3 SF).

B. EXCLUSIVE USE SPACE	
Administrative Offices	Variable size based on 18-12% of the drill strength (use 90 SF per person)
Conference Room	Size based upon 100% of active duty T/O (use 15 SF per person)
Recruiting	Fixed size.
Training Aid Storage	Fixed size.
LAN Control Center	Fixed size.
ISMT Training Room	Minimum size per training unit is 1,050 SF with a minimum ceiling height of 10 feet (each additional trainer requires another 1,050 SF).
Armory/Security Vault	Minimum size is 800 SF (for additional guidance use Cat Code 143-45). Size may increase based on units T/E.
Communication Maintenance Shop	Minimum size is 700 SF (for additional guidance use Cat Code 217)
Lockers	Size based on 100% of drill population requirement for 1 double-size locker per person.
Exercise/Fitness Center	Fixed size based on 15% of drill population working out at any one time (38.5 SF per person reference MIL-HDBK 1037/8).
Supply Storage	Minimum size listed with a minimum ceiling height of 20 feet (for additional guidance use Cat Code 441-10)

Table 17115-7(a) Derivation of Space Allowances for Table 17115-7 (Cont'd)

C. SPECIAL REQUIREMENTS	
Food Service Galley	Fixed size (400 SF)
Photo Unit (Dark Room)	Fixed size (100 SF)
Mobilization Station	Fixed size (500 SF)
Food Service Storage	Fixed size (700 SF)
Classified Material Storage	Fixed size (200 SF)
Communications/Electronics Shop	Fixed size (700 SF)
Medical Logistics Storage	Fixed size (5,000 SF). Should have a roll-up door for vehicle access
Embark Storage Shed	Fixed size (800 SF). Structure will have a vehicle access with roll-up door.
Dental Officer Office	Fixed size (180 SF). Only for dental battalions.
Medical Officer Office	Fixed size (180 SF). Only for medical battalions.

Table 17115-8 Space Criteria for Marine Corps Reserve Centers Vehicle Maintenance Facility

VMF Type	CCN	Type	Space (SF)
Select a type of VMF based on the Vehicle Maintenance Facility criteria. (See Table 17115-8(a) for space derivation data).			
Combat Vehicle Maintenance Facility	214-10	Type A	1,653 SF
		Type B	2,603 SF
		Type C	4,603 SF
		Type D	4,403 SF
		Type E	5,303 SF
		Type F	6,350 SF
		Type G	6,953 SF
VMF Type	**CCN**	**Space Formula**	**Space (SF)**
Automotive Vehicle Maintenance Facility	214-20	___ # of Bays x 480 sqft/bay	_____ SF

Table 17115-8(a) Derivation of Space Allowances for Table 17115-8

TYPE	SMALL BAYS		MEDIUM BAY		LUBE/PM BAY		LARGE BAY		GENERAL SPACE	MEZZANINE STORAGE	TOTAL (NET SF)
	# OF BAYS	SIZE	# OF BAYS	SIZE	# OF BAYS	SIZE	# OF BAYS	SIZE			
A	1	560	0	640	0	800	0	1,456	462	300	1,322
B	2	560	0	640	0	800	0	1,456	562	400	2,082
C	1	560	2	640	1	800	0	1,456	602	440	3,682
D	3	560	0	640	1	800	0	1,456	602	440	3,522
E	2	560	2	640	1	800	0	1,456	602	440	4,242
F	0	560	0	640	1	800	2	1,456	788	580	5,080
G	2	560	3	640	1	800	0	1,456	942	780	5,562

Notes - Table 17115-8

1) Total square footages are interior, functional space requirements. For total useable square footages, add mezzanine storage requirements. Mezzanine storage is to be constructed with ladder/stair access and removable safety rails over offices, tool rooms and heads.
2) Total gross square footages include 25% for walls and circulation.
3) The Lube/Preventative Maintenance Bay should be a separate bay, ideally with an air compressor lift vice a hydraulic lift. This bay should not be an exposed pit due to environmental concerns.
4) The Automotive Vehicle Maintenance Facility (Cat-Code 214-20) shall be 480 gross square feet, or 16' by 40' as directed by the P-80.

Table 17115-8(a) Derivation of Space Allowances for Table 17115-8 (cont'd)

TYPE A: Facility will not normally be incorporated into Marine Reserve Centers because their limited size does not allow for flexibility. Function breakdown is as follows:

SPACE	SIZE (SF)
Maintenance Bays	560
Flammable Storage	64
Tool Room	110
Head	80
Office Space	110
Maintenance Publications	98
Mezzanine	300
Total Useable Space	1,322
Gross Space	1,653

TYPE B: Function breakdown is as follows:

SPACE	SIZE (SF)
Maintenance Bays	1,120
Flammable Storage	64
Tool Room	160
Head	100
Office Space	140
Maint Publications	98
Mezzanine	400
Total Useable Space	2,082
Gross Space	2,603

Type B Units
Infantry Co/Bn
Supply Co/Bn
Recon Co/Bn
Medical Co/Bn
Dental Co/Bn
H&S Co
MP Co

Table 17115-8(a) Derivation of Space Allowances for Table 17115-8 (cont'd)

TYPE C: At least one small and one medium bay will be drive through, cost and space permitting. An overhead crane should be installed for the following types of units: AAV Co/Bn, LAR Co/Bn, and Maintenance Co/Bn. Function breakdown is as follows:

SPACE	SIZE (SF)
Maintenance Bays	1,840
Lube/PM Bay	800
Flammable Storage	64
Tool Room	200
Head	100
Office Space	140
Maint Publications	98
Mezzanine	440
Total Useable Space	3,682
Gross Space	4,603

Type C Units
Engineer Co/Bn
AAV Co/Bn
LAV Co/Bn
Maint Co/Bn
LSB Co/Bn

TYPE D: At least two small bays will be drive through, cost and space permitting. Function breakdown is as follows:

SPACE	SIZE (SF)
Maintenance Bays	1,680
Lube/PM Bay	800
Flammable Storage	64
Tool Room	200
Head	100
Office Space	140
Maint Publications	98
Mezzanine	440
Total Useable Space	3,522
Gross Space	4,403

Type D Units
Artillery Btry/Bn
ANGLICO
Truck Co
TOW Co
Comm Co/Bn
LAAD Bn

Table 17115-8(a) Derivation of Space Allowances for Table 17115-8 (cont'd)

TYPE E: At least one small bay and one medium bay will be drive through, cost and space permitting. Function breakdown is as follows:

SPACE	SIZE (SF)
Maintenance Bays	2,400
Lube/PM Bay	800
Flammable Storage	64
Tool Room	200
Head	100
Office Space	140
Maint Publications	98
Mezzanine	440
Total Useable Space	4,242
Gross Space	5,303

Type E Units
LAAM Bn
Engineer Supt Co
Collocated Units

TYPE F: At least one large bay and one medium bay will be drive through, cost and space permitting. An overhead crane should be installed. Function breakdown is as follows:

SPACE	SIZE (SF)
Maintenance Bays	2912
Lube/PM Bay	800
Flammable Storage	64
Tool Room	300
Head	100
Office Space	180
Maint Publications	98
Tank Skirt Storage	46
Mezzanine	580
Total Useable Space	5,080
Gross Space	6,350

Type F Units
Tank Co

Table 17115-8(a)
Derivation of Space Allowances for Table 17115-8 (cont'd)

TYPE G: At least one small and one medium bay will be drive through, cost and space permitting. Function breakdown is as follows:

SPACE	SIZE (SF)
Maintenance Bays	3,040
Lube/PM Bay	800
Flammable Storage	64
Tool Room	400
Head	100
Office Space	280
Maintenance Publications	98
Mezzanine	780
Total Useable Space	5,562
Gross Space	6,953

Type G Units
MWSS
Engineer Intensive Collocated Units

Table 17115-9 Space Criteria for Marine Corps Reserve Centers
Special Requirement Space Allowance

SPECIAL REQUIREMENTS –
Special requirements are not included in all reserve centers, and are justified by a unit's particular mission.

PART I (GROSS SQUARE FEET)

Each function must be approved by Headquarters, USMC and Commander, Marine Forces Reserve. Although these functions are located with the reserve center, for costing & scoping purposes they are not included in the 171-15 Category Code. Use appropriate Category Code unit cost. *See "Derivation of Special Requirement Space Allowances for Table 17115-9" for space requirement derivation data.*

Function	Cat. Code		Calculation	Scope	UOM
Indoor Pistol Range	171-50			900	SF
Rappelling Tower	179-50			400	SF
Tank, Combat Training Pool	179-55			4,200	SF
Parachute and Survival Equipment Shop	211-75			3,670	SF
Optics Shop	213-50			500	SF
Carpenter Shop	213-56			800	SF
Boat Shop	213-58			2,400	SF
Scuba Locker	213-68			250	SF
Field Maintenance Shop (Comm/Elect)	217-30			3,700	SF
Instrument Calibration Shop	218-45			3,600	SF
Boat Storage Shed	441-35			1,700	SF
Vehicle Holding Shed	214-40	___ # of tactical vehicles	___ # of bays (one per 30 vehicles) x 800 SF/bay =	_____	SF
Light Gun Shed	215-20		___ # of bays x 788 SF/bay =	_____	SF
Organic Equipment Storage Shed	441-12			Variable	SF

Table 17115-9 Space Criteria for Marine Corps Reserve Centers (continued)
Special Requirement Space Allowance

SPECIAL REQUIREMENTS – Special requirements are not included in all reserve centers, and are justified by a unit's particular mission.				
PART II (GROSS SQUARE YARDS)				
Each function must be approved by Headquarters, USMC and Commander, Marine Forces Reserve. Although these functions are located with the reserve center, for costing & scoping purposes they are not included in the 171-15 Category Code. Use appropriate Category Code unit cost. *See "Derivation of Special Requirement Space Allowances for Table 17115-9" for space requirement derivation data.*				
Function	**Cat. Code**	**Calculation**	**Scope**	**UOM**
Antennae Array	132-55		4,400	SY
Bulk Fuel Equipment Storage Shed	441-35		35	SY
Loading Ramp	851-15		35	SY
Vehicle Wash Platform	214-55	___ # of wash points x 90 SY/wash point =	_____	SY
Tactical Vehicle Parking (Wheeled)	852-35	___ # of wheeled vehicles x 50 SY/vehicle =	_____	SY
Tactical Vehicle Parking (Tracked)	852-35	___ # of tracked vehicles x 75 SY/vehicle =	_____	SY
Private Owned Vehicle Parking	852-10	___ # of personnel x 35 SY/vehicle (provide a min. of 80%) =	_____	SY
Quadcon Storage Pad	852-35	___ # of QUADCONS x 23 SY/QUADCON =	_____	SY
HAZMAT Storage Pad	852-35	___ # of HAZMAT sheds x 23 SY/HAZMAT shed =	_____	SY
MALS Van Pad	852-35	___ # of MALS vans x 34 SY/MALS van =	_____	SY
Generator Storage Shed	441-35	___ # of generators x 5 SY/generator =	_____	SY
Security Fencing	872-10		Variable	LF
Security fencing should be located, at a minimum, around the perimeter of the VMF, Tactical Vehicle Parking, Quad-Con Storage Lot, and Antennae Array, where applicable.				
Land	911-		10	AC

Table 17115-9(a) Derivation of Special Requirement Space Allowances for Table 17115-9

PART I		
Special requirements are not included in all reserve centers, and are justified by a unit's particular mission. Each function must be approved by Headquarters, USMC and Commander, Marine Forces Reserve.		
Function	**Cat. Code**	
Indoor Pistol Range	171-50	Fixed size (900 SF). For MP units only.
Rappelling Tower	179-50	Fixed size (400 SF)
Tank, Combat Training Pool	179-55	Fixed size (4,200 SF)
Parachute and Survival Equipment Shop	211-75	Fixed size (3,670 SF)
Optics Shop	213-50	Fixed size (500 SF). For units with special optical weapon system storage/maintenance requirements.
Carpenter Shop	213-56	Fixed size (800 SF)
Boat Shop	213-58	Fixed size (2,400 SF)
Scuba Locker	213-68	Fixed size (250 SF)
Vehicle Holding Shed	214-40	Variable size (1 bay at 800 gross SF for each 30 vehicles).
Light Gun Shed	215-20	Variable size (788 SF per bay). Multiply by number of bays required.
Field Maintenance Shop (Communications/Electronics)	217-30	Fixed size (3,700 SF). A separate structure with 200 SF of office space, 1,000 SF work area with tech benches, a head and vehicle access with roll-up door.
Instrument Calibration Shop	218-45	Fixed size (3,600 SF)
Organic Equipment Storage Facility	441-12	Based on 80% of unit's unique organic training allowance
Boat Storage Shed	441-35	Fixed size (1,700 SF)

Table 17115-9(a) Derivation of Special Requirement Space Allowances for Table 17115-9 (cont'd)

PART II		
Special requirements are not included in all reserve centers, and are justified by a unit's particular mission. Each function must be approved by Headquarters, USMC and Commander, Marine Forces Reserve.		
Function	**Cat. Code**	
Antennae Array	132-55	Fixed size (4,400 SY)
Vehicle Wash Platform	214-55	Variable size (800 SF per vehicle). Multiply by number vehicles washrack designed to accommodate.
Bulk Fuel Equipment Storage Shed	143-77	Fixed size (35 SY)
Quad Con Storage Lot	852-35	Variable size (23 SY per container)
HAZMAT Storage Pad	852-35	Variable size (23 SY per HAZMAT storage shed)
MALS Van Pad	852-35	Variable size (34 SY per van)
Generator Storage Shed	441-35	Variable size (5 SY per generator)
Loading Ramp	851-15	Fixed size (35 SY)
Tactical Vehicle Parking (Wheeled)	852-35	Variable size (50 SY per wheeled vehicle)
Tactical Vehicle Parking (Tracked)	852-35	Variable size (75 SY per tracked vehicle)
Private Owned Vehicle Parking	852-10	Variable size (35 SY per POV). Provide a minimum of parking for 80% of the drill strength
Security Fencing	872-10	Variable size around perimeter. Fencing required around VMF/tactical parking, Quad Con storage lot and antennae array, where applicable.
Land	911-	Minimum size (10 acres of useable land)

171 17 TV CENTER FOR INSTRUCTIONAL MATTER (SF)
FAC: 1441
BFR Required: Y

17117-1 **DEFINITION.** This facility may be provided only when specifically authorized by Naval Education and Training Command (NETC). Requirements will be determined for each individual case, with NETC guidance.

171 20 APPLIED INSTRUCTION BUILDING (SF)
FAC: 1712
BFR Required: Y

17120-1 **DEFINITION.** This facility provides for training personnel through the applied use of technical equipment and tools. Some of the characteristic features of applied instruction classrooms are:

- The use of drafting tables
- The use of workbenches to train personnel in trade/specialized skills such as electronics, machine tool operation, welding and similar.
- The use of operational training machinery such as automotive or other engines, refrigeration equipment, etc.
- The requirement for complete functional systems such as weapons delivery systems, fire control systems, etc.
- For planning purposes, applied instruction facilities can be divided into two general categories:
    a. **General Applied Instruction Facilities** (for example, Service School Shops and Laboratories).
    b. **Specialized Applied Instruction Facilities** (for example, Multiengine Patrol Plane Training Building).

17120-2 **PLANNING METHODOLOGY.** Facilities for each category must be planned separately because planning methodologies are different for each group. General applied instruction facilities have flexible space allowances and must be planned to individually suit the type of instruction to be accommodated. Specialized applied instruction facilities have fixed space allowances. In the following text, each category is discussed separately.

17120-3 **BROAD PLANNING FACTORS**

17120-3.1 **General Applied Instruction Facilities**. The gross SF building area (for BFR purposes) may be computed by <u>either one of the two alternate methods</u>:

- In the absence of detailed data or when close approximation to precise requirements is not considered necessary, the gross building area should be computed based on 150 gross square feet per student station.

- If specific personnel data is available follow the planning procedure and table given under Basic Category 171 and 171-20.

Figure 17120-1 provides a method to calculate floor area requirements for hands-on mockup training devices.

Figure 17120-1
Planning Formula for Determining Floor Requirements for Hands-on Mockup Space

FORMULA: A = B (CD + E)

DEFINITIONS

A = Area of classroom in net SF

B = Number of items of practice equipment required. This figure is obtained by dividing C into the average number of students in each class session.

C = Number of students assigned to each item of practice equipment.

D = Net SF of floor area required for one student working on an item of practice equipment.

E = Net SF of floor area occupied by one item of practice equipment. Includes clearances and aisles. Human engineering factors, including safety, must be considered. In cases where student working areas (item D) partially overlap equipment clearance areas, insure that the space requirements are not duplicated.

17120-3.2 **SPECIALIZED APPLIED INSTRUCTION FACILITIES.** This category includes facilities designed for training in specialized functions requiring a dedicated building. Space allowances are either fixed or given in gross SF per student and in every case includes all necessary support spaces, such as administration, lounges, training aid storage, library space, reproduction areas, learning centers, toilets, showers, locker rooms, corridors, and janitorial space. For some of the facilities listed below which require a specific building configuration, definitive designs have been prepared. Those cases are annotated in the text.

- **Flight Training and Briefing Building**. This building provides space for student pilots in support of direct flight training. Included in the allowance is space for lecture rooms and classrooms, instructor pilot offices, ready rooms, flight planning rooms, briefing rooms, and other support space.

The facility provides the necessary space for interaction of student and instructor in briefing and debriefing of actual training flight, singly or in groups. This space is over and above the space requirements for extensive classroom, instrument trainer or flight simulator training, which are covered in other category codes or in other sub listings under this category code. Also, this space is in addition to the normal squadron administrative space covered under category code 211 07. The planning factor for Flight Training and Briefing Building is 125 gross SF Per student, based on the average on-board student load.

- **Naval Air Maintenance Training Building**. Naval Air Maintenance Training Buildings provide the necessary classrooms and other space in support of one or more Maintenance Trainer Sets (MTS's). MTS's, consisting of instructional items as displays, actual systems/subsystems/equipment/parts/materials, cut-aways, mock-ups, audio/visual aids, provide maintenance personnel and pilots with technical training on aeronautical systems and associated equipment, organizational and intermediate maintenance, operation and special techniques as applied to aircraft subsystems, missiles and specific equipment and other training as the Chief of Naval Operations may direct.

17120-3.3 The planning factor for the Naval Air Maintenance Training Building is 160 gross SF per student. The number of students for planning purposes shall be the average on-board student loading.

17120-3.4 Highly sophisticated new weapon systems may require more space than-would be computed on the basis of 160 square feet per student. The facility or site study prepared for each new weapon system provides the necessary information for making such determination. When the maintenance training space requirement is found to exceed 160 square feet per student, the requirements shall be fully documented, to include data relative to size of trainers, students per trainer, support space requirements and other pertinent matters to enable evaluation of the actually required gross area.

- **Fleet Readiness Aviation Maintenance Personnel (FRAMP) and Aircrew Learning Center.** This facility provides classrooms, briefing rooms and environmentally protected FRAMP practical training work areas to support initial and recurrent training for fleet aircrew (pilots, Naval Flight Officers, and when applicable, enlisted crew members) and aircraft maintenance personnel. Gross area requirements vary with model of aircraft and student loading and must be determined for each individual case. Although FRAMP and aircrew training facilities can be separate, integrated facilities permit efficient utilization of classrooms, study carrels, media reproduction and support areas and administrative spaces. Simulator facilities (code 171 35) may be attached to this building.

- **All Weather Training Building**. The all-weather training building provides the necessary space to house the special devices used by pilots, crewmen, and ground controllers to maintain their operating proficiency for adverse weather conditions. The planning factor for this facility is one (1) standard all-weather training building for an all-weather training station supporting two or more all-weather squadrons. The standard all-weather training building has an area of 7702 gross SF. The building contains six classrooms of about 600 square feet each to house special devices, a map-making room, support spaces and space for routine maintenance and equipment testing.

- **Multi-engine Patrol Plane (VP) Training Building**. This facility houses special devices and gear used by patrol pilots and crewmen to maintain proficiency in submarine search and detection, aircraft and missile detection, and the employment of counter-measures against enemy radar. The planning factor is one (1) standard multi-engine patrol plane training building for a patrol plan e station with a mission for continuous support of two or more patrol squadrons. The facility has an area of 26,120 gross SF and contains 23 classrooms (18 feet by 22 feet average size), support spaces, and a lecture-demonstration hall.

- **Aviation Physiological Training Building**. This building provides classroom and support space for implementation of the aviation physiology training syllabus. The syllabus pertains to aeromedical aspects of night vision, acceleration and deceleration forces, explosive decompression, oxygen equipment, pressure suits, survival, protective and safety equipment. The planning factor is one (1) aviation physiological training building for each station that will support four carrier air groups or the equivalent of one HATWING OF VAH jet aircraft. The building is planned with the concurrence of NAVMEDCOM. The size of the building is 15,000 gross SF.

- **Delivery Retaining Detachment Building**. This facility provides refresher training for teams that handle and maintain special weapons and for pilots and crews assigned special weapons missions. The planning factor is one (1) delivery retraining detachment building for each air station supporting operational units with a special weapons capability. The building has an area of 1,590 gross SF.
- **Naval Construction Battalion Unit (CBU) Facility**. This facility provides a construction unit contingency augmentation capability to the Naval Construction Forces and assures unit and individual skill training essential to required readiness posture. Space requirements may be satisfied by a single or multiple building configuration. Facilities of this type will be planned only at locations designated by higher authority. Space allowances for CBU’s are given in Table 17120-1

- **Band Practice Facility**. Table 17120-2 provides a summary list of the recommended areas for each of the spaces for both small and large bands. Local differences in operational patterns and function programs may require some modifications to the space program. These differences may, for example, include; larger or smaller size for individual spaces; different relationship patterns between spaces; or elimination or addition of specific spaces.

- **Combat Training Pool/Tank, Enclosed.** This facility provides an enclosed pool/tank for instruction in swimming and survival under combat conditions. It includes the pool and supporting spaces, such as locker room, instructional deck, mechanical room, etc., however the actual composition of individual facilities may vary according to their particular training requirements. Unique pool/tank design considerations may be required for specialized training facilities such as aviators' survival training tanks and EOD/underwater demolition training. For general planning criteria, See Category Code 179 55.

Table 17120-1
Space Criteria for Naval Construction Battalion Units

Functional space	Notes	Gross Sq Ft	Gross Sq M
Administration		1,460	136
Engineering Lab		570	53
Locker/Showers	(3)	1,000	93
Classroom/Workbench		1,060	98
Classroom/Academic		580	54
Equipment Maintenance Shops	(1)	4,400	409
Vertical Shops (BU/SW/CE/UT)	(2)	4,000	372
Central Tool Room (CTR)	(2)	2,940	273
Project Material Storage (MLO)	(2)	2,540	236
Greens Issue/782 Issue	(2)	810	75
TOTAL GROSS AREA		19,360	1,799

Notes:

(1) Based on three equipment repair bays.
(2) Definition for the abbreviations used in this criterion are as follows:

BU = Builder
SW = Steelworker
CE = Construction Electrician
UT = Utilities man
CTR = Central Tool Room
MLO = Construction Project Material Storage (operated by the Materials Liaison Officer)
Greens/782 Issue = Organizational Clothing/Gear Issue

(3) Total Gross Area includes both men and women.

Table 17120-2
Recommended Space Allocations for Navy Band Training Facilities

Function-Space	Small Fleet Band (35 pieces)		Large Fleet Band (45 pieces) Or Large Fleet Band-Plus (60 pieces)	
	Approx. no. of spaces	Square Meters	Approx. no. of spaces	Square Meters
Main Rehearsal Room	1	146	1	211
Practice Rooms-Group				
Large Group	1	65	1	65
Small Group	1	28	2	30
Practice Rooms-Individual				
Large Individual	2-4	7-12 ea.	3-6	7-12 ea.
Small Individual	6-8	5-6 ea.	9-12	5-6 ea.
Subtotal	8-10	77	12-15	106
Recording/Audio Control Booth	1	23	1	23
Library	1	46	1	59
Offices (No. of persons)	9	109	13	157
Personal Support				
Individual Instructor Lockers	1	48	1	63
Instrument Cleaning	1	7	1	7
Day Area	1	59	1	80
Toilets/Lockers/Showers				
Men		82		112
Women		42		45
Officer’s Toilet				
Storage and Supply				
Unit Supply/Storage	1	93	1	121
Instrument Repair	1	9	1	9
Janitor’s Closet	1	5	1	5
Transition				
Lobby	1	56	1	84
Circulation				
Subtotal Indoor Space-Net Only		895		1182

Function-Space	Small Fleet Band (35 pieces)		Large Fleet Band (45 pieces) Or Large Fleet Band-Plus (60 pieces)	
	Approx. no. of spaces	Square Meters	Approx. no. of spaces	Square Meters
Circulation, Walls, etc. @25%		224		296
Subtotal		1119		1478
Mechanical Spaces @ 5%		56		74
GROSS TOTAL (Rounded)		1171		1552
Outdoor Spaces				
Drill Area	See CCN 179-60		See CCN 179-60	
Parking Area (1 space per band piece)	See CCN 852-10		See CCN 852-10	

171 21 DECONTAMINATION TRAINING FACILITY (DELETED)
FAC: 1712
BFR Required: Y

17121-1 This category code is deleted. Decontamination training areas are integral to the operational facilities they occupy and as such, are not a standalone facility.

171 25 GENERAL PURPOSE AUDITORIUM (SF)
FAC: 7431
BFR Required: Y

17125-1 **DEFINITION.** An auditorium may be authorized when required as an adjunct to training or other functions (except administration). The primary purpose of the auditorium is an assembly area for instruction and training. General purpose auditoriums will not be planned at an installation where a motion picture theater is authorized except where justified by special circumstances. Seating capacity of an auditorium is to be determined in each specific case and justification provided. The size of an auditorium shall be calculated based on 12 square feet per seat gross floor area or 9 square feet per seat net floor area (in cases where auditorium is a part of a multiple use building sharing common circulation and service spaces).

171 30 PHYSICAL EDUCATION FACILITY (SF)
FAC: 1715
BFR Required: Y

17130-1 **DEFINITION.** A building that houses physical education training facilities at the United States Naval Academy (USNA) at Annapolis, Maryland. These facilities are used for the fitness development program of instruction at the USNA. This CCN is for use only by the USNA.

17130-2 **GENERAL.** An engineering analysis is required to determine facility space allocations.

171 35 OPERATIONAL TRAINER FACILITY (SF)
FAC: 1721
BFR Required: Y

17135-1 **DEFINITION.** This category is assigned to training space which meets one or more of the following criteria:

17135-1.1 It houses large operational trainers, usually duplicating part or all of surface or air weapons system.

17135-1.2 It is specifically designed and sized for a trainer; has characteristics such as high ceiling height, large room dimensions, and removable exterior wall panels to facilitate servicing; it may also include special design features to satisfy stability requirements of visual systems, unique environmental control requirements (HVAC & filtering), loads associated with motion base(s), and abnormal power requirements.

17135-1.3 Actual space requirement is dictated by the size of the trainer rather than student loading.

Examples of the type of trainers which should be categorized under this code area:

a. Weapons System Trainer/Flight Simulator.
b. Part-Task Trainer (air).
c. Cockpit Procedure Trainer.
d. Instrument Trainer.
f. Full scale models of ships boiler rooms.
g. Full scale mock-up of a Trident tube.
h. Full scale mock-up of a Tomahawk Launcher.
i. Large scale models of water basins for practice of berthing procedures.
e. Mock-ups of ships and submarines and their associated armament.

17135-2 Space which houses small trainers, such as radios, etc., is not categorized under this code, even though the trainers are operational. Use Category Code 171 20.

As space for operational trainers may occur as either a separate facility or as a wing or room of an applied instruction building, the following method of assigning the appropriate category code shall be used.

17135-3 In the case of a building to be used solely for the housing of a trainer and its required support space, the entire building shall be categorized as Category Code 171 35. The support space includes corridors, storage, briefing rooms, offices, mechanical room, and the like.

17135-4 If an operational trainer is included as part of a larger instruction building, the room housing the trainer shall be categorized as Category Code 171 35. This Category Code also includes support spaces for the trainer, including storage, briefing room equipment, and repair room. If any of the support spaces are used jointly for the operation of the trainer and the instruction given in the rest of the building, the support space shall be given the category assigned to the building, usually Category Code 171 20.

17135-5 Planning factors are given for a limited number of operational trainer facilities. Others will be added as they are developed. Where planning factors are not available, space requirements must be fully justified by and Engineering Evaluation. Room sizes, size of trainers, and support space should be listed, and the justification should be accompanied by drawings.

17135-6 Flight Simulator Space. This facility houses the Flight Simulator/Weapon System Trainer (WST) and associated Part Task Trainers (PTT). It is planned for stations supporting naval aircraft and is sized depending on aircraft type and average number of squadrons on-board. The total number of organizational units permanently assigned plus the average number of organizational units of rotational and special aircraft on-board shall be used for planning. Table 171-35A provides information on the gross areas required. The 6,000-square-foot area for example, will contain the following basic components:

- Trainer Room. An air-conditioned room of 50 by 50 feet minimum size, to house the necessary equipment of one (1) Weapon System Trainer (WST).

- Briefing Room. A classroom to house a maximum class of 20 pilots at 20 square feet per man.

- Administration. Office space for the officer-in-charge and two assistants.

- Maintenance Shop. A 20- by 15-foot space for the periodic maintenance of the test equipment.

- Mechanical and Electrical Equipment Room. Space of about 15 by 20 feet for the heating, air conditioning, and electrical distribution panels.

- Part Task Trainer Rooms. A minimum of two rooms of 20 by 20 feet for the housing of two Part Task Trainers (PTT).

- The other sizes will have similar requirements.

Table 17135-1
Flight Simulator Trainer Space Requirements

Type of Squadron	Number of Squadrons	Number of Trainers	Gross Area (Sq Ft)
VA/VF/HS/HM	2 - 8	1-WST, 2-PTT	6,000
	9 - 15	2-WST, 2-PTT	7,500
VA/VP	1 - 4 (VS)	1-WST, 2-PTT	9,000
	1 - 2 (VP)		
VS/VP	5 - 8 (VS)	2-WST, 4-PTT	12,000
	3 - 5 (VP)		

17135-7 **Instrument Trainer Space**. This facility houses instrument trainers and cockpit procedure trainers. The size of this facility is based upon the number and type of aircraft squadrons or attack carrier air wings (CVW). Table 17135-2 provides information on the gross area requirements. Included is space for: administrative office, briefing room, technical order library, storage room, equipment maintenance shop, mechanical equipment room, and trainer room. In using Table 17135-2, the total number of permanently assigned organizational units on-board shall be counted.

Table 17135-2
Basic Instrument Trainer Space Requirements

Type of Unit	Number of Units	Gross Area (Sq Ft)
VP, VS, or AEW squadron	1 squadron	5,000
	2 squadrons	8,000
CVW of VF/VA/HS/HM	1 or 2 wings	5,000
	3 or 4 wings	8,000

171 36 RADAR SIMULATOR FACILITY (SF)
FAC: 1724
BFR Required: Y

17136-1 AUTHORIZATION. This facility may be provided only when specifically authorized by Naval Education and Training Command (NETC). Requirements will be determined for each individual case, with NETC guidance.

171 40 DRILL HALL (SF)
FAC: 1714
BFR Required: Y

17140-1 **JUSTIFICATION.** Need for this facility must be determined on an individual basis and requires specific justification; this code is generally intended for inventory purposes.

171 45 MOCK-UP AND TRAINING AID PREPARATION CENTER (SF)
FAC: 1732
BFR Required: Y

17145-1 **AUTHORIZATION.** This facility may be provided only when specifically authorized by Naval Education and Training Command (NETC). Requirements will be determined for each individual case, with NETC guidance.

171 50 SMALL ARMS RANGE - INDOORS (SF)
FAC: 1718
BFR Required: Y

17150-1 **DEFINITION.** An indoor small arms range provides training space for the use of pistols and small caliber (22) rifles. Ranges will be used by all services on a joint basis when feasible, and they must be of sufficient size and capacity to provide continual training and retraining for all military personnel that require weapons training/qualification.

17150-2 The capacity of existing ranges or new requirements can be determined by:

1. Identifying the number of personnel to be trained.
2. Establish the number and size of training sessions.
3. Determine the number of hours per session and schedule training over an annual basis.
4. Calculate the required number of firing points based upon efficient arrangement of the size and schedules of the training groups.

17150-3 Indoor ranges are generally planned at locations where prevailing weather conditions seriously interfere with the scheduling of training. Otherwise, plan for outdoor ranges (Category Code 179 40).

For indoor range design criteria, refer to UFC 4-160-01.

171 60 RECRUIT PROCESSING BUILDING (SF)
FAC: 6100
BFR Required: Y

17160-1 **DEFINITION.** A recruit processing building is a facility for receiving, examining, and outfitting recruits. The processing building must provide space for the complete orientation, examination, and processing (medical, dental, supply, administrative) of all newly inducted and recruited personnel. The size of the facility will be determined by an engineering survey.

171 77 TRAINING MATERIAL STORAGE (READY ISSUE / SHOP STORES / MISC) (SF)
FAC: 1732
BFR Required: Y

17177-1 **DEFINITION.** Storage facilities for miscellaneous goods or equipment related to training facility support will be provided only where it can be individually justified. There are no criteria for this type of facility. General information on storage parameters is provided in Category Code series 440.

172 30 GAS CHAMBER (SF)
FAC: 1723
BFR Required: Y

17230-1 **DEFINITION.** A gas chamber is a building used for training personnel in the use of protective masks and the effects of chemical warfare.

173 10 RANGE OPERATIONS BUILDING (SF)
FAC: 1731
BFR Required: Y

17310-1 **DEFINITION.** Range Operations Buildings are designed for direct support to range operations. Such buildings can support a variety of operations for a firing range, such as: range operations, administrative support, target storage and issue, equipment storage and maintenance, and ammunition breakdown and distribution (not storage). This category includes buildings associated with range operations such as range operations centers, operations/storage buildings, and ammo breakdown buildings (not ammunition storage). This Category Code is for buildings only; report structures used for these purposes as Category Code 173 30, Covered Training Area.

173 11 RANGE SUPPORT BUILDING (SF)
FAC: 1731
BFR Required: Y

17311-1 **DEFINITION.** A Range Support Building would be a building which houses support functions conducted at the range complex but not covered elsewhere. This includes range billets, classroom space at a range, buildings to conduct after action reviews, and all other range support activities with the exception of activities described in Range Operations Building (Category Code 173 10), Weapons Range Observation Tower (Category Code 179 35), and Public Toilet (Category Code 730 75). This Category Code is for buildings only; structures used for this purpose should be reported as Category Code 17330, Covered Training Area.

173 20 TRAINING AIDS CENTER (SF)
FAC: 1732
BFR Required: Y

17320-1 **DEFINITION.** A Training Aids Center is a building that is used to fabricate, maintain, store, and issue training devices and materials including Multiple Integrated Laser Equipment System (MILES) and visual information (VI) aids; it also provides the administrative space for the training support division (TSD) management staff.

173 30 COVERED TRAINING AREA (SF)
FAC: 1733
BFR Required: Y

17330-1 **DEFINITION.** Covered Training Areas are structures which provide a covered area to support and conduct training or for feeding of personnel on a training facility while providing protection for equipment and personnel from the elements. Typically, the sides of the structure are open with a solid roof. This category also includes structures that support range operations. These facilities are usually located in ranges, training areas, bivouac, or maneuver areas. Square footage is measured as the area under the room or cover. Also this Category Code is used to report covered physical training areas and covered martial arts training areas.

173-40 OBSERVATION TOWER/BUNKER (SF)
FAC: 1783
BFR Required: Y

17412-1 **DEFINITION.** An Observation Tower/Bunker is a protective shelter used at Navy/Marine Corps EOD ranges for the protection of EOD technicians and observers. Location of the Tower/Bunker must be IAW NAVSEA OP-5. An Engineering Evaluation must be conducted to determine the correct size of the facility.

174 10 MANEUVER/TRAINING AREA, LIGHT FORCES (AC)
FAC: 1741
BFR Required: N

17410-1 **DEFINITION.** This category includes all space for ground and air combat forces to practice movements and tactics. Different types of units may support one another (combined arms), or a unit may operate independently. The “light” designation refers to areas where maneuver is restricted to only small units or units having only wheeled vehicles. “Light” maneuver/training areas are not typically used by “heavy” or mechanized forces, other than in assembly areas where movement is restricted to roads or trails. Included in this category are bivouac sites, base camps, and other miscellaneous training areas. Account for each area, typically managed and scheduled by a range name or code through the installation training or range control manager with a separate facility number and individual real property record. When maneuver/training areas can be used for multiple purposes, priority of assignment is Maneuver/Training Area, Amphibious; Maneuver/Training Area, Heavy; Maneuver/Training Area, Light.

174 11 MANEUVER/TRAINING AREA, AMPHIBIOUS FORCES (AC)
FAC: 1741
BFR Required: N

17411-1 **DEFINITION.** This category includes all space for ground and air combat forces to practice movements and tactics during amphibious (ship-to-shore) operations. Different types of units may work in support of one another (combined arms), or the units may operate independently. Tasks can include both combat and logistics (especially logistics over the shore (LOTS)). This category also includes areas with bivouac sites, base camps, and other miscellaneous training areas. Account for each area, typically managed and scheduled by a range name or code through the installation training or range control manager, with a separate facility number and individual real property record. When maneuver/training areas can be used for multiple purposes, priority of assignment is Maneuver/Training Area, Amphibious; Maneuver/Training Area, Heavy; Maneuver/Training Area, Light.

174 12 LAND NAVIGATION COURSE (AC)
FAC: 1741
BFR Required: N

17412-1 **DEFINITION.** A Land Navigation Course is an area located within the training complex which is principally scheduled and used for map reading, terrain association, or navigational training.

174 13 FIELD TRAINING AREA (AC)
FAC: 1741
BFR Required: N

17413-1 **DEFINITION.** A Field Training Area is a specific area that is intended for the training of personnel or animals in a field environment that cannot be categorized by the other Category Codes in the 174 basic series. Training conducted in such an area may include medical, K-9, or communications equipment. Maneuver land shall not be included in this category; separately classify maneuver in other Category Codes within the 173 basic series.

174 20 MANEUVER/TRAINING AREA, HEAVY FORCES (AC)
FAC: 1742
BFR Required: N

17420-1 **DEFINITION.** This category includes all space for ground and air combat forces to practice movements and tactics. Different types of units may support one another (combined arms), or may operate independently. The “heavy” designation refers to areas where maneuver is unrestricted and can consist of all types of vehicles and equipment, including tracked vehicles. “Heavy” maneuver/training areas can be used by “light” forces. This category includes bivouac sites, base camps, and other miscellaneous training areas. This area is typically managed and scheduled by a range name or code through the installation training or range control manager and is accounted for with a separate facility number and individual real property record. When maneuver/training areas can be used for multiple purposes, priority of assignment is Maneuver/Training Area, Amphibious; Maneuver/Training Area, Heavy; Maneuver/Training Area, Light.

174 30 IMPACT AREA DUDDED (AC)
FAC: 1743
BFR Required: N

17430-1 **DEFINITION.** An area having designated boundaries within which all ordnance will detonate, or impact shall be categorized as Impact Area Dudded. This area includes all impact areas that do not contain automated targets or targets classified as real property. Vehicle bodies are sometimes placed in the area to act as targets for artillery direct and indirect fire. The primary function of the impact area is to contain weapons effects as much as possible using earthen berms or natural terrain features. Assume the impact areas contain unexploded ordnance and may not be used for maneuver. This area is typically managed and scheduled by a range name or code through the installation training or range control manager and is accounted for with a separate facility number and individual real property record.

174 31 IMPACT AREA NON-DUDDED (AC)
FAC: 1743
BFR Required: N

17431-1 **DEFINITION.** An area having designated boundaries within which ordnance that does not produce duds will impact is an Impact Area Non-Dudded. This area is composed mostly of the safety fans for small arms ranges. This area includes all impact areas that do not contain automated targets or targets classified as real property. The primary function of the impact area is to contain weapons effects as much as possible using earthen berms or natural terrain features. A separate facility number and individual real property record shall be issued to account for each area that should be managed and scheduled by a range name or code through the installation training or range control manager. Although these impact areas may be used for maneuver, when the weapons ranges are not in use, they will remain categorized as impact areas.

174 40 PERSONNEL/EQUIPMENT DROP ZONE (AC)
FAC: 1744
BFR Required: N

17440-1 **DEFINITION.** A large, flat, cleared area for personnel and equipment to land following a parachute jump shall be categorized as a Personnel/Equipment Drop Zone.

175 01 AUTOMATIC RIFLE RANGE (AC)
FAC: 1750
BFR Required: Y

17501-1 **DEFINITION.** The Automatic Rifle Range is designed for training target engagement techniques with rifles and squad automatic weapon (SAW). This range is used to train personnel on the skills necessary to employ automatic and semi-automatic firing techniques. Within this range targets are not fully automated, and the scenarios are not computer driven or scored. This Category Code will not be used for ranges where the principal use is defined in other Category Codes within the 175 series.

175 02 NON-STANDARD SMALL ARMS RANGE (AC)
FAC: 1750
BFR Required: Y

17502-1 **DEFINITION.** The Non-Standard Small Arms Range is designed for training requirements that are not associated with current published doctrine but fall within a commander’s training requirements. This range includes all small arms ranges that do not fit into other categories. Targets in this range are not fully automated and/or the scenarios are not computer driven or scored. This Category Code number includes dedicated dry fire areas.

175 10 BASIC 10M-25M FIRING RANGE (ZERO) (AC)
FAC: 1751
BFR Required: Y

17510-1 **DEFINITION.** A Basic Zero Firing Range is designed for training shot-grouping and zeroing exercises with rifles and machine guns. This range is used to train individual personnel on the skills necessary to align the sights and practice basic marksmanship techniques against stationary targets. This range requires no automation.

175 20 AUTOMATED FIELD FIRE (AFF) RANGE (AC)
FAC: 1752
BFR Required: Y

17520-1 **DEFINITION.** An Automate Field Fire Range is designed for training target engagement techniques with rifles. This range is used to train and familiarize personnel on the skills necessary to identify, engage, and hit stationary infantry targets. All targets are fully automated and in the event specific target scenario is computer driven and scored from the range operations center.

175 30 RECORD FIRE RANGE, NON-AUTOMATED (AC)
FAC: 1753
BFR Required: Y

17530-1 **DEFINITION.** A Record Fire Range is designed for training and day/night qualification requirements with rifles. This range is used to train and test personnel on the skills necessary to identify, engage, and hit stationary infantry targets. Targets are not fully automated and/or the scenarios are not computer driven or scored. This Category Code with not be used for Known-Distance (KD) Ranges, which are accounted for under Category Codes 175 50 and 175 70.

175 31 AUTOMATED RECORD FIRE (ARF) RANGE (AC)
FAC: 1753
BFR Required: Y

17531-1 **DEFINITION.** An Automated Record Fire Range is designed for training and day/night qualification requirements with rifles. This range is used to train and test personnel on the skills necessary to identify, engage, and hit stationary infantry targets. All targets are fully automated, and the event specific target scenario is computer driven and scored from the range operations center. This category code number will not be used for Known-Distance (KD) Ranges, which are accounted for under Category Codes 175 50 and 175 70.

175 32 MODIFIED RECORD FIRE RANGE (AC)
FAC: 1753
BFR Required: Y

17532-1 **DEFINITION.** A Modified Record Fire Range is designed for training and day/night qualification with rifles. This range combines the capabilities of 1752X, Automated Field Fire (AFF) Range; and 1753, Automated Record Fire (ARF) Range to reduce land and maintenance requirements. All targets are fully automated, and the event specific target scenario is computer driven and scored from the range operations center. This Category Code Number will not be used for Known-Distance (KD) Ranges, which are accounted for under Category Codes 175 50 and 175 70.

175 50 RIFLE KNOWN DISTANCE (KD) RANGE (AC)
FAC: 1755
BFR Required: Y

17550-1 **DEFINITION.** A Rifle Known Distance Range is designed for training rifle marksmanship and target engagement techniques. This range is used to train personnel on the skills necessary to identify, engage, and hit stationary targets in a static array from a known distance.

175 60 SNIPER FIELD FIRE RANGE (AC)
FAC: 1756
BFR Required: Y

17560-1 **DEFINITION.** A Sniper Field Fire Range is designed to meet training and qualification requirements with the sniper rifle. This range is used to train and test snipers on the skills necessary to detect, identify, engage, and hit stationary and moving infantry targets in a tactical array in accordance with applicable field manuals. In this range targets are not fully automated and/or the scenarios are not computer driven or scored.

175 61 AUTOMATED SNIPER FIELD FIRE RANGE (AC)
FAC: 1756
BFR Required: Y

17561-1 **DEFINITION.** An Automated Sniper Field Fire Range is designed to meet the training and qualification requirements with the sniper rifle. This range is used to train and test snipers on the skills necessary to detect, identify, engage, and hit stationary and moving infantry targets in a tactical array in accordance with applicable field manuals. All targets are fully automated, and the event specific target scenario is computer driven and scored from the range operations center.

175 70 PISTOL KNOWN DISTANCE (KD) RANGE (AC)
FAC: 1757
BFR Required: Y

17570-1 **DEFINITION.** A Pistol Known Distance (KD) Range is designed for training pistol and revolver marksmanship and target engagement techniques. This range is used to train personnel on the skills necessary to identify, engage, and hit stationary targets in a static array from a known distance.

175 71 COMBAT PISTOL/MP FIREARMS QUALIFICATION COURSE (AC)
FAC: 1757
BFR Required: Y

17571-1 **DEFINITION.** A Combat Pistol/MP Firearms Qualification Course is a range designed to meet training and qualification requirements with combat pistols and revolvers. This range is used to train and test personnel on the skills necessary to identify, engage, and hit stationary infantry targets. In this range targets are not fully automated and/or the scenarios are not computer driven or scored.

175 72 AUTOMATED COMBAT PISTOL / MP FIREARMS QUALIFICATION COURSE (AC)
FAC: 1757
BFR Required: Y

17572-1 **DEFINITION.** An Automated Combat Pistol/MP Firearms Qualification Course is a range designed to meet training and qualification requirements with combat pistols and revolvers. This range is used to train and test personnel on the skills necessary to identify, engage, and hit stationary infantry targets. All CPQC targets are fully automated, and the event specific target scenario is computer driven and scored from the range operations center.

175 73 SUBMACHINE GUN RANGE (AC)
FAC: 1757
BFR Required: Y

17573-1 **DEFINITION.** A Submachine Gun Range is designed for training target engagement techniques with the submachine gun. This range is used to train personnel on the skills necessary to identify, engage, and hit stationary infantry targets. Targets are not fully automated and/or the scenarios are not computer driven or scored within this range.

175 80 MACHINE GUN TRANSITION RANGE (AC)
FAC: 1758
BFR Required: Y

17580-1 **DEFINITION.** A Machine Gun Transition Range is designed to meet the training requirements with machine guns. This range is used to train personnel on the skills necessary to identify, engage, and hit stationary infantry targets at known distances. Targets within this range are not fully automated and/or the scenarios are not computer driven or scored. Ranges that fulfill purpose of both Machine Gun Transition Range (Category Code 175 80) and Machine Gun Field Fire Range (Category Code 175 81) will be carried as Machine Gun Field Fire Range (Category Code 175 81).

175 81 MACHINE GUN FIELD FIRE RANGE (AC)
FAC: 1758
BFR Required: Y

17581-1 **DEFINITION.** A Machine Gun Field Fire Range is designed to train target engagement techniques with squad assault weapons and machine guns. This range is used to train personnel on the skills necessary to identify, engage, and hit stationary infantry, vehicle, and bunker type targets. Distance to targets is not predetermined. Within this range targets are not fully automated and/or the scenarios are not computer driven or scored. Ranges that fulfill purpose of both Machine Gun Transition Range (Category Code 175 80) and Machine Gun Field Fire Range (Category Code 175 81) will be carried as Machine Gun Field Fire Range (Category Code 175 81).

175 82 AUTOMATED MULTIPURPOSE MACHINE GUN (MPMG) RANGE (AC)
FAC: 1758
BFR Required: Y

17582-1 **DEFINITION.** An Automated Multipurpose Machine Gun (MPMG) Range is designed for zeroing, training, and qualification requirements with squad assault weapons (SAW) and machine guns. This range is used to train personnel on the skills necessary to identify, engage, and hit stationary infantry targets. All targets within this range are fully automated and the event specific target scenario is computer driven and scored from the range operations center.

176 10 GRENADE LAUNCHER RANGE (AC)
FAC: 1761
BFR Required: Y

17610-1 **DEFINITION.** A Grenade Launcher Range is designed to meet training and qualification requirements of the 40mm M203 Grenade Launcher. This range is used to train and test personnel on the skills necessary to engage and defeat stationary target emplacements with the 40mm Grenade Launcher. No automation is required for this facility. Count FP as each collection of points or lanes that allow completion of all training objectives.

176 20 40MM (GRENADE) MACHINE GUN QUALIFICATION RANGE (AC)
FAC: 1762
BFR Required: Y

17620-1 **DEFINITION.** A 40MM Machine Gun Qualification Range is designed to conduct training qualification firing with the grenade machine gun (e.g., MK-19). This range is used to train personnel with the weapon either ground or vehicle mounted. Targets in this range may be either non-automated or fully automated and the event specific target scenario is computer driven and scored from the range operations center. A lane is defined as the area for one gunner/weapon system to complete the training objectives.

176 30 LIGHT ANTIARMOR WEAPONS RANGE SUBCALIBER (AC)
FAC: 1763
BFR Required: Y

17630-1 **DEFINITION.** A Light Anti-armor weapons range is designed for training target engagement techniques with light anti-armor weapons (e.g., LAW/AT-4). This range is used to train personnel on the skills necessary to employ the weapon and hit stationary and moving targets using a sub-caliber training device. Targets are not fully automated and/or the scenarios are not computer driven or scored. Ranges used for both live and sub caliber firing will be carried under the Light Anti-armor Weapons Range Live (Category Code 176 31).

176 31 LIGHT ANTIARMOR WEAPONS RANGE LIVE (AC)
FAC: 1763
BFR Required: Y

17631-1 **DEFINITION.** A Light Anti-armor Weapons Range Live is designed for training target engagement techniques with light anti-armor weapons (e.g., LAW/ AT-4). This range is used to train personnel on the skills necessary to employ the weapon and hit stationary and moving targets using live rockets or a sub-caliber training device. Targets are not fully automated and/or the scenarios are not computer driven or scored. Ranges used for both live and sub-caliber firing will be carried under this Category Code.

176 40 ANTIARMOR TRACKING AND LIVE-FIRE RANGE (AC)
FAC: 1764
BFR Required: Y

17640-1 **DEFINITION.** An Anti-armor Tracking and Live-Fire Range is a complex designed to meet training and qualification requirements with medium and heavy anti-armor weapons systems (e.g., Javelin, TOW, SMAW). This complex is used to train and test soldiers on the skills necessary to employ the weapon, identify, track, engage, and defeat stationary and moving armor targets presented individually or as part of a tactical array. In this complex targets are not fully automated and/or the scenarios are not computer driven or scored. One lane is designed to accommodate up to 10 gunners/weapons.

176 41 AUTOMATED ANTIARMOR TRACKING AND LIVE-FIRE RANGE (AC)
FAC: 1764
BFR Required: Y

17641-1 **DEFINITION.** An Automated Anti-armor Tracking and Live-Fire Range is a complex designed to meet training and qualification requirements with medium and heavy anti-armor weapons systems (e.g., Javelin, TOW, SMAW). This complex is used to train and test personnel on the skills necessary to employ the weapon, identify, track, engage, and defeat stationary and moving armor targets presented individually or as part of a tactical array. All targets within this range are fully automated, computer driven, and scored from the range operations center. One lane is designed to accommodate up to 10 gunners/weapons.

176 50 FIELD ARTILLERY DIRECT FIRE RANGE (AC)
FAC: 1765
BFR Required: Y

17650-1 **DEFINITION.** A Field Artillery Direct Fire Range is designed to meet training requirements of field artillery crews. This range is used to train field artillery crews on the skills nec4essary to employ direct fire gunnery techniques with indirect fire equipment against stationary targets in a tactical array using live direct fire artillery. No automation is required for this facility. EA is defined as the range area to support up to one battery of artillery.

176 60 TANK/FIGHTING VEHICLE STATIONARY GUNNERY RANGE (AC)
FAC: 1766
BFR Required: Y

17660-1 **DEFINITION.** A Tank/Fighting Vehicle Stationary Gunnery Range is designed for conducting weapons system bore sighting, screening, zeroing and/or harmonization. Armor, infantry and/or aviation crew use this range. Within this range targets may be fully automated and/or scored from the range operations center. EA is defined as the range area to support up to 15 guns.

176 70 MORTAR RANGE (AC)
FAC: 1767
BFR Required: N

17670-1 **DEFINITION.** A Mortar Range is designed to meet the training requirements of mortar crewmen. This range is used to train mortar crews on the skills necessary to apply fire mission data, engage, and hit stationary targets in a tactical array using live fire mortars. No automation is required for this facility. EA is defined as the range area to support up to the mortar section.

176 71 FIELD ARTILLERY INDIRECT FIRE RANGE (AC)
FAC: 1767
BFR Required: N

17671-1 **DEFINITION.** A Field Artillery Indirect Fire Range is designed to meet the training and qualification requirements of field artillery units. This range is used to train field artillery crews on the skills necessary to apply fire mission data, engage, and hit stationary targets in a tactical array with indirect fire. No automation is required for this facility. EA is defined as the range area to support up to one battery of artillery.

176 80 MORTAR SCALED RANGE (AC)
FAC: 1768
BFR Required: Y

17680-1 **DEFINITION.** A Mortar Scaled Range is designed to meet the training requirements of mortar crewmen. This range is used to train mortar crews on the skills necessary to apply fire mission data, engage, and hit stationary targets in a tactical array using sub-caliber training devices. No automation is required for this facility. EA is defined as the range area to support up to three mortars.

176 81 FIELD ARTILLERY SCALED RANGE (AC)
FAC: 1768
BFR Required: Y

17681-1 **DEFINITION.** A Field Artillery Scaled Range is designed to meet training requirements of field artillery crews. This range is used to train field artillery crews on the skills necessary to apply fire mission data, engage, and hit stationary targets in a tactical array using sub-caliber training devices. No automation is required for this facility. EA is defined as the range area to support up to three artillery pieces.

176 90 SCALED GUNNERY RANGE (1:30 AND 1:60) (AC)
FAC: 1769
BFR Required: Y

17690-1 **DEFINITION.** A Scaled Gunnery Range (1:30 and 1:60) is designed to meet training requirements of armor crews. This range is used to train armor crews on the skills necessary to detect, identify, engage, and hit stationary and moving scaled targets in a tactical array using sub-caliber training devices. No automation is required for this facility. No standard facilities are associated with this range. EA is defined as a range designed to handle 4 vehicles.

176 91 SCALED GUNNERY RANGE (1:5 AND 1:10)
FAC: 1769
BFR Required: Y

17691-1 **DEFINITION.** A Scaled Gunnery Range (1:50 and 1:10) is designed to meet training requirements of armor and infantry crews. This range is used to train armor and infantry crews on the skills necessary to detect, identify, engage, and hit stationary and moving scaled targets in a tactical array using sub-caliber training devices and/or simulations. All targets are fully automated, computer driven, and scored from the range operations center. EA is defined as a range designed to handle 4 vehicles.

177 10 MULTIPURPOSE TRAINING RANGE (AC)
FAC: 1771
BFR Required: Y

17710-1 **DEFINITION.** A Multipurpose Training Range is designed to meet the training and qualification requirements for the crews, teams and sections of combat units. This range is used to train and test armor, infantry, and aviation crews and sections on the skills necessary to detect, identify, engage, and defeat stationary and moving armor and infantry targets in a tactical array. Targets are not fully automated and/or the scenarios are not computer driven or scored. LN is defined as a range to support training for 2 vehicles.

177 11 AUTOMATED MULTIPURPOSE TRAINING RANGE (AC)
FAC: 1771
BFR Required: Y

17711-1 **DEFINITION.** An Automated Multipurpose Training Range is specifically designed to satisfy the training and qualification requirements for the crews, teams and sections of combat units. This range supports dismounted infantry squad tactical live-fire operations either independently of, or simultaneously with supporting vehicles. This range is used to train and test armor, infantry, and aviation teams, crews and sections on the skills necessary to detect, identify, engage, and defeat stationary and moving armor and infantry targets in a tactical array. All targets are fully automated, and the event specific targets scenario is computer driven and scored from the range operations center. LN is defined as a range to support training for 2 vehicles.

177 20 TANK/FIGHTING VEHICLE PLATOON BATTLE RUN (AC)
FAC: 1772
BFR Required: Y

17720-1 **DEFINITION.** A Tank/Fighting Vehicle Platoon Battle Run is designed to meet the training and qualification requirements for platoons of armor and infantry units. This range is used to train and test armor and infantry platoons and sections on the skills necessary to detect, identify, engage, and defeat stationary and moving armor and infantry targets in a tactical array. Targets are not fully automated and/or the scenarios are not computer driven or scored. EA is defined as a range area to support training of platoon-sized units up to six vehicles.

177 21 TANK / FIGHTING VEHICLE MULTIPURPOSE RANGE COMPLEX, LIGHT, AUTOMATED (AC)
FAC: 1772
BFR Required: Y

17721-1 **DEFINITION.** A Tank/Fighting Vehicle Multipurpose Range Complex, Light, Automated, is a complex designed to meet the training and qualification requirements for platoons of light and mechanized infantry, armor, and aviation units. This complex is used to train and test infantry, armor, and aviation platoons, sections, teams and crews on the skills necessary to detect, identify, engage, and defeat stationary and moving armor and infantry targets in a tactical array. All targets are fully automated, and the event specific target scenario is computer driven and scored from the range operations center. EA is defined as a range area to support training of platoon-sized units up to six vehicles.

177 22 TANK / FIGHTING VEHICLE MULTIPURPOSE RANGE COMPLEX, HEAVY, AUTOMATED (AC)
FAC: 1772
BFR Required: Y

17722-1 **DEFINITION.** A Tank/Fighting Vehicle Multipurpose Range Complex, Heavy, Automated, is a complex specifically designed to satisfy the training and qualification requirements for the crews and platoons of armor, infantry and aviation units. This complex supports dismounted infantry squad tactical live-fire operations either independently of, or simultaneously with supporting vehicles. This range is used to train and test armor, infantry, and aviation platoons, sections, teams and crews on the skills necessary to detect, identify, engage, and defeat stationary and moving armor and infantry targets in a tactical array. All targets are fully automated, and the event specific targets scenario is computer driven and scored from the range operations center. When range can be used for both heavy and light purposes, it will be classified under this Category Code. EA is defined as a range area to support training of platoon-sized units up to six vehicles.

177 30 FIRE AND MOVEMENT RANGE (AC)
FAC: 1773
BFR Required: Y

17730-1 **DEFINITION.** A Fire and Movement Range is designed for training individual and buddy/team fire and movement techniques. The team negotiates maneuver utilizing cover and concealment techniques. Targets are not fully automated and/or the scenarios are not computer driven or scored. LN is defined as the path or trails to support training for two persons.

177 40 SQUAD DEFENSE RANGE (AC)
FAC: 1774
BFR Required: Y

17740-1 **DEFINITION.** A Squad Defense Range is designed for training individuals and squads on defensive engagement techniques and mutually supporting fires. This range is used to train personnel on the skills necessary to designate sectors of fire, identify, and provide suppressive fire on stationary infantry targets. All targets are fully automated, and the event specific target scenario is computer driven and scored from the range operations center. EA is defined as a range area to support training for a squad-sized unit.

177 50 INFANTRY SQUAD BATTLE COURSE (AC)
FAC: 1775
BFR Required: Y

17750-1 **DEFINITION.** An Infantry Squad Battle Course is designed for the training and qualification requirements of teams and squads on individual and collective tactics, techniques, and procedures and employment in tactical situations. This complex is used to train and test teams and squads on the skills necessary to conduct tactical movement techniques, detect, identify, engage, and defeat stationary and moving armor and infantry targets in a tactical array. Targets are not fully automated and/or the scenarios are not computer driven or scored. EA is defined as a range area to support training of squad and platoon sized units.

177 51 AUTOMATED INFANTRY SQUAD BATTLE COURSE (AC)
FAC: 1775
BFR Required: Y

17751-1 **DEFINITION.** An Automated Infantry Squad Battle Course is designed for the training and qualification requirements of teams and squads on individual and collective tactics, techniques and procedures and employment in tactical situations. This complex is used to train and test teams and squads on the skills necessary to conduct tactical movement techniques, detect, identify, engage, and defeat stationary and moving armor and infantry targets in a tactical array. All targets are fully automated, and the event specific target scenario is computer driven and scored from the range operations center. EA is defined as a range area to support training of squad and platoon sized units.

177 52 INFANTRY PLATOON BATTLE COURSE (AC)
FAC: 1775
BFR Required: Y

17752-1 **DEFINITION.** An Infantry Platoon Battle Course is designed for the training and qualification requirements of infantry platoons, either mounted or dismounted, on movement techniques and operations. This complex is used to train and test platoons on the skills necessary to conduct tactical movement techniques, detect, identify, engage, and defeat stationary and moving armor and infantry targets in a tactical array. Targets are not fully automated and/or the scenarios are not computer driven or scored. EA is defined as a range area to support training of squad and platoon sized units.

177 53 AUTOMATED INFANTRY PLATOON BATTLE COURSE (AC)
FAC: 1775
BFR Required: Y

17753-1 **DEFINITION.** An Automated Infantry Platoon Battle Course is designed for the training and qualification requirements of infantry platoons, either mounted or dismounted, on movement techniques and operations. This complex is used to train and test platoons on the skills necessary to conduct tactical movement techniques, detect, identify, engage, and defeat stationary and moving armor and infantry targets in a tactical array. All targets are fully automated, and the event specific target scenario is computer driven and scored from the range operations center. EA is defined as a range area to support training of squad and platoon sized units.

177 60 MOUT ASSAULT COURSE (MAC) (AC)
FAC: 1776
BFR Required: Y

17760-1 **DEFINITION.** A MOUT Assault Course is a facility for low-level collective training using live fire or MILES. This facility is used for training specific tasks before training on unit proficiency MOUT sites or Combat in Cities facility, carried under Category Code 179 61. Targets are not fully automated and/or the scenarios are not computer driven or scored. EA is defined as a range area to support training of platoon-sized units.

178 10 LIVE HAND GRENADE RANGE (AC)
FAC: 1781
BFR Required: Y

17810-1 **DEFINITION.** A Live Hand Grenade Range is designed to satisfy the training requirement of throwing live fragmentation grenades. This range familiarizes soldiers with the effects of live fragmentation grenades. No automation is required for this facility. Count each throwing location as one FP.

178 20 ENGINEER QUALIFICATION RANGE, NON-STANDARDIZED (AC)
FAC: 1782
BFR Required: Y

17820-1 **DEFINITION.** An Engineer Qualification Range, Non-standardized, is designed to meet the training and qualification requirements for engineer and combat engineer crews. This range is used to train and test engineer crews on the skills necessary to zero and/or boresight weapons systems, identify, classify, and reduce obstacles. Targets are not fully automated and/or the scenarios are not computer driven or scored. Count each firing position on the stationary firing line as one FP. If a stationary firing line does not exist, then count each obstacle clearing station as one FP.

178 21 ENGINEER QUALIFICATION RANGE, AUTOMATED / STANDARDIZED (AC)
FAC: 1782
BFR Required: Y

17821-1 **DEFINITION.** An Engineer Qualification Range, Automated/Standardized, is designed for the training and qualification requirements of engineer and combat engineer crews. This range is used to train and test engineer Crews on the skills necessary to zero and / or boresight weapons systems, identify, classify, and reduce obstacles. All targets are fully automated, and the event specific target scenario is computer driven and scored from the range operations center. Count each firing position on the stationary firing line as one FP. If a stationary firing line does not exist, then count each obstacle clearing station as one FP.

178 30 LIGHT DEMOLITION RANGE (AC)
FAC: 1783
BFR Required: Y

17830-1 **DEFINITION.** A Light Demolition Range is designed for the training and qualification of employing explosives and demolition charges. This range is used to train personnel on the proper techniques of wire, minefield and concrete obstacle breaching, timber and steel cutting, road cratering, and explosive demolition. No automation is required for this facility. Count each prepared station as one FP. Planning and scoping this function should consider user requirements and explosive safety criteria.

179 TRAINING FACILITIES OTHER THAN BUILDINGS

179-1 This basic category includes requirements for weapons ranges, training courses and mockups, training pools/tanks, and parade and drill fields, but it does not include expendable targets.

179 01 BAYONET ASSAULT COURSE (AC)
FAC: 1790
BFR Required: Y

17901-1 **DEFINITION.** A Bayonet Assault Course is designed for training assault techniques with a rifle and bayonet. These techniques are applied through a series of obstacles. This facility requires no automation. Report the number of FP as the number of prepared paths or set of targets in a standard path to be used in training.

179 02 TARGET DETECTION (TD) RANGE, NON-FIRING
FAC: 1790
BFR Required: Y

17902-1 **DEFINITION.** A Target Detection Range, Non-Firing, is a non-firing range to teach soldiers how to detect personnel on the battlefield under varying degrees of concealment and visibility. No automation is required for this range.

179 03 HAND TO HAND COMBAT PIT
FAC: 1790
BFR Required: Y

17903-1 **DEFINITION.** A Hand to Hand Combat Pit is a structure containing a circle of sand or sawdust for training in hand-to-hand fighting.

179 04 PRISONER OF WAR TRAINING AREA
FAC: 1790
BFR Required: Y

17904-1 **DEFINITION.** A Prisoner of War Training Area is typically and area fenced in with barbed wire and with guard towers used for the training of personnel in the handling of prisoners-of-war. The facility may also be used for the training of personnel in a simulated POW environment.

179 05 MINE WARFARE AREA (AC)
FAC: 1790
BFR Required: Y

17905-1 **DEFINITION.** A Mine Warfare Area is a cleared area for training in the placement, arming, disarming, and detection of vehicle and anti-personnel mines using non-explosive training material.

179 06 WHEELED VEHICLE DRIVERS COURSE (AC)
FAC: 1790
BFR Required: Y

17906-1 **DEFINITION.** A Wheeled Vehicle Drivers Course is for teaching basic driving skills, and for practice in four-wheel drive situations, parking, and backing up.

179 07 TRACKED VEHICLE DRIVERS COURSE (AC)
FAC: 1790
BFR Required: Y

17907-1 **DEFINITION.** A Tracked Vehicle Drivers Course is an area to teach the basic driving skills of steering and gear shifting on a level course. The facility may also contain a hilly course for developing advanced tracked vehicle driving skills such as turning on slopes and negotiating steep grades.

179 08 AMPHIBIOUS VEHICLE TRAINING AREA (AC)
FAC: 1790
BFR Required: Y

17908-1 **DEFINITION.** An Amphibious Vehicle Training Area contains sand or is close to a beach for training military personnel on unique driving, technical and tactical tasks associated with amphibious operations.

179 09 SHIP LOADING AND UNLOADING MOCKUP (SF)
FAC: 1732
BFR Required: Y

17909-1 **DEFINITION.** A mockup of a ship used for training personnel in ship loading and off-loading. Training area can also include negotiating cargo nets used during amphibious operations and operations at dockside.

179 10 AIRCRAFT GUNNERY, BOMBING, AND ROCKET RANGES (EA)
FAC: 1793
BFR Required: N

17910-1 **DEFINITION.** Aircraft Gunnery, Bombing and Rocket Ranges (Aircraft Weapons Ranges) provide air crews with operating areas for the development of proficiency in gunnery, bombing, rocketry, missile delivery, strafing, and mine laying. Ranges should generally be within 100 miles of the supporting air installation. The following criteria are not absolute as far as requirements are concerned; however, any plans to deviate from these criteria shall be referred to the Naval Air Systems Command.

17910-1.1 **Air-to-Air Weapons Ranges**. The Air-to-Air Weapons Ranges are Gunnery and Missile Ranges and should, if possible, be over water. The minimum surface impact areas and coincident restricted airspaces, whose minimum altitude is based on the characteristics of the using aircraft, are as follows:

- Gunnery Range - 23 nautical miles by 50 nautical miles.

- Rocket and Missile Ranges - 50 nautical miles square.

17910-1.2 **Air-to-Ground Ranges**. The Air-to-Ground Ranges are for training in strafing, high-altitude level bombing, loft bombing, close air support, aerial mining, and missile delivery. Communications are required between ground stations and between target controller and aircraft at these ranges. See Table 179-10 for specific surface impact areas, minimum restricted airspace, and other data applicable to air-to-ground ranges.

The following information for Air-to-Ground Weapons Ranges is provided in addition to that contained in Table 17910-1.

- Strafing Range. A strafing range is for air-to-ground gunnery proficiency training in low-altitude strafing firing 20-millimeter and possibly 30-millimeter ammunition. Targets may be panels or may simulate aircraft, gun emplacements, truck convoys, etc., and may be automatic recording targets.

- High-Altitude Level-Bombing Range. The high altitude level bombing range provides training in high-speed, high-altitude, level-attitude bomb releases. The center of the target is visible from 10 nautical miles at 50,000 feet. Offset bombing exercises are also conducted.

- Multipurpose Target Range. The multipurpose range is used for training in conventional dive bombing, high-altitude dive bombing, glide bombing, strafing, and rocketry (excluding controlled air-to-ground missiles). Inert training weapons with small charges are used to facilitate spotting.

- Loft Bombing Range. The loft bombing range is a highly instrumented land range for practice bombing with simulated nuclear weapons. A minimum altitude approach is used; bomb release maneuvers practiced include loft, toss, and over-the-shoulder techniques providing training in rapid recovery and escape from atomic-weapon effects, detection, and retaliatory ground fire.

The restricted airspace includes a 5-nautical-mile radius from the target center extending upward from the surface to 24,000 feet above the target and multiple-approach corridors extending 25 miles from target center. A 6-nautical-mile corridor width is required when alternate left or right escape maneuvers are performed. Clearance above the corridors is 3,000 feet for the first 10 nautical miles of the approach, 5,000 feet for the next 8 nautical miles, and 9,000 feet for the remaining 2 nautical miles to the airspace cylinder around the target center. The initial point of aim is at 50,000 feet from the target center which must be visible from an aircraft at 100 feet altitude. Instrumentation along the primary approach to the target provides instantaneous speed measurements, photo coverage, and profile and escape information.

- Close Air Support and Combat Training Area. The close air support and combat training area is planned for training with live ordnance, shapes, napalm, and air-to-ground missiles.

- Aerial Mining Range. The aerial mining range is planned for training in low-altitude and high-altitude mining. The restricted airspace is generally parallel to an adjacent irregular coastline with readily identifiable landmarks.

- Guided Missile Range. The air-to-ground guided missile target range is used for training in controlled air-to-ground missiles.

17910-2 The restricted airspace is 24,000 feet in height and consists of a rectangular- shaped primary line of approach 4 nautical miles wide by 5 nautical miles long starting at a point 15 nautical miles from the center of the impact area. The total length of the range is 20 nautical miles.

Table 17910-1

Basic Requirement for Air-to-Ground Ranges

Range	Minimum surface impact area (nautical miles)	Minimum restricted airspace (nautical miles)	Maximum restricted airspace (feet)	Control and spotting towers Note (2)	Target illumination for night operations
A. Strafing	1 x ½	Radius 5	10,000	1 Control	Yes
B. High altitude level bombing	Radius 3	Radius 5	Unlimited	1 Control Note (3)	Yes
C. Multipurpose target	Radius 1-1/2	Radius 5	Note (1)	Note (4)	Yes
D. Loft bombing	Radius 1-1/2	Radius 5 Length 30 Note (8)	24,000 Note (8)	Note (5)	Yes
E. Close air support and combat training area	16 x 20	Radius 25	Note (1)	Note (6)	Yes
F. Aerial mining	3 x 8	3 x 8	Note (1)	Note (4)	No
G. Guided missile	8 x 8	Radius 5 Length 20 Note (8)	24,000	Note (6) and (7)	Yes

Notes:

(1) The restricted airspace extends vertically to the maximum altitude required by the using aircraft.
(2) See Operational Tower, Category Code 179 35.
(3) Two spotting towers also are required to provide accurate three-dimensional rake information where remote spotting devices are not used.
(4) One control and tow spotting towers are required to provide accurate three-dimensional rake information.
(5) One control and three spotting towers are required.
(6) One control tower and two spotting towers at each designated target site are required.
(7) Towers are required only at ranges where self-guiding missiles are fired.
(8) See detailed airspace description in text.

179 11 AIR TRANSPORT MOCKUP (SY)
FAC: 8526
BFR Required: Y

17911-1 **DEFINITION.** An Air Transport Mockup is a ramp, and a platform structure used to simulate varying types of fixed- and rotary-wing aircraft. Structure allows loading, securing, and unloading of vehicles, equipment, and/or personnel.

179 12 ELEVATED TRAINING TOWER/PLATFORM
FAC: 1734
BFR Required: Y

17912-1 **DEFINITION.** A Elevated Training Tower/Platform is a structure consisting of platforms built above a sandy landing area to train future paratroopers to make proper aircraft exiting and landing techniques. It can consist of a canopy area and platform, a mockup of an aircraft door to train future paratroopers the proper exiting techniques from an aircraft as well as for parachute landing falls that simulates the deceleration experienced during a parachute opening.

179 13 SUSPENDED HARNESS MOCKUP

CCN deleted in FY19. Assets have been consolidated into CCN 179 12.

179 14 MOCKUP JUMP TOWER

CCN deleted in FY19. Assets have been consolidated into CCN 179 12.

179 15 UNDERWATER FORDING SITE

CCN deleted in FY19.

179 16 COMBAT TRAIL (AC)
FAC: 1790
BFR Required: Y

17916-1 **DEFINITION.** A Combat Trail is a training site used for various types of proficiency and sustainment training by rotation through different stations in a round-robin scenario. Types of training can include nuclear, Biological, and Chemical (NBC) and common task training. This site is separate from other training areas and sites.

179 17 RAPPELLING TRAINING AREA (EA)
FAC: 1790
BFR Required: Y

17917-1 **DEFINITION.** A Rappelling Training Area is an area that includes at least one structure used to practice rappelling (rope descent). The training area may also include modified towers for training in helicopter rappels.

179 18 AIRFIELD DEMOLITION RANGE (ADR) (SY)
FAC: 1164
BFR Required: Y

17918-1 **DEFINITION.** An area for training in the placement, clearing, compaction, repair, and grading of fill and construction of drainage structures for airfields. Steel mats or other non-bituminous mats may be utilized. If the airfield is actually used by aircraft, it should be inventoried as an unpaved airfield facility using appropriate 100 s*eries Category Codes.

179 19 TIMBER BRIDGE AREA
FAC: 1790
BFR Required: Y

17919-1 **DEFINITION.** A Timber Bridge Area is a cleared area beside a ditch or ravine for engineer units to practice building timber bridges.

179 20 PANEL BRIDGE AREA
FAC: 1790
BFR Required: Y

17920-1 **DEFINITION.** A Panel Bridge Area is a cleared area beside a creek or ravine for engineer units to practice building panel bridges.

179 22 FLOATING BRIDGE SITE
FAC: 1790
BFR Required: Y

17922-1 **DEFINITION.** A Floating Bridge Site is a cleared riverbank area for engineer units to practice fording water obstacles and erection and retrieval of floating bridging equipment.

*

179 24 WATER SUPPLY TRAINING AREA (EA)
FAC: 1790
BFR Required: Y

17924-1 **DEFINITION.** A Water Supply Training Area is partially improved land for performing water purification and storage operations. It should be located on a flowing stream with firm banks and all-weather access roads.

179 25 AIRFIELD SITE SELECTION TRAINING AREA (AC)
FAC: 1790
BFR Required: Y

17925-1 **DEFINITION.** An Airfield Site Selection Training Area is cleared land used to train soldiers in the fundamentals of selecting and securing a site suitable for takeoffs and parking of rotary-wing aircraft.

179 26 AERIAL GUNNERY RANGE (AC)
FAC: 1792
BFR Required: Y

17926-1 **DEFINITION.** An Aerial Gunnery Range is designed to support the training and qualification requirements of helicopter gunnery. This range is used to train and test helicopter crews on the skills necessary to detect, identify, engage, and hit stationary armor and infantry targets in a tactical array. This range does not require automation but does require surveillance of the target area.

179 30 SURFACE PROJECTILE RANGE (EA)
FAC: 1767
BFR Required: N

17930-1 **DEFINITION.** This code is for ranges supporting surface-launched projectiles as opposed to ranges for air-launched projectiles which are coded as Category Code 179 10. Criteria are not presently available for surface projectile range requirements.

179 31 MEDIUM HEAVY EQUIPMENT TRAINING AREA (AC)
FAC: 1790
BFR Required: Y

17931-1 **DEFINITION.** A Medium Heavy Equipment Training Area is an unimproved area for training in placement, compaction, and grading of fill, and training in construction of drainage structures.

179 32 DECONTAMINATION TRAINING SITE (AC)
FAC: 1790
BFR Required: Y

17932-1 **DEFINITION.** A Decontamination Training Site is an area consisting of a pit filled with rock with an attached rock-filled sump to a drain bed. This structure is used primarily for vehicle decontamination training.

179 33 POL TRAINING AREA (AC)
FAC: 1790
BFR Required: Y

17933-1 **DEFINITION.** A POL Training Area is a materials handling area for training personnel in the proper handling of petroleum, oils, and lubricants. Also used for assembly and training in various POL storage and distribution systems.

179 35 WEAPONS RANGE OPERATIONS TOWER (EA)
FAC: 1734
BFR Required: N

17935-1 **DEFINITION.** Range operations towers are used at gunnery, bombing, and rocket ranges to provide an unobstructed view of target areas for purposes of control and spotting impacts. For the tower requirements associated with the various ranges, see Category Code 179 10 (Table 179-10). The two types of weapons range operations tower are:

> 17935-1.1 The control range operations tower (control tower) has a gross area of 1,428 square feet and provides for the radio control of all range activities, including the scoring of training missions both visually and electronically.
>
> 17935-1.2 The spotting range operations tower (spotting tower) has a gross area of 100 square feet and is a secondary observation point to provide for visual scoring.

179 36 CLOSE AIR SUPPORT RANGE (AC)
FAC: 1793
BFR Required: N

17936-1 **DEFINITION.** A Close Air Support Range is designed to support the training and qualification requirements of close air support aircraft. This range is used to train and test aircraft crews on the skills necessary to provide air support to ground forces under varying conditions. This range does not require automation but does require surveillance of the target area.

179 37 AERIAL BOMBING RANGE (AC)
FAC: 1793
BFR Required: N

17937-1 **DEFINITION.** An Aerial Bombing Range is designed to support the training and qualification requirements for fixed-wing aircraft dropping their ordnance. This range is used to train and test aircraft crews on the skills necessary to detect and suppress enemy targets in a tactical array. This range does not require automation but does require surveillance of the target area.

179 40 SMALL ARMS RANGE - OUTDOOR (EA)
FAC: 1750
BFR Required: Y

17940-1 **DEFINITION.** A small arms range provides an area for training in the use of pistols, small caliber rifles, and small caliber machine guns. Ranges must be available all year to provide continual training and retraining for personnel who must be proficient in the use of small arms. If feasible, a small-arms range should provide training facilities for all military services within the area.

17940-2 The capacity of existing ranges or new requirements can be determined by:

17940-2.1 Identifying the number of personnel to be trained.

17940-2.2 Establishing the number and size of training sessions.

17940-2.3 Determining the number of hours per session and scheduling training over an annual basis.

17940-2.4 Calculating the required number of firing points based upon efficient arrangement of the size and schedules of the training groups.

17940-3 In developing requirements, the base number of training days less holidays and weekends is 242 days. However, ranges require maintenance and periods of recovery for flora and fauna and are often unusable during periods of severe weather or peculiar local limitations. The basic number of training days can be further reduced to 180 days based on local conditions.

17940-4 For certain types of small arms and where prevailing weather conditions seriously interfere with scheduling of training, an indoor range (Code 171 50) may be planned.

179 41 AIR DEFENSE MISSILE FIRING RANGE (AC)
FAC: 1794
BFR Required: Y

17941-1 **DEFINITION.** An Air Defense Missile Firing Range is designed to meet training and qualification requirements of air defense (LAAD/Stinger) units. This range is used to train and test crews on the skills necessary to employ ground to air anti-aircraft missiles against ballistic aerial target systems (BATS).

179 45 TRAINING MOCK-UPS (EA)
FAC: 1790
BFR Required: Y

17945-1 **DEFINITION.** This code includes mockup structures representing all or parts of ships, aircraft, tanks, or buildings for training personnel in skills such as disaster control, firefighting, and equipment handling.

179 50 TRAINING COURSE (AC)
FAC: 1790
BFR Required: N

17950-1 **DEFINITION.** This code includes areas designated for personnel training in various skills under actual operational conditions. Table 17950-1 outlines the facilities of this group and approximate requirements.

Table 17950-1
Training Course Criteria

Type of Course	Approximate Size	Preferred Terrain	Typical Improvements
Obstacle	2 acres	Flat	Obstacles, drainage
Combat techniques, guerrilla warfare, counterinsurgency	100 acres	Rough, heavy vegetation	Provisional mess hall and toilets where justified
Weapons ranges	See Code 179-10		
Disaster control, firefighting, etc.	2 acres	Flat	Training mockups
Field engineering surveying practice	2 acres	Rolling	None
Building construction practice	2 acres	Flat	1,200 square yards of paved area
Construction equipment operations	20 acres	Rolling, no vegetation	None
Vehicle safety, driver testing	6 acres	Flat	Pave area, course markets
Swimming, survival	See Code 179-55		

179 51 UNENCLOSED FIRE FIGHTER TRAINER (SF)
FAC: 1795
BFR Required: Y

17951-1 **DEFINITION.** A Fire Fighting and Rescue Training Area is an open area or structure consisting of a mockup of a multistory building, aircraft, or vehicle for training in fire containment, ladder use, escape, and rescue from buildings.

179 53 ENCLOSED FIRE FIGHTER TRAINER FACILITY (SF)
FAC: 1726
BFR Required: Y

17953-1 **DEFINITION.** This is an enclosed facility that houses interior and exterior mockups of areas within a surface ship, submarine, or multistory building for live firefighting and rescue training.

179 54 DAMAGE CONTROL (WET) TRAINER (SF)
FAC: 1724
BFR Required: Y

17954-1 **DEFINITION.** This category code is used to capture facilities used in the training of shipboard flooding countermeasures. Facilities include below-deck shipboard mockups with water deluge systems, observation decks, training classrooms, administrative spaces, and water deluge pumps, piping, and drainage systems.

179 55 COMBAT TRAINING POOL/TANK (EA)
FAC: 1725
BFR Required: Y

17955-1 **DEFINITION.** A combat training pool/tank is planned for instructions in swimming and survival under combat conditions. The swimming pool/tank may be provided only as required for training purposes, normally on the following basis: for each increment of 5,000 men to be trained, one swimming pool; pool area not to exceed 13,000 square feet. If survival training is required at installations having less than 5,000 assigned strength, one swimming pool of appropriate size may be provided, but not to exceed 13,000 square feet in pool area. Outdoor pools may be provided where feasible.

179 60 PARADE AND DRILL FIELD (AC)
FAC: 1745
BFR Required: N

17960-1 **DEFINITION.** This facility provides space for formation drills, parade and review functions, and honor ceremonies. Such a field may be planned for stations having independent command functions. The size of the field is computed on the basis of 1 acre per 125 men, total planned military strength. Surface will be turf where feasible and will be stabilized where climate and other conditions dictate. A reviewing stand may be planned with a capacity based on 5 percent of the total officer strength.

179 61 COMBAT IN CITIES FACILITY (AC)
FAC: 1790
BFR Required: Y

17961-1 **DEFINITION.** A Combat in Cities Facility is a non-standard training facility that typically includes the buildings, roads, and sidewalks normally found in an urban environment, and which is used to train and sustain unit proficiency in an urban environment. This facility is used to train urban-type operations when a standard CACTF is not available. No automation is required for this facility.

179 62 MOUT COLLECTIVE TRAINING FACILITY (SMALL) (AC)
FAC: 1790
BFR Required: Y

17962-1 **DEFINITION.** A MOUT Collective Training Facility (small) is designed to meet the training requirements of an infantry company-sized unit in an urban environment. This structure contains 24 buildings or less and is used to train unit collective tasks associated with urban terrain. Targets are not fully automated and/or the scenarios are not computer driven or scored.

179 63 MOUT COLLECTIVE TRAINING FACILITY (LARGE) (AC)
FAC: 1796
BFR Required: Y

17963-1 **DEFINITION.** A MOUT Collective Training Facility (large) is designed to meet the training requirements of an infantry battalion-sized unit in an urban environment. This structure contains more than 24 buildings and is used to train unit collective tasks associated with urban terrain. Targets are not fully automated and/or the scenarios are not computer driven or scored.

179 70 RADAR BOMB SCORING FACILITY (EA)
FAC: 1790
BFR Required: N

17970-1 **DEFINITION.** A Radar Bomb Scoring Facility (RBS) is used to measure, electronically, aircraft simulated-bombing results and to produce graphic flight path tracking data and other pertinent aircraft target scoring information. An RBS facility is available as a self-contained trailer-mounted facility. The mobile RBS equipment includes an operations trailer, acquisition radar, tracking radar, maintenance and spare parts trailer, and power trailer. A permanent power supply at the range eliminates the power trailer requirement. Criteria are not presently available for a fixed RBS System which would utilize permanent structures. RBS facilities are provided for selected aircraft ranges as determined by CNIC.

179 71 ELECTRONIC WARFARE TRAINING RANGE (EA)
FAC: 1790
BFR Required: N

17971-1 Criteria for the Electronic Warfare Training Range are not currently available.

179 72 UNDERWATER TRACKING TRAINING RANGE (EA)
FAC: 1790
BFR Required: Y

17972-1 **DEFINITION.** The underwater tracking range is used primarily to support surface and subsurface weapon system accuracy trials and development, test, and evaluation projects. No planning factors are currently available for this facility. Planning factors, standards, and guides for computing requirements for facilities under this category are excluded from this publication because of the special provisions and variances in the application of criteria for planning underwater tracking ranges. In the absence of specific criteria, the quantitative requirements for the range facilities should be determined on an individual basis based on the experience and knowledge of the activity involved and the appropriate Systems Commands.

179 81 INFILTRATION COURSE (AC)
FAC: 1798
BFR Required: Y

17981-1 **DEFINITION.** An Infiltration Course is designed for training individual infiltration and combat movement techniques and then executing them while subject to live fire. No automation is required for this facility. Count each path or trail for a single Marine as one FP.

179 91 CONFIDENCE COURSE (AC)
FAC: 1799
BFR Required: Y

17991-1 **DEFINITION.** A Confidence Course is designed for developing individual soldier confidence and strength through a series of obstacles. No automation is required for this facility. Count each complete course as one EA.

179 92 OBSTACLE COURSE (AC)
FAC: 1799
BFR Required: Y

17992-1 **DEFINITION.** An Obstacle Course is a facility containing numerous obstacles designed for developing and measuring individual soldier speed, agility, and coordination utilizing various obstacles in an effort to reach the objective. No automation is required for this facility.

Version: 200.20250516

FACILITIES CRITERIA (FC)
FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

Series 200: Maintenance and Production Facilities

Record of Changes:

Date	CCN #	CCN Title	Description of change
Nov 2016	21154	Aircraft Armament Systems Shop	Title of this CCN is changed from "Aviation Armament Shop" to "Aircraft Armament Systems Shop". Criteria was also revised.
Dec 2016	21374	Landing Craft Rinse Rack	CCN deleted
Dec 2016	22940	Sawmill	CCN deleted
Dec 2016	22960	Baling Facility	CCN deleted
Dec 2016	21107	Maintenance Hangar - 02 Space (Administrative)	FAC code changed from 1444 to 6100
Jan 2017	21940	Sewage Hose Storage Facility	Reporting requirements corrected to “N”. CCN is inventory only.
Jan 2017	21820	Construction / Weight Handling Equipment Shop	Incorrect diagram reference deleted.
Feb 2017	21920	Pavement And Ground Equipment Shed	Change reporting requirements to “N” as per verbiage in CCN 21910
Feb 2017	21925	Public Works Shops Expendable/Work-In-Process Store	Change reporting requirements to “N” as per verbiage in CCN 21910
May 2018	21181	Engine Test Cell (Non-NAVAIR Depot)	Updated criteria
May 2018	21105	Maintenance Hangar – O/H Space (High Bay)	Updated criteria
May 2018	21106	MAINTENANCE HANGAR – 01 SPACE (Shops And Maintenance Space)	Updated criteria

Date	CCN #	CCN Title	Description of change
May 2018	21107	Maintenance Hangar – 02 Space (Administrative)	Updated criteria
Aug 2019	21101	Aircraft Engine Test Cell Building	Title of this CCN is changed from "Aircraft Acoustical Enclosure" to "Aircraft Engine Test Cell Building".
Sep 2019	21107	Maintenance Hangar – 02 Space (Administrative)	Replaced reference to “UFC 4-211-01N” with “UFC 4-211-01, as updated”
Sept 2019	21105	Maintenance Hangar – O/H Space (High Bay)	Corrected formula for OH required hangar width. Added references to Type IV hangar as a new standard type. Added details to clarify notes for Tables 21105-1a and 21105-1b regarding clearances in the OH space. Added a reference to UFC 4-211-01 for further details. Added clarification for computation of hangar width in Section 21105/06/07-2.1. Also added in this section was a clarification that if an additional designated space is required for PMI, one more space with spread configuration will be provided per Type/Model/Series per installation.
Mar 2020	21105 21105	Maintenance Hangar – O/H Space (High Bay), Table 21105-2 Maintenance Hangar – O/H Space (High Bay), Table 21105-1a	Interim update - Update hangar ratio for P-8A squadrons with a new ratio of ¼ to reflect actual maintenance frequencies. Expanded the width for Type I standard module for the US Marine Corps from 262.5 ft to 270.0 ft to provide the capabilities to conduct periodic maintenance interval work for both F-35B and F-35C Variants. Marine Corps squadrons operate both variants.
July 2020	21211	Missile Module Maintenance and Loading Facility	Added new CCN
July 2020	21331	Shore Depot Level Repair Shop	Added new CCN
July 2020	21332	Shipyard Demilitarization and Recycling Facility	Added new CCN
July 2020	21365	Ship Propulsion Maintenance Facility	Title change from “Nuclear Repair Shop” to remove the word “nuclear”, as per OSD. Also, revised description.

Date	CCN #	CCN Title	Description of change
Feb 2021	21105	Maintenance Hanger – OH Space	Updated hangar ratios in Table 21105-2 for training squadrons under CNATRA to reflect accurate maintenance frequencies. The updated ratios are 0.28 for T-44A and T-44C Variants, and 0.39 for T-6A and T-6B Variants.
June 2021	21105	Maintenance Hangar – OH Space	Add Table 21105-1b, OH Space Standard, F-35C Model. Add Table 21105-1c, OH Space Standard, F-35B Model. Add Figure 1 – OH Space Diagram of F-35C Add Figure 2 – OH Space Diagram of F-35B.
June 2021	21105 21106 21107	Maintenance Hangar – OH Space Shops and Maintenance Administration – 01 Space Operations, Training, and Administration – 02 Space	Information added for Type IV Maintenance Hangar Add Section 21105/06/07-2.4, Type IV Unmanned Aircraft System Requirements. Add Table 21105-2a, OH Space Navy Standard, MQ-4C Triton Model. Add Figure 3 – OH Space Diagram of MQ-4C Triton. Add 21105-7, 01 Space Calculations for MQ-4C Triton. Add 21105-8, 02 Space Calculations for MQ-4C Triton.
October 2021	211 64	Ground Support Equipment Holding Shed (NavAir Depot)	Changed FAC Code to 2185
October 2021	214 40	Vehicle Holding Shed	Changed FAC Code to 2185
October 2021	218 61	Ground Support Equipment Holding Shed	Changed FAC Code to 2185
October 2021	218 65	Equipment Holding Shed (for Code 218-20)	Changed FAC Code to 2185
31 July 2022	218 52	Battery Recharging Shed	Add new category code.
22 Sep 2022	21105 21106 21107	Maintenance Hangar – OH Space Shops and Maintenance Administration – 01 Space Operations, Training, and Administration – 02 Space	On page 200 Series - 31, delete the words “crew and equipment” and replace with the words “shop and maintenance.” On page 200 Series - 31, delete the word “administrative” and add the words “operations; training; and administration.”
30 Sep 2022	21105 21106 21107	Maintenance Hangar – OH Space Shops and Maintenance Administration – 01 Space Operations, Training, and	Change width of wings spread for the C-40A aircraft to 35.8 (meters) and 117-5 (ft.-in.) in Table 21105-3 (Aircraft Widths and Hangar Space Requirements).

Date	CCN #	CCN Title	Description of change
		Administration – 02 Space	
2 Mar 2023	200 Series	UFC 2-000-05N	Change UFC 2-000-05N to FC 2-000-05N document due to the fact that this planning criteria is not unified among the other DoD services.
9 Jun 2023	200 Series 211-05/06/07	FC 2-000-05N Section 21105/06/07-2.1 Category Code 211-05 – OH Space, page 42	Include the correct SI unit of area as m^2 throughout the criteria where applicable. Under heading “FOR P-8A AIRCRAFT,” add reference to table 21105-3 with that of table 21105-2.
28 Jun 2023	211-05	Maintenance Hangar – OH Space	Under the heading “Calculating OH Space,” update the following: Update nomenclature for aircraft spacing requirements. Revise Table 21105-4 (Required Hangar Width Formulas. Note: Updates are required to be commensurate with the Type I Maintenance Hangar Study.
26 Jul 2023	211-05	Maintenance Hangar – OH Space	For Type III Maintenance Hangar data in Table 21105-1d, change m^2 heading to sq.ft. heading to reflect the correct unit of measure units.
21 Aug 2023	211-05	Maintenance Hangar – OH Space	Add notes at the end of Table 21105-4, Required Hangar Width Formulas, which explain procedures for rounding numbers when calculating the number of aircraft in a hangar. Change “Sample Maintenance Hangar Calculation to align with the Type I Maintenance Hangar formula in Table 21105-4.
25 April 2025	213 10	Dry Dock	Identify Code 900F as the organization responsible for the Dry Dock Certification Program.
16 May 2025	213 10	Pre-Engineered Maintenance Hangar	Delete reference to MIL-HDBK 1028/1C and add reference to UFC 4-211-01 Aircraft Maintenance Hangars.
16 May 2025	211-75	Aviation Life Support Systems Shop	Delete reference to MIL-HDBK 1028/1C and add reference to UFC 4-211-01 Aircraft Maintenance Hangars.
16 May 2025	211-09	Aircraft Boresight Range	Delete reference to MIL-HDBK 1028/1C.
16 May 2025	211-15	Line Maintenance Shelter	Delete reference to MIL-HDBK 1028/1C.

Date	CCN #	CCN Title	Description of change
16 May 2025	211-08	Airframes Shop (Non-NAVAIR Depot)	Delete reference to MIL-HDBK 1028/1C and add reference to UFC 4-211-01 Aircraft Maintenance Hangars.
16 May 2025	211-45	Avionics Shop (Non-NAVAIR Depot)	Delete reference to MIL-HDBK 1028/1C and add reference to UFC 4-211-01 Aircraft Maintenance Hangars.

200 SERIES
MAINTENANCE AND PRODUCTION FACILITIES

Table of Contents

211 MAINTENANCE - AIRCRAFT, SPARES

211-1 GENERAL

Facilities for the maintenance and repair of Navy and Marine Corps aircraft and related spares, including airframes, aircraft engines, aircraft weapons systems, avionics systems, and other related aircraft equipment are planned in accordance with maintenance functions and levels as authorized by the Chief of Naval Operations (CNO). Maintenance classifications are defined in OPNAVINST 4790.2 (series) and are the basis for the Naval Aircraft Maintenance Program (NAMP). These classifications of aircraft maintenance activities of the Naval Establishment are divided into three levels: depot ("D" level) maintenance, intermediate ("I" level) maintenance, and organizational ("O" level) maintenance.

Depot or "D" level maintenance is performed at Naval Aviation industrial establishments to ensure continued flying integrity of airframes and flight systems during subsequent operational service periods. It is performed on material requiring major overhaul or rebuilding of parts, assemblies, subassemblies, and end items. It includes manufacturing parts, making modifications, testing, inspecting, sampling, and reclamations. Depot maintenance supports lower levels of maintenance by providing engineering assistance and performing maintenance that is beyond the capability of the lower level activities. Each requirement for depot maintenance facilities must be planned and justified individually.

"I" level maintenance is the responsibility of, and performed by, designated maintenance activities in support of organizational level activities. The intermediate level maintenance mission is to enhance and sustain the combat readiness and mission capability of supported activities by providing quality and timely support at the nearest location with the lowest practical resource expenditure. Intermediate level maintenance consists of on and off equipment material support and is usually performed at a central facility located either directly on or just off the flight line. Some specific functions of intermediate or "I" level maintenance are shown in Table 21100-1.

Intermediate Maintenance Activities (IMAs) are usually established to support an entire air station or Marine Air Group (MAG). In specific circumstances, IMA shops may be established for support of a specific unit as a department of what would normally be considered an organizational level unit. An example of this would be the establishment of an avionics shop to repair just the special mission equipment installed in reconnaissance aircraft, where only a single squadron at an air station has these aircraft. That shop would be inside the squadron hangar, under the direct control of the squadron Aircraft Maintenance Officer.

Table 21100-1
Intermediate Level Maintenance Functions

Title	Work Center Code	Category Code Number	Function
Aircraft Intermediate Maintenance Activity Management	000	211 16	Supervisory, production control, material and financial management, quality control, training, administration.
Engine Maintenance Shop	400	211 21	Repair of aircraft engines and components, including removal and replacement of compressor sections, combustion sections, turbine sections, engine accessories, propellers and rotor components, auxiliary power units, auxiliary fuel cells, and in-flight refueling stores.
Airframes Shop	500	211 08	Repair and manufacture of aircraft structural and hydraulic components including structural panels, tire and wheel assemblies, brakes, hydraulic pumps, actuators, and line, painting, machining and welding, and non-destructive inspection (NDI).
Avionics Shop	600	211 45	Repair of aircraft avionics and electrical systems including communication, navigation and identification systems, electrical and instrument systems, generators and batteries, fire control systems, radar and electronic counter measures systems, anti-submarine warfare systems, precision measuring equipment and calibration, reconnaissance and photo systems, and module repair and wire harness manufacture.
Armament Shop	700	211 54 211 55	Repair and storage of weapons racks, launchers, guns, tow reels, and, for the Marine Corps, weapons support equipment.
Parachute and Survival Equipment Shop	800	211 75	Repair, maintenance, and periodic inspection of parachutes, life rafts and flotation systems, aviators survival equipment, oxygen regulators and generating systems, ejection seats, and oxygen and nitrogen generating and storage.
Ground Support Equipment Shop	900	218 60 218 61	Repair, maintenance, and storage of aircraft ground support equipment including tow tractors, check stands, aircraft starting units, electrical power carts, hydraulic power carts and servicing units, oxygen and nitrogen servicing carts, and mobile maintenance facilities (vans).

Organizational, or “O” level maintenance, and intermediate, or “I” level maintenance is performed at the individual sites where aircraft are stationed. Both maintenance levels are segregated into nine divisions, three organizational and six intermediate. These divisions are coded as 100, 200, and 300 for the organizational level maintenance and 400 through 900 for the intermediate level maintenance.

Organizational or “O” level maintenance is normally performed by an operating unit on a day-to-day basis in support of their own operations. The organizational level maintenance mission is to maintain assigned aircraft and aeronautical equipment in a full mission capable status while continually improving the local maintenance process. While organizational level maintenance may be done by intermediate or depot level organizations, it is usually accomplished by maintenance personnel assigned to aircraft squadrons either in aircraft maintenance hangars or on the parking apron immediately outside of the hangar. Some specific functions of the organizational or “O” level maintenance are shown in Table 21100-2.

Table 21100-2
Organizational Level Maintenance Functions

Title	Work Center Code	Category Code Number	Function
Aircraft Division	100	211-06	On aircraft repair and removal and replacement of engines, structural and hydraulic components, aircrew personal and protective equipment, egress and environmental systems, and periodic maintenance.
Avionics/Armament Division	200	211-06	On aircraft repair and removal and replacement of avionics, electrical, instrument, and fire control systems.
Line Division	300	211-06	Plane captains, flight line troubleshooters, support equipment operators, and flight crew.

These are the basic definitions for each level of maintenance. However, when temporarily required by operational or combat necessity, any appropriate operational authorities may authorize or require the performance of any maintenance task that, in their judgment, is within the capability of the personnel, materials, and facilities available.

Any of the three levels of maintenance may be performed by a contracted maintenance organization. The requirements for facilities then are a function of the contract. Additional facilities will not be built to support contract maintenance.

When it is desirable to keep aircraft under local control, space may be required to perform aircraft in-service repair (ISR), integrated maintenance (IMC/IMP), modifications (MOD) and other program work that may concurrently involve depot, intermediate, and organizational level work on aircraft by squadron, IMA, Naval Air Depot (NAVAIR Depot), and/or contractor personnel. When the existing organizational level spaces cannot accommodate the additional workload generated by ISR, IMC/P, and/or MOD a separate facility will be required.

Those facilities generally categorized as Organizational “O” Level Maintenance facilities are as follows:

211 03	Corrosion Control Hangar
211 04	Pre-Engineered Hangar
211 05	Maintenance Hangar – OH Space
211 06	Maintenance Hangar – 01 Space
211 07	Maintenance Hangar – 02 Space

Those facilities generally categorized as Intermediate “I” Level Maintenance facilities are as follows (also noted as Non-NAVAIR Depot):

211 01	Aircraft Acoustical Enclosure (Non-NAVAIR Depot)
211 08	Airframes Shop (Non-NAVAIR Depot)
211 09	Aircraft Boresight Range (Non-NAVAIR Depot)
211 16	Aircraft Intermediate Maintenance Management (Non-NAVAIR Depot)
211 21	Engine Maintenance Shop (Non-NAVAIR Depot)
211 45	Avionics Shop (Non-NAVAIR Depot)
211 54	Aviation Armament Shop (Non-NAVAIR Depot)
211 55	Aviation Armament Equipment Holding Shed (Non-NAVAIR Depot)
211 75	Parachute/Survival Equipment Shop (Non-NAVAIR Depot)
211 81	Engine Test Cell (Non-NAVAIR Depot)
211 82	Aircraft Weapons Alignment Shelter (Non-NAVAIR Depot)
211 88	Power Check Pad with Sound Suppression (Non-NAVAIR Depot)
211 89	Power Check Pad without Sound Suppression (Non-NAVAIR Depot)

Those facilities generally categorized as Depot “D” Level Maintenance facilities are as follows (also noted as NAVAIR Depot):

211 10	Aircraft Overhaul and Repair Shop (NAVAIR Depot)
211 11	Corrosion Control – Cleaning Shop (NAVAIR Depot)
211 12	Paint and Finishing Hangar (NAVAIR Depot)
211 13	Aircraft Non-Destructive Testing Shop (NAVAIR Depot)
211 14	Aircraft Rework Shop (NAVAIR Depot)
211 20	Aircraft Engine Overhaul Shop (NAVAIR Depot)
211 22	Engine Preparation and Storage Shop (NAVAIR Depot)

211 23	Engine Examination and Evaluation Shop (NAVAIR Depot)
211 24	Dedicated Aircraft Engine Overhaul – General Process (NAVAIR Depot)
211 25	Jet Engine Overhaul Shop (NAVAIR Depot)
211 26	Reciprocating Engine Overhaul Shop (NAVAIR Depot)
211 27	Turbine Engine Overhaul Shop (NAVAIR Depot)
211 30	Aircraft and Engine Accessories Overhaul Shop (NAVAIR Depot)
211 31	Dedicated Aircraft and Engine Accessories Overhaul – General Process (NAVAIR Depot)
211 32	Metal Components Shop (NAVAIR Depot)
211 33	Non-Metals Components Shop (NAVAIR Depot)
211 34	Dynamic Components Shop (NAVAIR Depot)
211 35	Hydraulic Components Shop (NAVAIR Depot)
211 36	Electrical Component Shop (NAVAIR Depot)
211 37	Turbine Accessories Shop (NAVAIR Depot)
211 38	Pneumatic Oxygen Shop (NAVAIR Depot)
211 39	Optical and Photographic Components Shop (NAVAIR Depot)
211 40	Electronics, Communication and Armament System Shop (NAVAIR Depot)
211 41	Dedicated Electronics, Communication and Armament – General Process (NAVAIR Depot)
211 42	Electronic System Components Shop (NAVAIR Depot)
211 43	Inertial Quality Instrument Overhaul Shop (NAVAIR Depot)
211 44	Non-Inertial Quality Instrument Overhaul Shop (NAVAIR Depot)
211 50	Aircraft Armament/Missile Rework Shop (NAVAIR Depot)
211 51	Dedicated Aircraft Armament/Missile Rework – General Process (NAVAIR Depot)
211 52	Aircraft Weapon Overhaul and Test Shop (NAVAIR Depot)
211 53	Air Launched Missile Rework Shop (NAVAIR Depot)
211 60	Support Equipment Rework Shop (NAVAIR Depot)
211 61	Dedicated Support Equipment Rework – General Purpose Shop (NAVAIR Depot)
211 62	Support Equipment Calibration Shop (NAVAIR Depot)
211 63	Ground Support Equipment Rework Shop (NAVAIR Depot)
211 64	Ground Support Equipment Holding Shed (NAVAIR Depot)
211 65	Airborne Weapons Support Equipment Shop (NAVAIR Depot)
211 70	Manufacturing and Repair Shop (NAVAIR Depot)
211 71	Dedicated Manufacturing and Repair – General Purpose Shop (NAVAIR Depot)
211 72	Metal Fabrication/Manufacturing Shop (NAVAIR Depot)
211 73	Metal Treatment Shop (NAVAIR Depot)
211 74	Non-Metal Fabrication/Manufacturing Shop (NAVAIR Depot)
211 76	Miscellaneous Parts/Components Repair Shop (NAVAIR Depot)
211 80	Test and Calibration Shop (NAVAIR Depot)
211 83	Engine Test Cell (NAVAIR Depot)

211 84	Helicopter Blade Test Facility (NAVAIR Depot)
211 85	Radome Test Facility (NAVAIR Depot)
211 86	Radar/Antenna Test Facility (NAVAIR Depot)
211 87	Aircraft Weapons Alignment/Boresight Facility (NAVAIR Depot)
211 90	Other Support Facilities (NAVAIR Depot)
211 91	Uncovered Ramp (NAVAIR Depot)
211 92	Covered Ground Check/Flight Test Facility (NAVAIR Depot)
211 93	Engineering Laboratory (NAVAIR Depot)
211 94	Aircraft Power Check Facilities (NAVAIR Depot)
211 95	Material and Equipment Staging/Storage Facility (NAVAIR Depot)
211 96	Maintenance, Aircraft Spares Storage (Ready Issue/Shop Storage Miscellaneous)
211 97	Plant Services for Aircraft Overhaul (NAVAIR Depot)
211 98	Aircraft Acoustical Enclosure (NAVAIR Depot)
211 99	Hazardous Materials Storehouse (NAVAIR Depot)

211-2 NAVAIR DEPOT FACILITIES

Consistent with DoD Instruction 4151.15, "Depot Maintenance Support Programming Policies," dated November 22, 1976, NAVAIR Depot facilities can be further segregated into Production Shop Categories consistent with the material the shops are established and designed to process and produce as follows:

211-2.1. **Airframe.** These are covered areas associated with processing the airframe under those programs commonly identified as Standard Depot Level Maintenance (SDLM), Programmed Depot Maintenance (PDM), On-Condition Maintenance (OCM), crash damage repair and/or overhaul, modernization, modification, etc. The work functions include cleaning, stripping, disassembly, airframe repair, reassembly, systems check, refinishing, painting, and fueling/defueling using covered facilities. Typical facilities associated with the Airframe Production Shop and their associated Navy Category Codes are:

211 10	Aircraft Overhaul and Repair Shop (Small Aircraft)
211 10	Aircraft Overhaul and Repair Shop (Large Aircraft)
211 11	Corrosion Control Shop
211 12	Paint and Finishing Hangar
211 13	Airframes Nondestructive Inspection Shop
211 14	Airframe Dedicated Machine Shop
211 14	Airframe Dedicated Welding Shop
211 14	Airframe Dedicated Plating Shop
211 14	Airframe Examination and Evaluation, Pre-Shop Analysis and Examination and Inspection Shop
211 14	Maintenance Dock
211 14	Quick Engine Change Shop
211 14	Fuel Systems Maintenance Facility

211-2.2 **Engine.** These are covered areas associated with processing jet, turbojet, and reciprocating type aviation engines in terms of overhaul, low time repair, complete repair, and major inspection. The work functions include uncanning, disassembly, cleaning, material examination, parts reconditioning, subassembly, final assembly and preservation.

Typical facilities associated with the Engine Production Shop and their associated Navy Category Codes are:

211 22	Engine Preparation and Storage Shop
211 23	Engine Nondestructive Testing Shop
211 23	Engine Examination and Evaluation, Pre-Shop Analysis and Examination and Inspection Shop
211 24	Dedicated Engine Cleaning Shop
211 24	Dedicated Engine Paint Shop
211 24	Dedicated Engine Plating Shop
211 24	Dedicated Engine Welding Shop
211 24	Engine Modification and Repair Shop
211 25	Jet Engine Overhaul Shop
211 26	Reciprocating Engine Overhaul Shop
211 27	Turbine Engine Overhaul Shop

211-2.3 **Accessories and Components.** These are covered areas associated with processing airframe and engine accessories. Typical facilities associated with the Accessories and Components Production Shop and their associated Navy Category Codes are:

211 30	Aircraft and Engine Accessories Overhaul Shop
211 31	Dedicated Cleaning Shop
211 31	Dedicated Paint Shop
211 31	Dedicated Machine Shop
211 31	Dedicated Plating Shop
211 31	Dedicated Welding Shop
211 31	Examination and Evaluation, Pre-Shop Analysis, Examination and Inspection Shop
211 31	Hazardous Test Shop
211 31	Reclamation Shop
211 32	Tank and Radiator Repair Shop
211 32	Sheet Metal Shop
211 32	Metal Surface Shop
211 32	Seat Repair Shop
211 32	Metal Bonding Shop
211 32	Container Reclamation Shop
211 33	Life Raft Repair Shop
211 33	Rubber Repair Shop

211 33	Parachute Repair Shop
211 33	Fabric and Upholstery Shop
211 33	Tire Repair Shop
211 33	Plastic and Fiberglass Shop
211 33	Composite Rework Shop
211 34	Propeller and Propeller Control Overhaul Shop
211 34	Rotor Head Overhaul Shop
211 34	Rotor Blade Overhaul Shop
211 34	Transmission/Gearbox Overhaul Shop
211 34	Dynamic Drive System Overhaul Shop
211 35	Hydraulic Components Overhaul Shop
211 35	Bearings Shop
211 35	Aircraft Landing Gear Shop
211 36	Alternator Drive Overhaul Shop
211 36	Electrical Accessories Overhaul and Test Shop
211 36	Battery Shop
211 36	Constant Speed Drive Shop
211 36	Electro-Mechanical Components Shop
211 37	Turbine Accessories Overhaul Shop
211 37	Turbine Accessories Test Shop
211 37	General Purpose Units Shop
211 37	General Purpose Units Test Shop
211 37	Ram/Air Turbine Accessories Overhaul Shop
211 37	Ram/Air Turbine Accessories Test Shop
211 38	Pneumatic Components Overhaul Shop
211 38	Cryogenics Shop
211 38	Oxygen Equipment Shop
211 39	Photographic Equipment Repair Shop
211 39	Optical Component Shop

211-2.4 **Electronic, Communications and Armament Systems.** These are covered areas associated with processing airborne communication and navigation equipment, instruments, airborne data computers, fire control and bombing system equipment, gyroscopes, inertial guidance systems, and other avionics equipment. Typical facilities associated with the Electronic, Communications and Armament Systems Production Shop and their associated Navy Category Codes are:

211 41	Dedicated Cleaning Shop
211 41	Dedicated Paint Shop
211 41	Dedicated Machine Shop
211 41	Dedicated Welding Shop
211 41	Dedicated Plating Shop
211 41	Dedicated Bearings Shop
211 41	Instrument Overhaul Shop

211 42	Armament and Avionics Shop
211 42	Airborne Systems Software Shop
211 42	Navigational Aids Repair Shop
211 42	Avionics Testing Shop
211 43	Inertial Quality Gyroscope Overhaul Shop
211 43	Inertial Guidance System Overhaul and Calibration Shop
211 44	Electronic Instrument Overhaul Shop
211 44	Mechanical Instrument Overhaul Shop
211 44	Non-inertial Gyroscope Overhaul Shop
211 44	Magnetic Instrument Overhaul and Test Shop

211-2.5 **Armament.** These are covered areas associated with processing weapons including guns, missiles, bomb racks, weapon pylons, etc., used by the aircraft in carrying out its assigned mission. Typical facilities associated with the Armament Production Shop and their associated Navy Category Codes are:

211 51	Dedicated Cleaning Shop
211 51	Dedicated Paint Shop
211 51	Dedicated Machine Shop
211 51	Dedicated Welding Shop
211 51	Dedicated Plating Shop
211 52	Aircraft Weapon Overhaul and Test Shop
211 52	Ordnance Equipment Shop
211 52	Weapon Accessories Repair Shop
211 53	Missile Shop

211-2.6 **Support Equipment.** These are covered areas associated with processing aviation general and special support equipment and aerospace ground support equipment. Typical facilities associated with the Support Equipment Production Shop and their associated Navy Category Codes are:

211 61	Dedicated Cleaning Shop
211 61	Dedicated Paint Shop
211 61	Dedicated Machine Shop
211 61	Dedicated Plating Shop
211 61	Dedicated Welding Shop
211 62	Aeronautical Electronic Support Equipment Shop
211 62	Electronic Test Systems Repair Shop
211 62	Precision Measurement Equipment Shop
211 63	GSE Maintenance Shop
211 63	Training Devices Shop
211 63	Hydrostatics Shop
211 64	Ground Support Equipment Holding Shed
211 65	Airborne Weapons Support Equipment Shop

211-2.7 **Manufacture and Repair.** These are covered areas which are not an integral part of other categories previously described, and which contribute to aircraft repair operations by such work functions as parts cleaning and painting, plating and metal processing shop. Typical facilities associated with the Manufacture and Repair Production Shop and their associated Navy Category Codes are:

211 71	Welding Shop
211 71	Foundry Shop
211 71	Peening and Blasting Shop
211 71	Non-destructive Inspection Shop
211 71	Parts Cleaning Shop
211 71	Parts Painting Shop
211 72	Machine Shop
211 72	Grinding Shop
211 72	NC Machine Shop
211 72	Metal Parts Fabrication Shop
211 73	Metal Processing Shop
211 73	Plating Shop
211 73	Heat Treating Shop
211 74	Plastic Fabrication Shop
211 74	Pattern Shop
211 74	Decal Shop
211 74	Woodworking Shop
211 74	Rubber Fabrication Shop
211 76	Tubing Shop
211 76	Cable Shop
211 76	Cordage Shop
211 76	Electrical Cable/Harness Shop

211-2.8 **Test and Calibration.** These are covered areas which are dedicated to test, trim, or calibrate engines, electronics, communications or armament systems. Typical facilities associated with the Test and Calibration Production Shop and their associated Navy Category Codes are:

211 83	Jet Engine Test Cell (10,000 – 16,000 lbs. max. thrust)
211 83	Jet Engine Test Cell (Over 16,000 lbs. max. thrust)
211 83	Jet Engine Test Stand
211 83	Turbo Prop Test Cell
211 83	Reciprocating Engine Test Cell (3,000 HP or less)
211 83	Reciprocating Engine Test Cell (Over 3,000 HP)
211 83	Reciprocating Engine Test Stand
211 83	Turbo Shaft Test Cell
211 83	Turbo Fan Test Cell
211 83	Pneumatic Gas/Air Turbine Test Cell

211 84	Helicopter Blade Test Facility
211 85	Radome Test Facility
211 86	Radar/Antenna Test Facility
211 87	Aircraft Bore Sight Range

211-2.9 **Other.** These are areas used to perform productive work that are not included in the eight Categories listed above. This includes ramp, apron, and aircraft storage sites. Typical facilities associated with the Other Production Shop and their associated Navy Category Codes are:

211 91	Aircraft Rework Apron
211 91	Reclamation Apron
211 91	Armament and Disarmament Pad
211 91	Predock/Postdock Apron
211 91	Aircraft Corrosion Control Facility (Uncovered)
211 91	Ground Check/Flight Test Support (Uncovered)
211 92	Ground Check/Flight Test Support (Covered)
211 93	Material Handlers/Parts Expediters
211 93	Material Control Laboratory
211 93	Standards Laboratory
211 93	Automatic Test Equipment and Numerical Controlled Machine
211 94	Power Check Pad (Without Sound Suppression)
211 94	Power Check Pad (With Sound Suppression)
211 94	Propeller Aircraft Power Check Pad
211 94	Helicopter Aircraft Power Check Pad
211 94	VSTOL Aircraft Power Check Pad
211 95	Packaging and Preservation
211 98	Aircraft Power Check Facility (Covered with Sound Suppression)

211-3 ADDITIONAL MAINTENANCE FACILITIES

Additional air-related maintenance facilities are tabulated under the following category codes:

116 10	Airfield Washrack Pavement
116 15	Aircraft Rinse Facility
116 65	Tactical Van Support Pad
212 30	Missile Assembly and Test Building
214 30	Refueling Vehicle Shop
216 55	Air/Underwater Weapons Shop
218 50	Battery Shop
218 60	Aircraft Ground Support Equipment Shop
218 61	Ground Support Equipment Holding Shed

211-4 AIRCRAFT LOADING

The primary planning factors in determining the size of maintenance facilities are the number of aircraft and spare components that the facility is required to support. Due to the size and complexity of modern test and support equipment, a repair station can be significantly larger than the number of personnel needed to operate it. The following planning factors have taken this into account and are developed accordingly.

When planning aircraft maintenance facilities for a given installation, the number of aircraft and squadrons to be counted is determined by projecting peak scheduled occupancy of all aircraft for which the station will have an aircraft maintenance support mission. Peak scheduled occupancy is defined as the maximum number of aircraft that are scheduled for simultaneous assignment at the installation for the planned construction year.

In May 2003, the Navy developed a new inter-deployment readiness profile, the “Fleet Readiness Concept” (FRC) with the goal of improving the Navy’s speed of response to world events. The FRC developed into the Fleet Response Plan (FRP). FRP was fully implemented in mid-2004 and will modify current ship and squadron operating cycles by adjusting maintenance intervals, along with training and manpower processes, to increase unit availability for surge operations – that is, building the long-term institutional capability to support rapid, massive build-up in deployed Naval forces.

FRP will alter Aircraft Carrier Battle Group/Aircraft Carrier Strike Group deployment cycles such that all aircraft squadrons could be at their respective homebases at the same time. Therefore, the concept of “hot-racking” single-sited air wing airframes is no longer valid. When planning aircraft maintenance hangars, 100% of the squadrons must be allotted space.

In some instances, an installation may be assigned the intermediate maintenance responsibility for aircraft not permanently assigned to the installation. In this case, these aircraft should be added to the base loading for the planning of intermediate maintenance shops.

211-5 AIRCRAFT MAINTENANCE DEPARTMENT OFFICES

The shops comprising the Intermediate Maintenance Facility may be established separately or grouped together in a consolidated complex. Space requirements for each individual shop having a specific category code include the administrative and training space for that shop. In addition, administrative and training spaces are required for the Navy’s Aircraft Intermediate Maintenance Department (AIMD) or the Marine Corps Intermediate Maintenance (IM) offices, preferably in a centrally located administrative building within the maintenance complex. When shops are not consolidated into a complex, consideration shall be given to enlarging the administrative space in one of the intermediate shops to provide space for the AIMD offices. Space allocations shall be made in accordance with Category Code 211-16, Aircraft Intermediate Maintenance Activity Management.

211-6 MARINE CORPS CRITERIA

Marine Corps aircraft facilities are planned for utilizing the basic criteria for comparable Naval facilities.

211 01 AIRCRAFT ENGINE TEST CELL BUILDING (NON-NAVAIR DEPOT) (m^2 / SF)

FAC: 2114
BFR Required: Y

Design Criteria: UFC 4-212-01, Navy Standard Jet Engine Test Cells

21101-1 **GENERAL.** During the aircraft maintenance and testing process, aircraft engines are run-up while aboard the aircraft (in-frame testing) and when removed from the aircraft (out-of-frame testing). In both cases, high noise levels are generated in surrounding areas unless sound abatement is provided. The aircraft acoustical enclosure, sometimes referred to as a hush house, is a total enclosure for fixed wing aircraft designed to abate noise during in-frame run-up of jet engines. The facility consists of a hangar-like aircraft enclosure, an absorptive augmenter for inducing cooling air and absorbing noise, a 45-degree blast deflector, an observation room with lavatory, and a mechanical equipment room. The observation and mechanical rooms are located adjacent to, not within, the aircraft enclosure.

21101-2 **POLICY.** This Category Code shall be used for acoustical enclosures, which support organizational and intermediate level aircraft maintenance. Enclosures at Naval Air Depots (NAVAIR Depots) supporting depot maintenance shall be Category Code 211 98, Aircraft Acoustical Enclosure (NAVAIR Depot).

For out-of-frame testing see Category Code 211 81, Engine Test Cell (Non-NAVAIR Depot); Category Codes 211 88, Power Check Pad (with Sound Suppression); or 211 89, Power Check Pad (without Sound Suppression).

21101-3 **CRITERIA.** The design of the acoustical enclosure is governed by the size of aircraft and the number and location of the engines.

The acoustical enclosure provides a better working environment than open pads by providing protection from inclement weather and cross winds which adversely affect testing of engines, while at the same time significantly reducing exterior noise levels. NAVFAC P-970, Planning in the Noise Environment, specifies acceptable noise levels for various land uses. Noise levels generated during engine run ups, if not abated, would restrict land use, require that sound insulation be installed in nearby buildings, or require the run up pad be located at a considerable distance from inhabited buildings. The latter results in increased fuel consumption and lost time while transiting the aircraft to and from the run up area. In addition, noise generated during run ups can result in complaints from civilian communities resulting in local pressure to restrict operations. As indicated by P-970, the total noise environment must be evaluated and the hush house considered as one possible solution to reducing noise levels. Most air installations have had detailed noise studies done as part of the Air Installation Compatibility Use Zone (AICUZ) program. AICUZ studies address solutions to noise problems and may serve as a basis for justifying the requirements for an acoustical enclosure.

If an acoustical enclosure is justified by a detailed analysis of noise problems and potential solutions, then one (1) acoustical enclosure shall be provided for up to 140 aircraft and two (2) for up to 360 aircraft.

Three standard designs are available to support the aircraft mix set forth in Table 21101-1.

Table 21101-1
Aircraft Acoustical Enclosure

Enclosure Type	Chamber Size	Augmenter Length	Aircraft Types
I	25.6 m x 21.9 m (84 ft x 72 ft)	28.9 m (95 ft)	S-3, F-14, F/A-18, A-4, A-6, A-7, T-2
II	24.4 m x 21.9 m (80 ft x 72 ft)	27.4 m (90 ft)	F-14, F/A-18, A-4, A-7, T-2 For A-6 flare Augmenter Bellmouth to 6.24 meters (20.5 feet)
III	20.7 m x 19.5 m (68 ft x 64 ft)	20.4 m (67 ft)	F/A-18, A-4, A-6, A-7, T-2

211 03 CORROSION CONTROL HANGAR (m^2 / SF)
FAC: 2113
BFR Required: Y

Design Criteria: UFC 4-211-02, Aircraft Corrosion Control and Paint Facilities

21103-1 **GENERAL.** The corrosion control hangar provides space for washing, rinsing, paint stripping, corrosion removal, protective coating and painting of aircraft at intermediate and organizational maintenance levels. The hangar along with Aircraft Washback Pavements (Category Code 116 10) and Aircraft Rinse Facilities (Category Code 116 15) support the corrosion control program as described in NAVAIR Technical Manual NAVAIR 01-1A-509. Depot level maintenance facilities for stripping and complete repainting of aircraft shall be coded as Paint and Finishing Hangar (NAVAIR Depot) (Category Code 211 12).

The corrosion control hangar may be required at Navy and Marine Corps activities to support the OPNAV Corrosion Control Program and to meet the environmental restrictions of the local and state governments. This facility is to be available for repair of damaged paint systems only and not for complete de-paint/repaint of an entire aircraft. That function is restricted to depot level activities. Functions performed in the corrosion control facility include deicing, limited detergent washing and rinsing, paint stripping, corrosion removal, protective coating application and painting, and finish curing and drying. The requirement for a corrosion control hangar should be endorsed by the cognizant Type Commander and NAVAIRSYSCOM prior to approval for planning purposes.

Corrosion Control facilities should consist of at least two (2) bays, one for “dirty” work such as sanding, stripping, and blasting, and one for “clean” work such as priming and painting. One “dirty” bay can support up to 135 aircraft and one “clean” bay can support up to 45 aircraft. There are two (2) corrosion control hangar facility sizes (see Table 21103-1). The small facility will support fixed wing carrier-type and rotary wing aircraft. The large facility will support patrol and transport aircraft.

Consideration must be given to industrial safety and environmental contaminants. The facility will require a laminar flow exhaust system with filtered air intake and outflow. It will require compressed air, both tool air to operate sanders, buffers, and paint guns, and breathing air for personnel. Additional support space in the facility would be required for mixing paint, hazardous material and non-hazardous material storage, gear and tool storage, non-destructive inspection, office, and for locker rooms and toilet facilities.

Table 21103-1
Aircraft Corrosion Control Hangar

Facility Type	Hangar Bay (each bay)	Support Space (each facility)	Aircraft Types
Small	27.4 m x 25.5 m (90 ft x 83.5 ft) 699 m^2 (7,515 SF)	64.7 m x 6.9 m (212.3 ft x 22.7 ft) 446 m^2 (4,819 SF)	Fixed wing, Carrier-type and Rotary Wing (F/A-18, F-14, H-60, H-53, etc.)
Large	36.6 m x 46.2 m (120 ft x 151.5 ft) 1,691 m^2 (18,180 SF)	36.6 m x 11.7 m (120 ft x 38.3 ft) 428 m^2 (4,596 SF)	Patrol and Transport (P-3, C-130, etc.)

Table 21103-2
Aircraft Corrosion Control Hangar
Hangar Requirements

Aircraft Quantity	Hangar Bay "Clean"	Hangar Bay "Dirty"	Support Space
Up to 45	1	1	1
46 – 90	2	1	1
91 – 135	3	1	1
136 – 180	4	2	1
181 – 225	5	2	1
226 – 270	6	2	1

211 04 PRE-ENGINEERED MAINTENANCE HANGAR (m^2 / SF)
FAC: 2111
BFR Required: Y

Design Criteria: UFC 4-211-01, Aircraft Maintenance Hangars

21104-1 **GENERAL.** The pre-engineered maintenance hangar provides an austere facility for organizational level maintenance of Navy and Marine Corps aircraft. It is intended for use primarily at overseas locations, particularly those where tenure may be limited. When provided, the pre-engineered hangars are programmed in lieu of, not in addition to, the larger standard Type I and/or II hangars (Category Codes 211 05/06/07).

The pre-engineered maintenance hangar is intended for the support of a detachment size unit of from three to five aircraft. Each hangar consists of hangar bay (OH) space and limited crew/equipment (01) and administrative (02) space. Movable partitions are provided within the crew/equipment and administrative space to facilitate configuring these areas in accordance with the requirements of the occupant.

There are three (3) types of pre-engineered maintenance hangars (See Table 21104-1). The specific type of hangar depends on the size of aircraft to be maintained. The Type "A" pre-engineered maintenance hangar is designed primarily for fixed wing, carrier-type aircraft and helicopters. It should be noted that a Type "A" hangar may also be utilized for smaller transport aircraft with a wingspan less than 25.5 meters (85 feet). The Type "B" pre-engineered maintenance hangar is designed primarily for shore-based patrol aircraft and transport aircraft with wingspans up to 30.5 meters (100 feet). The Type "C" pre-engineered maintenance hangar is designed primarily for (K)C-130 aircraft but may also be configured to accommodate other large transport aircraft with wingspans up to 40.2 meters (132 feet).

Table 21104-1

Pre-Engineered Maintenance Hangar

Hangar Type	Width and Depth	Gross Area	Aircraft Types
A	32.0 m x 24.4 m (90 ft x 83.5 ft)	818 m^2 (8,800 SF)	Fixed wing, Carrier-type and Rotary Wing. *Note: May also be utilized by smaller transport aircraft with wingspan less than 25.5 meters (85 feet.)*
B	36.6 m x 36.6 m (120 ft x 120 ft)	1,366 m^2 (14,700 SF)	Shore-based Patrol and Transport aircraft with wingspans up to 30.5 meters (100 feet).
C	45.7 m x 42.7 m (150 ft x 140 feet)	1,995 m^2 (21,466 SF)	Primarily (K)C-130 aircraft. *Note: May also be configured to accommodate other large transport aircraft with wingspans up to 40.2 meters (132 feet.)*

Note: (1) Gross Area includes Hangar Door pockets.

211 05 MAINTENANCE HANGAR – O/H SPACE (HIGH BAY) (m^2 / SF)
FAC: 2111
BFR Required: Y

211 06 MAINTENANCE HANGAR – 01 SPACE (SHOPS AND MAINTENANCE ADMINISTARTION) (m^2 / SF)
FAC: 2112
BFR Required: Y

211 07 MAINTENANCE HANGAR – 02 SPACE (OPERATIONS, TRAINING, AND ADMINISTRATION) (m^2 / SF)
FAC: 6100
BFR Required: Y

Design Criteria: UFC 4-211-01, as updated, Aircraft Maintenance Hangars, Type I, Type II, Type III, and Type IV

21105/06/07-1 **GENERAL.** Maintenance hangars are required to provide weather-protected shelter for the servicing and repair of Navy and Marine Corps aircraft at an organizational level and emergency shelter for operable aircraft. Maintenance hangar configured for a Marine Air Logistics Squadron (MALS) may provide for the servicing and repair of aircraft at the intermediate level as well as at the organizational level. See Category 211 Appendix – Marine Corps Aircraft Maintenance Facilities, in which additional special guidance is provided. The supplement is located at the end of the 211 series criteria. There are four basic types of standard modular hangars: Type I, Type II, Type III, and Type IV. These hangars each contain a high bay (OH) space, shop and maintenance (01) space, and operations, training, and administration (02) space. Each of these spaces is assigned a separate category code.

It is extremely difficult to establish specific criteria to meet the requirements of the multi-sized squadrons existing within the various commands of the Navy and Marine Corps. Sizes range from a four aircraft AEW squadron with a complement of about one hundred seventy-five persons to a fifty or more aircraft training squadron with a complement of up to one thousand five hundred persons (including students). Accordingly, the criteria stated herein and further defined in the Unified Facility Criteria (UFC 4-211-01, as updated) “Aircraft Maintenance Hangars” depicts the Type I, Type II, Type III, and Type IV Maintenance Hangar modules developed primarily to maintain squadron facility integrity for standard size fleet squadrons. In this context, “standard size” is defined as a combination of the following factors:

1. A squadron with ten to eighteen carrier aircraft and one hundred fifty to four hundred personnel assigned.
2. A squadron with four to six carrier aircraft and one hundred twenty-five to two hundred personnel assigned.

3. A squadron with six to twelve land based patrol or large transport aircraft and one hundred fifty to four hundred personnel assigned.

In general, the size of the OH space is based on a percentage of the number of Primary Assigned Aircraft (PAA) in a squadron and the technical requirements for ensuring adequate clearances around the aircraft. Planning factors, such as number of personnel in a squadron or number of workspaces required, are used to define the 01 space and the 02 space.

All other squadrons and/or units operating aircraft are considered non-standard. Guidance for applying these criteria to both standard and non-standard size units is contained in subparagraphs 1 and 2 below.

UFC 4-211-01, as updated, contains conceptual floor plans and notional drawings for Type I, Type II, and Type III hangars.

Type I: Primarily designed for carrier aircraft, but adaptable to meet requirements for rotary wing and various types of smaller aircraft. The 01 and 02 spaces in this type of hangar are configured for a typical strike fighter squadron, two carrier airborne early warning squadrons, two carrier electronic attack squadrons, or a helicopter antisubmarine warfare squadron.

Type II: Primarily supports U.S. Marine Corps aviation. Hangar is designed to accommodate CH-53 helicopters, V-22 Ospreys, and C-130 Hercules aircraft. This type of hangar may also accommodate Navy variants of the C-130, V-22, and H-53 aircraft.

Type III: Principally designed for land based patrol (P-8A) and large transport (C-40A) aircraft.

Type IV: Intended for the largest Unmanned Aircraft System (UAS), which is currently the MQ-4C Triton.

Tables 21105-1a and 21105-1b show the standard hangar's dimensional statistics for planning purposes. See also UFC 4-211-01 Table 2-1 for all Minimum Aircraft Maintenance Bay Clearances and Table 7-1 for other standard Hangar Type dimensions and requirements.

Table 21105-1a
Modular Hangar Dimensional
Statistics for Planning Purposes
Type I Hangar

Category Code 21105 (OH Space)	**Dimension - Navy**		**Dimension - USMC**	
	ft	**m**	**ft**	**m**
Width	212	64.62	270	82.30
Depth	95	28.96	95	28.96
Useable Depth(1)	75	22.86	75	22.86
Useable Width(2)	197	60.05	255	77.72
1 Module	212	64.62	270	82.30
1-1/2 Module	318	96.93	405	123.44
2 Module	424	129.24	540	164.59
2-1/2 Module	530	161.54	675	205.74
3 Module	636	193.85	810	246.89
Each Additional 1/2 Module	106	32.31	135	41.15
Category Code 21105 (OH Space)	**Dimension - Navy**		**Dimension - USMC**	
	sq. ft	**sq. m**	**sq. ft**	**sq. m**
Net area per module	20,140	1,871	25,650	2,317
Gross area per module(3)	22,557	2,096	28,728	2,595
Category Code 21106 (01 Space) Shop and Maintenance	**Dimension - Navy**		**Dimension - USMC**	
	sq. ft	**sq. m**	**sq. ft**	**sq. m**
Net area per module	14,245	1,323	20,145	1,872
Gross area per module(4)	19,658	1,826	27,800	2,583
Category Code 21107 (02 Space) - Operations, Training, and Administration	**Dimension - Navy**		**Dimension - USMC**	
	sq. ft	**sq. m**	**sq. ft**	**sq. m**
Net area per module	10,062	935	12,532	1,164
Gross area per module(5)	13,181	1,225	16,417	1,525

Table 21105-1a Notes

(1) Type I useable depth computed upon the requirement for a 10-foot (3.05 meter) clearance from aircraft to nearest fixed obstruction along rear wall of the hangar and a 10-foot (3.05 meter) clearance between aircraft and inside face of front door.

(2) Type I useable width computed upon the requirement for a 7.5 foot (2.23 meter) clearance from aircraft to nearest fixed obstruction along side wall, and 7.5 foot (2.23 meter) clearance between aircraft wing tips.

(3) 12% net-to-gross mark-up factor applied to account for wall thickness, door pockets, and other structural components.

(4) 38% net-to-gross mark-up factor applied to account for wall thickness, elevator(s), mechanical equipment spaces, structural elements, and common spaces.

(5) 31% net-to-gross mark-up factor applied to account for wall thickness, elevator(s), mechanical equipment spaces, structural elements, and common spaces.

Table 21105-1b
OH Space Navy Standard
F-35C Model
Statistics Planning Purposes

CATEGORY	SPACE REQ'T		PLANNING METRICS	
Required Aircraft Parking Positions	5		0.33	% of PAA + 1
TOTAL WIDTH	212	LF		
Aircraft with Wings Spread	43	LF	43	F35C Aircraft Width with Wings Spread
Aircraft with Wings Folded (4 X 31')	124	LF	31	F35C Aircraft Width with Wings Folded
Wingtip Clearance (4 X 7.5')	30	LF	7.5	Clearance between Aircraft
Access Clearance (2 X 7.5')	15	LF	7.5	Clearance from Side Wall (Unusable)
TOTAL DEPTH	95	LF		
Aircraft Length	52	LF	52	Aircraft Length
Work Area Length	23	LF	23	Work Area
Personnel & Equipment Clearance	10	LF	10	Hangar Door Clearance (unusable)
Personnel & Equipment Clearance	10	LF	10	Back Wall Clearance (unusable)
NET OH SPACE	20,140	SF		
GROSS AREA	22,557	SF	1.12	OH SPACE Net-to-Gross (NTG)

Key: Variable, depends on PAA and squadron; Standard PAA and squadron; Calculation

FIGURE 1. OH Space Diagram – F35C

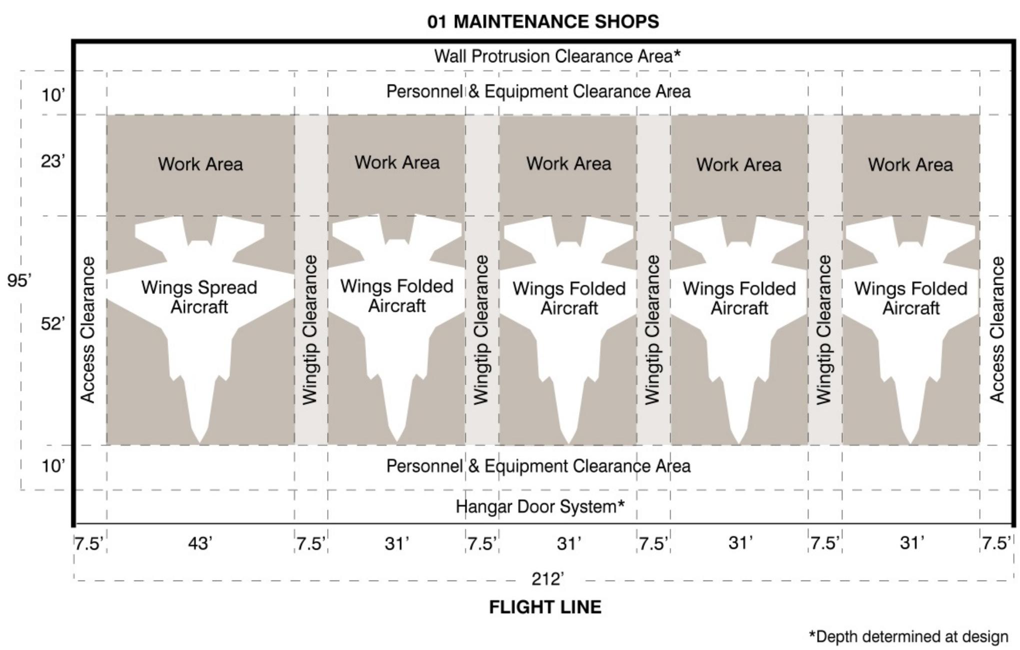


Table 21105-1c
OH Space Marine Corps Standard
F-35B Model
Statistics Planning Purposes

CATEGORY	SPACE REQ'T		PLANNING METRICS	
Required Aircraft Parking Positions	**6**		0.33	% of PAA + 1
TOTAL WIDTH	262.5	LF		
Aircraft with Wings Spread (6 X35')	210	LF	35	F35B Aircraft Width with Wings Spread
Total Wingtip Clearance (5 X 7.5')	37.5	LF	7.5	Clearance between Aircraft
Access Clearance (2 X 7.5')	15	LF	7.5	Clearance from Side Wall (Unusable)
TOTAL DEPTH	95	LF		
Aircraft Length	52	LF	52	Aircraft Length
Work Area Length	23	LF	23	Work Area
Personnel & Equipment Clearance	10	LF	10	Hangar Door Clearance (unusable)
Personnel & Equipment Clearance	10	LF	10	Back Wall Clearance (unusable)
NET OH SPACE	24,938	SF		
GROSS AREA	27,930	SF	1.12	OH SPACE Net-to-Gross (NTG)

Key: Variable, depends on PAA and squadron — Standard PAA and squadron — Calculation

FIGURE 2. OH Space Diagram – F35B

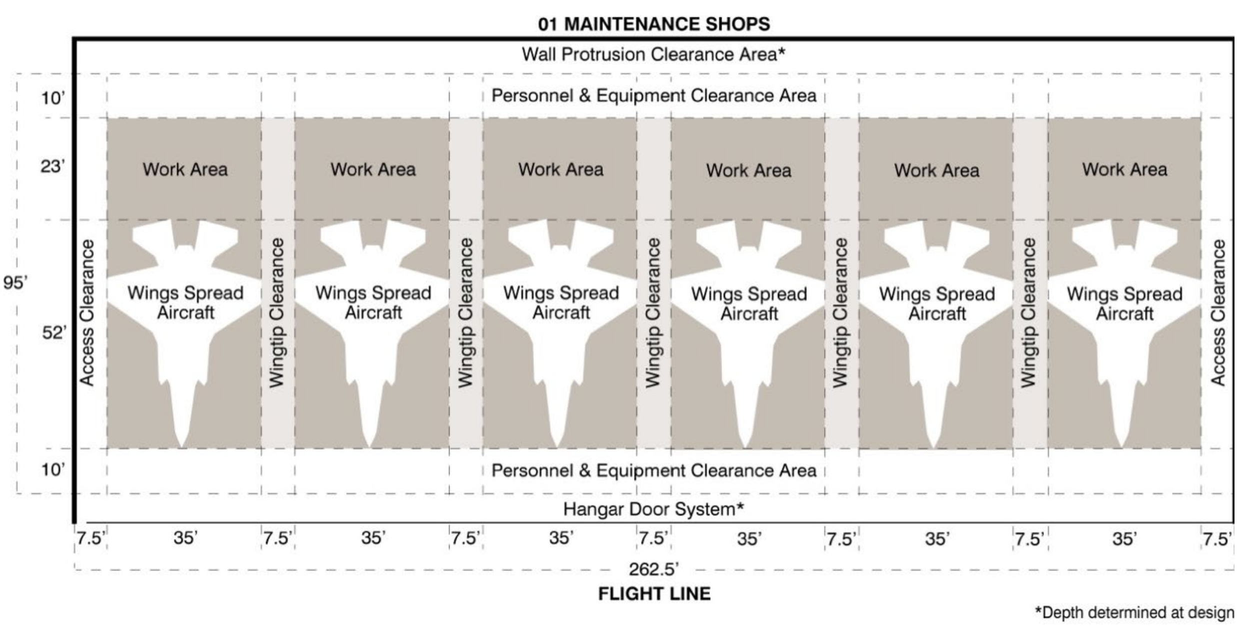


Table 21105-1d
Modular Hangar Dimensional Statistics for Planning Purposes
Type II and Type III Hangar

Category Code 21105 Hangar Module (OH)	**Type II**		**Type III**	
	ft	**m**	**ft**	**m**
Width	325	99.10	165	50.30
Depth	119	36.28	165	50.30
Clear Height	44	12.80	50	14.02
Useable Depth (1)	99	30.18	130	39.63
Useable Width (2)				
1 Module	305	92.99	125	38.11
1-1/2 Module	467	142.38	n/a	n/a
2 Modules	630	192.07	290	88.41
2-1/2 Modules	792	241.46	n/a	n/a
3 Modules	955	291.16	455	138.72
3-1/2 Modules	1,117	340.55	n/a	n/a
4 Modules	1,280	390.24	620	189.02
4-1/2 Modules	1,462	445.73	n/a	n/a
5 Modules	1,605	489.33	785	239.33
5-1/2 Modules	1,747	532.62	n/a	n/a
6 Modules	1,930	588.41	950	289.63
Each Add'n ½ Module	162	49.54	n/a	n/a
Category Code 21105 Hangar Module (OH)	**Type II**		**Type III**	
	sq.ft.	**m^2**	**sq.ft.**	**m^2**
Net Area per Module	38,675	3,593.03	27,225	2,529.29
Gross Area per Module (3)	40,609	3,772.70	28,586	2,655.73
Category Code 21106 Shop and Maintenance Admin. (01)	**Type II**		**Type III**	
	sq.ft.	**m^2**	**sq.ft.**	**m^2**
Gross Area per Module (4)	12,000	1,114.84	12,000	1,114.84
Category Code 21107 Operations, Training, and Administration(02)	**Type II**		**Type III**	
	sq.ft.	**m^2**	**sq.ft.**	**m^2**
Gross Area per Module	12,000	1,114.84	12,000	1,114.84

Table 21105-1b Notes

(1) Type II useable depth computed upon the requirement for a 10-foot (3.05 meter) clearance from aircraft to nearest fixed obstruction along rear wall of the hangar and a 10-foot (3.05 meter) clearance from aircraft to inside face of front door. Type III useable depth computed upon the requirement for a 20-foot (6.10 meter) clearance from aircraft to nearest fixed obstruction along rear wall of the hangar and a 15-foot (4.57 meter) clearance between aircraft and inside face of front door.

(2) Type II useable width computed upon the requirement for a 10-foot (3.05 meter) work clearance from aircraft to nearest fixed obstruction along side wall. Type III useable width computed upon the requirement for a 20-foot (6.10 meter) work clearance from aircraft to nearest fixed obstruction along the side wall.

(3) 5% net-to-gross mark-up factor applied to account for wall thickness and other structural loss. Additional net-to-gross mark-up may be required for hangars utilizing enclosed door pockets.

(4) Excludes an allowance of up to 1,536 sq. ft. (143 m^2.) for mechanical equipment space to house Aqueous Fire Foam Film (AFFF) fire suppression systems.

Due to the different attributes of the functions performed in the three space types, separate net-to-gross (NTG) ratios are provided for each space type in a Type I maintenance hangar:

- Hangar Bay (OH Space) – 1.12
- Shops and Maintenance (01 Space) – 1.38
- Operations, Training, and Administration (02 Space) – 1.31

21105/06/07-2 **Guidelines for Applying Maintenance Hangar Criteria**.
In the application of the criteria for the planning of Maintenance Hangars, the following guidelines are established:

21105/06/07-2.1 **Category Code 211-05 – OH Space.**

(1) One Type I standard hangar module OH space will be planned for each standard size squadron with twelve to eighteen carrier aircraft.

(2) One half a Type I standard hangar module OH space will be planned for each standard size squadron with four to six carrier aircraft.

(3) One Type II standard hangar module OH space will be planned for each standard size squadron with ten to sixteen large helicopter or tilt-rotor aircraft.

(4) One Type III standard hangar module OH space will be planned for each standard size squadron with four to eight land based patrol or large transport aircraft.

(5) The aircraft assigned to all other squadrons or units located on an air station or air facility, including pool or station aircraft, will be combined into a total loading, and the number of hangar modules required for these aircraft will be determined as follows:

Hangar space requirements for both scheduled and unscheduled maintenance vary by aircraft due to maintenance complexity and mission requirements. Carrier and rotary wing aircraft require more maintenance than patrol, special mission, and training aircraft, which require more maintenance than transport aircraft. Carrier and rotary wing aircraft normally require removing skin panels to gain access to Weapons Replaceable Assemblies (WRA). On patrol, special mission, and training aircraft a larger percentage of WRAs are readily accessible from the interior of the aircraft and, therefore, more maintenance is performed on the flight line (parking apron). In general, transport aircraft are less complex and require less hangar space. Consequently, hangar space requirements should be planned as follows (See Table 21105-2 for details):

(a) OP-Carrier, OP-Rotary, OP-Tilt-Rotor, TRG-Rotary, TRG-Carrier, TRG-Tilt-Rotor, RES-Rotary, RES-Carrier type squadrons: One (1) hangar space for every three (3) aircraft assigned.

(b) OP-Patrol, OP-Special Mission, TRG-Patrol, TRG-New Pilot, TRG-Special Mission, OTH(N)–SAR, OTH(N)-Station, OTH(N)-NTPS, OTH(N)-NSAWC, OTH(MC)-Station, RES-Patrol, RES-Station, RES-Special Mission type squadron: One (1) hangar space for every six (6) aircraft assigned.

(c) RES -Transport type squadron: One (1) hangar space for every nine (9) aircraft assigned.

(d) OP-UAS (BAMS Only) and TRG-UAS (BAMS Only) type squadrons: One (1) hangar space for every two (2) aircraft assigned.

(e) ETD type squadron: Due to the unique and critical nature of the mission, one (1) hangar space per aircraft assigned

(f) RDT&E type squadron: Hangaring requirements vary based on aircraft testing configuration. See Category Code 311-05, 311-06, and 311-07.

OP = Operational
TRG = Training
OTH(N) = Other, Navy
NSAWC = Naval Strike and Air Warfare Center
OTH(MC) = Other, Marine Corps
RES = Reserve
RDT&E = Research, Development, Testing and Evaluation
SAR = Search and Rescue
NTPS = Navy Test Pilot School
ETD = Executive Transport

FOR FIXED WING AIRCRAFT:

Except for Type I hangar (see Table 21105-1a) or special cases, hangar requirements are computed with a distance of 1.52 meters (5 feet) between aircraft and with the aircraft wings folded.

FOR ROTARY WING AIRCRAFT:

Except for Type I hangar (see Table 21105-1a) or special cases, hangar requirements are computed with a distance of 1.52 meters (5 feet) between aircraft and with seventy-five (75) percent of the aircraft with rotors folded. Twenty-five (25) percent of the aircraft are maintained with the rotors in the spread mode.

FOR SPECIAL CASES:

Some aircraft require greater separation distances between parked aircraft to accommodate maintenance equipment as well as proper ingress/egress aisles. These aircraft include the MV-22 and P-8A (MMA).

FOR MV-22 AIRCRAFT:

Hangar requirements are computed with a distance of 3.05 meters (10 feet) between aircraft and with seventy-five (75) percent of the aircraft with wings/rotors spread. Twenty-five (25) percent of the aircraft are maintained with the wing/rotors in the folded mode.

FOR P-8A AIRCRAFT:

Hangar requirements are computed with a distance of 5.18 meters (17 feet) between aircraft.

Tables 21105-2 and 21105-3 provide aircraft widths, hangar space requirements ratios, and type hangar for each aircraft.

Hangar OH space represents the hangar high bay space. While the OH space is intended primarily to provide squadron-level maintenance (organizational or O-level), it is expected that a hangar bay could include an additional space designated for Planned Maintenance Interval (PMI). Naval Aviation Maintenance Program (NAMP) defines PMI as period of time for execution of an Integrated Maintenance Concept/Program (IMC/P) or Phased Depot Maintenance. While PMI can include O-level, intermediate-level (I-level), and depot-level (D-level) actions, the PMI space in a hangar bay is necessary to provide D-level maintenance at an air installation as O-level maintenance is already accounted for elsewhere in the hangar bay and I-level maintenance is generally performed off-aircraft and does not require a hangar spot. Depot-level maintenance is defined as maintenance performed on material requiring major overhaul or rebuilding of parts, assemblies, subassemblies, and end items. This type of maintenance includes manufacturing parts, making modifications, testing, inspecting, sampling, and reclamation. PMI D-level actions may include major structural repair involving removal and replacement of frames, bulkheads, and frames, along with full H-60 strip and paint.

PMI hangars need to be planned for each Type/Model/Series (TMS) by Commander, Fleet Readiness Center (COMFRC). A designated PMI space within an operational-level hangar bay is only required if PMI D-level maintenance actions under the IMC/P cannot be satisfied by COMFRC with other D-level maintenance space available elsewhere. Input from Commander Naval Air Atlantic/Pacific is necessary for an accurate assessment of the PMI space requirement.

To support this evolution in maintenance functions, the required hangar modules will be calculated using the following methodology:

- First, the product of the PAA and the hangar ratio (hangar ratios are shown in Table 21105-2) will be rounded up to the next integer for any values ending with a fraction of 0.3 or above for the Navy. For the USMC, rounding will follow conventional method (i.e., numbers with a fraction of 0.5 or more will be rounded up to the next integer). The figure will be rounded down for numbers with a fraction less than 0.5.

- Second, the calculated hangar modules will be normalized up to the next 0.5 module to determine the required hangar modules.

This methodology is expected to provide additional hangar spaces for PMI at Navy/USMC installations. For Navy hangars, if an additional designated space is required for PMI, one more space with spread configuration will be provided per Type/Model/Series per installation. This additional requirement must be verified with Commander, Naval Air Force Command (CNAF).

Sensitive Compartmented Information Facility (SCIF)/Special Access Program – Facility (SAP-F): SCIF/SAP-F requirements are design features in DOD ICD 705 incorporated in various functional spaces to allow for the dissemination of sensitive information. Spaces in the 01 and 02 functional areas may require SCIF design features. The mission of the squadron determines whether or not certain spaces in the 01 and 02 functional areas require SCIF design features. SCIF design features typically include shielding of walls, floors, ceilings, and doors; and secure systems such as security, telephone, network, electrical, and room acoustics.

Table 21105-2
Navy and Marine Corps Squadron Types
with
Aircraft and Aircraft Designations

Acronym	Squadron Designation	Aircraft TMS	Squadron Type	Hangar Ratio
Operational Squadrons – Navy				
HS	Helicopter Antisubmarine Squadron	HH-60H SH-60F	OP – Rotary	1/3
HSC	Helicopter Sea Combat Squadron	HH-60H MH-60S SH-60F	OP – Rotary	1/3
HM	Helicopter Mine Countermeasures Squadron	MH-53E	OP - Rotary	1/3
HSL	Helicopter Antisubmarine Squadron (Light)	SH-60B SH-60F	OP - Rotary	1/3
HSM	Helicopter Maritime Strike Squadron	MH-60R	OP - Rotary	1/3
VAQ	Carrier Tactical Electronics Warfare Squadron or Tactical Electronics Warfare Squadron	EA-6B EA-18G	OP - Carrier	1/3
VAW	Carrier Airborne Early Warning Squadron	E-2C E-2D	OP - Carrier	1/3
VFA	Strike Fighter Squadron	F/A-18A F/A-18B F/A-18C F/A-18D F/A-18E F/A-18F JSF	OP - Carrier	1/3
VP	Patrol Squadron	P-3C	OP - Patrol	1/6
		P-8A		Note 1
VPU	Patrol Squadron Special Unit	P-3C	OP - Special Mission	1/6
VQ	Fleet Air Reconnaissance Squadron	P-3C EP-3E	OP - Special Mission	1/6
		EPX E-6B	OP - Special Mission	1/6
VRC	Fleet Logistics Support Squadron	C-2A	OP - Carrier	1/3
VS	Sea Control Squadron	S-3B	OP - Carrier	1/3
BAMS	Broad Area Maritime Surveillance Squadron	UAS	OP – UAS	1/2
TUAV	Tactical Unmanned Aerial Vehicle Squadron	MQ-8B	OP - UAS	TBD

Acronym	Squadron Designation	Aircraft TMS	Squadron Type	Hangar Ratio
Training Squadrons – Navy				
HM (FRS)	Helicopter Mine Countermeasures Squadron (Fleet Replacement Squadron)	MH-53E	TRG – Rotary	1/3
HS (FRS)	Helicopter Antisubmarine Squadron (Fleet Replacement Squadron)	HH-60H SH-60F	TRG – Rotary	1/3
HSC (FRS)	Helicopter Sea Combat Squadron (Fleet Replacement Squadron)	HH-60H MH-60S SH-60F	TRG - Rotary	1/3
HSL (FRS)	Helicopter Antisubmarine Squadron (Light) (Fleet Readiness Squadron)	SH-60B	TRG - Rotary	1/3
HSM (FRS)	Helicopter Maritime Strike Squadron (Fleet Replacement Squadron)	MH-60R	TRG - Rotary	1/3
JSFTS	Joint Strike Fight Training Squadron	F-35C	TRG - Carrier	1/3
VAQ (FRS)	Carrier Tactical Electronics Warfare Squadron or Tactical Electronics Warfare Squadron (Fleet Replacement Squadron)	EA-6B EA-18G	TRG - Carrier	1/3
VAW (FRS)	Carrier Airborne Early Warning Squadron and Fleet Logistics Support Squadron (Fleet Replacement Squadron)	E-2C E-2D C-2A TE-2C	TRG - Carrier	1/3
VFA (FRS)	Strike Fighter Squadron (Fleet Replacement Squadron)	F/A-18A F/A-18B F/A-18C F/A-18D F/A-18E F/A-18F T-34C	TRG - Carrier	1/3
VP (FRS)	Patrol Squadron (Fleet Readiness Squadron)	P-3C P-8A	TRG – Patrol	1/6 Note 1
BAMS (FRS)	Broad Area Maritime Surveillance (Fleet Replacement Squadron)	UAS	TRG – UAS	1/2
EPX (FRS)	Fleet Air Reconnaissance Squadron (Fleet Replacement Squadron)	TBD	TRG - Special Mission	1/6
HT	Helicopter Training Squadron	TH-57B TH-57C TH-57D	TRG – New Pilot	1/6
VT	Training Squadron	T-2C T-34C T-39G T-39N T-44A T-44C T-45A T-45C T-6A T-6B TC-12B	TRG – New Pilot	1/6 1/6 1/6 1/6 0.28 (Note 2) 0.28 (Note 2) 1/6 1/6 0.39 (Note 2) 0.39 (Note2) 1/6

Acronym	Squadron Designation	Aircraft TMS	Squadron Type	Hangar Ratio
Acronym	**Squadron Designation**	**Aircraft TMS**	**Squadron Type**	**Hangar Ratio**
Other – Navy				
N/A	Search and Rescue	SH-60F MH-60S	OTH(N) – SAR	1/6
N/A	Station Support Aircraft	C-26D MH-60S SH-60F T-34C UC-12B UC-12F UC-12M	OTH(N) – Station	1/6
NTPS	Navy Test Pilot School	C-12C F/A-18B F/A-18F NP-3D NU-1B NSH-60B OH-58C T-6A T-6B TH6REP U-6A UH-60L X-26A	OTH(N) – NTPS	1/6
NSAWC	Naval Strike and Air Warfare Center	E-2C E-2D F-16A F-16B F-35C F/A-18A F/A-18B F/A-18C F/A-18D F/A-18E F/A-18F MH-60S	OTH(N) – NSAWC	1/6
Operational Squadrons – Marine Corps				
HMH	Marine Heavy Helicopter Squadron	CH-53D CH-53E CH-53K	OP - Rotary	1/3
HMLA	Marine Light Attack Helicopter Squadron	AH-1W AH-1Z UH-1Y	OP - Rotary	1/3
HMM	Marine Medium Helicopter Squadron	C-46E	OP - Rotary	1/3
HMX	Marine Helicopter Squadron	CH-46E VH-3D	OP-Rotary	1/3

Acronym	Squadron Designation	Aircraft TMS	Squadron Type	Hangar Ratio
		VH-60N VH-71A VH-71B		
		CH-53E	OP-Rotary	1/3
		MV-22B	OP-Tilt-Rotor	1/3
VMA	Marine Attack Squadron	AV-8B	OP – Carrier	1/3
VMAQ	Marine Tactical Electronics Warfare Squadron	EA-6B	OP – Carrier	1/3
VMFA	Marine Fighter Attack Squadron	F/A-18A F/A-18C JSF	OP – Carrier	1/3
VMFA(AW)	Marine All-Weather Fighter Attack Squadron	F/A-18C F/A-18D JSF	OP – Carrier	1/3
VMGR	Marine Aerial Refueler Transport Squadron	KC-130J KC-130R	OP – Special Mission	1/6
VMM	Marine Medium Tilt-Rotor Squadron	MV-22B	OP – Tilt-Rotor	1/3
Training Squadrons – Marine Corps				
VMAT	Marine Attack Training Squadron	AV-8B TAV-8B	TRG – Carrier	1/3
HMLAT	Marine Light Attack Helicopter Training Squadron	AH-1W AH-1Z HH-1N UH-1N UH-1Y	TRG – Rotary	1/3
HMMT	Marine Medium Helicopter Training Squadron	C-46E	TRG – Rotary	1/3
HMT	Marine Helicopter Training Squadron	CH-53E CH-53K	TRG – Rotary	1/3
VMAQ	Marine Tactical Electronics Warfare Squadron	EA-6B	TRG – Carrier	1/3
JSFTS	Joint Strike Fighter Training Squadron	F-35B(JSF)	TRG – Carrier	1/3
VMFAT	Marine Fighter Attack Training Squadron	F/A-18A F/A-18B F/A-18C F/A-18D T-34C	TRG – Carrier	1/3
HMLAT	Marine Light Attack Helicopter Training Squadron	AH-1W AH-1Z HH-1N UH-1N UH-1Y	TRG - Rotary	1/3
VMGR (FRS)	Marine Aerial Refueler Transport Squadron	KC-130R	TRG – Special Mission	1/6
VMMT	Marine Medium Tiltrotor Training Squadron	MV-22B	TRG – Tilt-Rotor	1/3
Other - Marine Corps				
N/A	Station Support	HH-1N UH-1Y	OTH(MC) - Station	1/6

Acronym	Squadron Designation	Aircraft TMS	Squadron Type	Hangar Ratio
Reserve Force – Navy				
HSC	Helicopter Sea Combat Squadron	HH-60H MH-60S	RES - Rotary	1/3
Acronym	**Squadron Designation**	**Aircraft TMS**	**Squadron Type**	**Hangar Ratio**
HM	Helicopter Mine Countermeasures Squadron	MH-53E	RES - Rotary	1/3
HSL	Helicopter Antisubmarine Squadron (Light)	SH-60B	RES - Rotary	1/3
HSM	Helicopter Maritime Strike Squadron	MH-60R	RES - Rotary	1/3
VAQ	Carrier Tactical Electronics Warfare Squadron or Tactical Electronics Warfare Squadron	EA-6B	RES - Carrier	1/3
VAW	Carrier Airborne Early Warning Squadron	E-2C	RES - Carrier	1/3
VFA	Strike Fighter Squadron	F/A-18A	RES - Carrier	1/3
VFC	Fighter Squadron Composite	F-5F F-5N F/A-18C JSF	RES - Carrier	1/3
VP	Patrol Squadron	P-3C	RES - Patrol	1/6
VR	Fleet Logistics Support Squadron	C-130T C-20D C-20G C-37B C-40A C-9B DC-9	RES - Transport	1/9
ETD	Executive Transport	C-20A C-37A	RES – Transport	1/1
N/A	Miscellaneous Station Support	UC-12B	RES - Station	1/6

Acronym	Squadron Designation	Aircraft TMS	Squadron Type	Hangar Ratio
Reserve Force – Marine Corps				
HMLA	Marine Light Attack Helicopter Squadron	AH-1W AH-1Z UH-1N UH-1Y	RES - Rotary	1/3
HMM	Marine Medium Helicopter Squadron	CH-46E	RES - Rotary	1/3
HMH	Marine Heavy Helicopter Squadron	CH-53E	RES – Rotary	1/3
VMFA	Marine Fighter Attack Squadron	F/A-18A F/A-18C JSF	RES - Carrier	1/3
VMFT	Marine Fighter Training Squadron (Adversary)	F-5F F-5N	RES - Carrier	1/3
VMGR	Marine Aerial Refueler Transport Squadron	KC-130J KC-130T	RES - Special Mission	1/6
VMM	Marine Medium Tiltrotor Squadron	MV-22B	RES - Rotary	1/3
VMR	Marine Transport Squadron	C-20G	RES – Transport	1/9

Acronym	Squadron Designation	Aircraft TMS	Squadron Type	Hangar Ratio
		C-9B HH-46E UC-12B UC-12F UC-35C UC-35D		
N/A	Station Support Aircraft	UC-12B	RES - Station	1/6

Note

1. Based on scheduled maintenance loading of 48% and unscheduled maintenance loading of 52% P-8A VP squadrons experienced over the 4-year period ending 2019, the effective hangar ratio is determined to be to ¼, or 0.25. This ratio applies as an interim update (Source: PMA-290 criteria inquiry dated 21 February 2020).
2. Based on updated maintenance records submitted by Commander, Naval Training Command (CNATRA) with a criteria update request of December 2020.

Table 21105-3
Aircraft Widths and
Hangar Space Requirements

Aircraft TMS	Hangar Type	Width Wings Spread (meters)	Width Wings Spread (ft-in)	Width Wings Folded (meters)	Width Wings Folded (ft-in)	Overall Height (meters)	Overall Height (ft-in)	Length (meters)	Length (ft-in)
AH-1W	I	14.63	48-0	3.28 (2)	10-9 (2)	4.32	14-2	17.68	58-0
AH-1Z	I	14.48	47-6	4.60 (2)	15.1 (2)	4.37	13-6	13.87	45-6
AV-8B	I	9.25	30-4	N/A	N/A	3.55	11-7	14.13	46-4
BAMSUAS	II	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
C-12C	I	16.62	54-6	N/A	N/A	4.57	15-0	13.36	43-10
C-130T	II	40.40	132-7	N/A	N/A	11.69	38-4	29.83	97-10
C-20A	II	23.72	77-10	N/A	N/A	7.47	24-6	25.56	83-10
C-20D	II	23.72	77-10	N/A	N/A	7.47	24-6	25.56	83-10
C-20G	II	23.72	77-10	N/A	N/A	7.47	24-5	26.96	88-5
C-26D	I	17.38	57-0	N/A	N/A	5.09	16-8	18.11	59-5
C-2A	I	24.56	80-7	10.80 (1)	35-5 (1)	5.18	17-0	17.56	57-7
C-37A	II	28.50	93-6	N/A	N/A	7.90	25-10	29.39	96-5
C-37B	II	28.50	93-6	N/A	N/A	7.90	25-10	29.39	96-5
C-40A	III	35.8	117-5	N/A	N/A	12.55	41-2	33.64	110-4
C-9B	II	28.43	93-3	N/A	N/A	8.36	27-5	36.38	119-4
CH-46E	I	15.54	51-0	4.50 (2)	14-9 (2)	5.09	16-8	25.71	84-4
CH-53D	II	22.01	72-2.7	7.29 (2)	23-11 (2)	7.60	24-11	20.55	67-5
CH-53E	II	24.08	79-0	8.66 (2)	28-5 (2)	7.19	23-7	30.18	99-0
CH-53K	II	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
DC-9	II	28.43	93-3	N/A	N/A	8.36	27-5	36.38	119-4
E-2C	I	24.56	80-7	10.80 (1)	35-5 (1)	5.58	18-3.75 (4)	17.53	57-6
E-2D	I	24.56	80-7	10.80 (1)	35-5 (1)	5.58	18-3.75 (4)	17.53	57-6
E-6B	N/A	45.21	148-4	N/A	N/A	12.93	42-5	45.83	150-4
EA-18G	I	13.69	44-11	9.96	32-8	4.89	16-0	18.31	60-1.25
EA-6B	I	16.15	53-0	7.60	24-11	5.08 (5)	16-8 (5)	18.24	59-10
EP-3E	II	30.33	99-6	N/A	N/A	10.24	33-7	35.54	116-7
EPX	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
F-16A	I	9.93	32-7	N/A	N/A	5.06	16-7	15.09	49-6
F-16B	I	9.93	32-7	N/A	N/A	5.06	16-7	15.09	49-6
F-35A	I	10.67	35-0	N/A	N/A	4.33	14-3	15.40	50-6
F-35B	I	10.67	35-0	N/A	N/A	4.31	14-2	15.40	50-6
F-35C	I	13.11	43-0	9.54	31-3	4.42	14-6	15.50	50-10
F-5F	I	8.13	26-8	N/A	N/A	4.00	13-1	15.73	51-7
F-5N	I	8.13	26-8	N/A	N/A	4.07	13-4	14.68	48-2
F/A-18A	I	11.43	37-6	8.38	27-6	4.67	15-4	17.07	56-0
F/A-18B	I	11.43	37-6	8.38	27-6	4.67	15-4	17.07	56-0
F/A-18C	I	12.32	40-5	8.38	27-6	4.67	15-4	17.07	56-0
F/A-18D	I	12.32	40-5	8.38	27-6	4.67	15-4	17.07	56-0
F/A-18E	I	13.68	44-9	9.96	32-8	4.88	16-0	18.39	60-4

Aircraft TMS	Hangar Type	Width Wings Spread (meters)	Width Wings Spread (ft-in)	Width Wings Folded (meters)	Width Wings Folded (ft-in)	Overall Height (meters)	Overall Height (ft-in)	Length (meters)	Length (ft-in)
F/A-18F	I	13.68	44-9	9.96	32-8	4.88	16-0	18.39	60-4
GHMD	II	35.42	116-2	N/A	N/A	4.62	15-2	14.63	48-0
HH-1N	I	14.63	48-0	2.81 (2)	9-2.6 (2)	4.39	14-5	17.48	57-4
HH-46E	I	15.55	51-0	4.50 (2)	14-9 (2)	5.08	16-8	13.92	45-8
HH-60H	I	16.36	53-8	4.37 (2)	14-4 (2)	5.18	17-0	14.25	46-9
KC-130F	II	40.41	132-7	N/A	N/A	11.71	38-5	29.80	97-9
KC-130J	II	40.41	132-7	N/A	N/A	11.71	38-5	29.80	97-9
KC-130R	II	40.41	132-7	N/A	N/A	11.71	38-5	29.80	97-9
KC-130T	II	40.41	132-7	N/A	N/A	11.71	38-5	29.80	97-9
MH-53E	II	24.08	79-0	8.41 (2)	27-7 (2)	8.64	28-4	30.18	99-0
MH-60R	I	16.36	53-8	4.37 (2)	14-4 (2)	5.13	16-10	19.74	64-9
MH-60S	I	16.36	53-8	4.37 (2)	14-4 (2)	5.10	16-8	19.74	64-9
MQ-8B	I	8.38	27-6	1.88 (2)	6-2 (2)	2.87	9-5	9.60	31-6
MV-22B	II	25.82 (3)	84-7 (3)	5.61 (3)	18-5 (3)	6.73 (6)	22-1 (6)	17.50	57-4
NC-130H	II	40.41	132-7	N/A	N/A	11.71	38-5	29.80	97-9
NF/A-18C	I	12.32	40-5	8.38	27-6	4.67	15-4	17.07	56-0
NF/A-18D	I	12.32	40-5	8.38	27-6	4.67	15-4	17.07	56-0
NP-3C	II	30.38	99-8	N/A	N/A	10.26	33-8	35.61	116-9
NP-3D	II	30.38	99-8	N/A	N/A	10.26	33-8	35.61	116-9
NU-1B	I	17.68	58-0	N/A	N/A	3.79	12-5	12.75	41-10
NAV-8B	I	9.25	30-4	N/A	N/A	3.55	11-7	14.13	46-4
NC-12B	I	16.62	54-6	N/A	N/A	4.57	15-0	13.34	43-9
NSH-60B	I	16.36	53-8	4.37 (2)	14-4 (2)	4.57	15-0	19.76	64-9
NSH-60F	I	16.36	53-8	4.37 (2)	14-4 (2)	4.57	15-0	19.76	64-9
NVH-3A	I	18.90	62-0	4.98 (2)	16-4 (2)	5.18	17-0	22.18	72-9
NVH-3D	I	18.90	62-0	4.98 (2)	16-4 (2)	5.18	17-0	21.90	73-0
OH-58C	I	10.77	35-4			2.92	9-7	12.85	42-2
P-3C	II	30.38	99-8	N/A	N/A	10.26	33-8	35.61	116-9
P-8A	III	37.96	124-6	N/A	N/A	12.86	42-2	39.48	129-6
RC-12F	I	16.62	54-6	N/A	N/A	4.57	15-0	13.36	43-10
RC-12M	I	16.62	54-6	N/A	N/A	4.57	15-0	13.36	43-10
S-3B	I	20.93	68-8	8.99	29-6	6.94	22-9	16.26	53-4
SH-60B	I	16.36	53-8	4.37 (2)	14-4 (2)	4.57	15-0	19.76	64-9
SH-60F	I	16.36	53-8	4.37 (2)	14-4 (2)	4.57	15-0	19.76	64-9
T-2C	I	11.64	38-2	N/A	N/A	4.50	14-9	11.79	38-8
T-34C	I	10.19	33-5	N/A	N/A	3.02	9-11	8.74	28-8
T-38C	I	7.70	25-3	N/A	N/A	3.92	12-10.5	14.14	46-4.5
T-39D	I	13.61	44-8	N/A	N/A	4.88	16-0	13.41	44-0
T-39G	I	13.57	44-6	N/A	N/A	4.88	16-0	13.31	43-8
T-39N	I	13.57	44-6	N/A	N/A	4.88	16-0	14.28	46-10
T-44A	I	15.32	50-3	N/A	N/A	4.37	14-4	10.82	35-6
T-44C	I	14.00	45-11	N/A	N/A	4.70	15-5	12.17	39-11
T-45A	I	9.40	30-10	N/A	N/A	4.12	13-6	11.99	39-4

Aircraft TMS	Hangar Type	Width Wings Spread (meters)	Width Wings Spread (ft-in)	Width Wings Folded (meters)	Width Wings Folded (ft-in)	Overall Height (meters)	Overall Height (ft-in)	Length (meters)	Length (ft-in)
T-45C	I	9.40	30-10	N/A	N/A	4.12	13-6	11.99	39-4
T-6A	I	10.18	33-5	N/A	N/A	3.30	10-10	10.16	33-4
T-6B	I	10.18	33-5	N/A	N/A	3.25	10-3	10.16	33-4
TAV-8B	I	9.25	30-4	N/A	N/A	3.53	11-7	11.08	36-4
TC-12B	I	16.61	54-6	N/A	N/A	4.52	14-10	13.36	43-10
TE-2C	I	24.57	80-7	N/A	N/A	5.59	18-4	17.53	57-6
TH-57B	I	10.16	33-4	1.92 (2)	6-3.5 (2)	3.05	10-0	12.09	39-8
TH-57C	I	10.16	33-4	1.92 (2)	6-3.5 (2)	3.05	10-0	12.09	39-8
TH-57D	I	10.16	33-4	1.92 (2)	6-3.5 (2)	3.05	10-0	12.09	39-8
TH-6B	I					2.30	7-6.7	9.25	30-4
TH6REP	TBD								
U-6A	I	14.63	48-0	N/A	N/A	2.74	9-0	9.24	30-4
UC-12B	I	16.61	54-6	N/A	N/A	4.52	14-10	13.36	43-10
UC-12F	I	16.61	54-6	N/A	N/A	4.52	14-10	13.36	43-10
UC-12M	I	16.61	54-6	N/A	N/A	4.52	14-10	13.36	43-10
UC-35C	I	15.90	52-2	N/A	N/A	4.57	15-0	14.91	48-11
UC-35D	I	16.46	54-0	N/A	N/A	4.62	15-2	14.91	48-11
UH-1N	I	14.63	48-0	2.81 (2)	9-2.6 (2)	4.54	14-11		
UH-1Y	I	14.88	48-10			4.50	14-7	17.78	58-4
UH-3H	I	19.00	62-0			5.13	16-10	16.70	54-9
UH-60L	I	16.36	53-8			5.13	16-10	19.76	64-10
VH-3D	I	18.90	62-0	4.98 (2)	16-4 (2)	5.13	16-10	16.70	54-9
VH-60N	I	16.36	53-8			5.13	16-10	19.76	64-10
VH-71A	I	18.59	61-0			6.65	21-10	22.81	74-10
VH-71B	I	18.59	61-0			6.65	21-10	22.81	74-10
X-26A	I	17.42	57-1.5	N/A	N/A	2.82	9-3		

Table 21105-3 Notes:
(1) Propeller disc span, which exceeds folded wing dimension.
(2) Minimum aircraft width with rotors in line with or folded in line with aircraft fuselage.
(3) MV-22 aircraft has multiple stow positions: Flight Ready Position = 25.816 meters (84'7"), Fold Horizontal Position = 16.154 meters (53'0"), Fold Vertical Position = 16.495 meters (54'1"), and Full Stow Position = 5.613 meters (18'5"). Use Flight Ready Position for Wings Spread width and Full Stow Position for Wings Folded width.
(4) Height with rotodome in raised position.
(5) Height with wings folded. Maximum height during wing folding procedure is 6.57 meters (21'6.8"). Aircraft height with wing extended is 4.95 meters (16'3"). Group the total aircraft non-standard loading by type, model, and series and apply the following formulas to each group. Combine the results of each calculation into Type I and Type II module requirements to obtain the required hangar widths to perform both scheduled and unscheduled maintenance in each type of hangar.
(6) Height for spread configuration. If aircraft in folded configuration then height reduced to 5.51 meters (18'1").

Calculating OH Space

Given the standard size of the OH space described previously, when planning OH space, planners shall follow the process below for determining the number of standard hangar modules required, and the gross square feet required.

1. *Gather data input*

Important data is necessary to select and apply correct formula to determine the number of hangar modules required. Data inputs include the following:

- Squadron service type (i.e., Navy or Marine Corps)
- Number of Primary Aircraft Authorized (PAA) for squadron
- Airframe assigned
- Width of aircraft with wings spread (for fixed-wing aircraft)
- Width of aircraft with wings folded (for fixed-wing aircraft)
- Rotor diameter when rotors are spread (for Tilt-Rotor aircraft, Rotor Spread is Flight Ready Position)
- Width of aircraft when rotors are folded or minimum aircraft width with rotors in line or folded in line with aircraft fuselage (for Tilt-Rotor aircraft Rotor Fold is Full Stow Position)

2. *Calculate the required hangar width (RHW) using formulas in Table 21105-4 as follows:*

Using the formulas in Table 21105-04 that includes the following variables:

N = Number of Primary Assigned Aircraft (PAA)

WS = Width of aircraft with wings spread (See Table 21105-3)

WF = Width of aircraft with wings folded (See Table 21105-3)

W = Width of aircraft for aircraft with wings that do not fold

D = Clearance between wingtips and walls or other wingtips, that is 7.5 feet

RS = Rotor diameter when rotors are spread (for Tilt-Rotor aircraft, RS is Flight Ready Position)

RF = Width of aircraft with rotors folded or minimum aircraft width with rotors in line or folded in line with aircraft fuselage (for Tilt-Rotor aircraft RF is Full Stow Position)

Table 21105-4
Required Hangar Width Formulas

Aircraft Type	Required Hangar Width Formula
Carrier Aircraft[1,2,3]	(1 x WS) + (N/3 x WF) + [(N/3 + 1) x D] + WS (for IMP)
Rotary Wing Aircraft[1,2,3]	0.25 x N/3 x RS + 0.75 x N/3 x RF + [(N/3 + 1) x D] + RS (for IMP)
Patrol, Special Mission, and Training Aircraft[2]	N/6 x W + [(N/6 + 1) x D] + W (for IMP)
Transport Aircraft[2]	N/9 x W + [(N/9 + 1) x D] + W (for IMP)
Tilt-Rotor Aircraft[1,2,3]	0.75 x N/3 x RS + 0.25 x N/3 x RF + [(N/3 +1) x D] + RS (for IMP)
Executive Transport Aircraft[2]	N/1 x W + [(N/1 + 1) x D]

[1]If an additional PMI bay is required, add space for WS and D.

[2]When performing calculations for determining the number of aircraft to a hangar, the Navy will incorporate the rounding down of a number when that number is less than 0.3 and rounding up when the number is equal to 0.3 or greater.

[3]For determining the number of aircraft in a hangar for the Marine Corps, use the conventional rounding method, and round up to the nearest whole number when the number is 0.5 or higher.

3. *Determine the number of standard modules required*

Divide the RHW by 212 feet for Navy and 262.5 feet for Marine Corps for partial modules. To determine the number of standard modules required, normalize partial modules as follows:

(a) Less than one module, one module is required.

(b) More than one module but equal one and one half modules, one and a half modules are required

(c) More than one and one half module but less than two modules, two modules are required

(d) Additional modules are determined on the same basis.

4. Calculate the gross square footage (GSF) required

Multiply the net square feet of the standard one-module hangar for either the Navy or Marine Corps by the number of standard modules required then by the1.12 net-to-gross ratio for the GSF required.

Sample Calculation

1. *Gather data inputs*

   Squadron Service: Navy
   Number of PAA: 14 aircraft
   Aircraft Variance: F-35C aircraft
   F-35C wings spread = 43 feet
   F-35C wings folded = 31 feet
   Hangar Ratio: PAA x hangar ratio

2. *Calculate the required hangar width (RHW)*

   N = 14 aircraft

   Hangar Ratio = 14/3
   = 4.66
   = 5 (Round up from 4.66)

RWH = (1 x WS) + (N/3 x WF) + [(N/3 + 1) x D] + WS
= (1 x 43’) + (5 x 31’) + [(5 + 1) x 7.5’] + 43’
= 43’ + 155’ + 45’ + 43’
= 286’

3. *Determine the number of standard modules required*

   Partial modules = RHW / Standard Module Width
   = 286’/212’
   = 1.34
   = 2 (Round up from 1.34)

   Number of standard modules required = 2.0

4. *Calculate the GSF required*

   GSF = 2 x 212’ x 95’ x 1.12
   = 45,114 SF

21105/06/07-2.2. **Category Code 211 06 – 01 Space.**

(1) One Type I standard hangar module 01 space will be planned for each standard size squadron with ten to eighteen carrier aircraft.

(2) One half Type I standard hangar module 01 space will be planned for each standard size squadron with four to six carrier aircraft.

(a) Provide a minimum of 520.5 m^2 (5,600 SF) per squadron when two squadrons share the same Type I standard hangar module.

(3) One Type II standard hangar module 01 space will be planned for each standard size MV-22 squadron with ten to sixteen aircraft

(4) One Type III standard hangar module 01 space will be planned for each standard size squadron with six to twelve land based patrol aircraft.

(5) As with the aircraft, the personnel of all the other (non-standard) squadrons or units that operate aircraft, except Fleet Readiness Squadrons (FRS) and other training squadrons, will be combined. The authorized 01 space will be computed at the rate of 3 m^2 (32.5 SF) per person for this combined total complement. Movable partitions within the 01 space will facilitate prorating of area for non-standard size squadrons and units.

(6) Squadrons operating with detachments, such as the HSL squadrons, are authorized an additional 19 m^2 (200 SF) of 01 space per detachment based on the average number of detachments on board.

(7) Squadrons with a cargo/passenger transport mission are authorized additional 01 space for the storage of aircraft equipment as follows:

Helicopters and carrier aircraft – 2 m^2 (25 SF) per aircraft.

Multi-engine land based aircraft – 5 m^2 (50 SF) per aircraft.

(8) Since line operations and line maintenance functions must be performed as close as possible to the apron parked aircraft of a squadron, an additional 27.9 m^2 (300 SF) is authorized per squadron. Note, if line operations and line maintenance is currently provided in separate structures, use Category Code 141 30 Aircraft Line Operations Building

and Category Code 211 15 Line Maintenance Shelter for inventory purposes only.

(9) The authorized 01 space for FRS and other training squadrons will be computed at the rate of 3 m^2 (32.5 SF) per permanent billet, less the training department. An additional 12 m^2 (125 SF) per student based on the average on board student load is authorized under Applied Instruction Building (Category Code 171 20) (Flight Training and Briefing Building). The training department billets are deleted from the squadron's complement for requirements calculations as space for these billets is included in the student allowance of 12 m^2 (125 SF). In many squadrons, it may be desirable to locate all, or a portion of the student space allowance in a separate facility or to combine it with the Operational Trainer Facility (Category Code 171 35) (Flight Simulator).

(10) The width of the 01 spaces shall not exceed the width of the computed number of OH modules; however, should the computed 01 space requirement exceed the 01 space available in the computed number of OH modules by twenty percent, authorization for deviations from standard hangar dimensions (see paragraph 1. Design Considerations) may be requested from Commander, Naval Air Systems Command (AIR-8.0Y1).

Maintenance shops compose the majority of the 01 space. Planning factors for 01 space for F-35 aircraft are shown on Tables 21105-4 and 21105-5. Space within the maintenance shops is allocated by the work center planning factor (presented in square feet per work center) and the number of people in each work center. The number of work centers planned per maintenance shop is determined by multiplying the PAA by the hangar ratio (from Table 21105-2). The planning factor for each work center usually accommodates 2-4 maintenance personnel and includes space (based on function) for a computer monitor, worktables/benches, short- term material/tool storage, and internal circulation. For example, the airframes maintenance shop has a recommended planning factor of 350 square feet (SF) per work center. If 10 aircraft are assigned to an F-35C squadron with a 1/3 hangar ratio, three work centers are required to accommodate 6-12 people; therefore, the net area for work centers in the airframe shop is 1,050 SF. In order to account for the variability in shop work schedules and personnel working between the shop and the OH space, use conventional rounding based on the 1/3 hangar ratio for maintenance shop work centers.

Table 21105-5
01 Space Calculations for F-35C and F-35B

CATEGORY	Unit	Unit Metric	Unit Factor	Each		Planning Metrics		Space Req't (SF)	
				F-35C	F-35B			F-35C	F-35B
SHOPS									
Airframes	Work Centers[1]	0.33	per PAA	3	5	350	SF per Work Center	1,050	1,750
Avionics / Electricians (AT/AE)	Work Centers	0.33	per PAA	3	5	150		450	750
Avionics Vault	Storage Area	0.12	% of Avionics	1.0	1.0	20	% of Avionics room	90	150
Aviation Ordnance (AO)	Work Centers	0.33	per PAA	3	5	200	SF per Work center	600	1,000
Life Support (PR)[2]	Lockers	1.00	per Aircrew	18	24	45	SF per Aircrew	810	1,080
Line Operations	Work Centers	0.33	per PAA	3	5	200		600	1,000
Low Observability (LO) Maintenance	Work Centers	0.33	per PAA	3	5	150		450	750
Power Plant	Work Centers	0.33	per PAA	3	5	200	SF per Work Center	600	1,000
Seat & Canopy Maintenance / AME	Work Centers	1	per PAA	1	1	1000		1,000	1,000
Tool Room	Work Centers	0.33	per PAA	3	5	400		1,200	2,000
PMI Work Area	Each	1	per PAA	1	-	1000	SF per Room	1,000	1,000
Training Room	People	0.15	per Primary Shift	17	25	20	SF per Person	340	500
01 Shops Subtotal								**8,190**	**11,980**
MAINTENANCE ADMINISTRATION[3]									
Ordnance	People	1.00	per Room	1	1	90		90	90
Life Support (PR)	People	1.00	per Room	1	1	90		90	90
Division Office[4]	People	4.00	per Room	4	4	90	SF per Person	360	360
Maintenance Control Area	People	0.05	per Primary Shift	5	8	75		375	600
Maintenance Vault Room	Area	1.00	per Maintenance Control Area	-	-	20	% of Maintenance Control Room	75	120
Maintenance Admin Office	People	1.00	per Primary Shift	-	8	65		-	520
Maintenance Chief	People	1.00	per Room	1	1	90		90	90
Maintenance Officer	People	1.00	per Room	1		90		90	90
Maintenance/Material Control Officer (MCO/MMCO)	People	1	per Room	1	1	90	SF per Person	90	90
Quality Assurance Officer/Assistant	People	1.00	per Room	1	1	90		90	90
Quality Assurance/Quality Control (QA/QC)	People	9.00	per Room	5	8	75		375	600
01 Administration Subtotal								**1,725**	**2,740**
SUPPORT SPACES									
Storage	Room	1.00	per Aircraft	5	6	650	SF Per Aircraft in Hangar Bay	3,250	3,900
Breakroom	People	0.45	per Room	68	99	6	45% of Primary Shift X 6 SF	408	594
Duty/Bunk Room	People	1.00	per Room	1	1	125	SF per Room	125	125
Men's Locker Room[5]	People	0.70	per Room	80	118	4.5	70% of Maint Persons X 4.5 SF	360	531
Women's Locker Room[5]	People	0.30	per Room	34	50	5.5	30% of Maint Persons X 5.5 SF	187	275
01 Support Subtotal								**4,330**	**5,425**
NET 01 SPACE								**14,245**	**20,145**
GROSS 01 SPACE (Net-to-Gross Factor 1.38)								**19,658**	**27,800**

Notes: [1]A single Work Center equates to approximately 2-4 people and planning metric includes space (based on function) for computer desks, work tables/benches, storage, and circulation. [2] Includes flight equipment lockers and applicable work centers. [3] For maintenance administration area calculations, planners can use the 61010 guidance, which provides a maximum allowance of 162.5 GSF per person. [4] Includes Airframes officer, Avionics officer Powerplant officer, and Line officer. [5]Percentages for planning metrics need adjustment for male-female populations.

21105/06/07-2.3. **Category Code 211-07 – 02 Space.**

(1) One Type I standard hangar module 02 space will be planned for each standard size squadron with twelve to eighteen carrier aircraft.

(2) One half Type I standard hangar module 02 space will be planned for each standard size squadron with four to six carrier aircraft.

(3) One Type II standard hangar module 02 space will be planned for each standard size MV-22 squadron with ten to sixteen aircraft

(4) One Type II standard hangar module 02 space will be planned for each standard size squadron with six to twelve land based patrol aircraft.
(5) As with the aircraft, the personnel of all the other (non-standard) squadrons or units that operate aircraft, except FRS and other training squadrons, will be combined. The authorized 02 space will be computed at the rate of 3 m^2 (32.5 SF) per person for this combined total complement. Movable partitions within the 02 space will facilitate prorating of area for non-standard size squadrons and units.

(6) Squadrons operating with detachments such as the HSL squadrons are authorized an additional 19 m^2 (200 SF) of 02 space per detachment based on the average number of detachments on board.

(7) An additional 8 m^2 (80 SF) per squadron of 02 space is authorized for computer equipment room.

(8) The authorized 02 space for FRS and other training squadrons will be computed at the rate of 3 m^2 (32.5 SF) per permanent billet, less than the training department billets.

(9) The width of the 02 spaces shall not exceed the width of the computed number of OH modules; however, should the computed 02 space requirement exceed the 02 space available in the computed number of OH modules by twenty percent, authorization for deviations from standard hangar dimensions (see paragraph 1. Design Considerations) may be requested from Commander, Naval Air Systems Command (AIR-8.0Y1).

1. Design Considerations

In planning the authorized 01 and 02 spaces, the standard hangar modules shown in UFC 4-211-01, as updated, should be used whenever possible; however, due to the large diversity in the size of squadrons and other units, it is realized that deviations from the standard dimensions of 11.2 meters (36.8 feet) by 71.6 meters (235 feet) for Type I or 15.24 meters (50 feet) by 73.15 meters (240 feet) for Type II may be necessary.

2. Example

a. Background. A station supports 6 fleet operational F/A-18 squadrons. Each squadron has 12 aircraft and an average of 225 officers and enlisted. On average, one third of these squadrons are on extended deployment. In addition, the station supports an F/A-18A FRS operating 32 aircraft with an allowance of 600 officers and enlisted of which thirty-five are assigned to the training department. The squadron convenes 12 classes per year with 13 replacement pilots per class for a 24-week syllabus. Determine the number and type of maintenance hangars required to support these squadrons.

(1) The 6 fleet operational squadrons fit the criteria for standard size carrier type squadrons (12 to 18 carrier aircraft and 150 to 400 personnel); therefore, they each require one Type I hangar module. However, since one third of the squadrons normally are deployed, the station needs only 4 Type I modules to support the 6 squadrons.

(2) The FRS does not fit the criteria for any standard size squadron; therefore, its hangar requirements are determined using the criteria for non-standard squadrons.

Step 1. Determine RHW of O/H space. The F/A-18 is a carrier aircraft and requires one hangar space for every three aircraft. Total requirement is computed using the formula:

RHW = (N/3) x (W) + ((N/3) - 1) x (D) + 2 x SC

RHW = (32/3) x (8.38) + ((32/3) – 1) x (1.52) + 2 x (7.5)
RHW = (32/3) x (27.5) + ((32/3) –1) x (5) + 2 x (2.3)
RHW = 108.65 meters or two Type I modules (128.90 meters)
RHW = 356.47 feet or two Type I modules (424 feet)

Step 2. Determine required 01 space.

Personnel Allowance	600
Less Training Department Personnel	35
Total:	565

Space required for squadron personnel = (565) x (3) = 1,695 m^2 (18,363 SF)

Space required for line maintenance = 27.9 m^2 (300 SF)

Space for Mechanical/Electrical (AFFF) = 143 m^2 (1,536 SF)

Total 01 Space = 1,865.9 m^2 (20,199 SF)

Step 3. Determine required space 02.

Personnel Allowance	600
Less Training Department Personnel	35
	565

Space required for squadron personnel = (565) x (3) = 1,695 m^2 (18, 363 SF)

Space for Computer Equipment = 8 m^2 (80 SF)

Total 02 Space = 1,703 m^2 (18,443 SF)

Step 4. Determine required student support space.

Average student load =

$$\frac{(24 \text{ days}) \times (5 \text{ days/week}) \times (13 \text{ students}) \times (12 \text{ classes})}{(250 \text{ classroom days})} = 75$$

Total Training Area =75 Students x 12 m^2 = 900 m^2 (9,375 SF)

Note: Training Area can be located in the aircraft hangar, in a separate facility, or combined with the Operational Trainer Facility (Category Code 171 35) (Flight Simulator).

(10) Every unit requires dedicated administration and support spaces accessible by all personnel in the unit at the unclassified level. These spaces are generally allocated by square feet per person and are very similar to general administrative spaces found in other areas of a military installation. The administration and support areas are driven by the number of people in the squadron. The administration functions and support areas typically found in 02 space for a JSF squadron are listed in Table 21105-6. Depending on the PAA, more administration and support functions can be assigned to a squadron, in which case documentation must be provided for the additional space.

Table 21105-6
02 Space Calculations for F-35C and F-35B

CATEGORY	Unit	Unit Metric	Unit Factor	Each F-35C	Each F-35B	Planning Metrics		Space Req't (SF) F-35C	Space Req't (SF) F-35B
ADMINISTRATION									
Commanding Officer (CO)	People	1	per Room	1	1	200	SF per Person	200	200
Executive Officer (XO)	People	1	per Room	1	1	200	SF per Person	200	200
Senior Chief	People	1	per Room	1	1	150	SF per Person	150	150
Conference Room	Each	1	per Room	1	1	250	SF per Room	250	250
Reception/Waiting Area	Each	0.05	per Room	1	1	75	SF per Room	75	75
Administration Chief	People	1	per Room	1	1	110	SF per Person	110	110
Admin Personnel	People	6	per Room	4	6	90	SF per Person	360	540
Classified Material Control	People	1	per Room	1	1	110	SF per Person	110	110
Command Career Counselor	People	1	per Room	1	1	110	SF per Person	110	110
Family Readiness	People	1	per Room	1	1	110	SF per Person	110	110
Copy Room	Room	1	per Room	1	1	100	SF per Room	100	100
Flight Surgeon / Medical	People	2	per Room	2	1	100	SF per Physician (FC 2-000-05N, 61074)	200	100
Operations Administration	People	0.15	per Room	2	7	90	SF per Person	180	630
Operations Officer	People	1	per Room	1	1	110	SF per Person	110	110
Assistant Operations Officer	People	1	per Room	1	1	100	SF per Person	100	100
Scheduling	People	1	per Room	2	2	110	SF per Person	220	220
Intelligence Office	People	1	per Room	1	1	100	SF per Person	100	100
Logistics Staff	People	1	per Room	1	4	90	SF per Person	90	360
Logistics Officer	People	1	per Room	1	1	110	SF per Person	110	110
Safety Staff	People	1	per Room	2	3	90	SF per Person	180	270
Safety Officer	People	1	per Room	1	2	110	SF per Person	110	220
Information Systems	People	1	per Room	2	2	90	SF per Person	180	180
02 Administration Sub-total								**3,355**	**4,355**
OPERATIONS AND TRAINING									
Secured Operations Spaces 1	Work-spaces	20	per PAA	1	1	75	SF per workspace (flexible)	1,500	1,500
Secured Operations Spaces 2	Work-spaces	15	per PAA	1	1	100	SF per workspace (flexible)	1,500	1,500
Large Briefing Room(s)	People	1	per Room	2	3	300	SF per Room	600	900
Security Office	People	1	per Room	1	6	110	SF per Person	110	660
Secured Ready Room	People	1	per Pilot	18	24	35	SF per Person	630	840
Small Pilot Planning Rooms	Pilots	0.5	per Pilot	18	24	100	SF per Room	900	1,200
Server Room	Room	1	per PAA	1	1	750	SF per Squadron	750	750
Unisex Restroom	Each	1	per Room	1	1	75	SF per Restroom	75	75
02 Operations and Training Sub-total								**6,065**	**7,425**
SUPPORT SPACES									
First Lieutenant	People	0.10	per Room	1	-	90	SF per Room	90	-
Men's Locker Room[1]	People	0.70	per Room	25	37	4.5	70% of Off & Prof Persons X 4.5 SF	113	167
Breakroom	People	0.45	per Room	16	24	6	45% of Off & Prof Persons X 6 SF	96	144
Storage	Admin/Ops	0.03	per Room	1	1	3.0	% of Administration and Operations	283	353
Women's Locker Room[1]	People	0.30	per Room	11	16	5.5	30% of Off & Prof Persons X 5.5 SF	61	88
02 Support Sub-total								**642**	**752**
NET 02 SPACE								**10,062**	**12,532**
GROSS 02 SPACE (Net-to-Gross Factor 1.31)								**13,181**	**16,417**

Note: [1]Percentages for planning metrics need adjustment for male-female populations.

21105/06/07-2.4. **Type IV Unmanned Aircraft System Requirements.** The requirements of Unmanned Aircraft System (UAS) aircraft are unique and complex encompassing sensitive platform and functional space features. The current UAS aircraft is the MQ-4C Triton. The home basing plan for the Triton is four aircraft to a hangar.

OH Space

The Triton aircraft has a wingspan of 131 feet. The aircraft body, excluding the wings is five feet wide. The length of the aircraft is five feet. The length of the aircraft is 48 feet. All UAS aircraft must be kept in a hangar due to the sensitive components of the aircraft. The position of the aircraft is in two rows of two in the hangar bay. Two aircraft will be side by side and face the hangar door, and the other two aircraft will be in a position at the rear of the two rows of aircraft that face the hangar door.

Clearance Standards

The wingtip clearance between the aircraft is 30 feet. The clearance from the sides of the aircraft to the innermost protrusion from the hangar wall is 15 feet. The distance from the nose of the aircraft to the innermost protrusion of the hangar door is also 15 feet. The distance from the nose of the aircraft of the second row of aircraft to the tail of the first row of aircraft is 15 feet. The distance from the tail of the second aircraft to the innermost protrusion from the rear wall (usually power converters) is 15 feet.

01 and 02 Space

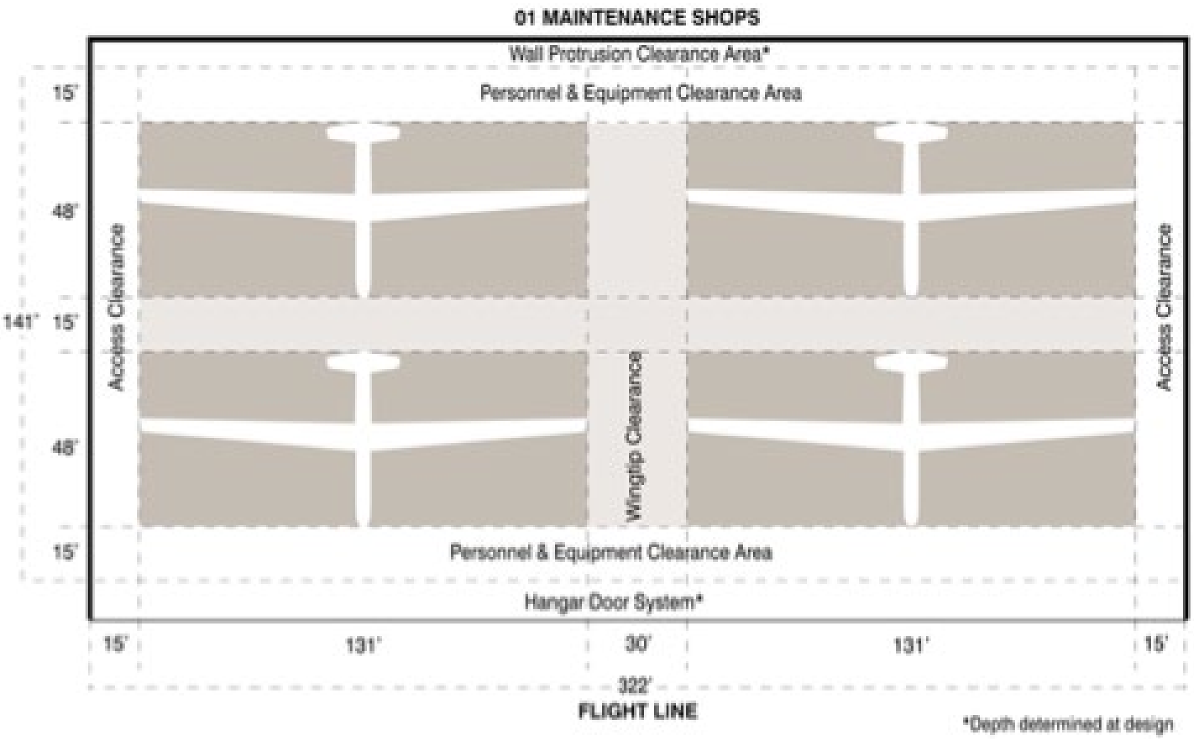
The planning factors for the 01 and 02 space requirements for a Triton hangar are shown in Table 7 and Table 8. The 01 and 02 space figures may differ due to the variation of rotational maintenance detachments for each installation location. The installation must contact CNAL/CNAP N2/N6 to obtain the most detailed information on the maintenance concept and personnel figures for a particular installation.

Table 211-05-2a
OH Space Navy Standard
MQ-4C Triton Model
Statistics Planning Purposes

CATEGORY	SPACE REQ'T		PLANNING METRICS	
Required Aircraft Parking Positions	**4**			
TOTAL WIDTH	322	LF		
Aircraft Width (131' X 2)	262	LF	131	Two adjacent aircraft
Total Wingtip Clearance	30	LF	30	Clearance between Aircraft
Access Clearance (2 X 15')	30	LF	15	Clearance from Side Wall (Unusable)
TOTAL DEPTH	141	LF		
Aircraft Length (48' X 2)	96	LF	48	Two aircraft nose to tail
Clearance to Hangar Door	15	LF	15	Innermost protrusion of hangar door
Nose to Tail Aircraft Clearance	15	LF	15	Clearance between column of two aircraft
Clearance of Aircraft to Rear Wall	15	LF	15	Back Wall Clearance (unusable)
NET OH SPACE	45,402	SFs		
GROSS AREA	50,850	SF	1.12	OH SPACE Net-to-Gross (NTG)

Key: Variable, depends on PAA and squadron (yellow) | Standard PAA and squadron (green) | Calculation (grey)

FIGURE 3. OH Space Diagram – MQ-4



C Triton

Table 21105-7
01 Space Calculations for MQ-4C Triton

CATEGORY	No. Work Centers	SF per Work Center	Space Req't (SF)
SHOPS			
Maintenance Control - Chief	9	100	900
Maintenance Control – Enlisted	8	60	480
Material Control – Officer	2	100	200
Material Control - Enlisted	9	60	540
Tool Room	3	400	1,200
Power Plants Shop (Aviation Mechanic Techs (AD))	3	175	525
Aviation Structural Mechanics (AM)	3	175	525
Aviation Electronics Techs (AT)	3	200	600
Aviation Electricians (AE)	3	200	600
Mission Control Systems Techs (MCS)	3	200	600
Plane Captains (PC) (Line Shack)	3	100	300
Shops Sub-total			6,470
SUPPORT			
Storage (transit case, secure, consumables)	1	1,300	1,300
Break Room	50	6	300
Male Locker Room	183	5	915
Female Locker Room	36	5	180
Printer Area	1	200	200
Security / Duty Office	1	120	120
Support Sub-total			3,015
Net 02 Space			9,485
Gross 01 Space (Net-to-Gross Ratio 1.38)			13,089

Table 21105-8
02 Space Calculations for MQ-4C Triton

CATEGORY	No. Work Centers	SF per Work Center	Space Req't (SF)
ADMINISTRATION, OPERATIONS, AND TRAINING			
Maintenance Officer	1	120	120
Maintenance Admin & Training - Chief	1	90	90
Maintenance Admin & Training - Enlisted	2	90	180
Quality Assurance & Safety - Officer	1	120	120
Quality Assurance & Safety - Chief	1	90	90
Quality Assurance & Safety - Enlisted	9	90	810
Administration - Chief	1	90	90
Administration - Enlisted	2	90	180
Personnel	3	90	270
1st Lieutenant	4	90	360
Operations	8	90	720
Pilots	4	90	360
Administration, Operations, and Training Sub-Total			3,390
SUPPORT			
Printer Area	1	200	200
SIPR Room	2	100	200
Break Room	40	6	240
Training Space	45	25	1,125
Training Storage	1	200	200
Secure Conference	10	40	400
Forward Operating Base Mission Control System	1	1,400	1,400
Visiting CO and CMC	2	120	240
Support Sub-Total			4,005
Net 01 Space			7,395
Gross 01 Space (Net-to-Gross Ratio 1.31)			9,687

211 08 AIRFRAMES SHOP (NON-NAVAIR DEPOT) (m^2 / SF)
FAC: 2112
BFR Required: Y

Design Criteria: UFC 4-211-01, Aircraft Maintenance Hangars

21108-1 **GENERAL.** An Airframes Division at the intermediate maintenance level is required at Navy and Marine Corps Air installations for the testing, maintenance and repair of airframes components. This section provides a method for determining the space requirements for this division.

The primary function of the airframes shop is to repair aircraft structural and hydraulic. It contains a Structures Branch, a Hydraulics/Pneumatics Branch, a Non-Destructive Inspection (NDI) Branch; and, if authorized by NAVAIRSYSCOM, an Electro-Plating/Anodizing Branch. The shop structure is shown in Table 21108-1. In addition to the specific shop structure shown, support space for material storage, administration, training, male and female locker and restrooms, and a mechanical equipment room.

In addition to the specific shop structure shown in Table 21108-1, other areas required within the Airframes Shop include support and training spaces. Typical support spaces would include personnel support (heads, locker rooms, cleaning gear storage, lounge, etc.), parts storage (parts awaiting maintenance (AWM), material awaiting parts (AWP), test equipment, tools not in use, storage for stock of sheet metal, tubing, hose, composite materials, consumable items, Pre-Expended Bin items, Hazardous Material, Hazardous Waste, and associated items), and specialized mechanical equipment spaces (HVAC, specialized environment control for paint shop to control temperature and humidity, specialized environment control for hydraulics shop for establishment of clean room environment, compressed air to most power tools, paint guns, and breathing apparatus). Typical training spaces may include a classroom.

Table 21108-1
Airframes Shop Structure

Branch Code	Shop Code	Function	Definition
500		**Airframes Division**	**Division supervision**
510		**Structures Division**	**Structures branch supervision**
	51A	Structures Shop	Repair and manufacture of structural components
	51B	Paint Shop	Paint and corrosion control
	51C	Welding Shop	Welding
	51D	Machine Shop	Machining of tools and manufacturing of parts
	51E	Tire/Wheel Shop	Tire replacement and wheel repair
	51F	Composites Shop	Repair of composite structural components
520		**Hydraulics/Pneumatics Branch**	**Hydraulics/Pneumatics branch supervision**
	52A	Hydraulics Shop	Repair and manufacture of hydraulics components
	52B	Brake Shop	Repair of brakes and components
	52C	Strut Shop	Repair of struts
530		**Non-Destructive Inspection (NDI) Branch**	**NDI branch supervision**
	53A	Radiography Shop	X-Ray inspection
	53B	Electrical/Chemical Shop	Electrical/Chemical inspection
540		**Electroplating/Anodizing Branch** ***(if authorized)***	**Electroplating/Anodizing of components**

To determine the square-meter (square-footage) requirements for a given installation, the number of aircraft of all types receiving maintenance support at that installation is totaled. This number is derived by determining the number of aircraft of all types assigned to the installation and subtracting out the number of aircraft normally deployed on ships or detached to another location. The sum is used to enter Column 1 of Table 21108-2, and the required basic area for the Airframes Shop is read in Columns 2 and 3. Table 21108-3 is then entered in order to determine if additional space is required. This area is added to the basic area from Table 21108-2 to provide the required Gross Area for the Airframes Shop. See the following example for a sample computation.

Table 21108-2
Basic Space Allowance for Airframes Shops

Column 1 Total Aircraft	Column 2 Basic Area (Square Meters)	Column 3 Basic Area (Square Feet)
Up to 75	1,283	13,800
76-100	1,422	15,300

Column 1 Total Aircraft	Column 2 Basic Area (Square Meters)	Column 3 Basic Area (Square Feet)
Column 1 Total Aircraft	Column 2 Basic Area (Square Meters)	Column 3 Basic Area (Square Feet)
101-125	1,571	16,900
126-150	1,710	18,400
151-175	1,850	19,900
176-200	1,989	21,400
201-225	2,119	22,800
226-250	2,259	24,300
251+	2,398	25,800

Note: An area of 1,283 m^2 (13,800 SF) is the smallest practical space for an Airframes Division with full capabilities. Some small IMAs may not be tasked to provide all airframes functions. Their space requirements shall be individually justified.

Table 21108-3
Special Space Allowance for Airframes Shops

Column 1 Special Requirement	Column 2 Additional Space (Square Meters)	Column 3 Additional Space (Square Feet)
F-14 Support (HCT-12 Equipment)	114	1,225
S-3 Support (Beryllium Brakes Maintenance)	51	550
E-2 Support (Vapor Cycle Maintenance)	57	610
Composite Shop (Note 1)	151	1,630
Electro-Plating/Anodizing Shop (Note 2)	63	680

Note 1: Required in support of AV-8, F/A-18, and SH-60 aircraft.
Note 2: Required only when authorized by COMNAVAIRSYSCOM IAW OPNAVINST 4790.2.

1. Example Computation

Number of Aircraft	Type
44	S-3
96	A-7
80	F/A-18
220	

In accordance with Table 211-08B, a total of 220 aircraft requires a basic area of 2,119 m^2 (22,800 SF). From Table 211-08C it is determined the S-3 support requires an additional 51 m^2 (550 SF) and the Composite Shop required for F/A-18 support adds an additional 151 m^2 (1,630 SF). This gives a gross area as follows:

Basic Area	-	2,119 m^2	22,800 SF
S-3 Support	-	51 m^2	550 SF
Composite Shop	-	151 m^2	1,630 SF
Gross Area	-	2,321 m^2	24,980 SF

211 09 AIRCRAFT BORESIGHT RANGE (NON- NAVAIR DEPOT) (EA)
FAC: 1791
BFR Required: Y

21109-1 **GENERAL.** One aircraft boresight range is required at Navy and Marine Corps air installations that service aircraft equipped with fixed guns or gun pods. One boresight range has the capacity to boresight and fire-in 40 such aircraft each month on a single shift basis. A requirement for more than one boresight range at any station must be individually justified. There are two (2) types of ranges:

1.) Type “A” Semi-Enclosed. The Type “A” range shall be located in proximity to taxiways, but special care must be taken to ensure that no visual obstruction occurs between the control tower and runways and taxiways. Due to noise generation and safety considerations, this facility shall be separated from inhabited structures and the station boundary by a minimum distance of 366 meters (1,200 feet).

2.) Type “B” Open. In addition to the location criteria listed above for a Type “A” range, the Type “B” range requires a danger zone area, 1,555 meters (1,700 yards) wide and 6,401 meters (7,000 yards) long.

Both the Type “A” and Type “B” boresight ranges shall have a length of 50.8 meters (2,000 inches) from the firing point of the aircraft to the target at the firing-in-butt.

Generally, a Type “A” range is used unless there is existing land or restricted water area available for the 6,401 meters (7,000 yard), 60-degree sector danger zone required by a Type “B” range. Prevailing winds shall be considered for orientation and noise abatement; however, where practicable, the boresight range should be oriented north and south to avoid firing toward the sun during early or late hours.

A taxiway, Category Code 112 10 is required for access to this facility. An aircraft parking apron with tie-downs, Category Code 113 20 is required to park and secure the aircraft during gun alignment.

In addition, a standard 12- by 20-foot line shelter is planned with this facility for crew shelter and storage of jacks and tiedown gear. See Category Code 211 15, Line Maintenance Shelter, for criteria.

211 10 AIRCRAFT OVERHAUL AND REPAIR SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21110-1 **GENERAL.** An Aircraft Overhaul and Repair Shop is required for the Airframe Production Shop of the Naval Air Depot (NAVAIR Depot). There are generally two types of aircraft overhaul and repair shops. One supports aircraft overhaul and repair of trainer aircraft, fighter aircraft, and helicopters and one supports aircraft overhaul and repair of cargo, transport, and patrol aircraft.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 11 CORROSION CONTROL – CLEANING SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21111-1 **GENERAL.** A Corrosion Control – Cleaning Shop is required to provide space for aircraft corrosion control and decontamination facilities designed for cleaning, paint stripping, etc., of the complete aircraft for the Airframe Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 12 PAINT AND FINISHING HANGAR (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21112-1 **GENERAL.** A Paint and Finishing Hangar is required for the Airframe Production Shop of the Naval Air Depot (NAVAIR Depot). This facility provides space to repaint an entire aircraft.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 13 AIRCRAFT NON-DESTRUCTIVE TESTING SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21113-1 **GENERAL.** An Aircraft Non-Destructive Testing Shop is required to provide space for the non-destructive inspection of airframes for the Airframe Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 14 AIRCRAFT REWORK SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21114-1 **GENERAL.** An Aircraft Rework Shop is required for the Airframe Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Airframe Dedicated Machine Shop
b. Airframe Dedicated Welding Shop
c. Airframe Dedicated Plating Shop
d. Airframe Examination and Evaluation, Pre-Shop Analysis and Examination and Inspection Shop
e. Maintenance Dock
f. Quick Engine Change Shop – Facility used for quick engine change and engine build-up including de-seal and re-seal operations.
g. Fuel Systems Maintenance Facility

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 15 LINE MAINTENANCE SHELTER (m^2 / SF)

FAC: 2112
BFR Required: Y

21115-1 **GENERAL.** Line maintenance shelters are required in support of aircraft located on aircraft parking aprons and at aircraft boresight ranges (Category Code 211 09). For aircraft located on the aircraft parking apron, they provide shelter for squadron line personnel awaiting aircraft that are ready for launch, returning from flight, or being serviced. For aircraft located at the aircraft boresight range, they provide crew shelter and storage for aircraft jacks and tiedown gear. For newer hangars, this requirement is included in the Aircraft Maintenance Hangar – 01 Space, Category Code 211 06 and as such included in the hangar. However, if space constraints exist in older hangars, or the aircraft parking apron is not in the immediate vicinity of the squadron hangar a line maintenance shelter will be provided. One (1) line maintenance shelter may be planned for each aircraft maintenance hangar module and one (1) for each aircraft boresight range.

The aircraft line maintenance shelter is 6.1 meters (20 feet) by 3.7 meters (12 feet) and is usually a portable facility that is planned as collateral equipment for the basic facility. Collateral equipment is not categorized as Class II real property and thus cannot be included in the real property inventory (RPI). However, this Category Code is being retained for real property inventory purposes since many of the existing facilities are not portable and accordingly must be reported in the Navy Facility Asset Data Base (NFADB).

For inventory purposes, the following guidance is provided:

a.) Line maintenance shelters directly associated with squadron line personnel awaiting aircraft that are readying for launch, returning from flight, or being serviced use Category Code 211 06, Aircraft Maintenance Hangar – 01 Space.

b.) Line maintenance shelters used at aircraft boresight ranges to provide crew shelter and storage for aircraft jacks and tiedown gear use this Category Code.

211 16 AIRCRAFT INTERMEDIATE MAINTENANCE ACTIVITY MANAGEMENT (NON-NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21116-1 **GENERAL.** Management space provides for the control, monitoring, and administration of the Intermediate Maintenance Activity (IMA). The Aircraft Maintenance Officer and staff are responsible for the administration and supervision of the maintenance effort for the IMA. These responsibilities include production control, material control, financial accounting, training, personnel, administration, quality control, technical publications library, data analysis, and tool control for common and special tools and test equipment. The Naval Aeronautical Engineering Services Unit staff and personnel perform In-Service Engineering Agent (ISEA) functions for aircraft and are often co-located in the same spaces. These functions and the specific requirements of each branch are defined by OPNAVINST 4790.2E (series) and are highlighted in Table 21116-1.

Table 21116-1
IMA Management

Branch Code	Shop Code	Function	Definition
010		Aircraft Maintenance Officer (AMO)	IMA Supervisory
01A		Assistant Aircraft Maintenance Officer (AAMO)	IMA Supervisory and Training
01S		AMO Secretary/Reception	Administration
011		Maintenance/Material Control Officer (MMCO)	Production/Material Control Supervisory
020		Production Control	Control of maintenance effort
030		Maintenance Administration	Administration, training, and personnel management of IMA
040		Quality Assurance	Quality Control
	04A	Technical Publication Library	Receipt, issue and storage of master copies of all publications used in the IMA
	04B	Ground Safety	IMA safety office
	04C	Data Analysis	Data gathering, analysis, and reporting. Also includes space for NALCOMIS master computers.
	04D	Quality Management/Verification	Quality Assurance Representatives office and files
050		Material Control	Receipt, issue, ordering, and technical support for all parts required by IMA
	05A	Material Screening	Receipt of all incoming parts to IMA, screening for reparability, issue to shop for repair, receipt from shop, and issue to Supply Dept.
	05B	Material Procurement/Accounting	Ordering and technical support for parts requested by shops. Financial accounting of all IMA accounts
	05C	Individual Material Requirements Readiness List (IMRL) Manager	Management of IMRL which includes all special tools, test equipment, support equipment, and associated items
	05D	Tool Control Center	Management of common hand tools
070		NAESU	Contractor and government technical instructors

Personnel requirements to meet these functions are not noticeably affected by aircraft loading. One size space will be provided for all IMAs. Provide 917 gross m^2 (9,875 GSF) for IMA management functions.

211 17 REGIONAL AIRCRAFT SERVICE FACILITY (m^2 / SF)
FAC: 2116
BFR Required: Y

21117-1 **DEFINITION.** During day-to-day aircraft operations, space often may be required to perform aircraft in-service repair (ISR), integrated maintenance (IMC/IMP), modifications (MOD) and other program work that may concurrently involve depot, intermediate, and organizational level work on aircraft by squadron, IMA, Naval Air Depot (NAVAIR Depot), and/or contractor personnel. When the existing organizational level spaces cannot accommodate the additional workload generated by ISR, IMC/P, and/or MOD and it is desirable to keep aircraft under local control, a separate facility will be required.

The Regional Aircraft Service Facility provides space to perform aircraft in-service repair (ISR), integrated maintenance (IMC/IMP), modifications (MOD) and other program work that may concurrently involve depot, intermediate, and organizational level work on aircraft by squadron, IMA, Naval Air Depot (NAVAIR Depot), and/or contractor personnel. Facility is comprised of High-Bay Maintenance Bays, Shop Area, and Administrative Support Space. Shop and Administrative Support areas will be limited to minimal required supporting current and projected programs.

Criteria for this Category Code are currently under development.

211 20 AIRCRAFT ENGINE OVERHAUL SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21120-1 **GENERAL.** An Engine Overhaul Shop is required to provide space associated with processing jet, turbojet, and reciprocating type aviation engines in terms of overhaul, low time repair, complete repair, and major inspection. The work functions performed within this space include un-canning, disassembly, cleaning, material examination, parts reconditioning, subassembly, final assembly and preservation.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 21 ENGINE MAINTENANCE SHOP (NON-NAVAIR DEPOT) (m^2 / SF)
FAC: 2112
BFR Required: Y

21121-1 **GENERAL.** An Engine Maintenance Shop provides space for all work centers within the Power Plants Division of an Intermediate Level Maintenance Activity (IMA). The CNO and the CMC assign aircraft maintenance tasks and responsibilities to activities of Naval operating/Training Forces and Fleet/non-Fleet Marine Forces. The NAVAIRSYSCOM, through the NAVAIRNOTE 4700, assigns maintenance tasks and responsibilities for Gas Turbine Engines. Individual IMAs will only be allocated the space required to perform maintenance on the engines, equipment or components authorized for repair at that activity by higher authority, (i.e., NAVAIR/Type Commanders). The authorized work centers may be obtained by the use of Individual Component Repair List (ICRL) for the given IMA.

The Power Plants or Aircraft Engine Maintenance Shop is required to maintain the aircraft engine and associated components. The primary function is to repair aircraft engines, engine components, propellers, rotors, auxiliary power units (APUs), and auxiliary fuel and refueling stores. It contains a Jet Engine Branch, Reciprocating Engine Branch, Propeller Branch, Rotor Dynamics Branch, Test Cell Branch, Auxiliary Fuel Stores Branch, and Navy Oil Analysis Program Laboratory. The shop structure is shown in Table 21121-1.

Table 21121-1
Aircraft Engine Maintenance Shop Structure

Branch Code	Shop Code	Function	Definition
400		**Power Plants Division**	**Division supervision**
410		**Jet Engine Division**	**Jet Engine Branch supervision**
	51A	Structures Shop	Repair and manufacture of structural components
	51B	Paint Shop	Paint and corrosion control
	51C	Welding Shop	Welding
	51D	Machine Shop	Machining of tools and manufacturing of parts
	51E	Tire/Wheel Shop	Tire replacement and wheel repair
	51F	Composites Shop	Repair of composite structural components
420		**Reciprocating Engine Branch**	**Repair of reciprocating engines**
	52A	Hydraulics Shop	Repair and manufacture of hydraulics components
	52B	Brake Shop	Repair of brakes and components
	52C	Strut Shop	Repair of struts
430		**Propeller Branch**	**Repair of aircraft propellers**
	53A	Radiography Shop	X-Ray inspection
	53B	Electrical/Chemical Shop	Electrical/Chemical inspection

Branch Code	Shop Code	Function	Definition
440		**Rotor Dynamics Branch**	**Repair of helicopter rotor and associated components**
450		**Test Cell Branch**	**Supervisory, scheduling, and maintenance for Test Cell operation**
460		**Auxiliary Fuel Stores Branch**	
470		**Navy Oil Analysis Program Laboratory**	
480		**Welding Shop**	

Table 21121-1 lists the space requirements for the main engine work area (high bay) for first and second degree engine maintenance for supported number of a given type of aircraft. The following data items were taken into consideration to arrive at the listed space requirements:

1. Size of engine
2. Number of engines per aircraft
3. Number, type and size of required maintenance stands
4. Work benches
5. Work center administrative and storage area
6. Fire lane/aisle space
7. Mean flight hours between failures (MFHBF) of engines requiring removal to an IMA.
8. Average turnaround time (TAT) of engine in IMA
9. Flight hours between inspections (FHBI)
10. Elapsed inspection time (EIT)
11. Quick engine change assembly (QECA) elapsed build up time (EBT)
12. Aircraft monthly utilization

Table 21121-2 lists the percentage factor of the sum total from Table 21121-1 to determine the additional space required for division administration, utilities and other support functions such as supply support, welding and cleaning shops. These spaces are normally provided in shop wing and/or mezzanine areas.

Table 21121-3 lists the space requirements of additional work centers required for applicable components within the Power Plants Division, if authorized by higher authority to be supported at a given IMA. These spaces may be housed in the high bay area or in a separate building/location.

Note: Though more than one type of the aircraft supported may have the same basic component, only one work center will be required.

Example: F-18 and AV-8 both have an Auxiliary Power Plant (APU); however, only one APU work center will be required.

Table 21121-4 list the space requirements in the main engine work area (high bay) for situations where an AIMD is assigned repair responsibilities for a predetermined number of given type engines not related to those generated by the aircraft directly supported.

To establish space requirements for the Power Plant Division, add the space required for the given numbers of each type aircraft supported from Table 21121-1 and space computed from Table 21121-4. Add to this the additional percentage of space authorized from Table 21121-2 and the additional authorized space from Table 21121-3.

Note: At most installations there are aircraft assigned in support roles, i.e. helicopters or utility type aircraft. These are not computed in the space requirements as they are normally supported by other designated IMAs or depot level activities.

Example Computation – Power Plants Division Shop Space Allowance using an aircraft mix of 44 A-6, 84 F-18, 62 P-3, 23 H-46 and 40 TF-30 engines.

From Table 21121-1

	No. A/C	Type A/C	Area (m^2)	Area (SF)
	44	A-6	648	6,975
	84	F-18	1,057	11,375
	62	P-3	630	6,775
	23	H-46	109	1,175
Subtotal			2,444 m^2	26,300 SF

From Table 21121-4

No. Eng.	Factor (m^2)	Factor (SF)	Area (m^2)	Area (SF)
40	7	76	280	3,040

Total 21121-1 and 21121-4

2,724 m^2
29,340 SF

From Table 21121-2

2,724 m^2. x 44% = 1,199 m^2
29,340 SF x 44% = 12,910 SF

Total space requirements from Tables 21121-1 and 21121-4 allow up to 2,724 m^2 (29,340 SF) for the high bay area. Table 21135-2 allows up to 1,199 m^2 (12,910 SF) which is 44% of the high bay area for shop wing/mezzanine space.

Table 21121-1		2,724	m^2
and 21121-4		29,340	SF
Table 21135-2	(44% of 2,724 m^2)	1,199	m^2
	(44% of 29,340 SF)	12,910	SF
Subtotal = 3,923			m^2
42,210			SF

3,923 m^2 (42,210 SF) constitutes the primary Power Plants Division. If authorized by higher authority, additional applicable work center space requirements from Table 21121-3 shall be added.

From Table 21121-3

	A-6	F-18	P-3	H-46				
Propeller			X		272	m^2	2,925	SF
APU		X	X	X	167	m^2	1,800	SF
Rotor Dynamics				X	314	m^2	3,375	SF
Aux. Fuel Stores	X	X			314	m^2	3,375	SF
					1,067	m^2	11,475	SF

Note: Only one work center of each type is required.

Table 21121-1
Space Allowance for Engine Maintenance Shop

A-4 J-52			A-6 J-52			A-7 TF-41			F-4 J79		
No. A/C	**Area (m^2)**	**Area (SF)**	**No. A/C**	**Area (m^2)**	**Area (SF)**	**No. A/C**	**Area (m^2)**	**Area (SF)**	**No. A/C**	**Area (m^2)**	**Area (SF)**
1-9	86	925	1-8	137	1,475	1-10	184	1,975	1-8	184	1,975
10-19	137	1,475	9-16	239	2,575	11-21	332	3,575	9-17	332	3,575
20-28	188	2,025	17-24	342	3,675	22-32	481	5,175	17-24	481	5,175
29-38	239	2,575	25-32	444	4,775	33-42	630	6,775	25-32	630	6,775
39-47	290	3,125	33-40	546	5,875	43-53	778	8,375	33-40	778	8,375
48-57	342	3,675	41-48	648	6,975	54-63	927	9,975	41-49	927	9,975
58-66	393	4,225	49-56	751	8,075	64-74	1,076	11,575	50-57	1,076	11,575
67-76	444	4,775	57-64	853	9,175	75-85	1,225	13,175	58-65	1,225	13,175
No. A/C	**Area (m^2)**	**Area (SF)**	**No. A/C**	**Area (m^2)**	**Area (SF)**	**No. A/C**	**Area (m^2)**	**Area (SF)**	**No. A/C**	**Area (m^2)**	**Area (SF)**

A-4 J-52			A-6 J-52			A-7 TF-41			F-4 J79		
77-85	495	5,325	65-72	955	10,275	86-95	1,373	14,775	66-73	1,373	14,775
86-95	546	5,875	73-80	1,057	11,375	96-106	1,522	16,375	74-81	1,522	16,375
96-104	597	6,425	81-88	1,160	12,475	107-116	1,671	17,975	82-89	1,671	17,975
105-114	648	6,975	89-96	1,262	13,575	117-127	1,820	19,575	90-98	1,820	19,575
115-123	699	7,525	97-104	1,364	14,675	128-135	1,968	21,175	99-106	1,968	21,175
124-133	751	8,075	105-112	1,466	15,775	136-148	2,117	22,775	107-114	2,117	22,775
134-142	802	8,625	113-120	1,568	16,875	149-150	2,191	23,575	115-122	2,266	24,375
143-150	853	9,175	121-128	1,671	17,975				123-130	2,414	25,975
			129-136	1,773	19,075				131-138	2,563	27,575
			137-145	1,875	20,175				139-150	2,712	29,175
			146-150	1,926	20,725						

Table 21121-1 (Continued)
Space Allowance for Engine Maintenance Shop

F-14 TF-30			F-18 F404			H-1 T400			H-2 T58		
No.A/C	Area (m^2)	Area (SF)	No.A/C	Area (m^2)	Area (SF)	No.A/C	Area (m^2)	Area (SF)	No.A/C	Area (m^2)	Area (SF)
1-8	184	1,975	1-8	137	1,475	1-16	72	775	1-6	109	1,175
9-17	332	3,575	9-17	239	2,575	17-33	109	1,175	7-12	184	1,975
18-26	481	5,175	18-25	342	3,675	34-49	146	1,575	13-19	258	2,775
27-35	630	6,775	26-34	444	4,775	50-66	184	1,975	20-25	332	3,575
36-44	778	8,375	35-43	546	5,875	67-83	221	2,375	26-32	407	4,375
45-53	927	9,975	44-51	648	6,975	84-99	258	2,775	33-38	481	5,175
54-62	1,076	11,575	52-60	751	8,075	100-116	295	3,175	39-45	555	5,975
63-71	1,225	13,175	61-69	853	9,175	117-133	332	3,575	46-51	630	6,775
72-79	1,373	14,775	70-77	955	10,275	134-150	369	3,975	52-57	704	7,575
80-88	1,522	16,375	78-86	1,057	11,375				58-64	778	8,375
89-97	1,671	17,975	87-94	1,160	12,475				65-70	853	9,175
98-106	1,820	19,575	95-103	1,262	13,575				71-77	927	9,975
107-115	1,968	21,175	104-112	1,364	14,675				78-83	1,002	10,775
116-124	2,117	22,775	113-121	1,466	15,775				84-90	1,076	11,575
125-133	2,266	24,375	122-129	1,569	16,875				91-96	1,150	12,375
134-142	2,414	25,975	130-138	1,671	17,975				97-102	1,225	13,175
143-150	2,563	27,575	139-147	1,773	19,075				103-115	1,373	14,775
			148-150	1,829	19,675				116-128	1,522	16,375
									129-141	1,671	17,975
									142-150	1,782	19,175

Table 21121-1 (Continued)
Space Allowance for Engine Maintenance Shop

H-3 T58			H-46 T58			H-53 T64			H-60 T700		
No.A/C	Area (m^2)	Area (SF)	No.A/C	Area (m^2)	Area (SF)	No.A/C	Area (m^2)	Area (SF)	No.A/C	Area (m^2)	Area (SF)
1-8	109	1,175	1-21	72	775	1-6	86	925	1-9	72	775
H-3 T58			H-46 T58			H-53 T64			H-60 T700		
No.A/C	Area (m^2)	Area (SF)	No.A/C	Area (m^2)	Area (SF)	No.A/C	Area (m^2)	Area (SF)	No.A/C	Area (m^2)	Area (SF)
9-16	184	1,975	22-42	109	1,175	7-12	137	1,475	10-18	109	1,175
17-24	258	2,775	43-64	146	1,575	13-18	188	2,025	19-28	146	1,575
25-32	332	3,575	65-85	184	1,975	19-24	239	2,575	29-37	184	1,975
33-41	407	4,375	86-107	221	2,375	25-30	290	3,125	38-47	221	2,375
42-49	481	5,175	108-128	258	2,775	31-36	342	3,675	48-56	258	2,775
50-57	555	5,975	129-150	295	3,175	37-42	393	4,225	57-65	295	3,175
58-65	630	6,775				43-48	444	4,775	66-75	332	3,575
66-74	704	7,575				49-54	495	5,325	76-84	369	3,975
75-82	778	8,375				55-60	546	5,875	85-94	407	4,375
83-90	853	9,175				61-66	597	6,425	95-103	444	4,775
91-98	927	9,975				67-72	648	6,975	104-113	481	5,175
99-106	1,002	10,775				73-78	699	7,5	114-122	518	5,575
107-115	1,076	11,575				79-85	751	8,075	123-131	555	5,975
116-123	1,150	12,375				86-91	802	8,625	132-141	593	6,375
124-131	1,225	13,175				92-103	904	9,725	142-150	630	6,775
132-139	1,299	13,975				104-115	1,006	10,825			
140-148	1,373	14,775				116-127	1,108	11,925			
149-150	1,411	15,175				128-139	1,211	13,025			
						140-150	1,313	14,125			

Table 21121-1 (Continued)
Space Allowance for Engine Maintenance Shop

C-2 T56		
No.A/C	Area (m^2)	Area (SF)
1-19	109	1,175
20-39	184	1,975
40-58	258	2,775
59-78	332	3,575
79-97	407	4,375
98-117	481	5,175
118-136	555	5,975
137-150	630	6,775

E-2 T56		
No.A/C	Area (m^2)	Area (SF)
1-39	109	1,175
40-78	184	1,975
79-116	258	2,775
117-150	332	3,575

C-130 T56		
No.A/C	Area (m^2)	Area (SF)
1-10	184	1,975
11-20	332	3,575
21-30	481	5,175
31-41	630	6,775
42-51	778	8,375
52-61	927	9,975
62-71	1,076	11,575
72-82	1,225	13,175
83-92	1,373	14,775
93-102	1,522	16,375
103-112	1,671	17,975
113-123	1,820	19,575
124-133	1,968	21,175
134-143	2,117	22,775
144-150	2,266	24,375

P-3 T56		
No.A/C	Area (m^2)	Area (SF)
1-8	109	1,175
9-16	184	1,975
17-24	211	2,275
25-32	332	3,575
33-40	407	4,375
41-48	481	5,175
49-57	555	5,975
58-65	630	6,775
66-73	704	7,575
74-81	778	8,375
82-89	853	9,175
90-97	927	9,975
98-106	1,002	10,775
107-114	1,076	11,575
115-122	1,150	12,375
123-130	1,225	13,175
131-138	1,299	13,975
139-146	1,373	14,775
147-150	1,448	15,575

S-3 TF34		
No.A/C	Area (m^2)	Area (SF)
1-6	86	925
7-13	137	1,475
14-19	188	2,025
20-26	239	2,575
27-32	290	3,125
33-39	342	3,675
40-45	393	4,225
46-52	444	4,775
53-59	495	5,325
60-65	546	5,875
66-72	597	6,425
73-78	648	6,975
79-85	699	7,525
86-91	751	8,075
92-98	802	8,625
99-105	853	9,175
106-111	904	9,725
112-124	1,006	10,825
125-137	1,108	11,925
138-142	1,211	13,025
143-150	1,313	14,125

Table 21121-1 (Continued)
Space Allowance for Engine Maintenance Shop

AV-8 F402			OV-10 T76			TA-4 J52			TH-1 T53		
No.A/C	Area (sq.m)	Area (SF)	No.A/C	Area (sq.m)	Area (SF)	No.A/C	Area (sq.m)	Area (SF)	No.A/C	Area (sq.m)	Area (SF)
1-11	258	2,775	1-8	72	775	1-7	86	925	1-26	72	775
12-22	481	5,175	9-16	109	1,175	8-15	137	1,475	27-53	109	1,175
23-33	704	7,575	17-24	146	1,575	16-23	188	2,025	54-80	146	1,575
34-45	927	9,975	25-32	184	1,975	24-30	239	2,575	81-107	184	1,975
46-56	1150	12,375	33-40	221	2,375	31-38	290	3,125	108-134	221	2,375
57-67	1373	14,775	41-49	258	2,775	39-46	342	3,675	135-150	258	2,775
68-78	1596	17,175	50-57	295	3,175	47-54	393	4,225			
79-90	1820	19,575	58-65	332	3,575	55-61	444	4,775			
91-101	2043	21,975	66-73	369	3,975	62-69	495	5,325			
102-112	2266	24,375	74-81	407	4,375	70-77	546	5,875			
113-123	2489	26,775	82-90	444	4,775	78-84	597	6,425			
124-135	2712	29,175	91-98	481	5,175	85-92	648	6,975			
136-146	2935	31,575	99-106	518	5,575	93-100	699	7,525			
147-150	3158	33,975	107-114	555	5,975	101-108	751	8,075			
			115-122	593	6,375	109-115	802	8,625			
			123-130	630	6,775	116-123	853	9,175			
			131-139	667	7,175	124-131	904	9,725			
			140-147	704	7,575	132-138	955	10,275			
			148-150	741	7,975	139-146	1006	10,825			
						147-150	1057	11,375			

Table 21121-1 (Continued)
Space Allowance for Engine Maintenance Shop

TH-57 T63			T2C J85			T-34C PT-6			T-39D J60		
No.A/C	Area (sq.m)	Area (SF)	No.A/C	Area (sq.m)	Area (SF)	No.A/C	Area (sq.m)	Area (SF)	No.A/C	Area (sq.m)	Area (SF)
1-15	53	575	1-7	109	1,175	1-6	72	775	1-6	137	1,475
16-30	72	775	8-14	184	1,975	7-13	109	1,175	7-13	239	2,575
31-45	91	975	15-22	258	2,775	14-20	146	1,575	14-20	342	3,675
46-60	109	1,175	23-29	332	3,575	21-27	184	1,975	21-27	444	4,775
61-75	128	1,375	30-37	407	4,375	28-33	221	2,375	28-34	546	5,875
76-90	146	1,575	38-44	481	5,175	34-40	258	2,775	35-41	648	6,975
91-105	165	1,775	45-52	555	5,975	41-47	295	3,175	42-48	751	8,075
106-120	184	1,975	53-59	630	6,775	48-54	332	3,575	49-55	853	9,175
121-135	202	2,175	60-67	704	7,575	55-60	369	3,975	56-62	955	10,275
136-150	221	2,375	68-74	778	8,375	61-67	407	4,375	63-68	1,057	11,375
			75-82	853	9,175	68-74	444	4,775	69-75	1,160	12,475
			83-89	927	9,975	75-81	481	5,175	76-82	1,262	13,575
			90-97	1,002	10,775	82-88	518	5,575	83-89	1,364	14,675
			98-104	1,076	11,575	89-94	555	5,975	90-96	1,466	15,775
			105-111	1,150	12,375	95-101	593	6,375	97-103	1,569	16,875
			112-119	1,225	13,175	102-108	630	6,775	104-110	1,671	17,975
			120-126	1,299	13,975	109-115	667	7,175	111-117	1,773	19,075
			127-134	1,373	14,775	116-121	704	7,575	118-124	1,875	20,175
			135-141	1,448	15,575	122-135	778	8,375	125-137	2,080	22,375
			142-150	1,522	16,375	136-150	853	9,175	138-150	2,284	24,575

Table 21121-1 (Continued)
Space Allowance for Engine Maintenance Shop

T-44A PT-6		
No.A/C	Area (sq.m)	Area (SF)
1-8	109	1,175
9-16	184	1,975
17-24	258	2,775
25-33	332	3,575
34-41	407	4,375
42-49	481	5,175
50-57	555	5,975
58-66	630	6,775
67-74	704	7,575
75-83	778	8,375
84-91	853	9,175
92-99	927	9,975
100-108	1,002	10,775
109-116	1,076	11,575
117-124	1,150	12,375
125-132	1,225	13,175
133-141	1,299	13,975
142-150	1,373	14,775

Table 21121-2
Additional Space Requirements

m^2	SF	Percentage	m^2	SF	Percentage
Up to 1,394	Up to 15,000	50%	3,021 – 3,253	32,501 – 35,000	42%
1,395 – 1,626	15,001 – 17,500	49%	3,254 – 3,485	35,001 – 37,500	41%
1,627 – 1,859	17,501 – 20,000	48%	3,486 – 3,718	37,501 – 40,000	40%
1,860 – 2,091	20,001 – 22,500	47%	3,719 – 3,950	40,001 – 42,500	39%
2,092 – 2,323	22,501 – 25,000	46%	3,951 – 4,182	42,501 – 45,000	38%
2,324 – 2,556	25,001 – 27,500	45%	4,183 – 4,415	45,001 – 47,500	37%
2,557 – 2,788	27,501 – 30,000	44%	4,416 – 4,647	47,501 – 50,000	36%
2,789 – 3,020	30,001 – 32,500	43%	4,648 and Up	50,001 and Up	35%

Table 21121-3
Support Work Centers

Group	Work Area	Aircraft	Adjustment (m^2)	Adjustment (SF)
A.	Auxiliary Fuel Stores	A-4, A-6, A-7,F-4, F-14, F-18	314	3,375
B.	Auxiliary Power Units	C-2, C-130, E-2, F-18, H-46, H-53, H-60, P-3, S-3, AV-8	167	1,800
C.	Propellers	C-2, C-130, E-2, P-3, T-34, OV-10	272	2,925
D.	Rotor Dynamics	H-1, H-2, H-3, H-46, H-53, H-60	314	3,375

Table 21121-4
Space Allowance for Additional Engines Processed

Type Engine	Factor (m^2)	Factor (SF)
J-52	7	77
J-79	12	126
F-404	5	54
T-58	4	46
T-700	4	44
TF-34	5	52
T-76	4	43
PT-6	4	40
T-53	3	30

Type Engine	Factor (m^2)	Factor (SF)
TF-41	10	112
TF-30	7	76
T-400	4	48
T-64	9	92
T-56	6	65
F-402	12	130
J-85	5	51
J-60	5	54
T-63	2	21

To calculate the required work space, multiply the factor by the number of engines projected to be processed in a 12 month period, add this to the existing work area from Table 211-21A and apply Table 211-21B.

If a new Work Center is established, the minimum area should be 2,000 Sq.ft.

Pavement is provided for outside storage of engines in sealed containers calculated at 25 percent of the gross building area.

211 22 ENGINE PREPARATION AND STORAGE SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21122-1 **GENERAL.** An Engine Preparation and Storage Shop is required provide space used in preparing engines for test, storage or shipment for the Engine Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 23 ENGINE EXAMINATION AND EVALUATION SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21123-1 **GENERAL.** An Engine Examination and Evaluation Shop is required for the Engine Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Engine Non-Destructive Testing Shop
b. Engine Examination and Evaluation, Pre-Shop Analysis, Examination and Inspection Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 24 DEDICATED AIRCRAFT ENGINE OVERHAUL – GENERAL PROCESS (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21124-1 **GENERAL.** A Dedicated Aircraft Engine Overhaul – General Process Shop is required for the Engine Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Engine Dedicated Cleaning Shop
b. Engine Dedicated Paint Shop
c. Engine Dedicated Machine Shop
d. Engine Dedicated Plating Shop
e. Engine Dedicated Welding Shop
f. Engine Modification and Repair Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 25 JET ENGINE OVERHAUL SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21125-1 **REQUIREMENT.** A Jet Engine Overhaul Shop is required for the Engine Production Shop of the Naval Air Depot (NAVAIR Depot).

211 26 RECIPROCATING ENGINE OVERHAUL SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21126-1 **REQUIREMENT.** A Reciprocating Engine Overhaul Shop is required for the Engine Production Shop of the Naval Air Depot (NAVAIR Depot).

211 27 TURBINE ENGINE OVERHAUL SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21127-1 **REQUIREMENT.** A Turbine Engine Overhaul Shop is required for the Engine Production Shop of the Naval Air Depot (NAVAIR Depot).

211 30 AIRCRAFT AND ENGINE ACCESSORIES OVERHAUL SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21130-1 **REQUIREMENT.** An Aircraft and Engine Accessories Overhaul Shop is required to provide space for the overhaul and testing of miscellaneous accessories such as control assemblies, engine fuel system components, and accessories gear drive for the Accessories and Components Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 31 DEDICATED AIRCRAFT AND ENGINE ACCESSORIES OVERHAUL – GENERAL PROCESS (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21131-1 **GENERAL.** A Dedicated Aircraft and Engine Accessories Overhaul – General Process Shop is required for the Accessories and Components Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Accessories and Components Dedicated Cleaning Shop
b. Accessories and Components Dedicated Paint Shop
c. Accessories and Components Dedicated Machine Shop
d. Accessories and Components Dedicated Plating Shop
e. Accessories and Components Dedicated Welding Shop
f. Examination and Evaluation, Pre-Shop Analysis, examination and Inspection Shop
g. Hazardous Test Shop – This facility is used to test a portion of the accessory items overhauled. Because of the volatile fluid with which they are tested or the hazardous conditions of testing, the test area must be rigidly controlled. Items such as fuel pumps, fuel controls, etc. are worked in this area.
h. Reclamation Shop – Facility for removal of useable parts from defective end item components.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 32 METAL COMPONENTS SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21132-1 **GENERAL.** A Metal Components Shop is required for the Accessories and Components Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Tank and Radiator Repair Shop – Facility to repair all types of radiators, inter-coolers and metal tanks.
b. Sheet Metal Shop – Facility for repair of surface sheet metal parts.
c. Metal Surface Shop – Facility for repair of wings, doors, stabilizers, tail booms, control surfaces, etc.
d. Seat Repair Shop.
e. Metal Bonding Shop.
f. Container Reclamation Shop – Facility for repair of engine, transmission, rotor blade and other type metal containers.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 33 NON-METAL COMPONENTS SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21133-1 **GENERAL.** A Non-Metal Components Shop is required for the Accessories and Components Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Life Raft Repair Shop – Facility to repair inflatable life vests, dinghies, etc..
b. Rubber Repair Shop – Facility for the repair of rubber equipment such as aircraft fuel cells and molded rubber products.
c. Parachute Repair Shop – Facility for repair of parachutes, aerial pickup gear, etc.
d. Fabric and Upholstery Shop.
e. Tire Repair Shop.
f. Plastic and Fiberglass Shop – Facility for the repair of fiberglass and reinforced plastic items such as radomes, wingtips, ducts, covers, canopies, hatches and windows.
g. Composite Rework Shop.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 34 DYNAMIC COMPONENTS SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21134-1 **GENERAL.** A Dynamic Components Shop is required for the Accessories and Components Production Shop of the Naval Air Depot (NADEP). Included within this Category Code are:

a. Propeller and Propeller Control Overhaul Shop
b. Rotor Head Overhaul Shop
c. Rotor Blade Overhaul Shop
d. Transmission/Gearbox Overhaul Shop
e. Dynamic Drive System Overhaul Shop – Facility used for the repair of drive shafts, pitch links, swash plates, etc..

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 35 HYDRAULIC COMPONENTS SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21135-1 **GENERAL.** A Hydraulic Components Shop is required for the Accessories and Components Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

A. Hydraulic Components Overhaul Shop
B. Bearings Shop - Specialized shop in which bearings are cleaned, disassembled, inspected, reassembled and tested.
C. Aircraft Landing Gear Shop - Facility used for the repair and overhaul of aircraft landing gear components such as wheels, brakes, and struts.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 36 ELECTRICAL COMPONENTS SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21136-1 **GENERAL.** An Electrical Components Shop is required for the Accessories and Components Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Alternator Drive Overhaul Shop
b. Electrical Accessories Overhaul and Test Shop – Facility used in the overhaul and test of electrical components including electrical systems, starters, control equipment and converters, etc..
c. Battery Shop – Facility for the repair and test of aircraft batteries.
d. Constant Speed Drive Shop
e. Electro-Mechanical Components Shop – Facility used to repair Electro-Mechanical actuators, cargo and rescue hoists, etc.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 37 TURBINE ACCESSORIES SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21137-1 **GENERAL.** A Turbine Accessories Shop is required for the Accessories and Components Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Turbine Accessories Overhaul Shop – Facility for overhaul of air compressor type equipment, such as air turbine starters, air conditioning packs, and air driven motors.
b. Turbine Accessories Test Shop
c. General Purpose Units Shop – Facility for the overhaul and repair of gas/air turbine engines and auxiliary power units, installed on the aircraft other than its' primary propulsion unit.
d. General Purpose Units Tests Shop
e. Ram/Air Turbine Accessories Overhaul Shop – Facility used for the overhaul of air driven accessories such as ram air turbines and scoops.
f. Ram/Air Turbine Accessories Test Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 38 PNEUMATIC OXYGEN SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21138-1 **GENERAL.** A Pneumatic Oxygen Shop is required for the Accessories and Components Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Pneumatic Components Overhaul Shop
b. Cryogenics Shop
c. Oxygen Equipment Shop – Facility used for repair of oxygen regulators, converters, etc.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 39 OPTICAL AND PHOTOGRAPHIC COMPONENTS SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21138-1 GENERAL. An Optical and Photographic Components Shop is required for the Accessories and Components Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Photographic Equipment Repair Shop – Facility for the repair of aircraft cameras and other photographic items.
b. Optical Component Repair Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 40 ELECTRONICS, COMMUNICATION, AND ARMAMENT SYSTEM SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21140-1 **GENERAL.** An Electronics, Communication, and Armament System Shop is required to provide space associated with processing airborne communication and navigation equipment, instruments, airborne data computers, fire control and bombing system equipment, gyroscopes, inertial guidance systems, and other avionics equipment.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 41 DEDICATED ELECTRONICS, COMMUNICATION, AND ARMAMENT – GENERAL PROCESS SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21141-1 **GENERAL.** A Dedicated Electronics, Communication, and Armament – General Process Shop is required for the Electronic, Communication, and Armament Systems Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Electronics, Communication, and Armament Systems Dedicated Cleaning Shop
b. Electronics, Communication, and Armament Systems Dedicated Paint Shop
c. Electronics, Communication, and Armament Systems Dedicated Machine Shop
d. Electronics, Communication, and Armament Systems Dedicated Welding Shop
e. Electronics, Communication, and Armament Systems Dedicated Plating Shop
f. Electronics, Communication, and Armament Systems Dedicated Plating Shop
g. Electronics, Communication, and Armament Systems Dedicated Bearings Shop
h. Instrument Overhaul Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 42 ELECTRONIC SYSTEM COMPONENTS SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21142-1 **GENERAL.** An Electronic System Components Shop is required for the Electronic, Communication, and Armament Systems Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Armament and Avionics Shop – Facility for the repair of navigational missile and bombing radar, electronic countermeasure equipment, flight facilities and communication equipment, electronic instruments, and fire control systems.
b. Airborne Systems Software Shop – Facility for the preparation, repair or modification of software packages for aircraft automated systems.
c. Navigational Aids Repair Shop – Facility for the repair of airborne navigational instruments such as celestial tracking system, sextants, driftmeters, etc..
d. Avionics Testing Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 43 INERTIAL QUALITY INSTRUMENT OVERHAUL SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21143-1 **GENERAL.** An Inertial Quality Instrument Overhaul Shop is required for the Electronic, Communication, and Armament Systems Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Inertial Quality Gyroscope Overhaul Shop – Environmental controlled space for the overhaul of inertial quality gyroscopes. Inertial quality gyroscopes are those having a radome drift rate of 0.25 degrees per hour or less. All other gyroscopes are considered non-inertial quality for facility categorization purposes.
b. Inertial Guidance System Overhaul and Calibration Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 44 NON-INERTIAL QUALITY INSTRUMENT OVERHAUL SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21144-1 **GENERAL.** A Non-Inertial Quality Instrument Overhaul Shop is required for the Electronic, Communication, and Armament Systems Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Electronic Instrument Overhaul Shop – Facility used to support communications electronic instruments such as systems and display panels, oscilloscopes, etc..
b. Mechanical Instrument Overhaul Shop – Facility for the overhaul of items such as bank indicators and air speed indicators.
c. Non-inertial Gyroscope Overhaul Shop – Facility used to overhaul non-inertial gyroscope devices such as N-1 compass gyroscopes, bomb navigational system gyroscopes, etc.
d. Magnetic Instrument Overhaul and Test Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 45 AVIONICS SHOP (NON-NAVAIR DEPOT) (m^2 / SF)
FAC: 2112
BFR Required: Y

21145-1 **GENERAL.** An Avionics Division at the intermediate maintenance level is required at Navy and Marine Corps Air installations for the testing, maintenance and repair of avionics systems. This section provides a method for determining the space requirements for this division. For additional guidance applicable to Marine Corps installations, see the 211 Supplement – Marine Corps Aircraft Maintenance Facilities. The Avionics Division is made up of standard size work centers, variable size work centers and support spaces.

a. Standard size work centers are those that do not vary with type/model of aircraft and size is determined by function and/or support equipment, i.e.: 60A Corrosion Control, 61D Crypto Repair, 62D Battery.

b. Variable size work centers are those that vary in size due to the quantity of support equipment required based on the number of aircraft supported, i.e.: 610 Comm./Nav., 62A Electrical, 64A Radar, 65A SACE, and 65P VAST.

c. Support spaces consist of those areas not directly involved in actual repair of aircraft components, i.e.: administrative, material control, production control, mechanical equipment room, passageways, locker rooms/heads, and the Precision Measuring Equipment (PME) work centers.

Refer to UFC 4-211-01 information on Avionics Shops.

The determination of gross square-footage requirements for a given air installation is accomplished through the use of Table 21145-1, Individual Aircraft Basic Allowance, and Table 21145-2, Multiple Aircraft Percentage Factors. This latter Table provides adjustments based on reduced requirements of support equipment due to commonality of aircraft components and to prevent duplicate allocations of standard size work centers and support spaces which are included in each individual aircraft basic space allowance.

Initially Table 21145-1 is entered using the number of assigned aircraft of each type/model. This provides the basic allowance for each type, and except as modified by Table 21145-3, is the total gross area for the support of a single type/model aircraft.

For installations supporting two or more type/model aircraft, the individual aircraft basic allowances from Table 21145-1 for each type/model are listed in descending order. Table 21145-2 is then entered with the first aircraft (largest basic space allowance) as the prime and the second aircraft as the secondary. The corresponding percentage factor is the percentage of the second aircraft's basic space allowance that will be added to the total space allowance of the first aircraft in computing the total space requirements. The percentage factor for the third (and succeeding) aircraft are determined by entering Table 21145-2 with each aircraft in the secondary column and selecting the smallest percentage factor when considered with all the other type/model aircraft with larger basic space allowances as the prime. These factors are applied to each aircraft's basic space allowance and the results added to compute the total space allowance for the installation.

Tables 21145-1 and 21145-2 are designed for Avionics Divisions of medium to large size Intermediate Maintenance Activities that normally require separate space for the full range of work centers. In smaller activities several functions are usually combined, reducing overall space requirements. Table 21145-3 provides an adjustment factor that is to be applied when the gross space allowance determined from Tables 21145-1 and 21145-2 is less than 40,000 square feet.

Table 21145-1
Individual Aircraft Basic Space Allowance
(Values in 100 m²/100 SF)

	A-4		TA-4		A-6		EA-6		KA-6		
Up to	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**Up to**
4	12.08	130	9.48	102	22.87	246	23.05	248	19.33	208	**4**
8	12.08	130	9.48	102	23.05	248	23.14	249	19.33	208	**8**
12	12.08	130	9.48	102	23.42	252	23.24	250	19.33	208	**12**
16	12.08	130	9.76	105	23.80	256	23.42	252	19.33	208	**16**
20	12.08	130	9.76	105	24.26	261	23.61	254	19.33	208	**20**
24	12.08	130	9.95	107	24.45	263	24.07	259	19.43	209	**24**
28	12.08	130	10.04	108	24.63	265	24.54	264	19.43	209	**28**
32	12.08	130	10.22	110	24.82	267	24.91	268	19.43	209	**32**
36	12.08	130	10.32	111	25.28	272	25.19	271	19.43	209	**36**
40	12.08	130	10.50	113	25.84	278	25.47	274	19.52	210	**40**
44	12.08	130	10.60	114	26.31	283	25.75	277	19.52	210	**44**
48	12.08	130	10.78	116	26.86	289	26.03	280	19.52	210	**48**
52	12.27	132	10.88	117	27.33	294	26.31	283	19.52	210	**52**
60	12.27	132	11.06	119	28.35	305	26.86	289	19.52	210	**60**
68	12.36	133	11.43	123	28.63	308	27.51	296	19.71	212	**68**
76	12.46	134	11.71	126	29.00	312	28.16	303	20.08	216	**76**
84	12.64	136	12.08	130	29.28	315	28.81	310	20.08	216	**84**
92	12.73	137	12.46	134	29.65	319	29.56	318	20.26	218	**92**
100	12.83	138	12.83	138	30.02	323	30.30	326	20.45	220	**100**
116	12.92	139	13.29	143	30.30	326					**116**
132	13.01	140	13.76	148	30.67	330					**132**
148	13.11	141	14.31	154	31.05	334					**148**
164						340					**164**
180						347					**180**
196						354					**196**

Table 21145-1 (Continued)
Individual Aircraft Basic Space Allowance
(Values in 100 m²/100 SF)

	A-7		C-2		C-130		E-2		F-4		
Up to	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**Up to**
4	27.70	298	16.17	174	11.71	126	20.08	216	13.85	149	**4**
8	27.70	298	16.17	174	11.71	126	20.64	222	14.13	152	**8**
12	27.70	298	16.17	174	11.71	126	20.64	222	14.41	155	**12**
16	27.98	301	16.17	174	11.71	126	21.75	234	14.69	158	**16**
20	27.98	301	16.17	174	11.71	126	22.40	241	14.97	161	**20**
24	28.26	304	16.27	175	11.71	126	22.40	241	15.06	162	**24**
28	28.44	306	16.27	175	11.90	128	22.40	241	15.15	163	**28**
32	28.63	308	16.27	175	12.08	130	22.40	241	15.24	164	**32**
36	28.63	308	16.36	176	12.27	132	22.59	243	15.24	164	**36**
40	28.81	310	16.36	176	12.36	133	22.77	245	15.34	165	**40**
44	29.09	313	16.45	177	12.46	134	22.87	246	15.34	165	**44**
48	29.19	314	16.55	178	12.64	136	23.05	248	15.43	166	**48**
52	29.37	316	16.55	178	12.83	138	23.42	252	15.52	167	**52**
60	29.84	321	16.73	180	13.01	140	23.70	255	15.62	168	**60**
68	30.30	326	16.73	180	13.20	142	23.80	256	15.71	169	**68**
76	30.77	331	16.82	181	13.38	144	23.98	258	15.80	170	**76**
84	31.23	336	16.92	182	13.66	147	24.07	259	15.89	171	**84**
92	31.70	341	16.92	182	13.94	150	24.26	261	15.99	172	**92**
100	32.16	346	17.01	183	14.22	153	24.35	262	16.08	173	**100**
116	33.46	360									**116**
132	34.86	375									**132**
148	36.16	389									**148**
164	37.55	404									**164**
180	38.95	419									**180**
196	40.34	434									**196**

Table 21145-1 (Continued)
Individual Aircraft Basic Space Allowance
(Values in 100 m^2/100 SF)

	F-14		F/A-18		AH-1T		AH-1W		UH-1		
Up to	m^2	SF	m^2	SF	m^2	SF	m^2	SF	m^2	SF	**Up to**
4	25.56	275	27.70	298	13.01	140	12.46	134	11.53	124	**4**
8	26.96	290	27.70	298	13.01	140	12.46	134	11.53	124	**8**
12	26.96	290	27.70	298	13.01	140	12.46	134	11.53	124	**12**
16	28.63	308	27.70	298	13.01	140	12.46	134	11.53	124	**16**
20	30.02	323	27.70	298	13.01	140	12.46	134	11.53	124	**20**
24	31.14	335	27.89	300	13.01	140	12.46	134	11.53	124	**24**
28	32.25	347	28.07	302	13.01	140	12.46	134	11.53	124	**28**
32	33.37	359	28.26	304	13.01	140	12.46	134	11.53	124	**32**
36	33.65	362	28.44	306	13.01	140	12.46	134	11.53	124	**36**
40	33.93	365	28.72	309	13.01	140	12.46	134	11.53	124	**40**
44	34.21	368	28.91	311	13.01	140	12.46	134	11.53	124	**44**
48	34.48	371	29.09	313	13.01	140	12.46	134	11.53	124	**48**
52	34.76	374	29.37	316	13.01	140	12.46	134	11.53	124	**52**
60	35.14	378	29.56	318	13.01	140	12.46	134	11.53	124	**60**
68	35.60	383	29.93	322	13.01	140	12.55	135	11.53	124	**68**
76	35.97	387	30.30	326	13.01	140	12.55	135	11.62	125	**76**
84	36.44	392	30.67	330	13.01	140	12.55	135	11.62	125	**84**
92	36.90	397	31.05	334	13.01	140	12.64	136	11.62	125	**92**
100	37.27	401	31.42	338	13.01	140	12.64	136	11.62	125	**100**
116	38.57	415	31.42	338	13.01	140					**116**
132	39.04	420	32.07	345	13.01	140					**132**
148	39.50	425	32.72	352	13.01	140					**148**
164	39.97	430	33.37	359	13.01	140					**164**
180	40.43	435	34.02	366	13.01	140					**180**
196	40.81	439	34.67	373	13.01	140					**196**

Table 21145-1 (Continued)
Individual Aircraft Basic Space Allowance
(Values in 100 m^2/100 SF)

	SH-2		SH-3		CH-46		CH-53		RH-53		
Up to	m^2	SF	m^2	SF	m^2	SF	m^2	SF	m^2	SF	**Up to**
4	11.53	124	13.11	141	12.73	137	10.13	109	21.01	226	**4**
8	11.53	124	13.11	141	12.73	137	10.13	109	21.19	228	**8**
12	11.53	124	13.11	141	12.73	137	10.13	109	21.29	229	**12**
16	11.53	124	13.11	141	12.73	137	10.13	109	21.47	231	**16**
20	11.53	124	13.11	141	12.73	137	10.13	109	21.56	232	**20**
24	11.53	124	13.11	141	12.73	137	10.13	109	21.75	234	**24**
28	11.62	125	13.11	141	12.73	137	10.13	109	21.94	236	**28**
32	11.62	125	13.11	141	12.73	137	10.13	109	22.12	238	**32**
36	11.71	126	13.11	141	12.83	138	10.22	110	22.31	240	**36**
40	11.71	126	13.20	142	12.83	138	10.22	110	22.59	243	**40**
44	11.71	126	13.20	142	12.83	138	10.32	111	22.96	247	**44**
48	11.80	127	13.20	142	12.83	138	10.41	112	23.33	251	**48**
52	11.80	127	13.20	142	12.83	138	10.41	112	23.52	253	**52**

	SH-2		SH-3		CH-46		CH-53		RH-53		
Up to	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**Up to**
60	11.80	127	13.20	142	12.83	138	10.50	113	23.89	257	**60**
68	11.90	128	13.29	143	12.92	139	10.69	115	24.26	261	**68**
76	11.99	129	13.29	143	12.92	139	10.88	117	24.63	265	**76**
84	11.99	129	13.29	143	12.92	139	11.06	119	25.00	269	**84**
92	12.08	130	13.38	144	13.01	140	11.25	121	25.47	274	**92**
100	12.18	131	13.38	144	13.01	140	11.43	123	25.84	278	**100**
116											**116**
132											**132**
148											**148**
164											**164**
180											**180**
196											**196**

Table 21145-1 (Continued)
Individual Aircraft Basic Space Allowance
(Values in 100 m²/100 SF)

	SH-60		P-3		S-3		AV-8		OV-10		
Up to	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**m²**	**SF**	**Up to**
4	16.55	178	23.42	252	27.89	300	16.55	178	12.83	138	**4**
8	16.55	178	23.42	252	30.77	331	16.55	178	13.01	140	**8**
12	16.55	178	23.42	252	32.25	347	16.55	178	13.29	143	**12**
16	16.55	178	23.52	253	33.65	362	16.55	178	13.48	145	**16**
20	16.55	178	23.61	254	33.65	362	16.55	178	13.85	149	**20**
24	16.55	178	23.80	256	33.93	365	16.55	178	14.41	155	**24**
28	16.55	178	23.98	258	34.21	368	16.55	178	14.69	158	**28**
32	16.55	178	24.07	259	34.39	370	16.55	178	14.97	161	**32**
36	16.55	178	24.35	262	34.67	373	16.64	179	15.06	162	**36**
40	16.55	178	24.72	266	34.95	376	16.73	180	15.15	163	**40**
44	16.55	178	25.00	269	35.14	378	16.73	180	15.24	164	**44**
48	16.55	178	25.38	273	35.41	381	16.82	181	15.43	166	**48**
52	16.55	178	26.03	280	35.69	384	16.92	182	15.62	168	**52**
60	16.55	178	26.68	287	35.97	387	17.10	184	15.89	171	**60**
68	16.64	179	27.33	294	36.44	392	17.29	186	16.08	173	**68**
76	16.73	180	28.26	304	36.81	396	17.47	188	16.36	176	**76**
84	16.92	182	28.91	311	37.27	401	17.66	190	16.64	179	**84**
92	17.10	184	29.56	318	37.74	406	17.85	192	16.92	182	**92**
100	17.29	186	30.12	324	38.11	410	17.94	193	17.20	185	**100**
116	17.38	187			39.04	420	18.40	198			**116**
132	17.57	189			40.06	431	18.87	203			**132**
148	17.66	190			40.99	441	19.33	208			**148**
164							19.80	213			**164**
180							20.26	218			**180**
196							20.73	223			**196**

Table 21145-2
Multiple Aircraft Percentage Factors

		PRIMARY AIRCRAFT											
		A-4	**TA-4**	**A-6**	**EA-6**	**KA-6**	**A-7**	**C-2**	**C-130**	**E-2**	**F-4**		
	A-4	--	26	12	21	8	13	27	28	17	14	**A-4**	
S	**TA-4**	11	--	12	25	11	9	11	14	11	10	**TA-4**	**S**
E	**A-6**	N/A	N/A	--	28	N/A	44	N/A	N/A	39	N/A	**A-6**	**E**
C	**EA-6**	N/A	N/A	34	--	N/A	51	N/A	N/A	44	N/A	**EA-6**	**C**
O	**KA-6**	N/A	N/A	5	10	--	26	N/A	N/A	32	N/A	**KA-6**	**O**
N	**A-7**	N/A	N/A	40	46	N/A	--	N/A	N/A	N/A	N/A	**A-7**	**N**
D	**C-2**	N/A	N/A	28	34	28	28	--	N/A	5	N/A	**C-2**	**D**
A	**C-130**	26	23	27	36	25	25	16	--	18	28	**C-130**	**A**
R	**E-2**	N/A	N/A	39	40	30	36	N/A	N/A	--	N/A	**E-2**	**R**
Y	**F-4**	N/A	37	32	41	32	31	44	38	35	--	**F-4**	**Y**
	F-14	N/A	N/A	44	47	N/A	36	N/A	N/A	N/A	N/A	**F-14**	
A	**F/A-18**	N/A	N/A	45	51	N/A	33	N/A	N/A	N/A	N/A	**F/A-18**	**A**
I	**AH-1T**	21	32	22	32	21	21	32	31	21	23	**AH-1T**	**I**
R	**AH-1W**	19	30	20	28	19	19	31	31	17	20	**AH-1W**	**R**
C	**UH-1**	12	24	12	23	11	11	24	23	11	14	**UH-1**	**C**
R	**SH-2**	23	22	24	33	23	23	24	23	21	24	**SH-2**	**R**
A	**SH-3**	24	32	23	28	23	23	32	33	22	25	**SH-3**	**A**
F	**CH-46**	27	38	28	30	27	27	38	36	25	30	**CH-46**	**F**
T	**CH-53**	15	29	15	27	14	16	29	28	14	18	**CH-53**	**T**
	RH-53	N/A	N/A	52	57	N/A	51	N/A	N/A	49	N/A	**RH-53**	
	SH-60	N/A	N/A	28	27	27	27	36	N/A	28	N/A	**SH-60**	
	P-3	N/A	N/A	49	60	N/A	48	N/A	N/A	47	N/A	**P-3**	
	S-3	N/A	N/A	47	51	N/A	36	N/A	N/A	N/A	N/A	**S-3**	
	AV-8	N/A	N/A	33	42	41	35	50	N/A	38	N/A	**AV-8**	
	OV-10	21	31	19	33	23	12	35	29	22	26	**OV-10**	

Table 21145-2 (Continued)
Multiple Aircraft Percentage Factors

PRIMARY AIRCRAFT

		F-14	F/A-18	AH-1T	AH-1W	UH-1	SH-2	SH-3	CH-46	CH-53	RH-53		
	A-4	8	15	15	16	N/A	27	18	23	N/A	14	**A-4**	
S	**TA-4**	13	21	12	12	12	10	11	24	28	10	**TA-4**	**S**
E	**A-6**	21	46	N/A	N/A	N/A	N/A	N/A	N/A	N/A	53	**A-6**	**E**
C	**EA-6**	25	52	N/A	N/A	N/A	N/A	N/A	N/A	N/A	55	**EA-6**	**C**
O	**KA-6**	27	32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	46	**KA-6**	**O**
N	**A-7**	33	36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**A-7**	**N**
D	**C-2**	27	34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	45	**C-2**	**D**
A	**C-130**	27	33	24	27	N/A	25	25	31	N/A	25	**C-130**	**A**
R	**E-2**	20	40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	46	**E-2**	**R**
Y	**F-4**	31	39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	33	**F-4**	**Y**
	F-14	--	39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	58	**F-14**	
A	**F/A-18**	45	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**F/A-18**	**A**
I	**AH-1T**	21	29	--	N/A	N/A	N/A	21	38	N/A	19	**AH-1T**	**I**
R	**AH-1W**	18	24	5	--	N/A	N/A	19	23	N/A	16	**AH-1W**	**R**
C	**UH-1**	12	21	6	24	--	23	12	17	N/A	9	**UH-1**	**C**
R	**SH-2**	25	33	23	25	23	--	10	N/A	N/A	21	**SH-2**	**R**
A	**SH-3**	23	31	N/A	N/A	N/A	N/A	--	31	N/A	19	**SH-3**	**A**
F	**CH-46**	27	20	25	N/A	N/A	N/A	27	--	N/A	21	**CH-46**	**F**
T	**CH-53**	15	24	10	12	11	28	13	19	--	7	**CH-53**	**T**
	RH-53	51	56	N/A	N/A	N/A	N/A	N/A	N/A	N/A	--	**RH-53**	
	SH-60	27	32	N/A	N/A	N/A	N/A	N/A	N/A	N/A	45	**SH-60**	
	P-3	19	45	N/A	N/A	N/A	N/A	N/A	N/A	N/A	62	**P-3**	
	S-3	24	39	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**S-3**	
	AV-8	33	26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	45	**AV-8**	
	OV-10	24	26	16	N/A	N/A	N/A	20	22	N/A	19	**OV-10**	

Table 21145-2 (Continued)
Multiple Aircraft Percentage Factors

		PRIMARY AIRCRAFT						
		SH-60	P-3	S-3	AV-8	OV-10		
	A-4	25	36	16	16	16	A-4	
S	TA-4	24	23	14	21	11	TA-4	S
E	A-6	N/A	49	44	N/A	N/A	A-6	E
C	EA-6	N/A	55	51	N/A	N/A	EA-6	C
O	KA-6	N/A	44	31	51	N/A	KA-6	O
N	A-7	N/A	48	28	N/A	N/A	A-7	N
D	C-2	37	27	22	51	47	C-2	D
A	C-130	35	25	19	33	24	C-130	A
R	E-2	N/A	45	34	50	N/A	E-2	R
Y	F-4	42	49	32	40	34	F-4	Y
	F-14	N/A	56	16	N/A	N/A	F-14	
A	F/A-18	N/A	50	45	N/A	N/A	F/A-18	A
I	AH-1T	30	38	20	29	18	AH-1T	I
R	AH-1W	26	37	18	23	16	AH-1W	R
C	UH-1	21	31	11	21	6	UH-1	C
R	SH-2	34	22	15	32	23	SH-2	R
A	SH-3	32	32	15	30	22	SH-3	A
F	CH-46	36	31	27	19	22	CH-46	F
T	CH-53	26	39	16	24	11	CH-53	T
	RH-53	N/A	63	52	N/A	N/A	RH-53	
	SH-60	--	42	27	50	44	SH-60	
	P-3	N/A	--	43	N/A	N/A	P-3	
	S-3	N/A	46	--	N/A	N/A	S-3	
	AV-8	N/A	44	37	--	43	AV-8	
	OV-10	32	30	12	30	--	OV-10	

Table 21145-3
Adjustment Factor for Small Avionics Divisions

Gross Space (m^2)	Gross Space (m^2 / SF)	Factor
929 – 1,208	10,000 – 12,999	.50
1,209 – 1,487	13,000 – 15,999	.55
1,488 – 1,765	16,000 – 18,999	.60
1,766 – 2,044	19,000 – 21,999	.65
2,045 – 2,323	22,000 – 24,999	.70
2,324 – 2,602	25,000 – 27,999	.75
2,603 – 2,881	28,000 – 30,999	.80
2,882 – 3,160	31,000 – 33,999	.85
3,161 – 3,439	34,000 – 36,999	.90
3,440 – 3,717	37,000 – 39,999	.95
3,718 and up	40,000 and up	1.00

Example 1 - One type/model aircraft assigned.

There are 100 assigned aircraft of the type/model indicated in Column (1) below. Column (2) contains the basic space requirement from Table 21145-1.

Step 1.

Obtain basic space requirement for the type/model aircraft by entering Table 21145-1 with the quantity of aircraft to be supported.

Column (1)	Column (2)
100 F-14	3,727 m^2 (40,100 SF)

Since there is only one type/model assigned and the space requirement is over 3,718 m^2 (40,000 SF), no further computations are required.

Gross space allowance for Avionics Division – 3,727 m^2 (40,100 SF)

Example 2 - One type/model aircraft assigned.

There are 8 assigned aircraft of the type/model indicated in Column (1) below. Column (2) contains the basic space requirement from Table 21145-1. Column (3) contains the adjustment factor for a small avionics division from Table 21145-3. Column (4) contains the adjusted space requirement.

Step 1.

Obtain basic requirement for the type/model aircraft by entering Table 21145-1 with the quantity of aircraft supported.

Column (1)	Column (2)
8 E-2	22,200 SF

Step 2.

Since the space requirement in Column (2) is less than 40,000 SF obtain the adjustment factor for small avionics divisions from Table 21145-3.

Column (1)	Column (2)		Column (3)		Column (4)
8 E-2	2,064 m^2	x	.70	=	1,445 m^2
	22,200 SF	x	.70	=	15,540 SF

Gross space allowance for Avionics Division – 1,445 m^2 (15,540 SF)

Example 3 - Two Type/Model aircraft assigned

There are 144 assigned aircraft of the type/model and number indicated in Column (1) below. Column (2) contains the basic space requirements from Table 21145-1. Column (3) contains the percentage factor for the secondary aircraft (smallest basic space allowance). Column (4) contains the total space requirement.

Step 1.

Obtain basic space requirements for both type/model aircraft by entering Table 21145-1 with quantity of aircraft to be supported.

Column (1)	Column (2)
100 F-14	3,727 m^2 (40,100 SF)
44 F-4	1,534 m^2 (16,500 SF)

Step 2.

Obtain percentage factor for secondary aircraft by crossing from that aircraft in secondary column to the column under the prime aircraft (F-4 to F-14 = 35%) of Table 21145-2.

Column (1)	Column (2)	Column (3)
100 F-14	3,727 m^2 (40,100 SF)	
44 F-4	1,534 m^2 (16,500 SF)	31%

Step 3.

Enter 100% of prime aircraft basic space requirement (Column (2)) in Column (4). Calculate percentage (Column (3)) of secondary aircraft space requirement (Column (2)) and enter in Column (4). Add requirements of Column (4) for total avionics division requirement.

Column (1)	Column (2)		Column (3)		Column (4)
100 F-14	3,727 m^2	x	1.00	=	3,727 m2
	40,100 SF	x	1.00	=	40,100 SF
	1,534 m^2	x	0.31	=	476 m^2
44 F-44	16,500 SF	x	0.31	=	5,115 SF
					4,203 m^2
					45,215 SF

Gross space allowance for Avionics Division – 4,203 m^2 (45,215 SF)

Example 4 - Three or more Type/Model aircraft assigned

There are 196 assigned aircraft of the type/model and number indicated in Column (1) below. Column (2) contains the basic space requirements from Table 21145-1 in descending order of size. Column (3) contains the lowest percentage factor from Table 21145-2 for each secondary type aircraft when considered against those with larger basic space requirements as prime. Column (4) contains the total space requirement.

Step 1.

Obtain basic space requirements for both type/model aircraft by entering Table 21145-1 with quantity of aircraft to be supported.

Column (1)	Column (2)
100 F-14	3,727 m^2 (40,100 SF)
28 E-2	2,240 m^2 (24,100 SF)
44 F-4	1,534 m^2 (16,500 SF)
24 TA-4	995 m^2 (10,700 SF)

Step 2.

Select lowest percentage factor for secondary type aircraft for Column (3) by crossing from that aircraft in secondary column and considering each aircraft assigned with a larger basic space requirement as a prime aircraft.

a.The E-2 has only the F-14 with a larger basic space requirement therefore 20% will be used in Column (3).

b.The F-4 has both the E-2 (35%) and the F-14 (31%) with larger basic requirements. The F-14 has the lowest percentage factor (31%) so this will be entered in Column (3).

c.The TA-4 has all the other types with larger basic space requirements. The E-2 (11%) has a lower percentage factor than the F-14 (13%), but a higher percentage factor than the F-4 (10%); therefore, 10% shall be entered in Column (3).

Step 3.

Enter 100% of prime aircraft basic space requirement in Column (4). Calculate percentage (Column (3)) of secondary aircraft space requirement (Column (2)) and enter in Column (4). Add requirements of Column (4) for total avionics division requirement.

Column (1)	Column (2)		Column (3)		Column (4)
100 F-14	3,727 m^2	x	1.00	=	3,727 m^2
	40,100 SF	x	1.00	=	40,100 SF
28 E-2	2,240 m^2	x	0.20	=	448 m^2
	24,100 SF	x	0.20	=	4,820 SF
44 F-44	1,534 m^2	x	0.31	=	476 m^2
	16,500 SF	x	0.31	=	5,115 SF
24 TA-4	995 m^2 x	0.10		=	100 m^2
	10,700 SF	x	0.10		1,070 SF
					4,751 m^2
					51,105 SF

Gross space allowance for Avionics Division – 4,751 m^2 (51,105 SF)

211 50 AIRCRAFT ARMAMENT/MISSILE REWORK SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21150-1 **GENERAL.** An Aircraft Armament/Missile Rework Shop is required to provide space associated with processing weapons including guns, missiles, bomb racks, weapon pylons, etc., used by aircraft in carrying out its assigned mission.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 51 DEDICATED AIRCRAFT ARMAMENT/MISSILE REWORK SHOP – GENERAL PURPOSE (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21151-1 **GENERAL.** A Dedicated Aircraft Armament/Missile Rework – General Purpose Shop is required for the Armament Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Armament Dedicated Cleaning Shop
b. Armament Dedicated Paint Shop
c. Armament Dedicated Machine Shop
d. Armament Dedicated Welding Shop
e. Armament Dedicated Plating Shop
f. Aircraft Weapon Overhaul and Test Shop
g. Ordnance Equipment Shop
h. Weapon Accessories Repair Shop – Facility for the repair of bomb racks, weapon pylons, etc.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 52 AIRCRAFT WEAPON OVERHAUL AND TEST SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21152-1 **GENERAL.** An Aircraft Weapon Overhaul and Test Shop is required for the Armament Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Aircraft Weapon Overhaul and Test Shop
b. Ordnance Equipment Shop
c. Weapon Accessories Repair Shop – Facility for the repair of bomb racks, weapon pylons, etc.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 53 AIR LAUNCHED MISSILE REWORK SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21153-1 **GENERAL.** An Air Launched Missile rework Shop is required to provide space for the repair of air launched missiles for the Armament Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 54 AIRCRAFT ARMAMENT SYSTEM SHOP (NON-NAVAIR DEPOT) (m^2 / SF)

Refer to the following publications for AAS storage facility preservation criteria:
CNAFINST 8380.2 and NAVAIR 15-01-500

FAC: 2112
BFR Required: Y

21154-1 **GENERAL.** Prior to commencing any I-Level facilities projects, coordination and planning must be conducted with the Command for which the facility is intended. Consideration must be made for other required duties of the occupying section. The Aircraft Armament Systems (AAS) shop and shops related to AAS sub-systems may be called different names. Within a Navy Command these shops fall under the Ordnance Division in the Maintenance Department. At a Marine Aviation Logistics Squadron (MALS), the AAS shop is under the Ordnance Department and not under the cognizance of the Maintenance Department. MALS Ordnance has the additional responsibilities of operating a Munitions shop, an Ammunition Stock Recording Section (ASRS), a Tool Room, a Production Control (PC) section, and an administrative section.

An Aircraft Armament Systems (AAS) shop is required at Navy and Marine Corps Intermediate Level (I-Level) maintenance activities to support combat aircraft. AAS encompasses five distinct subsystems; Aircraft Armament Equipment (AAE), Aircraft Gun Systems (AGS), Aircraft Crew Served Weapons (ACSW), ACSW mounts, and Laser Aiming Devices (LAD). Although missiles and rockets are handled at the missile maintenance shop or rocket assembly and loading areas, maintenance of AAS launchers is conducted in the AAS shop.

Aircraft that require support from this shop can be classified in three general groups, the attack/fighter group which require extensive support, the Anti-submarine Warfare (ASW), and Transport groups which require much less support. Table 21154-1 below lists the aircraft in each group. The Navy/Marine Corps aircraft that do not appear in either group generally do not require support from an AAS shop.

Table 21154-1
Aircraft Classification

Attack/Fighter	ASW	Transport
F-35	SH-60	KC-130HH
F/A-18	P-3	CH-53
AV-8	S-3	MV-22
AH-1/UH-1	P-8	
E/A-6		

The determination of gross square footage requirements for a given air installation is accomplished through the use of Table 21154-2 Space Allowance for Basic Aircraft Armament System Division, Table 21154-3 Space Allowance for AAS Pool, and Table 21154-4 Space Allowance for the Armament Weapons Support Equipment (AWSE) Work Center (for those activities having this responsibility). (Type Commander 8380 series instructions determine which activities have Aircraft Armament System Equipment Pool responsibilities).

Initially Table 21154-2 is entered in Column (1) using the total number of assigned attack and fighter aircraft. The gross area is read in Column (2). For those activities without any attack or fighter aircraft but having other type aircraft that require Armament Division support, such as P-3, S-3, etc., enter Column (1) with total number of these aircraft. The required gross area is read in Column (3).

Table 21154-2
Space Allowance for
Basic Aircraft Armament System Division

Column (1) No. Aircraft	Column (2) Attack/Fighter (m^2)	Column (2) Attack/Fighter (SF)	Column (3)* ASW (m^2)	Column (3)* ASW (SF)
Up to 50	325	3,500	251	2,700
51-75	409	4,400	288	3,100
76-100	465	5,000	325	3,500
101-125	502	5,400		
126-175	567	6,100		
176-225	623	6,700		
226 +	651	7,000		

*Do not use when activity also supports attack and/or fighter aircraft, use allowance from Column (2) only.

The above space allowances include space for degreasing, storage of guns, administration, production control, training, supply and tool room, male and female personnel facilities and a mechanical equipment room. If an I-level facility utilizes and stores Aircraft Crew Served Weapons (ACSW), the area which these systems are stowed must meet the Unified Facilities Criteria for Armories, Refer to UFC 4-215-1 (i.e. physical security and humidity controlled).

Example Computation 1 – Aircraft Armament Systems Shop

Assigned aircraft:	80	F-35
	56	F/A-18A
	42	S-3A
Total	178	

Since base loading includes attack and fighter aircraft, only those numbers are used to enter Table 21154-2. Therefore, Column (1) is entered with 136 aircraft. A required area of 567 m^2 (6,100 SF) is read from Column (2).

Example Computation 2 – Aircraft Armament Systems Shop

Assigned aircraft:	42	P-3C
	22	CH-53
Total	64	

This base loading does not include either attack or fighter aircraft, consequently the total number of aircraft is used to enter Table 21154-2. Entering Column (1) with 64 aircraft, a required area of 288 m^2 (3,100 SF) is read from Column (3).

Activities that have the assigned responsibilities of maintaining an Aircraft Armament System Equipment Pool, the basic shop requirement from Table 21154-2 will be increased by the requirement from Table 21154-3.

Table 21154-3
Space Allowance for
Aircraft Armament System Equipment Pool

Column (1) Aircraft	Column (2) Area Per Aircraft (m^2)	Column (2) Area Per Aircraft (SF)
E/A-6	3	32
F-35	6.1	66
F/A-18	5.9	64
AH-1/UH-1	5	54
MV-22	1.11	12
CH-53	7.1	76
SH-60	0.5	5
P-3	1.1	12
S-3	0.9	10
P-8	0.5	5
AV-8B	3.5	38
KC-130HH	1.11	12

The above allowance provides space for Pool storage and the issuing and receiving functions only. Administrative and other support functions are provided in the basic allowance from Table 21154-2.

Example Computation 3 – Aircraft Armament System Equipment Pool

Assigned aircraft are identical to Example Computation 1 above, however pool support is also provided for 30 SH-60B at another station.

Type A/C (Column (1))	Area Per A/C (m^2) (Column (2))	Area Per A/C (SF) (Column (2))	Number A/C	m^2	SF
F-35	6.1	66	80	488	5,253
F/A-18A	5.9	64	56	330	3,552
S-3A	0.9	10	42	38	409
SH-60B	0.5	5	30	15	161
Total space requirement				871	9,375

This requirement is added to the basic requirement from Table 21154-2, 567 m^2 (6,100 SF), to give a total requirement of 1,438 m^2 (15,475 SF) for the Aircraft Armament System Shop.

Marine Corps activities have the additional responsibility of conducting maintenance on AWSE. Space for this added function is provided by Table 21154-4. It is based on the activities' allowance for weapons trailers.

Table 21154-4
Space Allowance for
Armament Weapons Support Equipment Work Center

Column (1) Type Trailer	Column (2) Area Per Trailer (m^2)	Column (2) Area Per Trailer (SF)
AM32K-10	2.3	25
MHU-151/M	1.4	15

The above allowance provides space for the AWSE work center only. Administration and other support functions are provided in the basic allowance from Table 21154-2.

Example Computation 4 – Aircraft Armament Systems Shop

A Marine Corps activity has a base loading as shown below, with the armament equipment pool responsibility for the same number and type aircraft.

Base loading: 20 AV-8 Aircraft

24 AH-1Z Aircraft
16 CH-53E Aircraft
15 F-35 Aircraft
25 AM32K-10 Trailers
28 MHU-151/M Trailers

a.) Basic shop requirement

Attack Aircraft:	20	AV-8
	24	AH-1
	15	F-35
Total	59	

Enter Table 21154-2, Column (1) with 59 aircraft. A required area of 409 m^2 (4,400 SF) is read from Column (2).

b.) Aircraft Armament System Equipment Pool

Type A/C (Column (1))	Area Per A/C (m^2) (Column (2))	Area Per A/C (SF) (Column (2))	Number A/C	m^2	SF
AV-8	3.5	38	20	70	753
AH-1Z	5	54	24	120	1,292
CH-53E	7.1	76	16	114	1,227
F-35	6.1	66	15	92	990
Total space requirement				396	4,262

c.) Armament Weapons Support Equipment Work Center

Type Trailer	Area per Trailer (m^2)	Area per Trailer (SF)	No. Trailer	m^2	SF
AM32K-10	2.3	25	25	58	624
MHU-151/M	1.4	15	28	39	420
Total space requirement				97	1,044

Total gross square feet for Aircraft Armament System Shop

	m^2.	SF
a.) Basic Shop Requirement	409	4,400
b.) Equipment Pool Requirement	396	4,262
c.) Support Equipment W/C Requirement	97	1,044
Total	902	9,706

211 55 AVIATION ARMAMENT SUPPORT EQUIPMENT HOLDING SHED (NON-NAVAIR DEPOT) (m^2 / SF)

Refer to the following publications for AAS storage facility preservation criteria:
CNAFINST 8380.2 and NAVAIR 15-01-500

FAC: 4412
BFR Required: N

21155-1 **GENERAL.** For Marine Corps activities, an aviation armament support equipment holding shed is planned in conjunction with the Category Code 211 54, Aircraft Armament System Shop. The shed provides cover for weapons trailers, bomb cradles, and other armament support equipment and is an integral part of Marine Aviation Logistics Squadrons' Ordnance Department.

The holding shed requirement is based on a unit space for each weapons trailer in accordance with Table 21155-1. The gross square feet requirement is sized by multiplying the unit space for each type trailer by the activity's allowance.

Table 21155-1
Space Allowance for Armament Weapons Support Equipment Holding Shed

Type Trailer	Area per Trailer (m2)	Area per Trailer (SF)
A/M32K-10	12.4	133
MHU-151/M	6.7	72
U-21	12.4	133

Example Computation 1 – Holding Shed

A Marine Aviation Logistics Squadron (MALS) has an allowance of thirty AM32K-10 trailers and twenty-five of the smaller MHU-151/M trailers, and one U-21 maintenance trailer.

Type Trailer	Area per Trailer (m^2)	Area per Trailer (SF)	No. Trailer	m^2	SF
A/M32K-10	12.4	133	30	372	3,990
MHU-151/M	6.7	72	25	168	1,800
U-21	12.4	133	1	12.4	133
			Total	552.4	5,923

211 60 SUPPORT EQUIPMENT REWORK SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21160-1 **GENERAL.** A Support Equipment Rework Shop is required to provide space associated with processing aviation general and special support equipment and aerospace ground support equipment.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 61 DEDICATED SUPPORT EQUIPMENT REWORK GENERAL PURPOSE SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21161-1 **GENERAL.** A Dedicated Support Equipment Rework General Purpose Shop is required for the Support Equipment Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Support Equipment Dedicated Cleaning Shop
b. Support Equipment Dedicated Paint Shop
c. Support Equipment Dedicated Machine Shop
d. Support Equipment Dedicated Plating Shop
e. Support Equipment Dedicated Welding Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 62 SUPPORT EQUIPMENT CALIBRATION SHOP (NAVAIR DEPOT) (m2. / SF)
FAC: 2116
BFR Required: Y

21162-1 **GENERAL.** A Support Equipment Calibration Shop is required for the Support Equipment Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Aeronautical Electronic Support Equipment Shop – Includes mobile maintenance facility construction, outfitting and repair.
b. Electronic Test Systems Repair Shop – Facility for the repair of VAST, ATE, etc.

c. Precision Measurement Equipment Shop – Facility used to repair, calibrate and certify precision measurement and test equipment.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 63 GROUND SUPPORT EQUIPMENT REWORK SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21163-1 **GENERAL.** A Ground Support Equipment Rework Shop is required for the Support Equipment Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. GSE Maintenance Shop – Facility used for the servicing and maintaining of ground support equipment such as work stands, firefighting equipment, portable air conditioners, air compressors, generators, etc..
b. Training Devices Shop – Facility used to repair and modify training aids such as mock-ups, cut away models, etc.
c. Hydrostatics Shop – Facility used to periodically inspect and overhaul of hydrostatic equipment.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 64 GROUND SUPPORT EQUIPMENT HOLDING SHED (NAVAIR DEPOT) (m^2 / SF)
FAC: 2185
BFR Required: Y

21164-1 **GENERAL.** A Ground Support Equipment Holding Shed is required for the Support Equipment Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 65 AIRBORNE WEAPONS SUPPORT EQUIPMENT SHOP (NAVAIR DEPOT) (EA)

FAC: 2112
BFR Required: Y

21165-1 **GENERAL.** An Airborne Weapons Support Equipment Shop is required for the Support Equipment Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 70 MANUFACTURING AND REPAIR SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21170-1 **GENERAL.** A Manufacturing and Repair Shop is required to provide space for aircraft repair operations by such work functions as parts cleaning and painting, plating and metal processing shop.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 71 DEDICATED MANUFACTURING AND REPAIR – GENERAL PURPOSE SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21171-1 **GENERAL.** A Dedicated Manufacturing and Repair - General Purpose Shop is required for the Manufacture and Repair Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Welding Shop
b. Foundry Shop
c. Peening and Blasting Shop
d. Non-destructive Inspection – Magnetic particle, Dye Penetrant, etc..
e. Parts Cleaning Shop
f. Parts Painting Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 72 METAL FABRICATION/MANUFACTURING SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21172-1 **GENERAL.** A Metal Fabrication/Manufacturing Shop is required for the Manufacture and Repair Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Machine Shop
b. Grinding Shop – Facility is used primarily for close tolerance grinding of metal parts that have been built up by metalizing or electroplating processes.
c. NC Machine Shop – Facility primarily using numerically controlled machines; separate from common machine shop.
d. Metal Parts Fabrication Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 73 METAL TREATMENT SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21173-1 **GENERAL.** A Metal Treatment Shop is required for the Manufacture and Repair Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Metal Processing Shop – Facility for metal treating processes such as nickel braze, ceramic coating, plasma, etc.
b. Plating Shop
c. Heat Treating Shop – Facility for heat treating metals such as tempering, annealing, quenching, stress relieving, etc.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 74 NON-METAL FABRICATION/MANUFACTURING SHOP (NAVAIR DEPOT) (EA)

FAC: 2116
BFR Required: Y

21174-1 **GENERAL.** A Non-Metal Fabrication/Manufacturing Shop is required for the Manufacture and Repair Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Plastic Fabrication Shop – Facility for the manufacture of plastic items such as tubing, caps, covers, panels, foam container liners, templates, fixtures and tooling.
b. Pattern Shop
c. Decal (Graphic Arts) Shop
d. Woodworking Shop
e. Rubber Fabrication Shop – Facility for fabrication of rubber equipment such as aircraft fuel cells and molded rubber products.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 75 AVIATION LIFE SUPPORT SYSTEMS SHOP (NON-NAVAIR DEPOT) (m^2 / SF)

FAC: 2184
BFR Required: Y

Design Criteria: UFC 4-211-01, Aircraft Maintenance Hangars

21175-1 **GENERAL.** An Aviation Life Support Systems Shop is required at Navy and Marine Corps air installations for inspecting, repairing, and repacking of parachutes, flotation devices, oxygen and other life support equipment. See basic Category 211 Supplement, Maintenance, Aircraft spares for Marine Corps Aircraft Maintenance Facilities, for which special guidance is provided.

21175-2 **APPLYING CRITERIA**. To determine the gross square footage requirements for a given air installation, the number of each type assigned aircraft, Column (1), is multiplied by the corresponding sizing factor in Column (2) of Table 21175-1. The sum of the products for each type of aircraft becomes the "basic sizing factor" which determines the number of packing tables required. This is used to enter Table 21175-2 to obtain the basic area allowance. Add to this the square footage of the largest sized Aviators Safety Equipment (Flotation) Shop from Column (3) and the largest sized Oxygen Regulator and Equipment Shop from Column (4) of Table 21175-1 to obtain the "gross square foot" requirement.

The basic area allowance from Table 21175-2 includes the following support spaces:

Male and Female lavatories and lockers
Training/Conference room
Administrative office
Sewing/Fabrication room
Production Control
Storage area
Washer and Dryer room
Mechanical room

In the one (1) packing table shop no separate areas are planned for the training/conference, sewing/fabrication rooms nor the administrative office. Space is planned within the production control area for the administrative functions, while the other functions are planned for within the packing table area.

Planning factors do not include space for a parachute hanging tower, a Liquid Oxygen (LOX) Farm nor for an Ejection Seat Shop. If an intermediate maintenance activity plans to operate/maintain a LOX Farm and/or an Ejection Seat Shop or has a special requirement for a hanging tower, such as support of a SEAL team, space allocation must be justified separately.

Table 21175-1
Sizing Factors for
Aviation Life Support Systems Shop

Column (1) Type A/C	Column (2) Parachute Shop Factor	Column (3) Flotation Shop	Column (4) Oxygen Shop
A-4	0.0016	M	L
TA-4	0.0032	M	L
A-6	0.0032	M	L
EA-6	0.0064	M	L
A-7	0.0016	M	L
TA-7	0.0032	M	L
C-2	0.0032	L	L
C-130	0.0064	L	S
E-2	0.0080	M	L
F-4	0.0032	M	L
F-14	0.0032	M	L
F/A-18	0.0016	M	L
TF/A-18	0.0032	M	L
H-1	0.0001	S	S
H-2	0.0001	S	S

Column (1) Type A/C	Column (2) Parachute Shop Factor	Column (3) Flotation Shop	Column (4) Oxygen Shop
H-3	0.0001	L	S
H-46	0.0001	L	S
H-53	0.0001	L	S
H-60	0.0001	L	S
P-3	0.0368	L	S
S-3	0.0064	M	L
T-2	0.0032	M	S
AV-8	0.0016	M	L
TAV-8	0.0032	M	L
OV-10	0.0032	M	S
Values of Column (3) S = 300 Sq.Ft. M = 500 Sq.Ft. L = 900 Sq.Ft.		**Value of Column (4) S = 300 Sq.Ft. L = 500 Sq.Ft.**	

Table 21175-2
Basic Allowance for
Aviation Life Support Systems Shop

Factor Total	Basic Allowance
0 to 1	3,000 Sq.Ft.
More than 1 to 2	5,000 Sq.Ft.
More than 2	6,000 Sq.Ft.

Example Computation 1

A/C	No.	Column (2)	Factor Product	Column (3)	Column (4)
F-14	120	0.0032	0.3840	M	L
TA-4	18	0.0032	0.0576	M	L
A-4	6	0.0016	0.0096	M	L
E-2	30	0.0080	0.2400	M	L
			0.6912	M	L

From Table 211-75B	0.6912 =	3,000 sq.ft..
From Table 211-75A	Column (3) “M” =	500 sq.ft.
From Table 211-75A	Column (4) “L” =	500 sq.ft..
		4,000 sq.ft.

Example Computation 2

A/C	No.	Column (2)	Factor Product	Column (3)	Column (4)
P-3	60	0.0368	2.2080	L	S
H-2	10	0.0001	0.0010	S	S
H-3	40	0.0001	0.0040	L	S
			2.2130	L	S

From Table 211-75B	2.2130 =	6,000	sq.ft.
From Table 211-75A	Column (3) "L" =	900	sq.ft.
From Table 211-75A	Column (4) "S" =	300	sq.ft.
		7,200	sq.ft.

Example Computation 3

A/C	No.	Column (2)	Factor Product	Column (3)	Column (4)
A-7	115	0.0016	0.1840	M	L
S-3	40	0.0064	0.2560	M	L
F/A-18	24	0.0016	0.0384	M	L
TF/A-18	6	0.0032	0.0192	M	L
H-3	4	0.0001	0.0004	L	S
			0.4980	L	L

From Table 21175-2	0.4980 =	3,000	sq.ft.
From Table 21175-1	Column (3) "L" =	900	sq.ft.
From Table 21175-1	Column (4) "L" =	500	sq.ft.
		4,400	sq.ft.

211 76 MISCELLANEOUS PARTS/COMPONENTS REPAIR SHOP (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21176-1 **GENERAL.** A Miscellaneous Parts/Components Repair Shop is required for the Manufacture and Repair Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Tubing Shop
b. Cable Shop
c. Cordage (Flight Controls) Shop
d. Electrical Cable/Harness Shop

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 80 TEST AND CALIBRATION SHOP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21180-1 **GENERAL.** A Test and Calibration Shop is required to provide space dedicated to test, trim, or calibrate engines, electronics, communications or armament systems. This is the main Category Code used for the Test and Calibration Production Shop of the Naval Air Depot (NADEP).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 81 ENGINE TEST CELL (NON-NAVAIR DEPOT) (m^2 / SF)
FAC: 2118
BFR Required: Y

Design Criteria: UFC 4-212-01, Navy Standard Jet Engine Test Cells

21181-1 **GENERAL.** An engine test cell provides an acoustic attenuated and fully instrumented enclosure in which uninstalled turbojet and turbofan engines are tested at installations where intermediate level maintenance engine repair work is performed. The enclosure provides a better working environment than open pads by providing protection from inclement weather and cross winds which adversely affect testing of engines, while at the same time significantly reducing exterior noise levels. NAVFAC P-970, Planning in the Noise Environment, specifies acceptable noise levels for various land uses. See Category Code 211 01, Aircraft Acoustical Enclosure (Non-NAVAIR Depot), for P-970 requirements.
Current Navy aircraft inventory includes two types of jet engines: turbo fan/turbo jet engines and turbo shaft jet engines, which power aircraft with rotors or propellers. The test cells for these two types of engines would differ in size due to the differences in power requirements, volume of exhaust, and noise levels.

This facility shall support out of frame testing for the Intermediate-level Engine Maintenance Shop (Non-NAVAIR Depot), Category Code 211 21.
The facility includes spaces for engine mounts, fueling system, and observation and control. Engine test stands and Power Check Pads, without Sound Suppression (Non-NAVAIR Depot), Category Code 211 89 or with Sound Suppression (Non-NAVAIR Depot), Category Code 211 88, are normally authorized for all stations or activities requiring jet engine test facilities.

If possible, the Test Cell should be sited close to the Engine Maintenance Shop. It will require a paved access road for towing engines from the shop. Consideration should be given to enclosing existing open Power Check Pads.

The number of test cells required is based on the total monthly engine runs required and availability of a test cell for testing. The total monthly engine runs would be determined by the program management activity involved for each engine. The required monthly production could be estimated from total flight hours, number squadrons, and number of engine runs for each engine. The availability of a cell available for testing runs on a monthly basis can be determined with input from Fleet Readiness Center and NAVAIR Aircraft Engine Test System (AETS) Fleet Support Team (FST) based on operational data. It is estimated that 60% to 80% of the time a test cell is in operation is available for engine testing due to maintenance requirements, scheduled or unscheduled. For a newer test cell, percentage availability is closer to 80% whereas an older test cell is expected to be available closer to 60% of the time.

Besides availability, several other factors impact production rate including the time required for each engine run, number of shifts available for a test cell, and number of days a test cell is in operation on a monthly basis.

The following example illustrates the methodology for defining the requirement for test cells at Naval Air Oceana Test Cell involving two engines for F/A 18A-F aircraft.

Table 21181-1
Out-Of-Frame Engine Test Facility Requirements
Global Engine Repair
Naval Air Station Oceana

Item Description	Unit	Value	Note/Computation
Total Monthly Engine Runs Required			
Required production per month (projected up to the next 5-yrs)	F404 Engine	17	Data obtained from PMA
	F414 Engine	18	Data obtained from PMA
Total monthly production requirement	Engine Tests/Mo	35	Summary of monthly productions for all engines
Number of engine runs per engine test	Engine Runs/ Engine Test	2	Requirement set by PMA
Total monthly engine runs required	Engine Runs/Mo	70	Total monthly production requirement X Number of engine runs per engine test
Monthly Engine Runs Per Cell			

Item Description	Unit	Value	Note/Computation
Time required for one engine run	Hrs.	8	Data obtained from test cell operation
Shifts per available day		2	Average based on annual operation
Operating hours per shift	Hrs.	8	Data obtained from test cell operation
Operating hours per day	Hrs.	16	Shifts per available day X Operating hours per shift
Number of days test cell is available per month	Days/Cell/Mo	20	Average based on annual operation
Operating hours per cell per month	Hrs./Cell/Mo	160	Operating hours per day X Number of days test cell is available per month
Availability of test cell for engine testing	Percentage	60%	Average based on annual operation, determined with input from FRC/AETS FST
Available hours for engine testing per cell per month	Hrs./Cell/Mo	96	Operations hours per cell per month X Availability of test cell for engine testing
Monthly engine runs per test cell	Engine Runs/ Cell/Mo	24	Available hours for engine testing per month / Time required for one engine run
Number of Test Cells Required			
Number of test cells required	Cells	2.92	Total monthly engine runs required / Monthly engine runs per test cell
Number of test cells required, rounded up	Cells	**3**	

211 82 AIRCRAFT WEAPONS ALIGNMENT SHELTER (NON-NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21182-1 **GENERAL.** A minimum of one aircraft weapons alignment shelter is required at Navy and Marine Corps air installations having fighter or attack aircraft which require alignment of on-aircraft weapons systems. In addition to weapons systems alignment, which is the process of mechanically and electrically aligning aircraft weapons electronic systems to a common aircraft axis, this facility provides space for on-aircraft electronic maintenance of the weapons systems. For the mechanical alignment of guns attached to aircraft, see Aircraft Boresight Range (Non-NAVAIR Depot), Category Code 211 09. If vehicle and aircraft access pavement is required, see Category Code 851 10, Roads, and 113 40, Aircraft Access Apron.

To determine the square footage requirements for a given air installation, the number of assigned aircraft of the types that require weapons calibration is first determined. This number is used to enter column 1 of Table 21182-1. Columns 2 and 3 of Table 21182-1 show the number of bays and gross area of structure required respectively.

Table 21182-1
Space Allowances for Aircraft Weapons Alignment Shelter

Column 1	Column 2	Column 3
No. A/C	**No. Bays**	**Gross Area m^2 (SF)**
Up to 20	1	488 (5,246)
21 to 41	2	969 (10,423)
42-63	3	1,441 (15,503)
64-87	4	1,913 (20,583)
88-114	5	2,385 (25,663)
115-145	6	2,858 (30,743)
146-181	7	3,330 (35,822)
182-223	8	3,802 (40,902)
224-272	9	4,274 (45,983)
over 272	10	4,746 (51,063)

211 83 ENGINE TEST CELL (NAVAIR DEPOT) (m^2 / SF)
FAC: 2118
BFR Required: Y

21183-1 **GENERAL.** An Engine Test Cell is required for the Test and Calibration Production Shop of the Naval Air Depot (NAVAIR Depot). Included within this Category Code are:

a. Jet Engine Test Cell (10,000 – 16,000 lbs. maximum thrust)
b. Jet Engine Test Cell (Over 16,000 lbs. maximum thrust)
c. Jet Engine Test Stand – Facility for testing jet aircraft engines which has no acoustical noise abatement and is not part of an enclosed facility.
d. Turbo Prop Test Cell
e. Reciprocating Engine Test Cell (3,000 HP or less)
f. Reciprocating Engine Test Cell (Over 3,000 HP)
g. Reciprocating Engine Test Stand - Facility for testing reciprocating aircraft engines which has no acoustical noise abatement and is not part of an enclosed facility.
h. Turbo Shaft Test Cell
i. Turbo Fan Test Cell
j. Pneumatic Gas/Air Turbine Test Cell

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 84 HELICOPTER BLADE TEST FACILITY (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21184-1 **GENERAL.** A Helicopter Blade Test Facility is required for the Test and Calibration Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 85 RADOME TEST FACILITY (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21185-1 **GENERAL.** A Radome Test Facility is required for the Test and Calibration Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 86 RADAR/ANTENNA TEST FACILITY (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21186-1 **GENERAL.** A Radar/Antenna Test Facility is required for the Test and Calibration Production Shop of the Naval Air Depot (NAVAIR Depot).
There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 87 AIRCRAFT WEAPONS ALIGNMENT/BORESIGHT FACILITY (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21187-1 **GENERAL.** An Aircraft Weapons Alignment/Boresight Facility is required for the Test and Calibration Production Shop of the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 88 POWER CHECK PAD WITH SOUND SUPPRESSION (NON-NAVAIR DEPOT) (m^2 / SF)
FAC: 2118
BFR Required: Y

21188-1 **GENERAL.** Power check pads provided with fixed or portable sound suppressors which meet desired noise criteria are categorized here. Planning is the same as in Category Code 211-89. NAVFAC P-970 provides an analytical method for evaluating location of the power check pad with respect to inhabited areas. It shows how to calculate the expected noise levels and estimate the probable response to the noise. This noise survey is essential for substantiating the requirement for a power check pad with sound suppression.

211 89 POWER CHECK PAD WITHOUT SOUND SUPPRESSION (NON-NAVAIR DEPOT) (m^2 / SF)
FAC: 2118
BFR Required: Y

21189-1 **GENERAL.** Navy and Marine Corps air installations where aircraft are permanently assigned, and aircraft maintenance is performed require power check facilities. The power check pad is used to test and adjust engines mounted in the aircraft, in-frame testing. Employing portable engine test stands, the power check pad is used for uninstalled engine testing. A power check pad includes Portland cement concrete airfield pavement with securing fittings, and, where required, protection walls and blast deflectors. NAVFAC P-970, Planning in the Noise Environment, specifies acceptable noise levels for various land uses. See Category Code 211 01, Aircraft Acoustical Enclosure (Non-NAVAIR Depot), for P-970 requirements.

Power check pads without sound suppression shall only be planned when a noise survey, as laid out in P-970, has shown that the location will not result in the need for sound suppression.

One power check pad for in-frame testing shall be planned to support up to 140 aircraft and two will support up to 360 aircraft. Out-of-frame testing facilities should be planned in conjunction with Category Code 211 81, Engine Test Cell (Non-NAVAIR Depot). The power check pad should be at least 610 meters (2,000 feet) from any other activity, and preferably at greater distances from administrative, training, housing, and other inhabited buildings in order to reduce the sound suppression requirement. When used for uninstalled engine testing, the power check pad includes provision for portable fueling and instrumentation equipment and must be located for ready accessibility from the Engine Maintenance Shops, Category Code 211 21. At existing airfields, maximum use shall be made of surplus airfield pavement that can be modified to satisfy the power check pad requirement.

211 90 OTHER SUPPORT FACILITIES (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21190-1 **GENERAL.** Other Support Facilities are those areas used to perform productive NAVAIR Depot work that have not been previously identified. This includes ramp, apron, and aircraft storage sites.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 91 UNCOVERED RAMP (NAVAIR DEPOT) (m^2 / SF)
FAC: 2118
BFR Required: Y

21191-1 **GENERAL.** Uncovered Ramp is required to perform NAVAIR Depot-specific maintenance and production functions. Included within this Category Code are:

a. Aircraft Rework Apron – Uncovered areas specifically assigned for NAVAIR Depot maintenance.
b. Reclamation Apron – Uncovered areas assigned to depot maintenance used for performing aircraft reclamation work.
c. Armament and Disarmament Pad
d. Pre-dock /Post-dock Apron
e. Aircraft Corrosion Control Facility (Uncovered)
f. Ground Check/Flight Test Support (Uncovered)

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 92 COVERED GROUND CHECK/FLIGHT TEST FACILITY (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21192-1 **GENERAL.** A Covered Ground Check/Flight Test Facility is required for the Naval Air Depot (NAVAIR Depot).

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 93 ENGINEERED LAB (NAVAIR DEPOT) (m / SF)
FAC: 2116
BFR Required: Y

21193-1 **GENERAL.** An Engineering Lab is required to provide space to support NAVAIR Depot-specific maintenance and production functions. Included within this Category Code are:

a. Material Handlers/Parts Expediters
b. Material Control Laboratory
c. Standards Laboratory
d. Programmer’s – Automatic Test Equipment and Numerical Controlled Machine

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 94 AIRCRAFT POWER CHECK FACILITIES (NAVAIR DEPOT) (m^2 / SF)
FAC: 2118
BFR Required: Y

21194-1 **GENERAL.** Aircraft Power Check Facilities are required to perform NAVAIR Depot-specific maintenance and production functions. Included within this Category Code are:

a. Power Check Pad (No Sound Suppression)
b. Power Check Pad (With Sound Suppression)
c. Propeller Aircraft Power Check Pad
d. Helicopter Aircraft Power Check Pad
e. VSTOL Aircraft Power Check Pad

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 95 MATERIAL AND EQUIPMENT STAGING/STORAGE FACILITY (NAVAIR DEPOT) (m^2 / SF)
FAC: 2116
BFR Required: Y

21195-1 **GENERAL.** A Material and Equipment Staging/Storage Facility for Naval Air Depot (NAVAIR Depot) is required to provide space for Packaging and Preservation of material.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine the requirement.

211 96 MAINTENANCE – AIRCRAFT/SPARES STORAGE (m^2 / SF)
FAC: 2116
BFR Required: Y

21196-1 **GENERAL.** Storage facilities for miscellaneous aircraft equipment/parts/goods, etc., will be provided only where it can be individually justified. In addition to the method of determining the gross square-footage requirement, the justification should include an explanation as to why the storage requirement cannot be met through storage space provided within hangars/shops or 440 series covered general supply facilities. No specific criteria are available for this type of facility;

however, general information on normal stacking heights, SF per measurement ton, and other warehousing parameters are provided in Category Code 440 series.

211 97 PLANT SERVICES AND AIRCRAFT OVERHAUL (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21197-1 **GENERAL.** A Plant Services and Aircraft Overhaul Facility is required to provide space which is used in providing general support for all aircraft production operations. General support includes functions such as management, supervision, engineering, clerical functions, plant maintenance, central or general storage, quality assurance, and materials testing. This Category Code includes offices, cafeterias, supervisors' workspace, shop parts storage areas, dispatching facilities, inspection facilities, stairwells, auxiliary equipment rooms, walls, etc.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 98 AIRCRAFT ACOUSTICAL ENCLOSURE (NAVAIR DEPOT) (m^2 / SF)

FAC: 2116
BFR Required: Y

21198-1 **GENERAL.** An Aircraft Acoustical Enclosure is required to provide a covered facility for the in-frame aircraft engine run-up maintenance and testing performed by NAVAIR Depot. The aircraft acoustical enclosure, sometimes referred to as a hush house, is a total enclosure for fixed wing aircraft designed to abate noise during in-frame run-up of jet engines. The facility consists of a hangar-like aircraft enclosure, an absorptive augmenter for inducing cooling air and absorbing noise, a 45-degree blast deflector, an observation room with lavatory, and a mechanical equipment room. The observation and mechanical rooms are located adjacent to, not within, the aircraft enclosure.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 99 HAZARDOUS MATERIAL STOREHOUSE (NAVAIR DEPOT) (m^2 / SF)
FAC: 4413
BFR Required: Y

21199-1 **GENERAL.** A Hazardous Material Storehouse for Naval Air Depot (NAVAIR Depot) is required to provide space for the storage of hazardous substances and materials.

There are no specific criteria developed for this Category Code. An engineering study must be performed to determine requirement.

211 SUPPLEMENT – MARINE CORPS AIRCRAFT MAINTENANCE FACILITIES

211-1 GENERAL

Facilities for the maintenance and repair of Navy and Marine Corps aircraft and related spares, including airframes, aircraft engines, aircraft weapons systems, avionics systems, and other related aircraft equipment are planned in accordance with maintenance functions and levels as authorized by the Chief of Naval Operations (CNO). Maintenance classifications are defined in OPNAVINST 4790.2 (series) and are the basis for the Naval Aircraft Maintenance Program (NAMP). Within the Marine Corps, the Deputy Commandant for Aviation (DC/A) is responsible for planning and coordinating staff activities for all matters relative to organization, equipment, manpower, training, and support of Marine Corps aviation units and installations, including all Aviation Logistics (AVLOG) matters. Because Marine Corps aviation is an integral part of naval aviation, DC/A is responsible to the CNO to ensure that Marine Corps aviation is in consonance with the overall Naval Aviation Program.

OPNAVINST 4790.2 (series) supports CNO/Commandant of the Marine Corps (CMC) readiness and safety objectives, and provides for optimum use of manpower, facilities, materiel, and funds. The NAMP is founded upon three-level maintenance concept: depot (“D” level) maintenance, intermediate “I” level maintenance and organizational (“O” level) maintenance. It is the authority governing management of D-level, I-level, and O-level aviation and aeronautical equipment maintenance. It provides the management tools required for efficient and economical use of personnel and material resources in performing maintenance. It also provides the basis for establishing standard organizations, procedures, and responsibilities for accomplishing all maintenance on naval aircraft, associated materiel, and equipment. The division of maintenance into the three levels allows management to:

i. Classify maintenance functions by levels.

ii. Assign responsibility for maintenance functions to a specific level.

iii. Assign maintenance tasks consistent with the complexity, depth, scope, and range of work to be performed.

iv. Accomplish any particular maintenance task or support service at a level that ensures optimum economic use of resources.

v. Collect, analyze, and use data to assist all levels of NAMP management.

211-2 DEPOT LEVEL MAINTENANCE

D-level maintenance is performed at naval aviation industrial establishments to ensure continued flying integrity of airframes and flight systems during subsequent operational service periods. D-level maintenance is also performed on material requiring major overhaul or rebuilding of parts, assemblies, subassemblies, and end items. It includes manufacturing parts, modifying, testing, inspecting, sampling, and reclamation. D-level maintenance supports O-level and I-level maintenance by providing engineering assistance and performing maintenance beyond their capabilities. D-level maintenance functions are grouped as follows:

i. Standard D-level maintenance of aircraft.

ii. Rework and repair of engines, components, and support equipment.

iii. Calibration by Navy calibration laboratories.

iv. Incorporation of technical directives (TDs).

v. Modification of aircraft, engines, and support equipment.

vi. Manufacture or modification of parts or kits.

vii. Technical and engineering assistance by field teams.

viii. Aircraft armament or aircraft and equipment under reliability-centered maintenance (RCM).

ix. Rework of expeditionary airfield (EAF) components.

211-3. D-LEVEL MAINTENANCE CATEGORY CODES AND REQUIREMENT

Facilities that are generally categorized as D-level maintenance facilities (also noted as NAVAIR depot) are shown in Table 211-5 “”D” Level Maintenance Facilities” and described in Section 211-1.10 “Facilities Categorized as “D” Level Maintenance” of the introduction to this category code series, “Series 211 Maintenance – Aircraft, Spares”. Each requirement for depot maintenance facilities must be planned and justified individually.

211-4 ORGANIZATIONAL LEVEL MAINTENANCE

O-level maintenance is performed by operating units (squadrons) on a day-to-day basis in support of their operations. The O-level maintenance mission is to maintain assigned aircraft and aeronautical equipment in a full mission-capable status while continuing to improve the local maintenance process. While O-level maintenance may be done by I-level or D-level activities, O-level maintenance is usually accomplished by maintenance personnel assigned to aircraft squadrons. Generally, O-level maintenance can be grouped under the following categories:

i. Inspections.

ii. Servicing.

iii. Handling.

iv. On-equipment corrective and preventative maintenance, including repair, removal, and replacement of defective components.

v. Class V (A) ordnance loading/unloading and arming/dearming.

vi. Incorporation of TDs

vii. Recordkeeping and reports preparation.

viii. Age exploration or aircraft and equipment under RCM.

211-4.1 **O-level Maintenance Category Codes.** Facilities that are generally categorized as O-level maintenance facilities are shown in Table 21100-2 “”O” Level Maintenance Facilities” and described in Section 211-1 “Facilities Categorized as “O” Level Maintenance” of the introduction to this category code series, “Series 211 Maintenance – Aircraft, Spares”. Marine Corps requirements for organizational level aircraft maintenance facilities are computed in the same manner as Navy requirements. See Category Codes 211 03, 211 04, 211 05, 211 06, and 211 07 for individual computation methodologies.

211-5 INTERMEDIATE LEVEL MAINTENANCE

Marine Corps air installations may be assigned limited intermediate maintenance level responsibilities for its own aircraft; however, most I-level aircraft maintenance is performed by a Marine Air Logistics Squadron (MALS). The I-level maintenance mission is to enhance and sustain the combat readiness and mission capability of supported activities by providing quality and timely material support at the nearest location with the lowest practical resource expenditure. I-level maintenance consists of on-and off-equipment materiel support and may be grouped as follows:

i. Performance of maintenance on aeronautical components and related support equipment and EAF components.

ii. Calibration of designated equipment.

iii. Processing aircraft components from stricken aircraft.

iv. Providing technical assistance to supported units.

v. Incorporation of TDs.

vi. Manufacture of selected aeronautical components, liquids, and gases (cryogenics).

vi. Performance of on-aircraft maintenance when required.

vii. Age exploration of aircraft and equipment under RCM.

viii. Weapons preparation.

211-6 MARINE AIR LOGISTICS SQUADRON

MALS was developed by the Marine Corps to enhance the aviation unit’s transition from a garrison configuration to the composite Aviation Combat Element (ACE) of a Marine Air Ground Task Force (MAGTF).

The composition and size of a MAGTF may vary, but the organizational structure will always be composed of four elements. These elements consist of the Command Element (CE), the Ground Combat Element (GCE), the Aviation Combat Element (ACE), and the Combat Service Support Element (CSSE). The composition and size of the MAGTF is structured to achieve the missions required to meet the existing world threats. The MAGTF may be employed in three sizes: a Marine Expeditionary Unit (MEU), a Marine Expeditionary Brigade (MEB), and a Marine Expeditionary Force

(MEF). The composition of the ACE is task-organized to conduct tactical air operations to support each of these MAGTF elements.

211-6.1 **MALS Organization.** The MALS is a command entity emulating the organizational structure of other Marine squadrons. A typical MALS is composed of the following Departments:

1) MALS Maintenance Department
2) Aviation Supply Department (ASD)
3) MALS Operations Department
4) Aviation Information Systems Department

211-6.1.1 **MALS Maintenance Department.** The Aviation Logistics functions of the MALS maintenance department include aircraft, avionics, support equipment maintenance, flight equipment, cryogenics, aviation ordnance, and maintenance data collection and analysis. All available talents and resources are used to ensure components are repaired to the highest standard of quality to further enhance the warfighting capabilities of the customer (the tactical squadrons). Specific responsibilities are as follows:

- Coordinate control of aircraft maintenance performed by, and in support of, squadrons and units under the cognizance of the MAG Commanding Officer, and materiel condition and combat readiness of assigned weapons systems and equipment.

- Conduct liaison among squadrons, stations, MAWs, and other activities in connection with maintenance or materiel matters.

- Ensure squadrons within the MAG provide augmentation personnel on a temporary additional duty basis as required for training in the maintenance of organic systems and subsystems by the I-level.

- Coordinate pre-deployment planning for the provisioning of personnel, facilities, support equipment, and services for supported squadrons.

- Screen supported deploying squadron materiel to ensure only materiel considered essential to support the specific deployment is embarked, and consolidation of multiple squadron requirements is made whenever possible.

- Screen appropriate Marine Aviation Logistics Support Program (MALSP) individual material readiness list (IMRL) allowances to ensure they are tailored to support the quantity and type aircraft assigned to the MAG squadrons.

- Ensure the MAG aircraft assignment board (or equivalent) is maintained and reflects current status.

- Maintain liaison with supported squadron maintenance material control centers and the ASD and ensure adequate validation and reconciliation of outstanding requirements takes place.

- Monitor MAG squadrons to ensure an effective maintenance program is being conducted.

- Monitor MAG squadrons to ensure an active and effective quality assurance monitoring program exists.

- Monitor MAG squadrons to ensure correct maintenance, administration, and material handling procedures are used, directing particular attention to the detection and removal of all administrative impediments to aircraft readiness.

- Assist squadrons in obtaining technical engineering assistance.

- Coordinate with other staff organizations to ensure maintenance facility requirements for both MALS and O-level are updated and submitted as required.

- Coordinate the assignment of aircraft parking spaces within the MAG.

- Ensure an aggressive and effective management program is in place to control cannibalization of aeronautical equipment. To the maximum extent possible, ensure selective cannibalization actions are planned to prevent aircraft from being in a non-flyable status for more than 30 consecutive days.

- Ensure inter-MALS liaison is maintained for repair of components in the secondary repair site program.

- Coordinate D-level drive-in or field modifications of assigned aircraft.

- Ensure an effective program is in place to perform a quarterly review of the MALS individual component repair list.

- Conduct regular meetings, chaired by the maintenance officer and co-chaired by the Aviation Supply Officer, with supported units to ensure optimum communication and coordination.

- Analyze the mission accomplishment and capabilities of the department using reports provided by the maintenance data system (MDS) on a continuing basis.

Within the MALS Maintenance Department there are two divisions:

a) Avionics Division
b) Aviation Ordnance Division

a) Avionics Division. The avionics division provides maximum support, coordination, and leadership to the MALS' mission in the areas of aircraft maintenance, avionics equipment maintenance, integrated logistics resource management, and professional personnel development.

All maintenance and support of the MALS and supporting activities, avionics equipment – to include weapons repairable assemblies, shop repairable assemblies, support equipment, test measuring and diagnostic equipment, and "Navy funded" computers and peripherals – will be performed by personnel assigned within the avionics division. These functions encompass programs, equipment, and support for activities both internal and occasionally external to the MAG. The avionics division, responsible to the maintenance officer, has the overall responsibility for the production effort within the MALS, on matters dealing with the scheduling, prioritization, and production of avionics equipment.

An avionics division exists within each MALS and consists of the following functional branches: avionics branch, precision measurement equipment branch, and various production branches necessary to support flying squadrons of the MAG. Each branch is responsible for the maintenance of its avionics equipment, the welfare of its personnel, an accurate accountability of work center IMRL assets, and individual branch security. The avionics branch is responsible for overall division administrative duties and I-level maintenance on avionics equipment. Depending on the type of aircraft supported, the avionics branch may contain up to five work centers: communications/navigation, electrical/instrument repair, automatic test equipment, electronic warfare, and radar.

b) Aviation Ordnance Division. The function of the aviation ordnance division is to provide the MALS with logistical and management support of class V(A) ordnance, aircraft armament equipment (AAE), and armament weapons support equipment (AWSE). This is done by interpreting and implementing the ordnance policies and procedures for the MAG. The MALS ordnance staff:

- Ensures the management and distribution of authorized noncombat expenditure allocation (NCEA).

- Assists the MAG in developing testing and training requirements for aviation ordnance.

- Ensures proper logistical support and storage requirements for prepositioned ware reserve materiel requirements assets are identified, including buildup and delivery of class V(A), ammunition stock points, advanced bases, and forward arming and refueling points.

- Manages the MAG's ordnance safety program and ensures explosive safety policies and procedures are issued as required.

- Ensures compliance with the policies and procedures set forth in OPNAVINST 8000.16A, "Naval Ordnance Maintenance Management Program (NOMMP)", when preparing quality deficiency reports, explosive mishap reports, technical publication deficiency reports, and engineering investigation requests.

- Ensures class V(A) materiel is managed per the current revision of NAVSUP P-724, "Conventional Ordnance Stockpile Management Policies and Procedures Manual", and other related directives.

- Establishes and monitors the handling, qualification, and certification program for nonnuclear aviation ordnance and nonnuclear explosive devices for the MALS.

- Establishes and maintains a satellite production control work center.

- Analyzes production and readiness division using reports provided by the MDS.

- Ensures satellite production efforts support the maintenance department's goals, objectives, and standards.

- Publishes a monthly maintenance and training plan for airborne weapons, training assets, AWSE, AAE, and formal in-Service training of aviation ordnance personnel.

- Ensures all maintenance performed on the AAE pool and AWSE is per the standards and guidelines established by the MALS maintenance department.

- Provides information on manpower, equipment, class V(A) materiel, and facilities to appropriate authorities.

- Establishes a verification program for technical manuals and directives maintained by the division.

- Establishes an AAE pool per MAW and aircraft controlling custodian/type commander (TYCOM) directives.

- Ensures the Retail Ordnance Logistics Management System (ROLMS) and the standardized conventional ammunition automated inventory record are used to manage class V (A).

- Monitors and coordinates nonexpendable aviation ordnance support provided by the MALSP.
- Ensures the division maintains the capability to operate from advanced bases and forward arming and refueling points.

- Coordinates pre-deployment planning for ordnance personnel, facilities, support equipment, ordnance materiel, and services to support squadrons (NAVSEA OP-5 Vol III, "Ammunition and Explosives Ashore, Advance Bases").

- Screens squadron materiel requests and the availability of class V (A) assets to ensure only material considered essential is embarked.

- Ensures appropriate levels of support are identified in the time-phased force and deployment data (TPFDD) database.

211-6.1.2 **Aviation Supply Department (ASD)**. The ASD executes all functions dealing with the inventory, storage, and management of Navy-provided materiel. The ASD staff functions include, but are not limited to, the direct responsibilities listed in the following paragraphs. An ASD exists within each MALS with physical location of the divisions within the ASD varying depending upon local situations. However, preferred locations are adjacent to the maintenance department production divisions. The hours of operation will be consistent with the operating hours of supported organizations.

Within the ASD there are seven divisions:

a) Supply Response Division
b) Consumables Management Division
c) Repairables Management Division
d) Supply Accounting Division

e) Squadron Support Division
f) Supply Management Division
g) Supply Personnel and Administration Division

a) Supply Response Division. The supply response division is responsible for the initial screening and technical research of all requisitions assigned by Naval Aviation Logistics Command Management Information System (NALCOMIS). The supply response division will refer consumable requisitions that cannot be filled from supply officer stores to the appropriate supply point of entry. The supply response division is also responsible for the reconciliation and monitoring of all outstanding direct turn-over (DTO) requisitions except for custodial, pre-expended bins, and service market items.

b) Consumables Management Division. The consumables management division is responsible for the procurement, receipt, storage, issue, delivery, and inventory of all consumable material.

The consumables management division consists of the following five branches:

i. Receiving Branch
ii. Consumable Delivery Branch
iii. Consumables Storage Branch
iv. Consumable Control Branch
v. Pre-Expended Branch

i. Receiving Branch. The receiving branch receipts and redistributes all material shipped to the MAG/MALS from external sources.

ii. Consumable Delivery Branch. The consumable delivery branch delivers all consumable issues, consumable DTO receipts, and processes related transactions.

iii. Consumables Storage Branch. The consumables storage branch stores, issues, and inventories all consumable material in the supply officer's stores and is divided into the consumable storage section and the consumable issue section.

iv. Consumable Control Branch. The consumable control branch manages inventory of consumable material.

v. Pre-Expended Branch. The pre-expended branch establishes, manages, and replenishes pre-expended bin sites authorized by the AVNSUPO or maintenance officer.

c) Repairables Management Division. The repairables management division is responsible for:

- Repairables allowance management, procurement, receipt, storage, issue, delivery, and inventory of all repairable materiel.

- Induction and recovery of repairables into/from the Intermediate Maintenance Activity "abd" for shipment and tracking beyond-the-capability-of-maintenance components to the appropriate activity.

- Management and control of all classified and fleet controlled material (repairable and consumable).

The repairables management division consists of the following five branches:

i. Repairables Control Branch
ii. Repairables Delivery Branch
iii. Repairables Storage Branch
iv. Awaiting Parts Branch
v. Supply Shipping Branch

i. Repairables Control Branch. The repairables control branch:

- establishes and maintains repairable allowances and is responsible for their procurement, inventory, and accountability.

- processes repairable requisitions and receipts with exceptions, and all repairables returned from the Intermediate Maintenance Activity.

- screens and tracks carcasses that are beyond-the-capability-of-maintenance.

- performs all duties on classified material (receipt, storage, issue, packaging, and shipment). Procedures for handling classified material are in Secretary of the Navy Instruction (SECNAVINST) 5510.36, "DON Information Security Program Regulation", and OPNAVINST 5218.7B, "Navy Official Mail Management Instructions".

ii. Repairables Delivery Branch. The repairables delivery branch delivers all repairable materiel (issues and DTO) to the customer. It also picks up all non-ready for issue repairable components from the customer ensuring accuracy of all documents, i.e., logbook, scheduled removal card, and maintenance action form (MAF).

iii. Repairables Storage Branch. The repairables storage branch is responsible for the receipt, issue, storage, and inventory of all repairable materiel in the supply officer's store. The storage of repairables is broken down into two separate sections – weapons repairable assembly and shop repairable assembly.

iv. Awaiting Parts Branch. The awaiting parts branch stores and manages repairable components awaiting repair parts.

v. Supply Shipping Branch. The supply shipping branch packages and ships all aeronautical-related components and equipment.

d) Supply Accounting Division. The supply accounting division is responsible for all tasks related to maintaining and reporting the financial accounts granted to the ASD.

The supply accounting division consists of the following two branches:

i. End Use Branch
ii. Stock Fund Branch

i. End Use Branch. The end use branch maintains and reports all end use accounts allocated to the ASD and is divided by operating target (OPTAR) funding.

ii. Stock Fund Branch. The stock fund branch reports transactions, which affect the Navy Working Capital Fund (NWCF) special accounting class (SAC) 207 inventory. It also verifies the financial processing of all transactions processed by the MALS.

e) Squadron Support Division. The squadron support division is responsible for receiving, processing, and monitoring all requirements for aeronautical-related custodial materiel and maintaining custody records for all organizational allowances.

The squadron support division consists of the following two branches:

i. Customer Assistance Branch
ii. Custody Records Branch

i. Customer Assistance Branch. The customer assistance branch receives, processes, and monitors all requirements for aeronautical-related custodial material.

ii. Custody Records Branch. The custody records branch maintains the custody record cards for all organizational allowance material, such as IMRL, TBA, COSAL, controlled equipage listed in the NAVAIR 00-35QH-2 (Section H), and maintenance assist modules/test bench installations. This branch also formulates the quarterly and annual budgets and the mid-year budget review for all custodial material.

f) Supply Management Division. The supply management division is composed of the most knowledgeable and experienced aviation supply personnel responsible for monitoring the overall supply department operation, technical training, and MALSP allowances and pickups (as they pertain to deployed and contingency operations).

The supply management division consists of the following two branches:

i. Audit Branch
ii. MALSP Support Branch

i. Audit Branch. The audit branch monitors all supply functions within the ASD to ensure compliance with authorized procedures and achievement of established goals.

ii. MALSP Support Branch. The MALSP support branch validates and loads MALSP allowances and monitors pickups.

g) Supply Personnel and Administration Division. The supply personnel and administration division is responsible for the administrative control of all personnel assigned. The supply personnel and administration division perform clerical functions and maintains the master files of all messages, orders, correspondence, and directives for the ASD.

The supply personnel and administration division consist of the following two branches:

i. Supply Personnel Branch
ii. Supply Administrative Branch

i. **Supply Personnel Branch.** The supply personnel branch performs functions related to administrative control of all personnel within the ASD.

ii. **Supply Administrative Branch.** The supply administrative branch provides clerical assistance for the ASD as directed by the AVNSUPO or the aviation supply chief.

211-6.1.3 **MALS Operations Department.** The MALS is a command entity similar to other Marine squadrons. The MALS operations officer is the chief advisor to the MALS Commanding Officer for all matters pertaining to planning and execution of tactical operations involving aviation logistical support (ALS). The MALS operations department is responsible for identifying, planning, coordinating, and supervising all operational AVLOG planning requirements.

The MALS operations department coordinates with both the parent MAG and each supported squadron regarding ALS for deployed squadrons and detachments. It also serves as the MALS point of contact for all deployment support involving the unit deployment program, L-Class/aircraft carrier (CV)/aircraft carrier (nuclear) (CVN) and aviation logistics support ships (T-AVB)/maritime pre-positioning force (MPF) employment plans and milestone reporting. It is also responsible for AVLOG force deployment planning and execution (FDP&E) as it relates to deliberate and crisis action planning (CAP).

211-6.1.3.1 **Deliberate Planning**. Deliberate planning is conducted during peacetime to develop and refine war plans. Planning in this fashion allows for orderly and methodical command and staff participation in the preparation of a plan. Deliberate planning is conducted when there is ample time for detailed, methodical, and comprehensive planning and coordination. The deliberate planning process culminates with the creation and refinement of time-phased force and deployment data (TPFDD) and its placement into the Joint Operation Planning and Execution System (JOPES). The following steps will be followed during the deliberate planning process. The MALS operations department:

- Coordinates the range and depth of AVLOG support required to support the concept of operations as defined by the MAW AVLOG plans section.

- Reviews all plans that require employment of AVLOG and class V(A) support and coordinates operational AVLOG as required to support each plan.

- Coordinates the review of operational and contingency plans (OPLANs/CONPLANs) with internal MALS department.

- Determines, in coordination with consolidated administration, assignment of MALS core and augments personnel to:

- Maritime prepositioning ship (MPS) survey, liaison, and reconnaissance party, arrival and assembly operations element, and offload preparation party.

- T-AVB.

- CV/CVN/general purpose amphibious assault ship (LHA)/multi-purpose amphibious assault ship (LHD).

- Ashore ACE bed-down airfield.

The MALS operations department also reviews each applicable deliberate plan and determines:

- If the commander's intent and end state for each deliberate plan/CONPLAN have been met.

- The employment, configuration, and coordination of arrival date of the T-AVB.

- The TPFDD for of AVLOG assets into the theater of operations.

- Each MALS unit line number is identified on the TPFDD.

- Site survey for the MALS bed-down sites.

- Geo-prepositioning support equipment offload distribution and assignment plan.

211-6.1.3.2 **Crisis Action Planning**. CAP performed by AVLOG planners at all levels must recognize that CAP is not governed by rigid steps as it is a flexible means of coordinating staff action. However, certain conditions may be viewed as probable with respect to the preparation of deployment data in response to any crisis action situation. If the crisis is in response to a contingency for which deliberate planning has been conducted, the existing planning data can be used as a tool to develop tailored support. If the crisis is in response to a contingency for which no deliberate planning has been previously conducted, ALS must be tailored without the benefit of existing data. During CAP, the MALS operations department is responsible for:

- Recommending to the MALS CO operational priorities for the movement of MALS support.

- Acting as the MALS point of contact for the wing staff when the CAP is established.

- Coordinating the development and implementation of troop movements from home station to the sea/airport of embarkation.

- Coordinating with other MALS departments/sections to identify and tailor ALS.

- Determining priorities for MALS replacements in coordination with the S-1.

- Coordinating MALS operations security and signal security.

211-6.1.4 **Aviation Information Systems Department**. The Aviation Information Systems Department (AISD) provides data processing support to the supply and maintenance departments. The AISD is responsible for the administration, operation, and maintenance of all computer systems and networks throughout the supply, maintenance, and ordnance departments.

Within the AISD there are five divisions:

a) Administration Division
b) Customer Support Division
c) Network Administration Division
d) Systems Processing Division
e) Maintenance Support Division

a) Administration Division. The administration division is responsible for the administrative control of all personnel assigned. Personnel within the division perform clerical functions and maintain the master files for messages, orders, correspondence, and directives for the AISD.

b) Customer Support Division. The customer support division is the primary manager for customer support within the AISD. Unit/department representatives will forward discrepancies that cannot be resolved locally to the customer support division, who will then initiate the discrepancy into the maintenance cycle. The customer support division will further operate as the department issue and receive desk, production control/help desk call center, AISD asset manager, and supply/maintenance liaison, providing monitored support to the MAG relative to aviation information systems. In addition, the customer support division will substantiate and prioritize AISD requirements submitted via the supply department.

c) **Network Administration Division.** The network administration division is responsible for the management of all automated information systems (AIS) network resources within the MAG. These responsibilities include managing and upgrading network operating systems, data assurance, user account management, network architecture documentation and upgrade planning, network security, workstation software standardization.

d) **Systems Processing Division.** The systems processing division provides data processing support to the supply and maintenance departments. The systems processing division is responsible for administrative and operational control of the Intermediate Maintenance Activity Naval Tactical Command Support System (NTCSS) systems. The systems processing division is also responsible for coordination of application workload and output to the supply applications administrator and the maintenance applications manager.

e) **Maintenance Support Division.** The maintenance support division consists of AISD technicians that provide direct maintenance and installation support for all AIS and MALS core network assets.

Marine Corps Intermediate Maintenance Requirements Example Calculation:

Because of the expeditionary nature of the Marine Corps air support mission, many of the aircraft intermediate level maintenance shops are located in deployable mobile facilities (MFs). For this reason, Marine Corps aircraft intermediate level maintenance facilities in the continental United States are a combination of permanent facilities and mobile vans while Navy aircraft intermediate maintenance facilities are all permanent facilities.

The MFs (generally 2.4 m x 2.4 m x 6.1 m (8 ft x 8 ft x 20 ft) vans) used by the MALS conform to International Organization of Standardization container dimensions and are configured to perform a multitude of missions. MFs require a concrete pad and utility support when at home base. This allows the MFs to be used, maintained, and always ready to deploy for their primary mission. See Category Code 116 65, Mobile Facility Support Pad for concrete pad and utility support requirements.

When at home base, MFs are used primarily for training. It is also crucial to keep the MFs in good working order in case of rapid deployment need. If MFs are utilized at the home base, they should not reduce the various intermediate maintenance shop requirements.

Marine Corps aircraft intermediate level maintenance facilities are planned utilizing the basic criteria for comparable Navy facilities except that it is necessary to:

a. Provide one Type I hangar module for each Marine Air Logistics Squadron (MALS) assigned to an installation. This hangar supports the intermediate level maintenance program and is in addition to hangars required for organizational maintenance.

b. Size intermediate level maintenance shops in the same manner as Navy requirements.
c. Plan airframes shop requirements as part of the MALS hangar 01 space, and this space should be categorized as 211 06 rather than 211 08.

The following is an example of how to determine the amount of permanent intermediate level maintenance shop space required for a MALS (in addition to one Type I hangar), with the gross requirements for each shop being computed utilizing the appropriate criteria.

Example: Taking a MALS which supports a group composed of 4 VMA squadrons composed of 20 AV-8B aircraft each, 2 VMAQ squadrons composed of 8 EA-6B aircraft each, and 2 VMGR squadrons composed of 7 KC-130 aircraft each. Additionally, the MALS has 10 AM32K-4 and 10 MHU-151/M armament trailers. The MALS has mobile facilities, and the air station has 60 fixed point utility stations. Intermediate level maintenance shop space requirements are computed for each basic shop. In this example, airframes, avionics, aviation armament, aviation life support systems, and ground support equipment shops are computed. Hangar space requirements for organizational maintenance are computed utilizing the same criteria as for Navy hangars. See Aircraft Maintenance Hangar, Category Codes 211 05, 211 06, and 211 07. In addition, one Type I maintenance hangar is required for the MALS.

Step 1: Select the appropriate intermediate level shop Category Codes:

i. Airframes Shop: Category Code 211 08
ii. Aircraft Intermediate Maintenance Activity Management: Category Code 211 16
iii. Engine Maintenance Shop: Category Code 211 21
iv. Avionics Shop: Category Code 211 45
v. Aviation Armament Shop: Category Code 211 54
vi. Aviation Life Support Systems Shop: Category Code 211 75
vii. Ground Support Equipment Shop: Category Code 218 60
viii. Ground Support Equipment Shed: Category Code 218 61

Step 2: Airframes Shop (211 08)

a.) Using computation methodology for Category Code 211 08:

Type of Aircraft	Number of Aircraft
AV-8B	80
EA-6B	16
KC-130	14
Total	110

In accordance with Table 21108-2, a total of 110 aircraft requires a basic area of 1,571 m^2 (16,900 SF). Using Table 21108-3, it is determined the Composite Shop required for AV-8B support adds an additional 151 m^2 (1,630 SF). This gives a gross area as follows:

Airframes Shop Summary:

Component	m^2	SF
Basic Area	1,571	16,900
Composite Shop	151	1,630
Gross Airframes Shop Area	1,722	18,530

The Airframes Shop shall be located in the Type I hangar configured for the MALS.

Step 3: Aircraft Intermediate Maintenance Activity Management (211 16)

a.) Using computation methodology for Category Code 211 16:

The management spaces provide for the control, monitoring, and administration of the Intermediate Maintenance Activity (IMA). The Aircraft Maintenance Officer and staff are responsible for the administration and supervision of the maintenance effort for the IMA. These responsibilities include production control, material control, financial accounting, training, personnel, administration, quality control, technical publications library, data analysis, and tool control for common and special tools and test equipment. The Naval Aeronautical Engineering Services Unit (NAESU) staff and personnel performing In-Service Engineering Agent (ISEA) functions for aircraft are often collocated in these same spaces.

Provide 917 m^2 (9,875 SF) for IMA management functions.

Step 4: Engine Maintenance Shop (211 21):

a.) Using computation methodology for Category Code 211 21:

Type of Aircraft	Number of Aircraft
AV-8B	80
EA-6B	16
KC-130	14

Using Table 21121-2:

Aircraft		Area	
No.	Type	m^2	SF
80	AV-8B	1,820	19,575
16	EA-6B	239	2,575
14	KC-130	332	3,575
	Subtotal	2,391	25,725

Using Table 21121-3:

Additional Space Requirement based on total space allowance computed using Table 21121-2.

Computed Space Allowance (from table 21121-2)	Square Meters (from Table 21121-3)	Square Feet (from Table 21121-3)	Percent Factor (from Table 21121-3)
2,391 m^2 25,725 SF	2,324 – 2,556	25,001 – 27,500	45%

2,391 m^2 x 45% = 1,076 m^2 or 25,725 SF x 45% = 11,576 SF

High Bay Area (Subtotal from Table 21121-2): 2,931 m^2 (25,725 SF)
Shop Wing/Mezzanine (Subtotal from Table 21121-3): 1,076 m^2 (11,576 SF)

Total Engine Maintenance Shop = (2,931 + 1,076) m^2 = 4,007 m^2
(25,725 + 11,576) SF = 37,301 SF

If authorized by higher authority, additional applicable work center space requirements from Table 21121-4 shall be added.

Using table 21121-4:

Work Center	AV-8B	EA-6B	KC-130	M2	SF
Propeller			X	272	3,375

Auxiliary Power Unit	X		X	167	1,800
Rotor Dynamics				0	0
Auxiliary Fuel Stores		X		314	3,375
			Total	753	8,550

Note: Only one work center of each type is required.

Step 5: Avionics Shop (211 45)

a.) Using computation methodology for Category Code 211 45:

Obtain the basic space requirements for all type/model aircraft by entering Table 21145-1 with quantity of aircraft to be supported. Select the lowest percentage factor for secondary type aircraft for Column (3) by crossing from that aircraft in secondary column and considering each aircraft assigned with a larger basic space requirement as a prime aircraft.

i. The AV-8B has only the EA-6B with a larger basic space requirement therefore 42% will be used in Column (3).

ii. The KC-130 has both the AV-8B (33%) and the EA-6B (36%) with larger basic requirements. The AV-8B has the lowest percentage factor (33%) so this will be entered in Column (3).

iii. The EA-6B aircraft has the largest basic space requirement, therefore it is the prime aircraft with a percentage factor of 100% entered in Column (3).

Column (1)	Column (2) (Table 21145-1)		Column (3) (Table 21145-2)	Column (4) [Col(2) x Col(3)]	
	m^2	SF		m^2	SF
80 AV-8B	1,766	19,000	0.42	742	7,980
16 EA-6B	2,342	25,200	1.00	2,342	25,200
14 KC-130	1,171	12,600	0.33	386	4,158
Gross Avionics Shop Area				3,470	37,338

Step 6: Aviation Armament Shop (211 54)

a.) Using computation methodology for Category Code 211 54:

Type of Aircraft	Number of Aircraft	Trailer Type	Number of Trailers
AV-8B	80	AM32K-4A	10
EA-6B	16	MHU-151/M	10
KC-130	14	Total	20
Total	110		

i. Basic Shop Requirement

Determine the Aircraft Classification by entering Table 21154-1.

AV-8B: Attack/Fighter
EA-6B: Attack/Fighter
KC-130: Not Applicable

Obtain the basic space allowance by entering Table 21154-2. For a total of 96 Attack/Fighter Aircraft the basic space allowance is 465 m^2 (5,000 SF).

ii. Aviation Armament Equipment Pool Requirement

Column (1) Type A/C	Column (2) Area per A/C		Number of A/C	Pool Support Space	
	m^2	SF		m^2	SF
AV-8B	3.5	38	80	280	3,040
EA-6B	7.3	78	16	117	1,248
KC-130	N/A	N/A	14	0	0
Total Equipment Pool Support Space				397	4,288

iii. Armament Weapons Support Equipment Work Center (Marine Corps requirement ONLY)

Column (1) Type Trailer	Column (2) Area per Trailer		Number of Trailers	Area for Trailers	
	m^2	SF		m^2	SF
AM32K-A4	2.3	25	10	23	250
MHU-151/M	1.4	15	10	14	150
Total Equipment Pool Support Space				37	400

Aviation Armament Shop Summary:

Area	m^2	SF
Basic Shop	465	5,000

Aviation Armament Equipment Pool	397	4,288
Armament Weapons Support Equipment Work Center	37	400
Gross Aviation Armament Shop Area	899	9,688

Step 7: Aviation Life Support Systems Shop (211 75)

a.) Using computation methodology for Category Code 211 75:

Type of Aircraft	Number of Aircraft
AV-8B	80
EA-6B	16
KC-130	14
Total	110

Obtain the Parachute Shop Factor (Column (2)), Flotation Shop size (Column (3)), and Oxygen Shop size (Column (4)) for all type/model aircraft by entering Table 21175-1.

i. The Parachute Shop Factor is 0.0016, the Flotation Shop size is M (46.5 m^2 (500 SF)), and the Oxygen Shop size is L (46.5 m^2 (500 SF)) for the AV-8B aircraft.

ii. The Parachute Shop Factor is 0.0064, the Flotation Shop size is M (46.5 m^2 (500 SF)), and the Oxygen Shop size is L (46.5 m^2 (500 SF)) for the EA-6B aircraft.

iii. The Parachute Shop Factor is 0.0064, the Flotation Shop size is L (83.7 m^2 (900 SF)), and the Oxygen Shop size is S (27.9 m^2 (300 SF)) for the AV-8B aircraft.

A/C Type	Number of A/C	Table 21175-1 Column (2)	Factor Product	Table 21175-1 Column (3)	Table 21175-1 Column (4)
AV-8B	80	0.0016	0.1280	M	L
EA-6B	16	0.0064	0.1024	M	L
KC-130	14	0.0064	0.0896	L	S
		Total:	0.3200	L	L

From Table 21175-2, Basic Allowance for 0.3200 = 279 m^2 (3,000 SF)

From Table 21175-1, Column (3), Flotation Shop, “L”= 83.7 m^2 (900 SF)

From Table 21175-1, Column (4), Oxygen Shop, “L”= 46.5 m^2 (500 SF)

Total Aviation Life Support Systems Shop = 409.2 m^2 (4,400 SF)

Step 8: Ground Support Equipment Shop (218 60)

a.) Using computation methodology for Category Code 218 60:

Type of Aircraft	Number of Aircraft
AV-8B	80
EA-6B	16
KC-130	14
Total	110

b.) From Table 21860-1:

Component	Number of Aircraft	
	80 (up to 120)	
	m^2	SF
Support Equipment Division/admin/ production control/tool room/ IMRL/ material control/SE pool	104	1,114
SE Training/License	28	300
Support	90	967
Net to gross (19%)	149	1,600
SE Gas Engine and Turbine Shop	28	300
SE Structural/Hydraulics Shop	74	800
SE Corrosion Control Shop	74	800
SE Electrical Repair Shop	28	300
SE Component Repair Shop	65	700
SE Periodic Maintenance Shop	63	680
Air Conditioning Repair Shop	-	-
SE Repair Lanes/Service Bays	229	2,460
Total Shop Area	931	10,021

c.) Shop Area size adjustment for existing Fixed Point Utility Stations (FPUS).

Number of apron parking spaces with FPUS = 60

60 apron spaces with FPUS multiplied by 1.0 m^2 (11.2 SF) = 60 m^2 (672 SF)

Reduce area by 60 m^2 (672 SF)

Total Ground Support Equipment Shop Area = (931 – 60) m^2 = 871 m^2
(10,021 – 672) SF = 9,349 SF

Step 9: Ground Support Equipment Shed (218 61)

a.) Using computation methodology for Category Code 218 61:

Type of Aircraft	Number of Aircraft
AV-8B	80
EA-6B	16
KC-130	14
Total	110

b.) From Table 21861-1:

No. of Aircraft	Shed Area	
	m^2	SF
101-125	1,771	19,050

Total Ground Support Equipment Shed = 1,771 m^2
(19,050 SF)

In summary, the Intermediate Maintenance Shop space requirements for the MALS used for this example are:

1.	Airframes Shop	=	1,722	m^2	18,530	SF
2.	IMA Management	=	917	m^2.	9,875	SF
3.	Engine Maintenance Shop	=	4,007	m^2.	37,301	SF
4.	Avionics Shop	=	3,470	m^2.	37,338	SF
5.	Aviation Armament Shop	=	899	m^2	9,688	SF
6.	Aviation Life Support Systems Shop	=	409	m^2.	4,400	SF
7.	Ground Support Equipment Shop	=	871	m^2	9,349	SF
8.	Ground Support Equipment Shed	=	1,771	m^2	19,050	SF

In addition to the shop spaces listed above, one Type I hangar is required for support of the MALS. The hangar requirement is in addition to the hangar modules for organizational level maintenance as computed in Category Codes 211-05, 211-06, and 211-07.

212 MAINTENANCE - GUIDED MISSILES

212-1 This basic category provides facilities and shops for maintenance and repair of guided missile systems, ground handling, and launching equipment. Under certain circumstances, the maintenance and storage for these missiles are integrated and the missiles are maintained where they are stored.

212 10 GUIDED MISSILE INTEGRATION FACILITY (SF)
FAC: 2121
BFR Required: Y

21210-1 **DESCRIPTION.** The purpose of this facility is to assemble new-production components of air launched guided missiles and perform any required maintenance on fleet returned All-Up-Round (AUR) missiles or components. Missiles are returned from the fleet at service inspection time when the maintenance due date is assigned to the missiles so require. This type of facility is primarily found at Naval Weapons Stations. However, it is also found at Naval Air Stations and other ordnance related activities.
21210-2 **REQUIREMENT.** A typical facility is capable of servicing four different types of missiles and is composed of six basic areas which are expressed in net square feet (NSF) as shown in Table 21210-1 below.

Table 21210-1 Basic Areas of Guided Missile Integration Facility

Description of Basic Area	NSF
De-canning and Storage Area	3,050
Open Work Area and Support Maintenance	3,050
Assembly Area (Test Cell)	4,169
Missile Storage	1,229
Office/Library	1,160
Mechanical Equipment Room & Toilet	1,146
Total	**13,804**

21210-2.1 **Net to Gross Conversion.** The net to gross conversion factor for this facility is 1.24. Therefore, multiply the NSF times 1.24 to obtain the gross square feet (GSF) for the facility (i.e., 13,804 NSF x 1.24 = 17,117 GSF).

21210-2.2 **Facilities Servicing More Than Four Missile Types.** In the event that more than four types of missiles are required to be serviced, the size of the facility may be increased by 3,451 NSF or 4,280 GSF per additional type of missile.

21210-3 **Air Launched Missile Industrial Processing Guide (ALM-IPG).** Additional information pertaining to the type of test performed and the amount of time required for each test involving the Sidewinder, Sparrow, Walleye, Shrike and Phoenix missile may be obtained from the ALM-IPG which is promulgated by Technical Manual Identification Number (TMIN) TW 800-AA-MMI-000/ALM - IPG.

21210-3.1 **Volumes in ALM-IPG.** The Guide consists of a general information volume and five additional volumes of data, each of which is dedicated to a particular missile. The Guide presently consists of the volumes shown in Table 21210-2.

Table 21210-2. Volumes Contained in ALM-IPG

Volume	Title	Technical Manual ID Number
1	General Information	TW 800-AA-MMI-010/ALM-IPG
2	SIDEWINDER AIM-9G/H/L	TW 800-AA-MMI-020-/ALM-IPG
3	SPARROW AIM-7E/F and RIM-7E/H	TW 800-AA-MMI-030/ALM-IPG
4	WALLEYE Guided Weapon	TW 800-AA-MMI-040/ALM-IPG
5	SHRIKE AGM-45A/B	TW 800-AA-MMI-050/ALM-IPG
6	PHOENIX AIM-54A	TW 800-AA-MMI-060/ALM-IPG

21210-3.2 **Ordering the ALM-IPG.** Copies of the Guide may be ordered from Code 2242 of the Pacific Missile Test Center, Point Mugu, CA, either as a complete set under TMIN-TW 800-AA- 000/ALM-IPG or as individual volumes using the individual volume Technical Manual Identification Number.

212 11 MISSILE MODULE MAINTENANCE AND LOADING FACILITY (SF)
FAC: 2121
BFR Required: Y

21211-1 **DESCRIPTION.** This facility will provide the Maintenance and Explosive Operation Location, EOL, for the Navy’s new Missile Module Weapons Systems. The facility will be sited for Ordnance handling and provide maintenance/ordnance loading high bay, a tool room, parts room, pressurized wash system, MM elevated cleaning pit(s), Male/Female locker/shower rooms, overhead crane, and administrative support space.

21211-2 No planning factors are currently available for this facility. An engineering analysis is needed to determine facility space requirements.

212 20 MISSILE EQUIPMENT MAINTENANCE SHOP (SF)
FAC: 2123
BFR Required: Y

21220-1 No planning factors are currently available for this facility. Activities with a limited amount of missile-handling equipment should consider performing their maintenance in an Automotive Vehicle Maintenance Shop (Category Code 214 20).

212 30 MISSILE ASSEMBLY AND TEST BUILDING (SF)
FAC: 2121
BFR Required: Y

21230-1 **DESCRIPTION.** This facility is required to support intermediate level maintenance of surface launched guided missiles. Component sections of the missile are tested, assembled into a missile of the required configuration, and tested as an all-up-round. Missiles may be received/shipped as bare missiles or packaged in containers.

21230-2 **REQUIREMENT.** Bridge cranes are needed to handle the missiles in the receiving/shipping area and onto the test beds in the test cells. Test cells should be constructed for an explosion hazard of 300 lbs. net explosives weight. See Table 21230-1 for guidance on sizing the facility.

Table 21230-1. Space Allowances for Surface Launched Guided Missiles

Weapons System	Gross SF
Standard	
Assembly	9,300
Control Cell	1,045
4 Test Cells	2,040
Packaging	2,500
Warheading, SW	450
Component rework, stores	6,600
Other	5,755
TOTAL	**27,690**
Harpoon	
Assembly and holding area	13,425
Control Cell	925

Weapons System	Gross SF
2 Test Cells	920
Office and stores	860
TOTAL	**16,130**

212 40 MISSILE COMPONENT SLING TEST TOWER (EA)
FAC: 2124
BFR Required: N

21240-1 **DESCRIPTION.** This facility is used to test the tensile strength of all forms of weapons handling equipment such as slings, beams, bars, etc. It is used in testing developmental equipment and the periodic testing of handling equipment.

21240-2 **REQUIREMENT.** The tower is a requirement of any station that is involved with handling heavy loads of ammunition, such as weapon stations and those activities that load and offload ammunition ships.

212 50 SUBMARINE LAUNCHED BALLISTIC MISSILE PROCESSING FACILITIES (SF)
FAC: 2126
BFR Required: Y

21250-1 **DESCRIPTION**. These facilities are required to receive components; checkout, assemble, refurbish, and repair Submarine Launched Ballistic Missiles (SLBMs) such as the TRIDENT II, D5 missile. Criteria for these facilities are dependent on the type of missile and have been developed and are available from the Navy's Strategic Systems Programs (SSP). All SLBM processing facilities are within high security areas and have special construction features such as high capacity environmental control systems, super flat floors, special trenching and conveying systems, and ordinance grounding and lightning protection systems.

21250-2 **REQUIREMENT**. No planning factors are currently available for this facility. For administrative spaces within these facilities, see Facility Class 600.

21250-2.1 Motor Transfer Facility (MTF). This facility provides the capability of receiving and transshipping SLBM missile motors and components and Active Inert Missiles (AIMs).

21250-2.2 Inert Component Control Building (ICCB). The ICCB provides for the support of missile systems level package processing, storage for guidance systems, missile assembly checkout, instrumentation sub-system/package checkout, AIM recertification, and electronic repair.

21250-2.3 Radiographic Inspection Building (RIB). The RIB provides the capability for film and computed tomography of SLBM rocket motors. It also provides a film radiographic capability for small ordnance components and low energy real-time radiography capability for gas generators.

21250-2.4 Missile Inspection Building (MIB). The MIB provides buildup and checkout of first, second, and third stage motors, Thrust Vector control (TVC) systems installation/ removal and leak test, motor pressurization (leak search), conduit installation, and igniter installation; additionally, a cell will be provided to support motor nozzle removal/installation.

21250-2.5 Missile Assembly Building (MAB). The MAB provides the assembly, disassembly, and checkout of tactical SLBMs.

21250-2.6 Limited Area Processing and Storage Complex (LAPSC). The LAPSC receives processes and stores Strategic weapons Systems (SWS) components.

21250-2.7 Vertical Missile Packaging Building (VMPB). The VMPB provides for the packaging/un-packaging of SLBMs and the mating and de-mating of their SWS systems.

212 77 GUIDED MISSILES/SPARES STORAGE (READY ISSUE/ SHOP STORES/MISC.) (SF)

FAC: 2121
BFR Required: Y

21277-1 **DESCRIPTION.** These facilities are storage facilities for miscellaneous equipment or goods related to guided missiles that will be provided only where it can be individually justified.

21277-2 **REQUIREMENT.** There are no criteria for this type of facility. General information on normal stacking heights, SF per measurement ton requirements, and other parameters are provided in the Category Code 440 series.

213 MAINTENANCE - SHIPS AND FLOATING EQUIPMENT

213-1 **FACILITY MAINTENANCE.** This basic category provides facilities for maintenance of vessels of all types. These facilities include graving dry docks, fixed cranes, marine railways, ship repair shops, and amphibian vehicle maintenance shops. For waterfront operational facilities, see Category Group 150. For administrative facilities, see Facility Class 600.

213 10 DRY DOCK (SF)
FAC: 2131
BFR Required: Y

21310-1 **DESCRIPTION.** A dry dock is a long narrow basin sited in the foreshore of a harbor. Its entrance is closed by a movable caisson or by gates. The basin is so constructed that a vessel may be placed in it and the water removed, allowing the vessel to settle on supports located on the dock floor. In this way the underwater portion of the vessel is exposed for routine maintenance and repair or for those coming into a dry dock in a damaged condition. Dry docks vary in size in accordance with the dimensional characteristics of the vessels to be serviced. Hence, each dock is designed and constructed to satisfy the special requirements of a particular vessel or class of vessels.

21310-2 **SITING A DRY DOCK.** The siting of a dry dock at an existing naval shipyard entails the analysis of many vital factors. Some recommendations for siting are the following:

1. Locate the dry dock near the shipyard shop area for access to piping, electrical, woodworking, metalworking, machining and similar shops.

2. Locate near sources of power and fresh water.

3. Orient the dry dock to require the minimum length of track for gantry cranes.

4. Provide adequate ship approaches to the docks. The approach or turning basin should have a width in front of the dock of at least two times the dock length properly oriented for turning. The depth should be no less than that at the entrance sill of the dry dock.

5. Clearance must be provided from structures flanking the approach path of the ship. A distance of not less than 150 feet should be planned between such structures and the side of the ship to provide space for tugs to operate while maneuvering the ship.

21310-3 **Dry Dock Certification.** Coordinate with the local shipyard Facilities Program Manager, Code 900F, to obtain information on the Dry Dock Certification Program.

213 20 MARINE RAILWAY (EA)
FAC: 2132
BFR Required: Y

21320-1 **DESCRIPTION.** The function of a marine railway is to bring a vessel out of the water for the purpose of making all parts available for overhaul, and to return the vessel to the water when the work is finished. The facility consists of rail trackage from a point on shore to an anchored position at a submerged depth; a railway beaching cradle or dolly for mating a vessel or small boat; and hauling machinery (hoist house) to pull the cradle-mounted vessel up the inclined track to a position on shore.

21320-2 **CAPACITY.** The capacity of a marine railway is usually given as the weight (displacement) in long tons of the largest ship that can be lifted. The maximum size and capacity of Navy marine railways has been restricted to about 3,000 tons that is the size required for the largest destroyer.

21320-3 **SITING.** The sites chosen for marine railways should satisfy the following requirements:

21320-3.1 **Distance to the Channel.** The distance from the high water line or the bulkhead line to the navigation channels must be adequate for construction of the offshore end of the railway and must provide a safe fairway for vessels approaching and leaving the cradle.

21320-3.2 **Inshore Area.** The space available on land, including the frontage along the shore, must be sufficient for the inshore end of the railway, the hoist house, necessary clearances, spur tracks, roadways, cranes and working areas. Some of the larger marine railways will extend approximately 500 feet inshore.

21320-3.3 **Hydrographic Conditions.** The natural slope of the bottom along the offshore end of the railway, to prevent silting, should be lower than the grade of the tracks.

21320-3.4 **Foundations.** The soil conditions for the length of the railway must be of sufficiently high quality to make possible a design of foundations that will assure rigid control of settlement.

21320-3.5 **Favorable Climatic and Tidal Conditions.** The proposed location should be protected as much as possible from strong winds and waves.

21320-4 **DESIGN CRITERIA.** For design criteria, see NAVFAC DM-29.

213 30 SHORE INTERMEDIATE MAINTENANCE ACTIVITY (SIMA) (SF)
FAC: 2133
BFR Required: Y

21330-1 **DESCRIPTION.** This facility (SIMA) provides space for the fleet intermediate level maintenance operations. A SIMA has two basic components: maintenance shops and administration. These components may be established separately or as a consolidated complex.

21330-1.1 **Maintenance Shops.** Following is a partial list of functions in the maintenance component:

1. Machine Shop (Inside and Outside)
2. Hydraulic Shop; Valve and Regulator Shop; Pump and Pipe Shops
3. Boiler Shop; Automatic Combustion Control Shop
4. Optical Shop; Gyro Compass Shop; Test Equipment Shop
5. Internal Combustion Engine Shop; Gas Turbine Shop
6. Air Conditioning and Refrigeration Shop
7. Electrical, Electronics and Crypto Equipment Shops; Battery Shop
8. Sheet metal, Ship fitter and Welding Shops; Foundry
9. Carpenter, Pattern and Boat Repair Shops; Lagging and Insulation Shop
10. Riggers, Canvas and Paint Shops
11. Sandblasting Shop
12. Chemical, Metallurgical and Non-Destructive Testing Laboratories
13. Instrument Repair and Calibration Laboratory
14. Noise and Vibration-Analysis Laboratory

21330-1.2 **ADMINISTRATIVE SPACES.** The administrative component provides space for:

1. Offices; Central, Technical and Study Libraries; Records Storage
2. Classrooms, Projection Room, Audio-Visual Aid Preparation
3. Computer Operations and Analyst Record Storage

213 31 SHORE DEPOT LEVEL REPAIR SHOP (SF)
FAC: 2133
BFR Required: Y

21211-1 **DESCRIPTION.** An enclosed building used to perform depot level maintenance on components and accessories of ships and amphibious vehicles that cannot be repaired on board the vessels. This shop may include areas for electronics repair, welding, painting, small item fabrication, and a variety of other repair shop functions.

21211-2 No planning factors are currently available for this facility. An engineering analysis is needed to determine facility space requirements.

213 32 SHIPYARD DEMILITARIZATION AND RECYCLING FACILITY (SF)
FAC: 2134
BFR Required: Y

21211-1 **DESCRIPTION.** A Shipyard Demilitarization and Recycling Facility that is used to provide administrative, shop, logistics, and personnel support space in direct support of demilitarization and recycling of surface ships and submarines.

21211-2 No planning factors are currently available for this facility. An engineering analysis is needed to determine facility space requirements.

213 40 FIXED CRANE STRUCTURES (EA)
FAC: 2137
BFR Required: Y

21340-1 **DESCRIPTION.** The principal types of fixed cranes are pillar, pillar-jib, and jib. The hammerhead and tower cranes are also classed as stationary when mounted on fixed towers.

21340-2 **CRITERIA.** See NAVFAC DM-38, for criteria and procedures to be followed in the selection of weight handling equipment for specific installations.

213 41 THROUGH 213 67 - SHIP REPAIR SHOPS

21341 through 21367-1 **CATEGORY CODES.** Ship repair shops and related facilities included in Category Code series 213 are shown in Table 21341 through 21367-1.

Tables 21341 through 21367-1. Ship Repair Shops and Related Facilities

Category Code	Description
213 41	Central Tool Shop
213 42	Shipfitting Shop
213 43	Sheet Metal Shop
213 44	Forge and Heat Treat Shop
213 45	Welding Shop
213 48	Quality Assurance Office
213 49	Inside Machining Shop
213 50	Optical Shop
213 51	Weapons Shop
213 52	Marine Machining Shop
213 53	Boilermaking Shop
213 54	Electrical Shop
213 55	Pipefitting Shop
213 56	Woodworking Shop
213 57	Electronics Shop
213 58	Boat Shop
213 59	Abrasive Blast Facility
213 60	Paint and Blasting Shop
213 61	Rigging Shop
213 62	Sail Loft
213 63	Foundry
213 64	Patternmaking Shop
213 65	Nuclear Repair Shop
213 66	Temporary Services Shop
213 67	Pumphouse, Dry Docks

21341 through 21367-2 **DELETED CATEGORY CODES.** The following category codes have been deleted and the functions formerly performed therein have been reassigned to other category codes as indicated:

21341 through 21367-2.1 Category Code 213 46 (Galvanizing Shop) and Category Code 213 47 (Plating Shop) are now included in Category Code 213 49 (Inside Machining Shop).

21341 through 21367-2.2 Category Codes 213 50 (Optical Shop), 213 58 (Boat Shop), 213 59 (Abrasive Blast Facility) and 213-62 (Sail Loft) are not for use at the shipyards since these functions are included in other category codes for shipyards. These category codes are intended for use by other ship maintenance activities which support the repair of ships, such as ship repair facilities located at naval stations, intermediate maintenance activities, and other activities performing intermediate level maintenance rather than depot level maintenance.

21341 through 21367-3 **REQUIREMENTS.** There are currently no criteria available for these category codes. The quantitative requirements for shop facilities in Basic Category 213 should be determined on an individual basis, based on the experience and knowledge of the activity involved and the Naval Sea Systems Command. One method which can be used to develop the requirement for a specific shop is discussed below.

21341 through 21367-3.1 **EQUIPMENT TABLE.** Determine the types and number of pieces of equipment and laydown/workstation areas that the shop requires to perform their work. Develop a table that shows the following information: (a) name of equipment or laydown/workstation area; (b) actual floor area occupied by the equipment or area; and (c) any clearances required to allow access to the equipment/area, provide safety zones, or meet operational requirements. A sample table is shown in Table 21341 through 21367-2.

Tables 21341 through 21367-2. Sample Equipment/Work Area Table

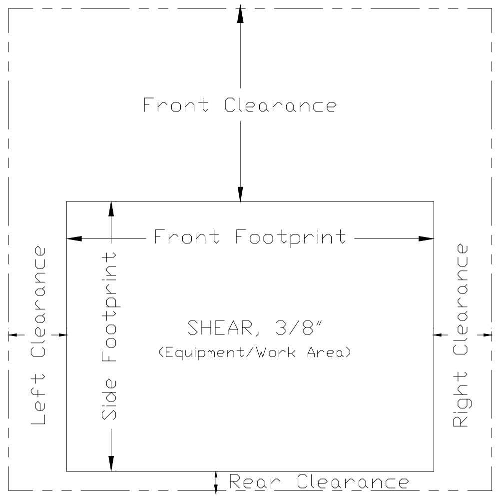
Equipment/ Work Area	Qty	Footprint (LF)		Clearance (LF)				Overall Dimension (LF)		Total Area (SF)
		Front	Side	Right	Left	Front	Rear	Front	Side	
Table, Small	4	5	4	0	0	4	4	5	12	240
Table, Large	1	13	5	4	4	4	4	21	13	273
Grinder	1	3	3	3	3	3(1)	0	9	6	54
Drill Press	1	7	3	3	3	5(1)	5	13	13	169
Shear, 3/8"	1	19	14	3	3	10	1	25	25	625
TIG Welder	2	3	2	0	0	4(2)	1(2)	3	7	42

Equipment/ Work Area	Qty	Footprint (LF)		Clearance (LF)				Overall Dimension (LF)		Total Area (SF)
		Front	Side	Right	Left	Front	Rear	Front	Side	
Storage Rack	9	9	4	0	0	10	3	9	17	1,377

Equipment/Work Area clearances can be shared with other equipment clearances and circulation unless otherwise noted:
(1) Clearances can be shared with clearances for other equipment/work areas, but not circulation.
(2) Clearances can not be shared with other clearances or circulation.

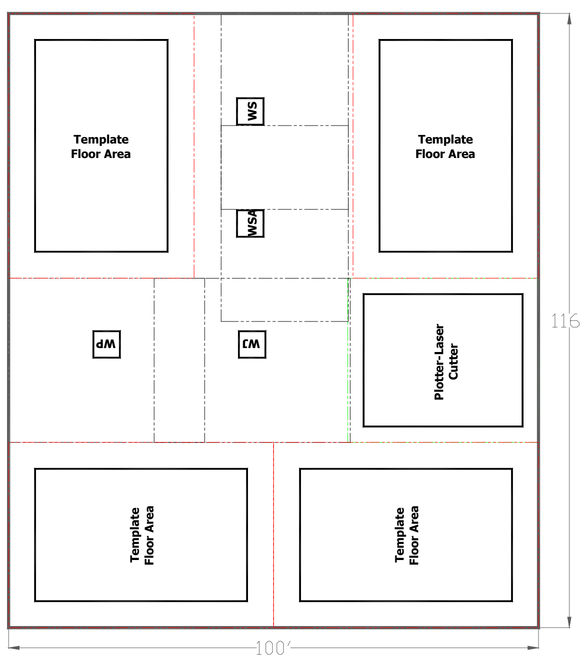
21341 through 21367-3.2 **DRAWINGS.** Once the table is completed, a conceptual drawing of an “ideal” shop containing the required equipment and areas can be completed to develop a net floor area requirement. As the drawing is developed, it is important to account for the following: (a) material and personnel flow in the shop and (b) how clearances can or cannot be shared. A sample drawing of a single piece of equipment/area is shown in Figure 21341 through 21367-1.

Figures 21341 through 21367-1. Drawing of Equipment/Area and Clearances



See Figure 21341 through 21367-2 for a sample drawing of a conceptual shop layout, where the solid lines show the actual equipment/area dimensions, and the dashed lines show the clearance requirements.

Figures 21341 through 21367-2. Sample Shop Layout Drawing



21341 through 21367-3.3 **NET TO GROSS CONVERSION.** The drawing yields a net requirement in square feet for the shop. To convert this into a gross requirement, multiply the net requirement by 1.25.

213 41 CENTRAL TOOL SHOP (SF)
FAC: 2133
BFR Required: Y

21341-1 **CENTRAL TOOL SHOP (SHOP 06).** The central tool shop is responsible for the design, development, manufacture and maintenance of prototype and conventional tooling such as cutting machines, dies, molds, cleanliness plugs, cutters, jigs, fixtures, and special tools. The shop conducts the maintenance program for electrical and mechanical maintenance of numerically controlled and conventional machine tools and plant equipment. This includes installation, preventive maintenance, repair, analytical checkout, rehabilitation, and lubrication. This shop operates all tool rooms throughout the shipyard. Additionally, the shop operates high-pressure air equipment servicing ship systems as well as refilling high-pressure cylinders.

213 42 SHIPFITTING SHOP (SF)
FAC: 2133
BFR Required: Y

21342-1 **SHIPFITTING SHOP (SHOP 11).** The shipfitting shop is responsible for the back-shop modification, fabrication, repair, and assembly of various metal structural parts of the ship's hull, superstructure and interior ship structure by using shipfitting equipment, plate and shape structures, and other metals; and then through computer design, templating, laying-out, cutting, shaping, flanging, straightening, bending, and hot forming of all types and sizes of metal plates and shapes; and then positioning, aligning, fitting-up, and securing parts and subassemblies into ship component assemblies.

213 43 SHEET METAL SHOP (SF)
FAC: 2133
BFR Required: Y

21343-1 **SHEET METAL SHOP (SHOP 17).** The sheet metal shop is responsible for developing, fabricating, and installing ventilation and air conditioning ductwork; fabricating and installing store-room workshop and stowage facilities, non-structural bulkheads and partitions; the manufacture and installation of label plates; and outfitting of galley, berthing, habitability and office space for naval vessels.

213 44 FORGE AND HEAT TREATING SHOP (SF)
FAC: 2133
BFR Required: Y

21344-1 **FORGE AND HEAT TREATING SHOP (SHOP 11).** The forge and heat treating shop is responsible for hot-forging, heat treating, inspecting, cleaning, and repairing various metal structural parts of a ship’s hull, superstructure, interior ship structure, mechanical systems, machinery systems, anchor chain, and ship’s propellers by using forging equipment, material billets, and other metals; and then through hammering, pressing, hot-rolling, heat-treating (annealing, tempering, hardening, quenching), sawing, threading, grinding, inspecting, and surface finishing (tumbling, cleaning, coating) of all types and sizes of metal shapes into a ready ship component.

213 45 WELDING SHOP (SF)
FAC: 2133
BFR Required: Y

21345-1 **WELDING SHOP (SHOP 26).** The welding shop is responsible for all of the welding, flame cutting, carbon arc gauging, and related processes required by the various shops of the Operations and Production Resources Departments of the shipyard and the Public Works Center located at the shipyard. In addition to the major involvements of cutting and welding the various structural, sheet metal, and piping materials, operations include repair of castings, combating of valves, hard-surfacing of materials subjected to abrasive wear, shooting and welding studs and fasteners, metal spraying, casting, bonding, and welding of lead shielding, and stress relieving of shipboard elements.

213 48 QUALITY ASSURANCE OFFICE
FAC: 2133
BFR Required: Y

21348-1 **QUALITY ASSURANCE OFFICE (CODE 130).** The quality assurance office is responsible for inspection and tests to determine compliance with specifications, plans, orders, directives, and sound shop and marine practices; non-destructive testing services; and technical direction, consulting and advisory services on those processes, materials, and systems for fabrication and repair to shops. It is also responsible for providing chemical and metallic laboratory services; test instrument calibration; and technical support for test, analyses, evaluation, and procedures for use of metallic and non-metallic materials.

213 49 INSIDE MACHINING SHOP (SF)
FAC: 2133
BFR Required: Y

21349-1 **INSIDE MACHINING SHOP (SHOP 31).** The inside machining shop is responsible for performing horizontal boring, vertical boring, planing and heavy lathe work in manufacturing, altering, and repairing ship machinery and shipyard manufactured items; performing engine lathe turning, horizontal and vertical turret lathe turning, boring, facing, and other turning work; performing milling, grinding, hobbing, broaching, shaping, slotting, lapping, honing, balancing work, layout work and drilling on castings and fabrications; and performing disassembly, inspection, reverse engineering, repair, reassembly, and testing of main propulsion units, pumps, valves, turbines, air compressors, propellers, and miscellaneous auxiliary machinery. This shop also assembles new manufactured equipment. Additionally, this shop is responsible for all metal finishing processes including electroplating, dalic plating, galvanizing, and metal polishing.

213 50 OPTICAL SHOP (SF)
FAC: 2133
BFR Required: Y

No criteria are currently available for this code. This category code is not for use by shipyards. See the general discussion in paragraph 21341 through 21367-2.2.

213 51 WEAPONS SHOP (SF)
FAC: 2133
BFR Required: Y

21351-1 **WEAPONS SHOP.** The weapons shop is responsible for the repair, overhaul, alignment, installation, checking out, testing and calibration of all weapons systems, integrated systems, such as missile systems and associated components, including gun mounts, turrets, saluting batteries, launching pads, mechanical components of fire control, radar antennas and sonar equipment. This shop is also responsible for the repair, overhaul, calibration, and adjustments and testing of gunsights, range-finders, torpedo directors, telescopic gunsights, periscopes, binoculars, stereo-trainers, and other miscellaneous repair of instruments, etc.

213 52 MARINE MACHINING SHOP (SF)
FAC: 2133
BFR Required: Y

21352-1 **MARINE MACHINING SHOP (SHOP 38).** The marine machining shop is responsible for the installation and testing of all main propulsion machinery, auxiliaries, rudders, shafting, sea valves, deck machinery, laundry and galley equipment, arresting gear, and catapults on ships undergoing repair and conversion. This shop repairs, installs, and performs necessary tests on main and auxiliary diesel engines and their associated equipment as well as hydraulic speed gears on ships. The marine machining shop also refuels, repairs, and tests nuclear reactor plants as well as their associated systems and components. This shop works on any mechanical component that is removed from or installed on a ship or submarine.

213 53 BOILERMAKING SHOP (41) (D) (SF)
FAC: 2133
BFR Required: Y

21353-1 **BOILERMAKING SHOP (SHOP 41).** The boilermaking shop is responsible for the repair, conversion, and building of steam generating equipment used to furnish steam to main and auxiliary machinery. This includes the fabrication, assembly, installation, testing, cleaning, and repair of the steam generators, uptakes, stacks, and blower ducts as well as the fabrication, repair and testing of pressure vessels, incinerators, and spark arrestors.

213 54 ELECTRICAL SHOP (SF)
FAC: 2133
BFR Required: Y

21354-1 **ELECTRICAL SHOP (SHOP 51).** The electrical shop is responsible for accomplishing the installation, repair, maintenance, alteration, troubleshooting, and test of all power, lighting, and interior communication systems and equipment aboard Naval ships and submarines; for manufacture of switchboards, electrical control equipment, and components; for the installation, repair and alteration of nuclear electrical components and systems; and for repair and calibration of all electrical instrumentation.

213 55 PIPEFITTING SHOP (SF)
FAC: 2133
BFR Required: Y

21355-1 **PIPEFITTING (SHOP 56).** The pipefitting shop is responsible for accomplishing the layout, fabrication, installation, dismantling, repair, cleaning, testing, and inspection of piping systems and gaskets on both nuclear and non-nuclear systems in the shop as well as onboard ships and submarines; fabrication, repair, and installation of radar waveguides; installation, repair, and testing of refrigeration systems, air conditioning systems, and oxygen-nitrogen systems; and cleaning, testing and inspection of pressure vessels.

21355-2 **PIPE AND COMPONENT INSULATING (SHOP 57).** This group insulates steam, hot water and chilled water piping systems, ductwork and bulkheads aboard ship and performs some insulation and maintenance and repair on shipyard equipment such as furnaces.

213 56 WOODWORKING SHOP (SF)
FAC: 2133
BFR Required: Y

21356-1 **WOODWORKING SHOP (SHOP 64).** The woodworking shop is responsible for accomplishing operations performed by boat builders, woodcraftsmen, and shipwrights to construct and repair wooden and plastic boats, wooden portable buildings and shelters, hollow booms, wooden tank, practice torpedoes, and flight deck panels; repairing and manufacturing furniture and cabinets; laminating all sizes of wooden members; manufacture and repair accommodation ladders; perform dry kiln operations; and install and repair all types of acoustic and thermal insulations. Working from plans and specifications, they arrange docking blocks to provide for the dry docking of all classes of naval vessels and direct the positioning of the vessel for proper landing on the blocks. Additionally, the woodworking shop repairs and installs wooden decks, erects pipe stagings and lifelines; fabricates and installs boat stowages, builds shipping cradles, shores and blocks cargo aboard ships, manufactures and repairs wooden gangways and platforms, and fabricates and constructs refrigerated spaces aboard ships. This shop also manufactures plastic items such as pipe, radomes, fairwaters, tanks, antenna cones, and submarine fairing plates. They make resin foam pours in voids and perform grouting operations. The woodworking shop also installs and repairs plastic laminates and hull dampening materials on naval vessels and installs polyethylene shielding around nuclear reactors. They provide reference lines used in construction, repair, and alteration of all types of ships as well as taking measurements of ships' characteristics. This shop applies plastisol coatings; installs linoleum, rubber, asphalt, and ceramic tile. The sail loft section fabricates, repairs and installs containments for nuclear and non-nuclear use, tents, weather covers, shrink wrap enclosures, upholstery, gun and other assorted covers.

213 57 ELECTRONICS SHOP (SF)
FAC: 2133
BFR Required: Y

21357-1 **ELECTRONICS SHOP (SHOPS 52, 66 AND 67).** The electronics shop is responsible for accomplishing installation, repair, overhaul, modification check-out, adjustment, test, and calibration of radar, sonar, communications, cryptographic data processing, antennas, navigation, and electronic countermeasure equipment and systems on and for surface ships, submarines, and shore stations. The electronics shop is also responsible for repair, calibration, and certification of electronic and nuclear instruments for the shipyard, ships, and shore activities, and installation, repair, and testing of gyro compasses.

213 58 BOAT SHOP (SF)
FAC: 2133
BFR Required: Y

No criteria are currently available for this Category Code. This Category Code is not for use by shipyards. See the general discussion in paragraph 21341 through 21367-2.2.

213 59 ABRASIVE BLAST FACILITY (SF)
FAC: 2133
BFR Required: Y

No criteria are currently available for this code. This Category Code is not for use by shipyards. See the general discussion in paragraph 21341 through 21367-2.2.

213 60 PAINT AND BLASTING SHOP (SF)
FAC: 2133
BFR Required: Y

21360-1 **PAINT AND BLASTING SHOP (SHOP 71).** The paint and blasting shop is responsible for surface preparation, including abrasive blasting, for the application or installation of protective, decorative, and functional paints, coatings, films, and for installation of deck, floor, and wall coverings. This includes design, layout, lettering, sign and poster making; silk screen processing; artificial and natural wood finishing; all types of painting and preservation on board ship; operation of pickling and chemical cleaning plant for preservation of material; abrasive blasting services; and the laying or installation of terrazzo, magnesite, and concrete.

213 61 RIGGING SHOP (SF)
FAC: 2133
BFR Required: Y

21361-1 **RIGGING SHOP (SHOP 72/CODE 700).** The rigging shop is responsible for operations performed by riggers, sailmakers, tank and component cleaners, laborers, upholsterers, fabric workers, and diving operations required for repair, overhaul, conversion, and construction of Naval vessels and equipment.

213 62 SAIL LOFT (SF)
FAC: 2133
BFR Required: Y

No criteria are currently available for this code. This category code is not for use by shipyards. See the general discussion in paragraph 21341 through 21367-2.2.

213 63 FOUNDRY (SF)
FAC: 2133
BFR Required: Y

21363-1 **FOUNDRY.** The foundry is responsible for manufacturing cores for iron, steel, and non-ferrous casting in the Core Unit; preparing and mixing sand, processing and making molds, steel castings, pouring steel from furnaces, melting, and manufacturing steel, and shaking out steel castings from molds after pouring in the steel foundry unit; pouring and melting non-ferrous metals and alloys, processing and making molds for brass castings, and shaking out non-ferrous castings in the non-ferrous unit; processing and making molds for iron castings, pouring iron, melting iron-alloys and shaking out iron castings from molds in the iron unit; clearing castings, shipping finished castings.

213 64 PATTERNMAKING SHOP (SF)
FAC: 2133
BFR Required: Y

21364-1 **PATTERNMAKING SHOP.** The patternmaking shop is responsible for the manufacture, repair, and alteration of wood patterns required to produce castings; manufacture of metal parts for wood and plastic patterns and metal patterns; manufacture of mock-ups for patterns; manufacture of sheet plastic by forming, fabricating, cementing, and dyeing; manufacture of plastic patterns; and receiving, storing and issuing pattern mock-ups and models.

213 65 SHIP PROPULSION MAINTENANCE FACILITY (SF)
FAC: 2136
BFR Required: Y

21365-1 **DESCRIPTION.** The Ship Propulsion Maintenance Facility is responsible for the repair of reactor plant components of ship propulsion systems.

213 66 TEMPORARY SERVICES SHOP (SF)
FAC: 2133
BFR Required: Y

21366-1 **TEMPORARY SERVICES SHOP (SHOP 99).** The temporary services shop is responsible for electrical, piping, and ventilation systems as related to temporary services. Temporary services include compressed air, water, steam, oxygen, electrical power and lighting, ventilation, telephones, inerting, air analysis, shipside sewage connections, communications systems, distilled water for ships' boilers, CO2 fire extinguishers, static dehumidification, electric, steam, and induction heat; besides responsibility for radioactive waste collection systems, delivery and distribution of pure water systems, distribution of temporary electric power, breathing air systems for reactor plants, chilled water and air conditioning systems, filtering for reactor plants, ventilation systems, communications systems involved in nuclear refueling operations, and deoxygenating pure water nitrogen systems. This shop also manufactures and repairs rubber products.

213 67 PUMPHOUSE, DRY DOCKS (SF)
FAC: 2134
BFR Required: Y

21367-1 **DESCRIPTION.** The dry dock pumphouse is used to house dry dock dewatering pumps and associated equipment.

213 68 DIVE SHOP (SF)
FAC: 2134
BFR Required: Y

21368-1 **CRITERIA.** No criteria are currently available for this code.

213 70 SHIP SERVICES SUPPORT BUILDING (SF)
FAC: 2134
BFR Required: Y

21370-1 **DESCRIPTION.** A ship services support building is used to provide office and shop space in direct support of maintenance and repair work for surface ships and submarines. The office area supports those individuals involved in executing work onboard ships, and includes people such as project superintendents, work supervisors, design engineers and test personnel. Additionally, quality assurance inspectors responsible for ship work inspection operate from these facilities. Another function in this type of facility is an area for kitting of material and work packaging. The purpose of the shop area is to perform rapid minor work required to support the maintenance and repair operations, i.e., rather than sending a small item requiring a minor modification back to the shop, the modification would be made at the dry dock or pier site.

21370-2 **REQUIREMENTS.** With the exception of shop space, all requirements are based upon the corresponding category codes providing those particular types of functions. For example, the administrative space for the office area is based on the criteria provided for in Category Code 610 10, Administrative Office. Required storage should be categorized under Category Code 213 77, Maintenance-Ship/Spares Storage (Ready Issue/Shop Stores/Miscellaneous). The quantitative requirements for shop facilities should be determined on an individual basis, based on the experience and knowledge of the activity involved and the Naval Sea Systems Command. See paragraph 21341 through 21367-3 for additional guidance on developing shop space requirements.

213 73 LANDING CRAFT WASH RACK (EA)
FAC: 2135
BFR Required: Y

21373-1 **DESCRIPTION.** The primary function of this facility is to wash down Landing Craft Air Cushions (LCAC) vehicles after every mission in order to remove sand and salt spray. However, this type of washdown pit may be used for other types of amphibious landing craft requiring similar purging. Wash water treatment is incorporated into the design of the facility.

21373-2 **REQUIREMENT.**

21373-2.1 **JEFF Type Craft.** A wash rack for JEFF type craft is 75 ft wide by 150 ft long. This criteria can be modified to suit other amphibious landing crafts as well.

21373-2.2 **All Other Amphibious Landing Craft.** For all other types of amphibious landing craft requiring similar cleaning, select the largest craft that the facility will service and add 27 feet to its width and 30 feet to its overall length (with all ramps, doors, etc., extended) to determine the size of the washdown pit.

213 75 AMPHIBIAN VEHICLE MAINTENANCE SHOP (SF)
FAC: 2134
BFR Required: Y

21375-1 **DESCRIPTION.** The amphibian vehicle maintenance shop provides special work areas for performing all organizational maintenance functions on the amphibian vehicles of the Marine Corps Amphibious Tractor Battalion and in the case of the Navy, all organizational and intermediate level maintenance on Landing Craft Air Cushion (LCAC) vehicles. In the case of the latter, the depot level maintenance is performed at a Naval Air Rework Facility or contractor plant.

21375-2 **REQUIREMENT FOR MARINE CORPS.** The maintenance shop for the amphibian vehicles of the Marine Corps Amphibious Tractor Battalion includes administrative and training areas as well as storage space for OEM equipment, tools and mount out. The total shop area will vary depending upon the number of companies assigned to the Amphibious Tractor Battalion. A typical Marine Corp facility that would accommodate one battalion, i.e., four companies, would have a space requirement of 42,600 gross square feet of which 700 gross square feet would be dedicated to the mechanical equipment room. The size of the facility would be adjusted accordingly as the number of companies in the battalion increase or decrease.

21375-3 **REQUIREMENT FOR LCAC (NAVY).** Criteria for a typical LCAC maintenance facility with 54 assigned craft is as follows:

21375-3.1 **Maintenance Bay.** Provide maintenance bay space for 15% of assigned craft. Note: LCAC craft is 48 ft. x 90 ft. with 15 ft. ramps on each end. Accordingly, bay space is increased to 75 ft. x 150 ft. or 11,250 net square ft. to allow sufficient work area around each craft. Net to gross conversion is 1 to1.15, or:

11,250 NSF x 1.15 = 12,937.5 GSF
12,937.5 GSF/craft x 8 craft = 103,500 GSF

21375-3.2 **Maintenance Shops.** Maintenance shops capable of providing organizational and intermediate level support are as follows:

Propeller shop	3,642 SF
Engine shop	1,101 SF
Hydraulic shop	522 SF
Skirt repair shop	2,216 SF

Welding shop	720 SF
Sheet metal shop	1,260 SF
Gluing shop	726 SF
Electrical shop	1,050 SF
Electronics shop	1,041 SF
Battery shop	396 SF
Tool room	1,185 SF
Locker room	5,375 SF
Maintenance control	900 SF
	20,134 SF

Net to Gross Conversion: 1:1.25 or 20,134 x 1.25 = 25,168 GSF

21375-3.3 **Control Tower/Operations Room.** A Control Tower/Operations Room is an additional requirement for a LCAC Operational Base and can be an integral part of the maintenance facility by providing an additional 190 GSF. This facility should have an unobstructed view of the parking apron, taxiway, ramp and waterfront in order to allow coordination of operations to preclude accidents. Communications equipment and traffic controllers are housed in this facility.

21375-3.4 **Squadron Operations/Training Space.** Squadron Operations/Training Space requirements are met by providing space for classrooms briefing room and a structural maintenance laboratory. The following areas are provided to meet the requirements for a LCAC Operational Base having 54 assigned craft.

21375-3.4.1 **Training/Maintenance Space.** Compute the requirement for training/maintenance space within the Squadron Operations/Training Space as follows:

- Classroom Requirements: Using criteria for category code 171 10 for one 20 person operational class and one 20 person maintenance class, 2 x 20 PN x 22 SF/PN = 880 NSF

- Briefing Room: A large classroom is required for general briefing and combined classes. Maximum loading is 40 persons. Accordingly, 40 PN x 21 SF/PN = 840 NSF

- Structural Maintenance Laboratory: Three mock-up equipment modules for skirt, prop, turbine, gear box and electronic bench yield 219 NSF x 3 = 657 NSF

- Therefore, the total net requirement (classroom + briefing room + structural maintenance laboratory) equals 880 NSF + 840 NSF + 657 NSF, which equals 2,377. To convert the net requirement to a gross requirement, use a conversion factor of 1.33; i.e., 2,377 NSF x 1.33 = 3,160 GSF.

21375-3.4.2 **Administrative Space.** The administrative space for 27 officers and 69 enlisted personnel = 96 personnel x 150 GSF/PN = 14,400 GSF.

21375-3.4.3 **Composite Space Requirement.** The composite space requirement equals the combined sum of the training/maintenance and administrative spaces or: 3,140 GSF (training/maintenance) + 14,400 GSF (administrative) = 17, 560 GSF (total).

21375-3.5 **Total Requirement for a LCAC Maintenance Facility.** Accordingly, the total requirement for a LCAC maintenance facility supporting 54 craft is:

Maintenance Bay Space	103,500 GSF
Maintenance Shops	25,168 GSF
Control Tower/Operations Room	190 GSF
Squadron Operations/Training Space	17,560 GSF
Total	146,418 GSF

213 77 MAINTENANCE - SHIPS/SPARES STORAGE (READY ISSUE/SHOP STORES/MISC.) (SF)
FAC: 4421
BFR Required: Y

21377-1 **DESCRIPTION.** Storage facilities for miscellaneous equipment or goods related to ship maintenance facility support will be provided only where it can be individually justified.

21377-2 **REQUIREMENT.** There are no criteria for this type of facility. General information on normal stacking heights, square feet per measurement ton requirements, and other parameters are provided in the Category Code 440 series.

214 MAINTENANCE - TANK, AUTOMOTIVE

214 Facilities for maintenance and repair of combat and noncombat motorized vehicles. For weapons, see Category Code series 215; for tracked amphibious vehicles see Category Code series 213; for construction equipment see Category Code series 218.

214 10 COMBAT VEHICLE MAINTENANCE SHOP (SF)
FAC: 2141
BFR Required: Y

21410-1 This facility provides specialized work areas, equipment, and storage for overhaul of combat vehicles such as self-propelled gun carriages and tanks. For Marine Corps Organizational Maintenance Shop, see Category Code 214 51; for Field Maintenance Shop, see Category Code 214 53.

214 20 AUTOMOTIVE VEHICLE MAINTENANCE SHOP (SF)
FAC: 2141
BFR Required: Y

21420-1 **PURPOSE AND FUNCTION**. Automotive vehicle maintenance facilities are required to provide covered work areas for inspection, maintenance, and repair of all transportation equipment assigned to an installation, and as applicable, its supported activities. For reasons of overall efficiency and economy, the maintenance and operations function for automotive, construction, materials handling, and railroad equipment are combined. In areas where combined facilities are not feasible, special facilities for construction equipment maintenance and railroad equipment maintenance will be provided. See Category Codes 218 20 and 218 40 for planning data for separate shop facilities.

21420-2 **REQUIREMENTS**. The number and types of the equipment maintained by the activity will govern the size of the facility required, that is, the size is directly proportional to the number of general repair bays required to perform the assigned maintenance task. General repair space requirements are computed from the productive space factors contained in Tables 21420-1, 21420-2 and 21420-3. A 2-bay facility will be considered as the minimum requirement. After the repair bay requirements have been computed, the area required for administrative and indirect as well as direct support functions can be determined from Table 21420-4.

21420-3 **SPACE REQUIREMENTS**. Space requirements for an automotive vehicle maintenance shop are computed as follows:

> 21420-3.1 **Step 1.** Prepare an inventory listing by equipment costs codes for all of the equipment supported (see Column 1 of Tables 21420-1, 21420-2, and 21420-3). If a combined automotive/construction equipment/weight-handling maintenance shop is planned, consider all equipment codes; if a separate construction/weight-handling equipment shop is planned under Category Code 218 20, omit equipment cost codes 2300 to 2840, 3100 to 3720, 4210 to 4952, and 8120 to 8800 (to be used for determining Category Code 218 20 requirements).

21420-3.2 **Step 2.** Multiply the total equipment inventory as listed in Step 1 for each equipment code group by its corresponding space factor, (shown in Column 3 of the tables) to determine the repair bay requirements for that specific code group.

21420-3.3 **Step 3**. Total the individual code computations to determine the number of repair bays required for all of the equipment supported. For example:

Equipment Code	Number of Pieces	Productive Space Factor	Repair Bay Requirements
0061-0099	1	0.063	0.063
0102-0299	11	0.015	0.165
0300-0700	60	0.023	1.380
0800	25	0.016	0.400
1000	26	0.020	0.520
2000	2	0.016	0.032
3000	1	0.025	0.025
4000	26	0.020	0.520
5000	47	0.016	0.752
7000	6	0.030	0.180
8000	3	0.092	0.276
Total repair bay requirements			4.313 (or 4 bays)

21420-4 Column (1) is done in even numbers. If the calculation of the number of repair bays is less than the odd number 5 as shown in the example, round down to the next even number 4. If the calculation is more than the odd number of bays (i.e., 5.313), round up to the next even number of bays (i.e., 6).

21420-5 To determine the total square-footage of area required for general repair bays multiply the number of bays determined in Step 3 by 480 (the square footage of a single 16 by 30 foot general repair bay). The number of square feet of administrative and indirect support area requirements is directly proportional to the number of repair bays, as shown in Column 3 of Table 21420-4.

21420-5.1 The administrative and indirect support area includes the following facilities:

1. Administrative office for maintenance and operations personnel.
2. Drivers and operators training, licensing, and ready room.
3. Locker, lunch, and conference room.
4. Toilet facilities.
5. Parts supply, issue, and storage room.
6. Tool room.

21420-6 In addition to repair bay and administrative area requirements, consideration must also be given to such direct support facilities as tire shop, body shop, battery shop, engine and accessories overhaul shop, paint shop, dynamometer test bay, steam cleaning and wash bay, and lube storage. Engine overhaul and paint and body shops should be provided.

21420-7 The direct support facility requirements shown in column 4 of Table 21420-4 provide for complete shop facilities. The total gross space allowance in column 5 is the maximum allowed for the indicated number of repair bays.

General Work Bay Space Factors
Table 21420-1. Automotive Equipment Codes 0061 through 0905

Equipment Cost Code (Column 1)	Abbreviated Description (Column 2)	Productive Space Factor (Column 3)
0061 to 0099	Buses	0.063
0102 to 0299	Sedans, station wagons, and ambulances	0.015
0300 to 0745	Trucks	0.023
0800 to 0897	Trailers	0.016
0900 to 0905	Motorcycles, scooters, etc.	0.004

Table 21420-2. Materials Handling Equipment Codes 1100 through 1900

Equipment Cost Code (Column 1)	Abbreviated Description (Column 2)	Productive Space Factor (Column 3)
1100 to 1900	Tractors (warehouse) Trucks (fork-lift, crane platform and side loaders)	0.020

Table 21420-3. Construction and Allied Equipment Codes 2300 Through 8800

Equipment Cost Code (Column 1)	Abbreviated Description (Column 2)	Productive Space Factor (Column 3)
2300 to 2840	Crushing, mixing, batching and paving equipment (mixers, pavers, distributors, spreaders, heaters)	0.016
3100 to 3720	Drilling, blasting, and driving equipment (compressors and drills)	0.025
4210 to 4952	Excavating and grading equipment (crawler cranes, graders, loaders, rollers, scrapers, tractors, etc.)	0.020
5110 to 5930	Miscellaneous construction and maintenance equipment (generators, pumps, cleaners, sweepers, mowers, snowplows, garbage trucks, mobile shops)	0.016
7100 to 7501	Firefighting equipment (trucks, pumps, etc.	0.030
8120 to 8800	Weight handling equipment (truck mounted, cruiser, and boat cranes)	0.092

21420-8 **SITE LOCATION**. In choosing a site for new transportation equipment maintenance facility a number of conditions should be given careful consideration. The facility should be located adjacent to or within the major industrial area which it serves. Caution should be exercised to ensure that the site selected has adequate land area to accommodate all support facilities, equipment holding and parking area, and sufficient room for employee parking. Criteria for employee parking can be found in Category Code 852 10. Site location may be influenced to some degree when railroad equipment is involved because of the track location and approach.

21420-9 **MAINTENANCE FACILITY**. When available sites for the automotive vehicle maintenance facility prove to be either inadequate or inappropriate for the inclusion of construction and/or railroad equipment maintenance, separate shop structures for the service and maintenance of these types of equipment will be provided. See Code 218 40 for planning criteria for a special railroad equipment maintenance shop.

Table 21420-4. Space Requirements for Automotive Vehicle Maintenance Facility

Repair Bays		Administrative and Indirect Support Area (Sq. ft.) (Column 3)	Direct Support Area (Sq. ft.) (Column 4)	Total Gross Space Allowance (Sq. ft.) (Column 5)
(No.) (Column 1)	(Sq. ft.) (Column 2)			
2	960	600	1,440	3,000
4	1,920	1,500	2,720	6,140
6	2,880	1,950	3,480	8,310
8	3,840	2,400	4,230	10,470
10	4,800	3,100	4,270	12,170
12	5,760	3,800	5,210	14,770
14	6,720	4,200	6,000	16,920
16	7,680	4,700	6,070	18,450
18	8,640	5,100	6,080	19,820
20	9,600	5,500	6,170	21,270
22	10,560	5,900	6,210	22,670
24	11,520	6,300	6,250	24,070
26	12,480	6,850	6,290	25,620
28	13,440	7,400	6,330	27,170
30	14,400	7,750	6,370	28,520
32	15,360	8,100	6,480	29,940
34	16,320	8,400	6,520	31,240
36	17,280	8,700	6,560	32,540
37	18,240	9,000	6,580	33,820
40	19,200	9,300	6,600	35,100
42	20,160	9,600	6,640	36,400
44	21,120	9,900	6,680	37,700
46	22,080	10,200	6,720	39,000
48	23,040	10,500	6,780	40,320

214 30 REFUELING VEHICLE SHOP (SF)
FAC: 2141
BFR Required: Y

21430-1 **AIRCRAFT REFUELER TRUCKS.** Aircraft refueler trucks and other portable fuel dispensing equipment are not serviced or repaired in the automotive vehicle maintenance shop because of the explosive hazard involved. Accordingly, a separate explosion proof and fire-resistant maintenance/repair facility is provided. The facility is located a minimum of 100 feet from other structures. See Table 21430-1 for the refueling vehicle shop space allowances.

Table 21430-1. Space Allowances - Refueling Vehicle Shop

No. of Refuelers Supported	No. of Repair Stalls	Gross Area (Sq ft)
Up to 8	1	1,080
9 to 16*	2	1,800

* One additional 720-square-foot (16 x 45 ft) stall may be planned for each increment of eight refuelers above sixteen.

One 16 x 45 foot pad for purging fuel tanks should be provided for each facility.

214 40 VEHICLE HOLDING SHED (AWAITING PARTS AND REPAIR) (SF)
FAC: 2185
BFR Required: Y

21440-1 **DEADLINED EQUIPMENT**. This facility is a part of the automotive vehicle maintenance shop with the main purpose of providing a covered area for holding deadline equipment awaiting repairs. Whenever possible, it should be located near the main repair shops. Space requirements are computed as follows:

21440-1.1 **Self-propelled Equipment**. Provide one bay or stall for every 30 pieces of self-propelled equipment supported up to 1,000 units and one additional bay for every 50 units supported over 1,000. Bays will be 12 feet by 35 feet or 420 square feet in area.

214 51 AUTOMOTIVE ORGANIZATIONAL SHOP (SF)
FAC: 2141
BFR Required: Y

21451-1 This facility provides work areas for Fleet Marine Force (FMF) units to perform maintenance on items of organizational equipment. The shop space includes administrative and dispatching areas as well as storage for OEM equipment, tools, and parts.

21451-2 This category code includes requirements previously given in Category Code 214 52, Combat Organizational Shop (now deleted).

21451-3 Conduct an engineering study to determine requirements.

214 53 FIELD MAINTENANCE SHOP (COMBAT / AUTOMOTIVE / TRACK) (SF)
FAC: 2141
BFR Required: Y

21453-1 This facility provides specialized work areas for performing 3rd and 4th echelon maintenance functions on items of tactical equipment involving primarily rolling stock items of motor transport and engineer equipment. These are limited to use by the Service Battalion of the Marine Division and appropriate elements of the Force Service Regiment. The shop space includes administrative and training areas as well as storage space for tools, parts, and maintenance float equipment.

21453-2 For other field maintenance functions see Category Codes 215 60, 217 30, and 218 80.

21453-3 Conduct an engineering study to determine requirements.

214 55 VEHICLE WASH PLATFORM (SF)
FAC: 2145
BFR Required: N

21455-1 **REQUIREMENTS.** Vehicle wash platforms equipped with hose connections should be provided on the basis of one vehicle washing space for each 50 vehicles assigned to the motor pool. Where the motor pool supports multiple commands (Expeditionary Support Units) vehicle wash platforms should be sized based on the number of self-powered Civil Engineering Support Equipment (CESE) assigned to the ESU and the largest single command's CESE in the supportive Command. Where CESE and Service Craft and Boat Accounting Report (SABAR; vehicles/boats) are both present in the command, it is to be assumed that the CESE count alone will support the wash platform requirements. Where a single motor pool supports a single command of 150 plus pieces of self-powered CESE, the wash platform will be sized on the average number of self-powered pieces of CESE withdrawn in support either training or deployment. Vehicle wash platforms are also used to clean the SABAR assigned to the command but the SABAR does not count against total component count. A sediment basin for grit and soil will be provided and will drain into an oil water separator. Gross calculated area includes the sediment basin. . Vehicle wash platform/sediment basin(s) should be covered to reduce the amount of rain water to be treated by the oil water separator (see below for property record card use). Although a BFR is not required for the CCN, a BFR is provided for planning purposes. Final platform/ sediment basin details will be developed at design/construction phases.

21455-2 **PROPERTY RECORD CARD (PRC) USE.** See below guidance on appropriate property record card use. Use CCN 14313 “Operational Vehicle and Equipment Canopy” to capture any canopies associated with wash racks:

- Capture all vehicle wash racks at single location on a single property record card. Record the quantity of wash racks using the primary UM (EA) and the total square footage amount (cumulative for all racks) under the area UM (SF).
- Capture any overhead canopies under CCN 14313 (see above) on separate property record cards from the wash platform. If the canopy is contiguous, one PRC will suffice and both its quantity (1; EA) and area (SF) should be captured. If the actual canopy dimensions or design drawings are unavailable to determine the area, an estimate can be made by measuring the structural system layout and adding an estimate of the canopy overhang on each side. Where multiple canopies are observed, each will have its own facility number and PRC.
- In the “Notes” section of all associated PRCs, delineate the site location for references purposes.

214 56 GREASE RACK (EA)
FAC: 2145
BFR Required: N

21456-1 One grease rack (two vehicles) will be provided for each 125 vehicles.

215 MAINTENANCE - WEAPONS, SPARES

215-1 This group includes facilities for maintenance of small arms, automatic weapons, mortars, artillery guns, launchers, flamethrowers, torpedo tubes, harbor protective nets, and non-electronic equipment. See UFC 4-229-01N for design criteria. For missile maintenance facilities, see Category Group 212.

215 10 SMALL ARMS SHOP (SF)
FAC: 2152
BFR Required: Y

21510-1 A small arms shop is used to support small arms maintenance and repair for various Marine Corps activities or units. This shop is required to perform the pre-fire inspection (LTI) of all small arms weapons issued and recovered and to repair those weapons which are damaged or malfunctioned. The weapons are broken down, visually inspected, inspected by use of various gages, magnifying glasses, etc., repaired, lubricated, etc., and reassembled.

21510-2 The criteria indicated for category code 143-45, Armory, should provide adequate space allocation for any type of small arms shop provided: (a) the armory services only the activity at which it is located and (b) the small arms weapons are limited to those personnel physically stationed at that activity.

21510-3 This shop is a small arms maintenance and repair facility, and the weapons serviced here are not limited to those handled by the personnel assigned to the activity at which it is located. Accordingly, the size of the shop is based upon the number of weapons repaired per month and not like the armory, whose size is determined by the number of personnel stationed at the activity.

21510-3.1 A small arms shop shall meet the following requirements:

a. Positive weapon security in a humidity controlled, secure environment.
b. A rapid, individual weapon issue/recovery system.
c. A quick, twice daily inventory capability of all weapons.
d. Weapon repair bench (each).
e. A weapon maintenance area for individual weapon maintenance by the person to whom the weapon is assigned.
f. Space for a technical library.
g. Space for the storage of sensitive or highly pilferable emergency supplies for assigned reaction forces.
h. Parts storage.
i. Weapons cleaning and coating area.
j. Secured flammable storage area.

21510-4 The size of the shop is governed by the average number of weapons serviced during an average month. See Table 21510-1 for gross square foot allowance to determine the area requirement.

Table 21510-1. Small Arms Shop

Number of Weapons Serviced per Month	Gross Square Feet per Weapon
Up to 1,000	1.25
1,000 to 2,000	1.10
2,000 to 5,000	1.00
5,000 to 10,000	0.074
For each weapon over 10,000	Add 0.20

Example: The number of gross square feet required for a small arms shop servicing 10,350 weapons per month is: 10,350 x 0.20 + 2,070 gross square feet.

215 20 LIGHT GUN (20 MM TO 5 IN) SHOP (SF)
FAC: 2152
BFR Required: Y

215 30 HEAVY GUN (6 IN TO 16 IN) SHOP (SF)
FAC: 2152
BFR Required: Y

215 40 HARBOR PROTECTIVE NET SHOP (SF)
FAC: 2134
BFR Required: N

215 50 LAUNCHER AND PROJECTOR MAINTENANCE SHOP (SF)
FAC: 2152
BFR Required: Y

21520/30/40/50-1 At present there are no criteria for Category Codes 215 20 through 215 50. However, an engineering space analysis based on maintenance throughput, ordnance equipment size, maintenance staffing, and support space should determine the space requirements.

215 60 FIELD MAINTENANCE SHOP (ORDNANCE) (SF)
FAC: 2151
BFR Required: Y

21560-1 This field maintenance shop provides specialized work areas for performing 3rd and 4th echelon maintenance on all items of ordnance equipment authorized repaired by the Force Service Support Group (FSSG). The shop space includes administrative and training areas as well as storage space for tools, parts, and maintenance float equipment. Perform an engineering space analysis based on maintenance throughput, ordnance equipment size, maintenance staffing and support space should determine the space requirements.

21560-2 For other field maintenance functions, see Category Codes 214 53, 217 30, and 218 80.

216 MAINTENANCE AMMUNITION, EXPLOSIVES & TOXICS

216-1 **DEFINITION.** This group includes facilities for maintenance of ammunition, rockets, bombs, mines, grenades, torpedoes, depth charges, demolition materials, pyrotechnics, missile fuels, and related chemicals. OPNAV Instruction 8000.16 series provides maintenance policies, procedures, and responsibilities for the conduct of the Naval Ordnance Maintenance Management Program. Siting criteria and guidance on standard operating procedures for these facilities can be found in NAVSEA OP-5 Vol. 1. Consult the design criteria, UFC 4-216-02, when developing space requirements.

216 05 CHANGE/RELIEF HOUSE (SF)
FAC: 2162
BFR Required: N

21605-1 **DEFINITION.** This is a building, typically associated with explosives operating building(s), containing facilities for employees to change to and from work clothes. This facility may provide sanitary services, drinking fountains, lockers, and lunchrooms and may house the explosive plant office. See NAVSEA OP-5 for siting considerations.

21605-2 **CRITERIA.** There is no planning criterion for this function. Given the above listed functions and the number of personnel expected to use the facility, an engineering space analysis should produce an adequate requirement.

216 10 AMMUNITION REWORK AND OVERHAUL SHOP (SF)
FAC: 2162
BFR Required: Y

21610-1 **DEFINITION.** Overhauling ammunition includes determining the serviceability of the primary components of an item, and performing exterior maintenance as required to render the item fully serviceable.

21610-2 **CRITERIA.** There is no planning criterion for this function. An engineering space analysis based on the type of ammunition, maintenance throughput, ordnance equipment size, maintenance staffing, storage and support space should determine the space requirements.

216 20 ROCKET REWORK AND OVERHAUL SHOP (SF)
FAC: 2162
BFR Required: Y

21620-1 **DEFINITION.** Overhauling rockets includes determining the serviceability of the primary components of an item, and performing exterior maintenance as required to render the item fully serviceable.

21620-2 **CRITERIA.** There is no planning criterion for this function. An engineering space analysis based on maintenance throughput, ordnance equipment size, maintenance staffing, storage and support space should determine the space requirements.

216 30 MINES AND DEPTH CHARGE REWORK AND OVERHAUL SHOP (SF)
FAC: 2162
BFR Required: Y

21630-1 **DEFINITION.** Overhauling mines and depth charges includes determining the serviceability of the primary components of an item, and performing exterior maintenance as required to render the item fully serviceable.

21630-2 **CRITERIA.** There is no planning criterion for this function. An engineering space analysis based on maintenance throughput, ordnance equipment size, maintenance staffing, storage and support space should determine the space requirements.

216 40 TORPEDO SHOP (SF)
FAC: 2162
BFR Required: Y

21640-1 **DEFINITION.** Torpedo shop functions include but are not limited to: preventive and corrective maintenance as wells as hardware and operational software upgrades on torpedo Warshot and Exercise configurations. The Exercise configuration is recovered after firing and is processed for reuse. Torpedo processing includes complete disassembly, repair and reassembly into the desired configuration. The torpedo shops require special industrial processes to handle the OTTO fuel II used in torpedo propulsion systems. Typically, suites of electronic and mechanical test equipment are required to support different torpedo functions and components.

Maintenance processes are documented in Technical Manuals series SW13-EO-PRO-10 thru 060, which are maintained by Naval Undersea Warfare Center Newport.

21640-2 **CRITERIA.** There is no planning criterion for this function. An engineering space analysis based on maintenance throughput, equipment size, maintenance staffing, storage and support space should determine the space requirements.

216 50 SPECIAL WEAPONS SHOP (SF)
FAC: 2153
BFR Required: Y

21650-1 **DEFINITION.** Special weapons shop functions include, but are not limited to, determining the serviceability of the primary components of an item, and performing exterior maintenance as required to render the item fully serviceable.

21650-2 **CRITERIA.** There is no planning criterion for this function. An engineering space analysis based on maintenance throughput, ordnance equipment size, maintenance staffing, storage and support space should determine the space requirements.

216 55 AIR/UNDERWATER WEAPONS SHOP (AIRBORNE TORPEDOES/ AIRDROP WEAPONS) (SF)
FAC: 2161
BFR Required: Y

21655-1 **AIR/UNDERWATER WEAPONS (AUW) SHOP.** An Air/Underwater Weapons (AUW) Shop is required at Navy and Marine Corps air stations as designated by the Chief of Naval Operations. The AUW shop contains space and equipment for the storage, test, check, assembly, and limited maintenance of airborne torpedoes and other airdrop weapons.

21655-2 **CRITERIA.** When an AUW Shop is authorized, the standard shop has the following requirements:

Shop Building	7,192 gross square feet
Vehicle Shelter	1,612 gross square feet

Floor plan templates are shown in UFC 4-126-02.

216 60 QUALITY EVALUATION LABORATORY (SF)
FAC: 2162
BFR Required: Y

21660-1 **QUALITY EVALUATION LABORATORY.** A Quality Evaluation Laboratory (QEL) supports the QE program by performing analysis and tests to determine and maintain quality assurance of ammunition, explosives and toxins.

21660-2 **CRITERIA.** There is no planning criterion for this function. An engineering space analysis based on throughput, equipment size, lab space requirements, staffing and support space should determine the space requirements.

216 77 AMMUNITION/EXPLOSIVES MAINTENANCE STORAGE (SF)
FAC: 2162
BFR Required: Y

21677-1 **AMMUNITION/EXPLOSIVES MAINTENANCE STORAGE.** Storage facilities for miscellaneous equipment related to ammunition/explosives maintenance facilities will be provided only where it can be individually justified.

21677-2 **CRITERIA.** There are no criteria for this type of facility. General information on normal stacking heights, net to gross multipliers, and other parameters are provided in Category Code 440 series.

217 MAINTENANCE - ELECTRONICS AND COMMUNICATION EQUIPMENT

217-1 This basic category includes facilities and shops for maintenance and repair of radio and radar equipment, antennas, radiation aids, sonar equipment, transmission and reception equipment, and guided bombs.

217 10 ELECTRONICS/COMMUNICATIONS MAINTENANCE SHOP (SF)
FAC: 2171
BFR Required: Y

21710-1 Electronics maintenance shops at Naval and Marine Corps activities provide facilities for maintenance and repair of non-airborne equipment (see Category Code 211 45, Avionics Shop (Non-NAVAIR Depot) for airborne equipment repair facilities).

21710-2 It contains office and support spaces for the Equipment Maintenance Officer (EMO) and the EMO Staff, equipment maintenance and training areas, and a small storage area for parts and supplies directly under the control of the EMO. A small electronics and communications maintenance shop integral to the function it supports should be contained within the analysis of that function and not classified as Category Code 217 10.

21710-3 No specific criteria are provided. An engineering evaluation can be conducted to determine the office space and support area requirements using guidance contained within the Category Code series 131 Introductory section. For maintenance and training area, the quantity and type of items required may be selected from Table 131 and appropriate allowances applied. For storage area, an engineering evaluation can be used to determine the volume of material required to be stored. The standard stacking height for this type of material is 1.83 meters (6 feet). A factor of 1.07nsm/cm is applied to the volume of material to determine the required net square meters (m^2). A conversion factor of 1.65 for net square meters to gross square meters is appropriate.

217 20 COLLIMATION TOWER (EA)
FAC: 2173
BFR Required: N

21720-1 Collimation facilities are required at shipyards for electronic and optical alignment of fire control and radar equipment aboard ships. This facility consists of a steel tower approximately 125 to 150 feet in height and a small instrument building at the lower base.

217 30 FIELD MAINTENANCE SHOP (COMMUNICATIONS/ ELECTRONICS) (SF)
FAC: 2171
BFR Required: Y

21730-1 This field maintenance shop provides specialized work areas for performing 3rd and 4th echelon maintenance on all items of communications/electronics equipment authorized repaired by the Service Battalion of the Marine Division and the Force Service Regiment. The shop space includes administrative and training areas as well as storage space for tools, parts, and maintenance float equipment. For other field maintenance functions, see Category Codes 214 53, 215 60 and 218 80. Conduct an engineering study to determine requirements.

217 40 ANTENNA TEST RANGE (EA)
FAC: 2173
BFR Required: N

21740-1 This facility is for testing electronic equipment and communication antennas after completion of maintenance, repair and overhaul work. This range has to be individually planned. Standard planning factors are not available.

217 50 SENSOR ACCURACY CHECK SITE (SACS) (EA)
FAC: 2173
BFR Required: Y

21750-1 The primary purpose of this facility is to measure the performance of shipboard sensors in an in-port environment on completion of overhaul or during normal port upkeep of Navy ships. This facility can be planned for only when authorized by the Commander, Naval Sea Systems Command.

21750-2 The SACS is a unique test and evaluation facility which provides an independent, real-time measure of gyrocompass, sonar, echo sounder and sonar communications set performance and accuracy. The SACS design permits sensor evaluations under test conditions especially favorable to the ship: (1) the ship is tested in port with all normal dockside facilities available; (2) measurements are external to the ship so that "at sea" performance is determined; (3) data are analyzed in real-time providing immediate identification of sensor deficiencies and verification of corrective actions; and (4) all major sonar parameters are measured in a single comprehensive test.

21750-3 **MAJOR FACILITY COMPONENTS.**

21750-3.1 **Control Center**: The building in which test points on the ship's sensors are monitored, and control is maintained over all SACS equipment. The building contains signal generating, receiving and processing devices and automatic data acquisition and analysis equipment.

21750-3.2 **Pile Mounted Transducers.** Transducers mounted to the 31 pilings of the SACS array. The transducers are spaced at 10-degree intervals and are used for sonar range and bearing error measurements.

21750-3.3 **Moveable Carriage with Transducer.** A calibrated directional transducer that can be moved vertically and in azimuth; it is used for receiver and transmitter performance measurements.

21750-3.4 **Ship's Transducer Location System (STLS).** A system of three transducers used to continuously monitor the position of the ship's sonar transducer to an uncertainty of less than one inch.

21750-3.5 **Automatic Ship's Head Measuring System (ASHMS).** A system of specially configured TV cameras that is used to provide ship's heading to an accuracy of better than 0.01 degree.

21750-3.6 **Mooring System**. A system of five hydraulic winches from which wire ropes are extended to the ship in order to maintain the ship's sonar transducer near the center of the SACS array.

21750-3.7 **Slip Services.** The ship receives 800 amps, 440 volts, steam, fresh water, telephone connections and generous parking space while in port.

21750-3.8 **Echo Sounder Test Array**: An array of four transducers placed on the bottom of the bay directly below the ship's fathometer.

21750-3.9 **Depth.** A minimum depth of 50 feet Mean Lower Low Water is required at the site of the subject facility due to the variety of vessels that can be expected to be serviced.

217 77 ELECTRONICS - SPARES AND STORAGE (READY ISSUE/SHOP STORES / MISCELLANEOUS) (SF)
FAC: 2171
BFR Required: Y

21777-1 **Electronics and Communications Storage.** Support multiple commands or multiple Departments/Divisions within a command. It is under the control of the Communications Department. Storage of material under the control of the Logistics and Supply Department should be classified within CCN 143-77. Storage areas in support of small electronics and communications maintenance shops integral to the function they support are considered part of those functions.

21777-2 **No specific criteria provided**. An engineering evaluation can be used to determine the volume, in cubic meters (cm), of material required to be stored. The standard stacking height for this type of material is 1.83 meters (6 feet). A factor of 1.07nsm/cm is applied to the volume of material to determine the required net square meters (m^2). A conversion factor of 1.65 for net square meters to gross square meters is appropriate.

218 MAINTENANCE - MISCELLANEOUS PROCURED ITEMS AND EQUIPMENT

218 10 CONTAINER REPAIR AND TEST BUILDING (SF)
FAC: 2182
BFR Required: Y

21810-1 A container repair and test facility services only empty containers. The size of the facility is relevant to processing approximately 1 percent of the containers and chassis involved in the handling and shipping operations. The facility provides for structural testing, minor repairs, and cosmetic services for damaged or structurally marginal containers.

21810-2 Assuming a 750-container throughput capability per 24-hour day, the number of bays in the repair facility can be estimated as follows:

1% x 750 = 7.5 containers per day
Assume 4 hours work per container - 4 x 7.5 = 30 hours
Assume 8 hours working day - 30 / 8 = 3.75, say 4 bays

21810-3 A typical 4-bay facility with supporting tool room, administrative space, and personnel support area is shown in Figure 218-10. The bays are serviced by a bridge crane with a lifting capacity of 5 tons. Storage space of 2,130 square yards for 16 empty containers should be provided adjacent to the facility. The 4 bays testing and repair area is 1,920 square feet. The administrative space is 800 square feet for a total gross area of 2,720 square feet.

218 20 CONSTRUCTION/WEIGHT HANDLING EQUIPMENT SHOP (SF)
FAC: 2182
BFR Required: Y

21820-1 Special shop structures for the maintenance and repair of construction/weight-handling equipment are planned only for areas where combined automotive, weight-handling, railroad and/or construction equipment maintenance facilities are not feasible. Construction/weight-handling equipment shop requirements are based on the space factors contained in Category Code 214 20, Automotive Vehicle Maintenance Shop.

21820-2 Included in this category are special construction and utility shops for Marine Corps units. These shops are normally part of the Headquarters Battalion, Force Service Regiment, and the Fleet Marine Force (FMF) Engineer Battalions. Conduct an engineering study to determine requirements.

218 25 MARINE AIR-BASE SQUADRON (MABS) FACILITY (SF)
FAC: 2181
BFR Required: Y

21825-1 This Category Code is used for inventory purposes only.

218 30 DRUM RECONDITIONING PLANT (SF)
FAC: 2182
BFR Required: Y

21830-1 The drum reconditioning plant is planned for those fuel facilities where fuel drums are returned for refilling or storage before reissue. Normal drums that require reconditioning at frequent intervals are the 55-gallon steel type. The drum reconditioning facility requires a minimum of two buildings: one for the boiler plant and the other housing the reconditioning facilities. The boiler house will be approximately 800 square feet, and the reconditioning building housing the internal washing, removal of surface depressions, internal chaining, external wire brushing, chime rolling, testing, welding, internal preservation, and painting will be approximately 3,600 square feet. This plant has a capacity of approximately 3,000 55-gallon drums per month.

218 35 CABLE REPAIR HOUSE (SF)
FAC: 2182
BFR Required: Y

21835-1 No criteria are currently available for this Category Code.

218 40 RAILROAD EQUIPMENT SHOP (SF)
FAC: 2183
BFR Required: Y

21840-1 The railroad equipment maintenance facility is a special shop structure to house material and equipment for the service and maintenance of railroad locomotives and locomotive cranes. The facility is required where installations operate and maintain railroad equipment for the handling of supplies. In areas where it is practicable, the railroad equipment maintenance shop will be combined with the Automotive Vehicle Maintenance Shop and/or the Construction/Weight-Handling Equipment Shop, and the number of repair bays (with pits) may be determined as follows:

Locomotives Supported	Repair Bays	Area SF
1-5	1	960
6-12	2	1,980
13 and over	3	2,880

21840-2 The numbers of additional bays are similarly determined from the above table.

218 45 INSTRUMENT CALIBRATION SHOP (SF)
FAC: 2182
BFR Required: Y

21845-1 **REPAIR.** This shop performs calibration, repair, and certification of all measurement instruments assigned to an activity. Space requirements are governed primarily by the number of pieces of equipment requiring calibration. The facility should be dust-free, temperature and humidity controlled and protected from electromagnetic interference. It is essential that the site selected for the location of this facility be free of ambient vibration to avoid interference with calibration operations. Normally the following spaces are included:

21845-1.1 **Calibration Laboratory**

21845-1.2 **Cleaning Room** is used for cleaning and drying equipment to be calibrated.

21845-1.3 **Utilities Room** is required so that utilities components can be isolated from the laboratory working area.

21845-1.4 **Storage Areas** for incoming and outgoing items, spare parts and equipment.

21845-1.5 **Administration Area.** The administration area provides office space, technical library, and file storage. Space allowances are planned in accordance with Category Code 610-10.

21845-2 **FOR SPECIFIC GUIDANCE.** See Joint Systems Commands publication Calibration Facility Requirements (NAVAIR 17-35 FR-02 NAVSEA OD 45842 and NAVELEX 0967-LP-465-8010) and Naval Shore Electronics Criteria (NAVELEX 0101, 114) calibration program.

218 50 BATTERY SHOP (SF)
FAC: 2181
BFR Required: Y

21850-1 A battery shop is required to service and charge batteries. As an example, typical batteries serviced at an air installation are lead-acid batteries used for ground support equipment (GSE) and nickel-cadmium and silver-zinc batteries for aircraft at the intermediate maintenance level. A shop is normally required at each Navy and Marine Corps air installation having approximately 75 or more aircraft. The gross area of the battery shop is 1,110 square feet. This shop size can accommodate a maximum workload of eight nickel-cadmium and 40 lead acid batteries per work shift. The shop size should be modified for other workloads, with the major change being in the amount of space needed for charging benches.

218 51 BATTERY RECHARGING SHOP (SF)
FAC: 2181
BFR Required: Y

21851-1 This category code is for use at activities which have a requirement to recharge battery powered equipment such as forklift trucks used at supply centers. The requirement is a function of the number and size of the equipment being serviced and must be determined on an individual basis or in the case of forklift trucks, the following criteria may be used: 100 square feet per forklift which includes 40 square feet for the average vehicle itself and 60 square feet for aisle and workspace, based on a 1.5:1.0 ratio. In all instances, compliance must be maintained to OSHA regulations regarding the venting of hydrogen gas, floor drains, flush facilities, explosion proof wiring and lighting, etc.

218 52 BATTERY RECHARGING SHED (SF)
FAC: 2185
BFR Required: Y

21852-1 This category code captures battery charging structures/sheds at activities that have a requirement to recharge battery powered equipment such as forklifts and similar equipment. It supports either charging batteries outside of equipment or for temporarily supporting the requirement to charge housing equipment batteries.

218 60 GROUND SUPPORT EQUIPMENT SHOP (SF)
FAC: 2181
BFR Required: Y

21860-1 The intermediate level maintenance of aircraft ground support equipment (GSE) is performed in this shop. Ground support equipment, often referred to as yellow gear, includes such items as tow tractors, trucks, forklifts, trailers, compressors, power generators, maintenance stands, jacks and other ground equipment which support aircraft operations.

The GSE shop requirement is based upon the average number of on-board aircraft and is sized in accordance with Table 21860-1 with the following modifications:

1. The areas shown in the table were developed for base loadings comprised mainly of VF, VA, VP, and VEW aircraft. Activities supporting primarily helicopter or basic propeller training operations normally would not require a shop size greater than 12,500 SF regardless if the station loading exceeds 100 aircraft.

2. Stations which have a Fixed Point Utility System (FPUS) installed in the aircraft parking apron shall reduce the shop requirement by 640 square feet for each full increment of 75 aircraft spaces equipped with FPUS. See the example at the end of this section.

3. Stations having less than 40 aircraft shall individually justify a requirement for a GSE shop. Consideration will be given to maintaining the GSE gear in the Automotive Vehicle Maintenance Shop (Category Code 214 20) prior to requesting a separate GSE shop.

Table 21860-1
Ground Support Equipment Shop

Number of Aircraft	Shop Area (SF)
40-50	6,250
51-75	9,400
76-100	12,500
101-125	13,950
126-150	15,400
151-175	16,850
176-200	18,300
201-250	21,200
251-300	24,100

The above shop allowance includes workspace for: battery shop, engine shop, paint shop, tire and wheel repair, jack repair and vehicle framework. Supporting space for ready issue of parts, tool storage, classrooms, locker room, offices, and a mechanical equipment room are also included. A covered storage area for GSE gear is planned in conjunction with the GSE shop (see Category Code 218 61, Ground Support Equipment Holding Shed). A sample computation for a GSE shop is given below:

Example – GSE Shop

Given: Average on board aircraft – 179
Fixed Point Utility System (FPUS) provided for 90 apron parking spaces

From Table 21860-1, shop area to support 179 aircraft equals 18,300 SF.

Reduction for FPUS:
90 apron spaces with FPUS divided by 75 = 1.2, use 1.0
Reduce area by 1.0 x 640 SF
Requirement equals 17,660 SF (18,300 – 640).

218 61 GROUND SUPPORT EQUIPMENT HOLDING SHED (SF)
FAC: 2185
BFR Required: Y

21861-1 DEFINITION. The ground support equipment (GSE) holding shed is planned in conjunction with the Category Code 218 60, Ground Support Equipment (GSE) Shop. The shed provides protective cover for GSE gear awaiting and undergoing intermediate level maintenance and is an integral part of the GSE Shop compound.

The GSE shed requirement is based upon the average number of on-board aircraft and is sized in accordance with Table 21861-1 with the following modifications:

1. The areas shown in the table were developed for base loadings comprised mainly of VF, VA, VP, and VEW aircraft. Activities supporting primarily helicopter or basic propeller training operations normally would not require a shop size greater than 19,500 SF regardless if the station loading exceeds 100 aircraft.

2. Stations which have a Fixed Point Utility System (FPUS) installed in the aircraft parking apron shall reduce the shop requirement by 640 square feet for each full increment of 75 aircraft spaces equipped with FPUS. See Category Code 218 60 for an application for a similar reduction to the GSE shop.

Table 21861-1
GSE Holding Shed

Number of Aircraft	Shed Area (SF)
40-50	9,750
51-75	14,625
76-100	19,500
101-125	19,967
126-150	20,435
151-175	20,902
176-200	21,370
201-250	22,300
251-300	23,230

218 62 SHIPBOARD AIRCRAFT SUPPORT EQUIPMENT FACILITY (SF)
FAC: 2182
BFR Required: Y

21862-1 No criteria are currently available for this Category Code.

218 65 EQUIPMENT HOLDING SHED (For Category Code 218 20) (SF)
FAC: 2185
BFR Required: Y

21865-1 This facility is required in conjunction with Construction/Weight-Handling Equipment Shop, Category Code 218 20 for the purpose of protection of equipment awaiting repairs. The number and size of holding bays has to be determined on an individual basis and is dependent upon the type of equipment to be supported.

218 68 PRODUCTION EQUIPMENT MAINTENANCE SHOP (SF)
FAC: 2182
BFR Required: Y

21868-1 No criteria are currently available for this Category Code.

218 70 OFFICE EQUIPMENT/APPLIANCE REPAIR SHOP (SF)
FAC: 2182
BFR Required: Y

21870-1 Appropriate facilities may be provided to perform maintenance and repair of office equipment and small appliances. The space requirement for this facility is governed by the number of machines supported by the activity. See Table 21870-1.

Table 21870-1. Space Allowance - Office Equipment/Appliance Repair Shop

Number of Machines Supported	Gross SF Area
500	400
1,000	600
1,500	800
2,000	1,000
2,500	1,200
3,000	1,400
5,000	1,600

218 71 DENTAL EQUIPMENT MAINTENANCE BUILDING (SF)
FAC: 2182
BFR Required: Y

21871-1 No criteria are currently available for this Category Code.

218 77 REPAIR SHOP STORAGE (SF)
FAC: 2182
BFR Required: Y

21877-1 No criteria are currently available for this Category Code.

218 80 FIELD MAINTENANCE SHOP (GENERAL SUPPLY) (SF)
FAC: 2182
BFR Required: Y

21880-1 This field maintenance shop provides specialized work areas for Fleet Marine Force (FMF) units performing 3rd and 4th echelon maintenance on all items of general supply equipment. This function is performed primarily by the General Supply

Maintenance Company, Maintenance Battalion, of the Force Service Regiment. The shop space includes administrative and storage space for tools, parts, and maintenance float equipment.

21880-2 For other field maintenance functions see Category Codes 214 53, 215 60, and 217 30.

21880-3 Conduct an engineering study to determine requirements.

218 90 AVIATION SUPPORT EQUIPMENT SHOP (NALC) (SF)
FAC: 2182
BFR Required: Y

21890-1 No criteria are currently available for this Category Code.

218 91 MOBILE VAN SHOP (NALC) (SF)
FAC: 2181
BFR Required: Y

21891-1 No criteria are currently available for this Category Code.

218 92 AVIATION SUPPORT / FEEDER SHOP (NALC) (SF)
FAC: 2182
BFR Required: Y

21892-1 No criteria are currently available for this Category Code.

219 MAINTENANCE - INSTALLATION, REPAIR AND OPERATION

219-1 This basic category includes maintenance shops for repair and overhaul of installation facilities (public works and public utilities), including installed shop and other equipment, and utility distribution systems, used in support of maintenance operations at military and/or industrial installations. The maintenance and repair of vehicles and weight-handling and construction equipment, utility plant, and maintenance shops are not included in this category. For the former, see Category Code series' 214 and 218, and the latter, see Category Code series 811.

219 10 PUBLIC WORKS SHOP (SF)
FAC: 2191
BFR Required: Y

NOTE: For shop planning in Public Work Centers, individual guidance will be provided by NAVFAC.

21910-1 This facility supports the Maintenance Division of the Public Works Department. This Division is responsible for management of the Preventive, Maintenance Inspection (PMI) program and is tasked to perform maintenance on:

21910-1.1 All buildings, grounds and ground structures.

21910-1.2 Utilities plants and distribution systems when requested by the Utilities Division.

21910-1.3 Heating, air-conditioning and refrigeration systems.

21910-1.4 Internal communications and alarm systems.

21910-1.5 Roads and trackage.

21910-2 This work includes repairs, alterations and new construction incident to maintenance; except work that may be accomplished by private contract. In addition, the Maintenance Division is responsible for the following services:

21910-2.1 Respond to emergency and/or service work requests.

21910-2.2 Provide caretaking services.

21910-2.3 Provide upkeep to all grounds of the activity.

21910-2.4 Provide for solid waste collection.

21910-2.5 Provide pest control service.

21910-3 Certain Public Works Department functions are not performed at the Public Works Shop as defined for Category Code 219 10, such as:

21910-3.1 Administration when not in direct support of a maintenance shop. This includes offices for the Public Works Officer (PWO), Assistant PWO, Maintenance Control Division, Maintenance Division supervisor and staff, Engineering Division, Administrative Division and Housing Division.

21910-3.2 Work performed by the Utilities Division such as operating utilities plants and distribution systems.

21910-3.3 Maintenance and repair of automotive equipment.

21910-4 Facilities for these functions are categorized under the following Category Groups as appropriate: 610- Administration, 218- Maintenance—Facilities for Miscellaneous Procured Items and Equipment, 214- Maintenance—Tank, Automotive, and the applicable code groups in the 800 series – Utilities and Ground Improvements.

21910-5 The maximum allowable gross area for public works shops, including space for heating and mechanical equipment, is based on the number of military and civilian maintenance personnel permanently assigned to the maintenance organization. This does not include those personnel involved in functions not directly performed by the shop as outlined above. Table 21910-1 lists the gross area for the various sizes of maintenance shops including Category Code 219 20, Pavement and Grounds Equipment Shed and 219 25, Public Works Shops Expendable/Work-in-Process Store.

Table 21910-1. Space Allowance - Public Works Shops*

Shop Type	Total Maintenance Personnel	Gross Area (SF)*
A	10-30	8,700
B	31-50	12,100
C	51-100	16,700
D	101-150	21,100
E	151-300	28,300
F	301-500	34,800
	Over 500	100 SF/Pers.

* The areas indicated in Table 21910-1 represent the entire composite area for the Public Works Maintenance Shop. Included within these figures are the areas allocated for category codes 219 20, Pavement and Grounds Equipment Shed, Table 21920-1, and 219 25, Public Works Shops Expendable/Work-In-Process Store, Table 21925-1. The requirement for the last two codes must not be added to this code but rather are considered an integral part of it. The figures indicated in the tables for these two codes are provided as a guide as to how category code 219 10 may be subdivided. In the event the requirement for category codes 219 20 and 219 25 are less than indicated, it is not necessary to reduce the figures indicated in Table 21910-1 but rather, this difference in area may be used for other functions performed by this shop.

21910-6 The gross areas listed in Table 21910-1 provide for the following functions: (1) the woodworking shop, including furniture repair, packing, and crating, excluding the packing and crating in Category Code series' 441 and 442); (2) the electrical shop, refrigeration and air conditioning shop; (3) plumbing and heating shop; (4) metal work shop, including machine shop, sheet metal, iron work, welding, and blacksmith facilities; (5) paint shop; (6) routine maintenance and service shops, including custodial, preventive maintenance, refuse collection, insect and rodent control, road maintenance facilities, moving and rigging, and emergency service shops; (7)

central tool issue, shop stores and shop toilets, and locker rooms, and (8) administrative spaces in direct support to shop operations, corridors, and necessary service space directly related to the shop. If other than the foregoing functions are required, space may be appropriately increased if justifications are documented.

219 20 PAVEMENT AND GROUNDS EQUIPMENT SHED (SF)
FAC: 4422
BFR Required: N

21920-1 The pavement and ground equipment shop will provide holding space and minor maintenance space for tractors, lawnmowers, snowplows, and other miscellaneous equipment used for roads and ground maintenance. This shop can be independent of the Public Works Maintenance Shop (Category Code 219 10) but is related for space allowances to the corresponding PW shop type. The gross square foot allowances on Table 21920-1 are provided for planning guidance only and are not additive to the Public Works shop allowances. See footnote to Table 21910-1.

Table 21920-1. Space Allowance - Pavement and Grounds Equipment Shop

Shop Type	Gross Area (SF)
A	525
B	700
C	850
D	1,100
E	1,800
F	2,200

219 25 PUBLIC WORKS SHOPS EXPENDABLE/WORK-IN-PROCESS STORE (SF)
FAC: 2191
BFR Required: N

21925-1 The public works shops expendable/work-in-process store holds the ready-issue items for public works daily maintenance, job order materials for the maintenance of station facilities and materials that are considered critical items for emergencies/service. It is independent of the General Supply Storage (Category Code 441 10). The shop can also be independent of the Public Works Shop (Category Code 219 10) but is related for space allowances to the corresponding PW shop type. See Table 21925-1. The gross square foot allowances on Table 21925-1 are provided for planning guidance only and are not additive to the Public Works shop allowances. See footnote to Table 21910-1.

Table 21925-1. Space Allowances - Public Works Shop Store

Shop Type	Gross Area (SF)
A	650
B	1,000
C	1,100
D	1,400
E	2,200
F	2,500

219 30 PAINTING AND RELATED OPERATIONS BUILDING (SF)
FAC: 2191
BFR Required: Y

21930-1 The function of the painting and related operations building is to provide space for painting and other operations which may not be functionally compatible or hazardous to the building or types of operation conducted in the public works shop, Category Code 219 10. This facility is considered as an integral part of Category Code 219 10 but may, in some instances, be a separate building if safety or functional requirements so dictate. However, in all cases, the area allocated for this facility must be considered as part of the area for the corresponding shop types listed in Table 21910-1 and must not be considered as an additional requirement.

219 31 PAINTING AND RELATED OPERATIONS STRUCTURE (EA)
FAC: 2192
BFR Required: N

21931-1 The painting and related operations structure is a facility used for painting and those operations which are not suitable to be carried on in Category Code 219 30, Painting and Related Operations Building. This code may include structures like a sandblast scaffold, paint spray booth, preservation dip tank, pickling tank, sandhopper, sandblasting facilities, open paint canopy, sand handling bin, etc. There are no specific planning criteria for these structures; each requirement must be individually justified.

219 40 SEWAGE HOSE STORAGE FACILITY (EA)
FAC: 2192
BFR Required: N

21940-1 This Category Code is for inventory purposes only.

219 77 PUBLIC WORKS MAINTENANCE STORAGE (READY ISSUE/SHOP STORES/MISC.) (SF)
FAC: 2191
BFR Required: Y

21977-1 This facility is a general warehouse for the storage of items and materials required for the maintenance of station buildings and grounds. It is independent of the ready-issue storage facilities required in direct support of the public works shops (use Category Code 219 25).
21977-2 Shed storage space is required to provide covered storage for certain items of equipment and supplies needed for base operation and maintenance, which do not require regular warehouse storage, yet must be protected from the weather. Table 21977-1 may be used to determine covered storage requirements for various sizes of public works facilities.

Table 21977-1. Public Works Storage Areas

Shop Type	Gross SF Area	
	Covered	Shed
A	3,400	2,300
B	3,400	2,300
C	3,400	2,300
D	6,000	4,000
E	12,500	8,300
F	19,200	12,800

NOTE: For Public Works Storage supporting PW shops larger than type F, add the following areas for each maintenance craftsman over 500: covered 40 SF; Shed - 25 SF

220 PRODUCTION

220-1 The production facility is part of the production system that processes raw materials, components and labor into finished goods.[1] Production facilities are typically "one-of-a-kind" therefore space requirements should be developed "from the ground up"; first for the individual workstations; then departmental requirements by summing the workstations within the department. Applying industrial engineering practices and methods would provide sufficient and accurate space requirements. Accurate future product demand forecasts are necessary so the facility can be sized for future growth. The facility should be sized for forecasted production growth 5 to 10 years beyond initial operating capability. [2]

This methodology applies for the following category codes:

221 10 AIRCRAFT ENGINE-ASSEMBLY PLANT (SF)
FAC: 2211
BFR Required: Y

221 20 AIRFRAME ASSEMBLY PLANT (SF)
FAC: 2211
BFR Required: Y

221 30 AIRCRAFT ACCESSORIES –ASSEMBLY PLANT (SF)
FAC: 2211
BFR Required: Y

222 10 MISSILE ASSEMBLY-PLANT (SF)
FAC: 2221
BFR Required: Y

222 20 MISSILE HANDLING LAUNCH EQUIPMENT (SF)
FAC: 2221
BFR Required: Y

223 10 FABRICATION & ASSEMBLY BUILDING (SF)
FAC: 2231
BFR Required: Y

223 30 SHIP-BUILDING DRYDOCKS (SF)
FAC: 2233
BFR Required: Y

224 10 COMBAT-VEHICLE ASSEMBLY PLANT (SF)
FAC: 2241
BFR Required: Y

224 20 AUTOMOTIVE-VEHICLE ASSEMBLY PLANT (SF)
FAC: 2241
BFR Required: Y

225 10 SMALL-ARMS PLANT (SF)
FAC: 2251
BFR Required: Y

225 20 LIGHT-GUN PLANT (SF)
FAC: 2251
BFR Required: Y

225 30 HEAVY-GUN PLANT (SF)
FAC: 2251
BFR Required: Y

225 40 HARBOR-PROTECTIVE-NET PLANT (SF)
FAC: 2251
BFR Required: Y

225 50 LAUNCHER & PROJECTOR PLANT (SF)
FAC: 2251
BFR Required: Y

225 60 ARMOR-PLATE PLANT (SF)
FAC: 2251
BFR Required: Y

226 10 BAG-CHARGE-FILLING PLANT (SF)
FAC: 2261
BFR Required: Y

226 15 CASE-FILLING PLANT (SF)
FAC: 2261
BFR Required: Y

226 20 CASE-OVERHAUL TANK-REPAIR FACILITY (SF)
FAC: 2261
BFR Required: Y

226 25 40MM-LOADING PLANT (SF)
FAC: 2261
BFR Required: Y

226 30 20MM-LOADING PLANT (SF)
FAC: 2261
BFR Required: Y

226 35 MAJOR-CALIBER PROJECTILE-LOADING PLANT (SF)
FAC: 2261
BFR Required: Y

226 40 MEDIUM-CALIBER PROJECTILE-LOADING PLANT (SF)
FAC: 2261
BFR Required: Y

226 45 LARGE-CALIBER ROCKET-MOTOR LOADING PLANT (SF)
FAC: 2261
BFR Required: Y

226 50 MEDIUM-CALIBER ROCKET-MOTOR-LOADING PLANT (SF)
FAC: 2261
BFR Required: Y

226 55 CAST-HIGH-EXPLOSIVES FILLING PLANT (SF)
FAC: 2261
BFR Required: Y

226 56 CAST-HIGH-EXPLOSIVES FILLING FACILITY (SF)
FAC: 2262
BFR Required: N

226 60 SPECIAL-WEAPONS PLANT (SF)
FAC: 2261
BFR Required: Y

226 65 PROPELLANT & RELATED-CHEMICAL PLANT (SF)
FAC: 2261
BFR Required: Y

226 66 PROPELLANT & RELATED-CHEMICAL FACILITY (SF)
FAC: 2262
BFR Required: N

226 70 READY-AMMUNITION BELTING PLANT (SF)
FAC: 2261
BFR Required: Y

226 75 UNDERWATER DEMOLITION EQUIPMENT PLANT (SF)
FAC: 2261
BFR Required: Y

226 80 AMMUNITION-LOADING PLANT (SF)
FAC: 2261
BFR Required: Y

226 81 DEMILITARIZATION BUILDING (SF)
FAC: 2264
BFR Required: Y

226 82 DEMILITARIZATION FACILITY (EA)
FAC: 2265
BFR Required: N

226 85 FUSE-ASSEMBLY PLANT (SF)
FAC: 2261
BFR Required: Y

226 86 MINE-ASSEMBLY PLANT (SF)
FAC: 2261
BFR Required: Y

226 88 PYROTECHNIC PRODUCTION FACILITY (SF)
FAC: 2261
BFR Required: Y

227 10 RADIO & RADAR EQUIPMENT PLANT (SF)
FAC: 2271
BFR Required: Y

227 20 SONAR EQUIPMENT PLANT (SF)
FAC: 2271
BFR Required: Y

227 30 GUIDANCE EQUIPMENT PLANT (SF)
FAC: 2271
BFR Required: Y

227 35 PRINTED-CIRCUIT SHOP (SF)
FAC: 2271
BFR Required: Y

228 10 PARACHUTE & SURVIVAL-EQUIPMENT PLANT (SF)
FAC: 2281
BFR Required: Y

228 20 CONSTRUCTION EQUIPMENT PLANT (SF)
FAC: 2281
BFR Required: Y

228 30 RAILROAD EQUIPMENT PLANT (SF)
FAC: 2281
BFR Required: Y

228 35 OPTHALMIC-SUPPORT BUILDING (SF)
FAC: 5302
BFR Required: Y

229 10 ASPHALT PLANT (EA)
FAC: 2291
BFR Required: Y

229 20 CONCRETE-BATCHING PLANT (EA)
FAC: 2291
BFR Required: Y

229 30 ROCK-CRUSHER PLANT (EA)
FAC: 2291
BFR Required: Y

229 35 POWDER-TANK/FLAKE-TANK STORAGE (BL)
FAC: 8999
BFR Required: N

229 50 PRINTING PLANT (SF)
FAC: 6103
BFR Required: Y

229 77 MAINTENANCE-PRODUCTION STORAGE-READY ISSUE ETC. (SF)
FAC: 2281
BFR Required: Y

229 80 CONTAINER ASSEMBLY BUILDING (SF)
FAC: 2281
BFR Required: Y

Version: 300.20230302

FACILITIES CRITERIA (FC)
FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

Series 300: RESEARCH, DEVELOPMENT, ACQUISITION, TEST, AND EVALUATION FACILITIES

Record of Changes:

Date	CCN #	CCN Title	Description of Change
08 May 2018	300-6	Research, Development, Acquisition, Test And Evaluation Facilities	Updated criteria to meet minor changes that reference 131 Introductory criteria.
08 May 2018	310 33	Computation And Analysis Laboratory	Minor criteria rewording.
08 May 2018	317 10	Communications Systems Laboratory	Minor criteria rewording.
08 May 2018	317 25	Electrical, Electronics And Communication Systems Integration Laboratory	Minor criteria rewording.
08 May 2018	319 15	Telecommunications Distribution Facility	Minor criteria rewording.
14 August 2019	31105	RDAT&E Maintenance Hangar-Oh Space (High Bay)	Change title to: "RDAT&E Maintenance Hangar" and consolidated 31106 and 31107 into 31105.
14 August 2019	31106	RDAT&E Maintenance Hangar - 01 Space (Crew And Equipment)	Deleted CCN
14 August 2019	31107	RDAT&E Maintenance Hangar - 02 Space (Administrative)	Deleted CCN
July 2020	31013	Chemistry and Toxicology Laboratory	Description revised to remove the word "nuclear", as per OSD direction.
July 2020	31019	Physics Laboratory	Description revised to remove the word "nuclear", as per OSD direction.
July 2020	31815	Propulsion Fuel Laboratory	Description revised to remove the word "nuclear", as per OSD direction.
2 Mar 2023	300 Series	UFC 2-000-05N	Change UFC 2-000-05N to FC 2-000-05N document due to the fact that this planning criteria is not unified among the other DoD services.

SERIES 300
RESEARCH, DEVELOPMENT, ACQUISITION, TEST, AND EVALUATION FACILITIES

Table of Contents

300 RESEARCH, DEVELOPMENT, ACQUISITION, TEST AND EVALUATION FACILITIES

300-1 INTRODUCTION

Research, development, acquisition, test and evaluation facilities include the buildings and other scientific structures and facilities used directly in theoretical and/or applied research, development, acquisition, test and evaluation operations. Category code groups pertaining to these facilities are:

300-1.1 **Category Code 310 through 321.** Research, development, acquisition, test and evaluation buildings

300-1.2 **Category Codes 371 and 390.** Research, development, acquisition, test and evaluation structures

Associated facilities assigned function in support of research, development, acquisition, test and evaluation are assigned appropriate codes such as Category Code series 200 for normal maintenance, repair and overhaul purposes; Category Code series 400 for warehouse, as opposed to storage functions; Category Code series 600 for administrative facilities; Category Code series 800 for utilities, and Category Code series 900 for real estate.

300-2 CATEGORY CODE DESIGNATION.

After a determination is made of the gross floor/building area, a specific category can be assigned to the total space, based on the primary use for the facility. As a general guideline, offices and support areas which are directly related to a particular type of research activity carry the same category code as the laboratory areas themselves.

300-3 DEFINITION OF TERMS

The following definitions of terms are used in the research criteria:

300-3.1 **Gross Floor/Building Area**. The total areas of all floors, measured between the exterior faces of outside walls. It includes full areas of basements, on-grade and above grade floors, service and equipment rooms, boiler plants and heater rooms, mezzanines, penthouses, enclosed passages and raised covered platforms. Excluded is all enclosed space with an average ceiling height of less than seven feet.

300-3.2 **Net Floor Area**. This is total gross floor area, less space taken up by outside walls, stair towers, elevator shafts, interior partitions, toilets, basements unsuited for specific use, permanent hallways, elevator machinery and machinery or equipment used for heating and/or ventilating the building, and NMCI/telecomm room servers and ducts. The net floor area does include special equipment bays peculiar to a particular laboratory function.

300-3.3 **Prime Unit Generator**. A special object (e.g., tow tank, wind tunnel, environmental chamber, multi-axis rate table) which tends to have the room built around it, rather than fitting into an existing room. Prime unit generators usually require "high bay" areas and often have overhead cranes or other heavy handling equipment associated with them.

300-3.4 **NTG Factor** (net-to-gross conversion factor) That factor which is used to convert a net floor area to a gross floor/building area (net floor area x NTG factor = gross floor/building area).

300-4 OVERALL METHODOLOGY

The basic problem in planning any research facility is the same: how to meet an existing need while at the same time providing for flexibility and growth. Research ranges from microscopic investigations to factory type testing set-ups. The methods described below provide a good prediction of the type and quantity of space that should be built to satisfy a specific program need, while at the same time allowing for flexibility to accommodate future RDAT&E program.

300-4.1 In approaching any research facility planning project, it is advisable to break down the facility requirements into basic functional components. These components consist of:

- Research Offices
- Research Support
- Bench Type Labs
- Specialized Research Facilities

300-4.2 Not all of these components will be present in all research facilities. To arrive at total requirements for a facility, each of the components which are present should be looked at separately, using the appropriate method described in succeeding paragraphs. Net floor areas should be developed first for each component, and gross floor/building areas calculated for each by multiplying the net areas by the appropriate NTG conversion factor. The total space requirement for the research facility is obtained by adding the gross floor/building areas for each of the components, as diagrammed below:

Total Area		Research Office		Research Support		Bench Type Labs		Specialized Research Facilities
(Gross)	=	(Net SF x NTG)	+	(Net SF x NTG)	+	(Net SF x NTG)	+	(Net SF x NTG)

300-4.3 There are three basic methods for developing and justifying net floor areas for research facilities. These consist of:

300-4.3.1 **Architectural Method** - This method consists of the development of scaled floor plans which depict a layout of equipment items within a required “envelope” of space. Such layouts should show the equipment as it should be placed within the space, which may not necessarily correspond to the manner in which such space is actually arranged in existing facilities. Such layouts should strive to be as efficient as possible.

300-4.3.2 **Industrial Method** - This method consists of identifying in a tabular format the net floor area required for each item of required equipment. When this method is used, the table should include three columns of information: (a) name of equipment item; (b) actual floor area occupied by the item, i.e., the size of its “footprint”; (c) size of the required working area within which the item sits, which permits all normal operations associated with the equipment as well as required services access to all sides. The sum of all the areas shown in item (c) will be the total net floor area for the space as a whole, and is equivalent to the “envelope” which would be shown graphically if the architectural method were used.

Note: the Introduction of category code 131 provides requirements for various types of workstations and for equipment mounted in racks. Table 131 provides requirements for typical equipment found in offices and labs.

300-4.3.3 **Use of Criteria** - For many types of facilities, approved rules of thumb (criteria) may be used to generate net floor areas. These are identified in terms of space per person, space per module, etc., and have been incorporated wherever possible into the P-80 guidance. Use of criteria generally requires less time and effort than either of the other methods.

300-4.3.4 In developing requirements for research facilities, any of the above methods may be used or a combination of these methods to develop the net floor areas for each functional component of the research facility.

300-5 OVERALL METHODOLOGY: RECOMMENDED PROCEDURES BY FUNCTIONAL COMPONENT

300-5.1 **Research Office**. Net floor areas for office spaces should be calculated by utilizing the criteria and guidance contained in Category Code 610 10. Gross floor/building areas should be developed using the NTG factors shown under this code. In utilizing the criteria, care must be taken to identify by administrative component, which personnel require office type space.

300-5.2 **Research Support**. The term “research support” is used to include lunch/locker spaces, libraries, auditoriums, etc., which may be required in direct support of an RDAT&E function. Studies have shown that space requirements for these types of space are similar, whether in support of a laboratory or other Navy uses. Therefore, the appropriate criteria may be used to calculate the requirements. If these criteria are to be used, refer to the appropriate category codes for guidance.

Examples of such codes are:

Installation Restaurant	Category Code 740 26
Academic Instruction Building	Category Code 171 10
Applied Instruction Building	Category Code 171 20
Auditorium	Category Code 171 25

Storage requirements are included in bench type labs or these requirements can be identified with Category Codes outside of the 300 series (Category Code 610 77 Admin storage or 171 77 Training Material Storage, etc.).

Net to gross conversion factors to be used for research support spaces are the same as for research offices.

300-5.3 **Bench Type Labs**. The bench lab component of research facilities tends (if present) to be organized into repetitive modules. Because of the nature of research, one scientist may share a laboratory module with another scientist, or in some instances, one scientist may have a need for two or more dedicated labs. Note: photographic darkrooms and control rooms are treated as bench labs, not as support space.

The basic laboratory module that is most adaptable to various types of research and which also works well within modern structural systems is 11.5 x 24 feet in size. This design allocates 276 square feet for net floor area per laboratory module.

The net to gross conversion factor to be used for bench type laboratories contains a built-in allowance for storage space, and laboratory support shop space. These are as follows:

For buildings supported by a central heating/cooling plant	1.35
For buildings containing their own HVAC equipment	1.65

300-5.4 **Specialized Research Facilities**. Specialized research facilities can be subdivided into three types: (1) Large set-ups of bench lab type activities which are too big to fit into a single bench lab module; (2) Systems Simulation including data processing laboratories, and (3) One-of-a-kind facilities such as tow tanks, environmental chambers, and wind tunnels.

300-5.5 **Large Set-Ups.** Large Set-Ups of relatively small and ordinary laboratory items arranged into a combination too large to fit into a single laboratory module, space allocation should be in multiples of a single 276 square foot bench lab module. These multiples usually range from 1 to 4 modules, only rarely exceeding 4 modules is size.

Net to gross conversion factors for large set-ups are the same as for bench labs spaces, and contain built-in allowances for storage and shop space. NTG factors to be used for large set-up spaces are as follows:

For buildings supported by a central heating/cooling plant	1.35
For buildings containing their own HVAC equipment	1.65

300-5.6 **Systems Simulation Facilities.** Allow 28 square feet of net floor area for each data processing unit such as communication hubs, data transmitters/receivers, display sets, or cryptographic modules or console. Do not count supplemental air handlers or programmers' desks—allowance for these is already included in the 28 square foot module.

Specialized equipment associated with the data processing equipment is treated as one-of-a-kind equipment (see below).

The Introduction of Category Code series 131 provides requirements for various types of workstations and for equipment mounted in racks. Table 131 provides requirements for typical equipment found in offices and labs.

NTG factors to be used for system simulation facilities are as follows:

For buildings supported by a central heating/cooling plant	1.35
For buildings containing their own HVAC equipment	1.65

300-5.7 **One-of-a-Kind Facilities.** One-of-a-kind facilities are built to house large and unique equipment such as wind tunnels, flow channels, shaker tables, environmental chambers, autoclaves, etc. A method for allocating space for one-of-a-kind facilities involves identifying the "Prime Unit Generator". The prime unit generator is the item or assemblage of equipment which is the primary justification for the facility. Because of the specialized nature of these items, (which can be as small as a 6' diameter pressure vessel, or as large as a 20 x 30 x 50 foot space shuttle avionics test fixture) it is necessary to have some special rules for defining prime unit generators. These rules include the following:

- Internal wind tunnels (where the entire tunnel is contained in a large room): Include compressors and/or suckers or reservoir vessels inside the building along with the tunnel tube itself.

- External wind tunnels (where most of the tube is outside and only a working chamber is housed inside the building): Do not include any mechanism which is outside the building. Do include the entire working chamber, even if one wall of the chamber constitutes or is in contact with the outside wall of the building.

- Tow tanks/flow channels/turning basins: Include in the prime unit generator all fundamentally necessary equipment which is inside the building and essential to the operation of the tank, channel, etc. Examples are pumps with flow channels, and wave making mechanisms with turning basins.

- Irradiation equipment including X-ray: Include as a part of the prime unit generator power generation equipment, (as with wind tunnels), flow channels, etc. For track mounted units, include the entire track as part of the prime unit generator. For remote controlled units operating in a shielded room, treat the room only as a prime unit generator, and the controls as bench lab if part of a larger building. If the controls are a freestanding building, the controls are considered a control console as described in the following paragraph.

- Control consoles: If freestanding in an otherwise open area, add 4 feet or clearance to working side and use the bench lab NTG factor. If in a separate room devoted exclusively to the control function, treat the entire room as a bench laboratory.

- Internal aisles and walk space in specialized research facility areas, and within bench labs accounted for in the NTG factor.

- General case. For RDAT&E equipment and installations not specifically discussed above, treat the primary functional unit, and any unique “custom tailored” ancillaries as the prime unit generator. Other support items of an off-the-shelf nature are not counted as part of the prime unit generator but allowed for in the NTG factor.

After the footprint (floor plan area) of the prime unit generator is identified, a 6-foot working clearance is provided on all sides. For irregular shaped items some smoothing of the outline should be allowed to simplify calculation.

Note that the 6-foot working clearance is a theoretical space allocation tool, not intended to reflect realistic working requirements. In cases where the equipment is close to a building wall, the 6-foot clearance may extend outside the building wall, but is still counted in determining the required net floor area.

The total area of the prime unit generator and its 6-foot working clearance is called the “Working Net” for that item.

The net to gross conversion factor applied to the working net of one-of-a-kind facilities depends upon the type of heating service provided to the building:

For buildings supported by a central heating/cooling plant	1.5
For buildings containing their own HVAC equipment	2.2

As an alternative to the above procedure, a scaled floor plan (Architectural Method) may be developed and provided as justification for the space requirement.

300-5.8 **Other.** Other research, development, testing, and evaluation facilities that are required but are not contained within a facility may also be required. These types of facilities may include testing ranges, outdoor testing or evaluation staging areas, or outdoor equipment laydown areas. An Engineering Analysis shall be provided to justify this type of facility.

300-6 SUMMARY OF RECOMMENDED PROCEDURES

For convenience, a brief summary is provided:

- **Offices** - Use criteria for Category Code 610 10.
- **Research Support** - Use criteria for Category Code 610 10
- **Bench Labs** - Use 276 square foot per lab. Treat darkrooms and control rooms as bench lab space. The NTG factor includes allowance for storage and direct shops support and varies with the type of building heating system.
- **Specialized Research Facilities** –

a. Large Set-Ups: Use multiple of bench lab module, same NTG factors as for bench labs.

b. Systems Simulation: Use 28 square foot module for each piece of data processing equipment. Add area for any specialized equipment (which is treated as one-of-a-kind equipment). Refer to Table 131-4 for lab equipment other than data processing equipment. The NTG factor equals 1.35 or 1.65, depending on the type of building heating system. If the facility requires back up requirements associated with Tier I-IV communications facilities, refer to 131 Introductory series NTG factors.

c. One-of-a-kind facilities: Identify prime unit generator. Add 6 foot working space to obtain working net. The NTG factor equals 1.5 or 2.2 depending on the type of building heating system.

d. Other: Use engineering analysis is to calculate the requirement for testing ranges, outdoor staging areas, outdoor equipment laydown areas, etc.

310 SCIENCE LABORATORIES

310-1 **DEFINITION.** Buildings used directly in theoretical or applied research, development and testing operations related to basic research such as chemistry, materials, medical, biological, sonic, physics, geophysics, etc.

310 11 ASTRONOMY & ASTROPHYSICS LABORATORY (SF)

FAC: 3101
BFR Required: Y

31011-1 **DEFINITION.** A facility required to support the investigation of radio astronomy equipment, satellite research, and development for navigational and communication programs. The facility is also utilized in conducting research and development in the fields of atmospheric physics, astrophysics in radio, radar and meteor astronomy, upper air physics, rocket astronomy, solar spectroscopy, and cosmic radiation, etc.

310 13 CHEMISTRY AND TOXICOLOGY LABORATORY (SF)

FAC: 3101
BFR Required: Y

31013-1 **DEFINITION.** The facility required to support the conducting of research, development, test and evaluation in the areas of physical, organic, inorganic, and biological chemistry, directed towards problems concerning fuels, lubricants, corrosion, protective coatings, electrochemistry, submarine atmosphere purification, protection against biological and chemical warfare agents, polymers, molecular structure, and related programs. This facility is further utilized to support the application of chemicals to explosives, propellants, pyrotechnics, etc., and the effects of the chemistry of the ocean as it affects acoustic absorption, sound speed, thermocline and water mass identification.

310 15 MATERIALS LABORATORY (SF)

FAC: 3101
BFR Required: Y

31015-1 **DEFINITION.** This facility is used for research, development, test and evaluation of static, pneumatic non-destructive as well as destructive testing of components and assemblies for Navy weapons, vehicles, engines, ships and aircraft. Includes testing such as Zyglo, ultra violet light, sonic, X-ray, magna-flux and other techniques for accomplishing non-destructive testing of metals, plastics, etc.

31015-2 **USAGE.** This facility also supports research in the areas of physical, mechanical, chemical and structural metallurgy directed towards marine corrosion, high temperature flow and fracture mechanics, irradiation effects on metals, fracture-safe design, and in developing materials for use in transducers, underwater structures, sensing devices, weapons ships and aircraft. Also supports the synthesizing, modifying, fabricating and studying of metallic and nonmetallic materials such as plastics, rubber, adhesives, ceramics, resins, but excluding explosives and propellants, with emphasis on resistance to unusual conditions such as high and low temperatures, stresses, aerodynamic heating, etc.

310 17 OPTICS LABORATORY (SF)

FAC: 3101
BFR Required: Y

31017-1 **DEFINITION.** This facility is used in conducting research, development, test and evaluation programs in quantum optics, optical propagation, laser physics, optical materials and optical warfare. The facility is also used in efforts directed at discovering and understanding the basic physical principles and mechanisms involved in optical devices and phenomena.

310 19 PHYSICS LABORATORY (SF)

FAC: 3101
BFR Required: Y

31019-1 **DEFINITION.** This facility is used in research, development, test and evaluation studies in the applied science of matter and energy. It includes research in such areas as acoustics, mechanics, light, thermodynamics, electromagnetism, atomic physics, cryogenics, solid state physics, particle physics and plasma physics, etc.

310 21 RADIATION EFFECTS LABORATORY (SF)

FAC: 3101
BFR Required: Y

31021-1 **DEFINITION.** This facility is used in conducting research, development, test and evaluation on radiation characteristics of various devices and their effect on performance of various systems in the air and in the ocean environment. The facility is also used in the study of effects of radiation on people and marine life (e.g., acoustic pollution, hearing damage, and radioactivity) and the accomplishment of studies to determine reliable methods for detecting radiation sources.

310 23 COMBINED RESEARCH LABORATORY (SF)

FAC: 3101
BFR Required: Y

31023-1 **DEFINITION.** This facility is used for research, development, test and evaluation of naval systems which utilized several of the sciences in a combined system applied directly to a Fleet problem or area of RDAT&E. It is also used to support research, development, test and evaluation of naval systems which do not logically fit the other categories of RDAT&E.

310 25 BIOLOGICAL LABORATORY (SF)

FAC: 3101
BFR Required: Y

31025-1 **DEFINITION.** This facility is used in research, development, test and evaluation in terrestrial and marine biology as related to structure capabilities, functioning habitat, health, growth environmental indicators, ecological relationships of living organisms and association of biological phenomenon to man's existence and operations in the land, ocean and space environment. The facility also can include research in microbiology and environmental biology and the life process or characteristic phenomena of any group.

310 27 ENVIRONMENTAL LABORATORY (SF)

FAC: 3101
BFR Required: Y

31027-1 **DEFINITION.** This facility is used to support the research, development, test and evaluation of instrumentation and computer systems for measurement and analysis of the evaluation of environmental effects on various equipment, weapons systems, facilities, etc. The principle thrust of research and development in this area is in the fields of mechanical shock, vibration, pressure, and in the natural environments of temperature, humidity, corrosion, etc. Also includes working mock-ups of environmental studies relating man to the test environment.

310 29 ANIMAL APPLICATIONS LABORATORY (SF)

FAC: 3101
BFR Required: Y

31029-1 **DEFINITION.** This facility is used to support the research, development, test and evaluation on non-human animals in pure research and ocean support applications. This would include the use of whales and dolphins as trained deep sea divers, seals for shallow water tool recovery and dogs as sentries. It can also include research and development in application and knowledge of animal capabilities in sensing, homing and identification to improve the operation of man-made ocean devices. It provides veterinary medical support for marine mammal projects including applied research on diagnosis, treatment, surgery, husbandry and nutrition.

310 31 MEDICAL LABORATORY (SF)

FAC: 3102
BFR Required: Y

31031-1 **DEFINITION.** This facility is used in conducting research toward methodology for diagnosis, treatment, or prevention of disease or damage to the body or mind.

310 33 COMPUTATION AND ANALYSIS LABORATORY (SF)

FAC: 3101
BFR Required: Y

31033-1 **DEFINITION.** This facility supports research, development, test and evaluation in the areas of information processing and data handling, especially when concerned with identification of conditions responsible for data configurations. This facility supports mathematical data analysis utilizing both digital and analog computers to research, develop, test and evaluate new naval systems from simulated and real time data.

31033-2 **FUNCTIONAL AREAS.** A Computation and Analysis Laboratory may contain the following functional areas: research offices, research support, bench type labs, and specialized research facilities. Please refer to the guidelines provided in the introduction of the 300 series Category Codes for RDAT&E to calculate the requirement.

310 37 OCEAN SCIENCES LABORATORY (SF)

FAC: 3101
BFR Required: Y

31037-1 **DEFINITION.** This facility is used to accomplish research, development, test and evaluation in marine biosystems, environmental protection and management, development of analytical systems for evaluation of the ocean environment, studies of wave dynamics, current flow, thermoclines, chemical variances, bottom sampling, as well as development of new techniques and equipment to increase man's knowledge and utilization of the total ocean environment.

310 39 LEVEL III BIOSAFETY LABORATORY (SF)

FAC: 3103

BFR Required: Y

31039-1 **DEFINITION.** This type of laboratory applies to clinical, diagnostic, and teaching, research, or production facilities for work involving indigenous or exotic agents that have the potential to transmit infection through the respiratory system, which may cause serious and potentially lethal infection. Biosafety Level III applies to Risk Group 3 agents that are associated with serious or lethal human disease for which preventive or therapeutic interventions may be available. Risk Group 3 agents are defined by the guidelines of “Biosafety in Microbiological and Biomedical Laboratories,” US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, and National Institutes of Health.

31039-2 **USAGE.** Laboratory facilities must be separated from other areas that are subject to unrestricted traffic flow within a building. If a laboratory is separated into different laboratories (zones), a sink must be provided for hand washing in each zone. Access to the laboratory will be restricted to entry by a series of two self-closing doors. A clothing change room (anteroom) may be included in the passageway between the two self-closing doors. An area for decontaminating all laboratory wastes should be planned in the facility, preferably within the laboratory (e.g., autoclave, chemical disinfection, incineration, or other validated decontamination method). The facility must also include an area for decontaminating large pieces of equipment to facilitate removal of the equipment from the laboratory.

310 40 LEVEL IV BIOSAFETY LABORATORY (SF)

FAC: 3104
BFR Required: Y

31040-1 **DEFINITION.** This type of laboratory is associated with work on dangerous and exotic agents that pose a high individual risk of life-threatening disease, aerosol transmission, or related agent with unknown risk of transmission. Biosafety Level IV applies to Risk Group 4 agents that are likely to cause serious or lethal human disease for which preventive or therapeutic interventions are not usually available. Risk Group 4 agents are defined by the guidelines of “Biosafety in Microbiological and Biomedical Laboratories,” US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, and National Institutes of Health.

31040-2 **USAGE.** A Laboratory facility consists of either a separate building or a clearly demarcated and isolated zone within a building. Rooms in the facility must be arranged to ensure exit by sequential passage through the chemical shower, inner (dirty) change room, personal shower, and outer (clean) changing area. A chemical shower must be provided to decontaminate the surface of the positive pressure suit before the worker leaves the laboratory. Sinks inside the suit laboratory should be placed near procedure areas and contain traps and be connected to the wastewater decontamination system. An eyewash station must be readily available in the laboratory area for use during maintenance and repair activities.

311 AIRCRAFT

311-1 Buildings used directly in the research, development and testing of air frames and related assemblies and spares, and other aircraft equipment.

311 05 RDAT&E MAINTENANCE HANGAR (SQ. M. / SF)

FAC: 2111
BFR Required: Y

Catcodes 311 06 and 311 07 are now included in catcode 311 05

311 06 RDAT&E MAINTENANCE HANGAR – 01 SPACE (CREW AND EQUIPMENT) (SQ. M. / SF)

Catcode 311 06 is now contained in catcode 311 05

311 07 RDAT&E MAINTENANCE HANGAR – 02 SPACE (ADMINISTRATIVE) (SQ. M. / SF)

Catcode 311 07 is now contained in catcode 311 05

31105/06/07-1 **DEFINITION.** This criteria is currently in development and will be posted upon completion.

311 10 AIRCRAFT FLIGHT AND NAVIGATIONAL EQUIPMENT LABORATORY (SF)

FAC: 3111
BFR Required: Y

31110-1 **DEFINITION.** This facility is utilized in conducting research, development, test and evaluation of aerodynamic design of aircraft and weapons systems and navigational systems. Equipment is evaluated to assure optimum flight performance, stability, and control characteristics and on airborne equipment. The facility is also used in conducting RDAT&E in aerodynamic science in support of advanced aircraft and weapon concepts. The facility can also be an operating test facility for air navigation systems, equipment and component acceptance testing, design and performance analysis, and diagnostic and analytic evaluation to ensure proper system equipment and component function.

311 20 AIRCRAFT GROUND SUPPORT EQUIPMENT LABORATORY (SF)

FAC: 3111
BFR Required: Y

31120-1 **DEFINITION.** This facility is used to research, development, test and evaluation of aircraft ground support equipment, systems and techniques for the takeoff, recovery, maintenance, and test of aircraft. The facility is used to test and evaluate ground support equipment for aircraft armament and weapons, aircraft handling, servicing and inspection equipment and aircraft avionics equipment. This does not include missile and missile system ground handling equipment.

311 25 AIRCRAFT SYSTEMS INTEGRATION LABORATORY (SF)

FAC: 3111
BFR Required: Y

31125-1 **DEFINITION.** This facility is used for research, development, test and evaluation of various groupings and collections of interacting aircraft systems such as the effects of airframe, structure, flight control, electrical, environmental control, fuel, hydraulic, mechanical, pneumatic, propulsion, gun, life support and related ground support systems on ECM, air to air missile launch, etc. This does not include work on aircraft engine design characteristics.

312 MISSILE AND SPACE

312-1 Buildings used directly in the research, development and testing of missiles, missile system, related ground handling, and launching equipment, and other aerospace equipment.

312 10 GUIDED MISSILE LABORATORY (SF)

FAC: 3121
BFR Required: Y

31210-1 **DEFINITION.** This facility is used in support of research, development, test and evaluation of advance simulation, instrumentation, environmental test techniques and improved serviceability and reliability characteristics of guided missile weapon systems. It includes assembly, disassembly, test modification and analysis of test firing results of guided missiles.

31210-2 **USAGE.** This facility also may support research, development, test and evaluation of missile navigation systems and related equipment. It includes design and testing of guidance and control systems for guided missiles and launch and arming systems for ballistic missiles, component testing, error diagnosis, and performance analysis as applied to missiles and missile systems.

312 20 MISSILE SUPPORT EQUIPMENT LABORATORY (SF)

FAC: 3121
BFR Required: Y

31220-1 **DEFINITION.** This facility is used for research, development, test and evaluation of equipment and techniques for the launching, recovery, maintenance, transport and testing of missiles and guided missile support equipment.

312 25 SPACECRAFT/SATELLITE LABORATORY (SF)

FAC: 3121
BFR Required: Y

31225-1 **DEFINITION.** This facility supports research, development, test and evaluation of spacecraft, satellites or components of each not otherwise classified as a missile weapon system. This facility would include related ground support/launching equipment.

312 30 MISSILE SYSTEMS INTEGRATION LABORATORY (SF)

FAC: 3121
BFR Required: Y

31230-1 **DEFINITION.** This facility is used for research, development, test and evaluation of related and interconnected systems that are necessary for launching, and in direct support of guided missile systems.

313 SHIP AND MARINE EQUIPMENT

313 10 SHIP AND MARINE LABORATORY (SF)

FAC: 3131

BFR Required: Y

31310-1 **DEFINITION.** This facility is used in conducting research, development, test and evaluation on ships, by use of models in high and low speed tow tanks, maneuvering and seakeeping basins, water tunnels, circulating water channels, fluid phenomenon basins, etc. The facility is also used in conducting fundamental and applied research related to the efficiency of ship structures, other marine vessels, including tracked amphibious vehicles, and the development of methods to assist the effect of static and dynamic loads imposed by submergence depth, wave and submarine structures.

31310-2 **USAGE.** The facility is also an operating test facility for ship and marine vessel navigation systems, equipment and component acceptance testing, design and performance analysis and diagnostic and analytic evaluation to ensure proper system equipment and component function.

313 20 SHIPS AND MARINE EQUIPMENT LABORATORY (SF)

FAC: 3131
BFR Required: Y

31320-1 **DEFINITION.** This facility is used to conduct research, development, test and evaluation of ships and marine support requirement. This includes repair and maintenance equipment as well as equipment for direct support and operation of ships and marine vessels such as periscopes, towed arrays, etc. It is further utilized to support the study of methods for designing shipboard and other marine equipment for resistance to service loads, attacks, and combat reliability.

313 25 SHIPS AND MARINE SYSTEMS INTEGRATION LABORATORY (SF)

FAC: 3131
BFR Required: Y

31325-1 **DEFINITION.** This facility is used for research, development, test and evaluation of related and interconnected ships and marine systems such as the ship platform integrated with the weapons systems, communication systems, command and control systems, surveillance systems, navigation systems, etc. The facility would include mock-up facilities for establishing adaptability, compatibility and space requirements for both man and machine.

314 TANK AND AUTOMOTIVE

314 10 GROUND TRANSPORTATION EQUIPMENT LABORATORY (SF)

FAC: 3141
BFR Required: Y

31410-1 **DEFINITION.** This facility is used in conducting research, development, test and evaluation in the field of automotive design as applied to tanks, APC's, and related military automotive equipment. This facility is also used in conducting RDAT&E on ground equipment in direct support of tank and automotive equipment such as power units, mobile maintenance, test equipment, heavy handling, lifting equipment, etc.

315 WEAPONS AND WEAPON SYSTEMS

315-1 RDAT&E facilities for guided missiles and related items are included under Category Code series 312.

315 10 AIRCRAFT WEAPON SYSTEMS LABORATORY (SF)

FAC: 3151
BFR Required: Y

31510-1 **DEFINITION.** This facility supports the research, development, test and evaluation of aircraft weapon systems including projectiles, mines and bombs, and defensive countermeasures devices/weapons.

315 15 SHIP WEAPON SYSTEM LABORATORY (SF)

FAC: 3151
BFR Required: Y

31515-1 **DEFINITION.** This facility is used for research, development, test and evaluation of weapons and weapon systems deployed from a surface ship. This would include guns, fire control, etc. This does not include aircraft or missile systems.

315 20 UNDERWATER WEAPON SYSTEM LABORATORY (SF)

FAC: 3151
BFR Required: Y

31520-1 **DEFINITION.** This facility is used for research, development, test and evaluation of undersea weaponry such as mines and torpedoes. This would include submarine mounted guns but not submarine launched missiles. Key platform components include sonar, combat control, underwater submarine warfare (USW) weapons targets, unmanned underwater vehicles (UUVs), and fleet training systems.

An underwater weapon system laboratory typically includes the following areas:

- Research offices
- Electronic assembly
- Prototype and electronic repair
- Commercial-off-the-shelf (COTS) laboratory
- Technical library
- Conference room
- Reproduction
- Lounge
- Storage

The typical net-to-gross factor for such a facility is 1.45.

315 25 GROUND WEAPON SYSTEMS LABORATORY (SF)

FAC: 3151
BFR Required: Y

31525-1 **DEFINITION.** This facility is used for research, development, test and evaluation of weaponry in use on or deployed from a ground base platform and would include small arms, automatic weapons, mortars, artillery, flame throwers, etc.

315 30 WEAPON SYSTEMS INTEGRATION LABORATORY (SF)

FAC: 3151
BFR Required: Y

31530-1 **DEFINITION.** This facility is used to accomplish research, development, test and evaluation associated with the integration of weapon systems with the weapons platform and with other interfaces between other weapons systems, guidance systems, surveillance systems, etc.

316 AMMUNITION, EXPLOSIVES AND TOXICS

316 10 AMMUNITION, EXPLOSIVES AND TOXICS LABORATORY (SF)

FAC: 3161
BFR Required: Y

31610-1 **DEFINITION.** This facility is used to support the research, development, test and evaluation of ammunition, rockets, bombs, mines, grenades, torpedoes, depth charges, demolition materials, pyrotechnics, AT0 units, related chemicals, and their components and materials. This Category Code does not include facilities for guided missiles, guided bombs, or commercial type petroleum products.

317 ELECTRONIC, COMMUNICATION AND ELECTRICAL EQUIPMENT

317-1 Buildings used directly in the research, development and testing or radio and radar equipment, signal equipment, radiation aids, electrical equipment and its controls, transmitting and receiving equipment, avionics equipment, sonar, and guided bombs.

317 10 COMMUNICATIONS SYSTEMS LABORATORY (SF)

FAC: 3171
BFR Required: Y

31710-1 **DEFINITION.** This facility is used for conducting research, development, test and evaluation in the areas of radio communication, instrumentation, satellite communication, electromagnetic propagation, radio antennas, underwater sound systems, optical systems (infrared), etc.

31710-2 **FUNCTIONAL AREAS.** A Communications Systems Laboratory may contain the following functional areas: research offices, research support, bench type labs, and specialized research facilities. Please refer to the guidelines provided in the introduction of the 300 series Category Codes for RDAT&E to calculate the requirement.

317 15 DETECTION SYSTEMS LABORATORY (SF)

FAC: 3171
BFR Required: Y

31715-1 **DEFINITION.** This facility is used in conducting research, development, test and evaluation in basic physical phenomena of importance to radar, sonar, and related sensors, also the development of systems analysis and evaluation of the sensors used in satellites, ships, submarines, and aircraft, etc. It includes surveillance for detection, localization, identification and classification of surface, aerospace and sub-surface objects.

317 20 ELECTRICAL AND ELECTRONICS SYSTEMS LABORATORY (SF)

FAC: 3171
BFR Required: Y

31720-1 **DEFINITION.** This facility is used in conducting research, development, test and evaluation in the areas of electrical power and its control, magnetic fields and ship's control systems. Research in this area involves development of motors and generators, frequency converters, voltage and current control devices, and shipboard power distribution systems. In the magnetic fields, studies are conducted in the reduction of stray fields produced by naval equipment, methods of determining ship's magnetic signature and new concepts in degaussing systems.

31720-2 **USAGE.** This facility is also used in the fields of electronics and electromagnetic phenomena in support of components, subsystems, and systems in detection, communication, navigation, countermeasures, acoustics, electromagnetics, identification, and classification as they apply to naval ordnance, submarine weapons systems, surface ships and aircrafts.

317 25 ELECTRICAL, ELECTRONICS AND COMMUNICATION SYSTEMS INTEGRATION LABORATORY (SF)

FAC: 3171
BFR Required: Y

31725-1 **DEFINITION.** This facility is used to accomplish research, development, test and evaluation associated with the integration of related systems and subsystems of electrical, electronics and communications systems with the platform (air, sea, ground, etc.) upon which they will operate and verify interface consideration with other systems operating on the respective platform.

31725-2 **FUNCTIONAL AREAS.** An Electrical, Electronics, and Communications Systems Integration Laboratory may contain the following functional areas: research offices, research support, bench type labs, and specialized research facilities. Please refer to the guidelines provided in the introduction of the 300 series Category Codes for RDAT&E to calculate the requirement.

318 PROPULSION

318 10 PROPULSION SYSTEMS LABORATORY (SF)

FAC: 3181
BFR Required: Y

31810-1 **DEFINITION.** This facility is used to support research, development, test and evaluation of propulsion systems in order to determine operational capabilities and in studying the acoustics and electromagnetic noise effects on performance and efficiency of drive units.

318 15 PROPULSION FUEL LABORATORY (SF)

FAC: 3181
BFR Required: Y

31815-1 **DEFINITION.** This facility is used to support research, development, test, and evaluation of propulsion fuels in order to maximize a propulsion system's operational characteristics. This facility would also support investigation into new fuels and propulsive energy systems.

319 MISCELLANEOUS ITEMS AND EQUIPMENT

319 10 MISCELLANEOUS EQUIPMENT AND ITEMS LABORATORY (SF)

FAC: 3191
BFR Required: Y

31910-1 **DEFINITION.** This facility supports research, development, test, and evaluation of miscellaneous military equipment such as landing mats, valves (e.g. safety, pressure reducing, fuel regulating), and hyperbaric facilities not appropriate in another category code.

319 15 RDAT&E STORAGE LABORATORY (SF)

FAC: 3191

BFR Required: Y

31915-1 **DEFINITION.** This building is a storage facility for research, development, test, and evaluation equipment and materials directly related to RDAT&E programs.

31915-2 Storage facilities for equipment related to RDAT&E facilities will be provided only where it can be individually justified. There are no criteria for this type of facility. General information on normal stacking heights, SF per measurement ton requirements, and calculation methods are provided in the Category Code 440 series.

319 20 CIVIL ENGINEERING LABORATORY (SF)

FAC: 3191
BFR Required: Y

31920-1 **DEFINITION.** This facility is used to support research, development, test and evaluation in the area of civil engineering. This would include military type bridging, hand tools, construction equipment, construction techniques, on land, in and under the ocean.

319 25 HUMAN FACTORS LABORATORY (SF)

FAC: 3191
BFR Required: Y

31925-1 **DEFINITION.** This facility is used to determine the effects of wartime atmosphere and material on military personnel and non-combatants. This facility would also deal with man-man interfacing (morale, command control, and the like) and man-machine interfacing (console design, payload design, work area requirements, etc.)

319 30 SURVIVAL EQUIPMENT AND CLOTHING LABORATORY (SF)

FAC: 3191
BFR Required: Y

31930-1 **DEFINITION.** This facility supports research, development, test and evaluation of pilot's and sailor's need for special equipment, clothing and techniques for survival in various hostile environments.

319 35 METROLOGY AND CALIBRATION LABORATORY (SF)

FAC: 3191
BFR Required: Y

31935-1 **DEFINITION.** This facility will be used in direct support of research, development, test and evaluation programs where precise weights and measures are required in calibrating RDAT&E equipment. This facility would include the metrology and calibration equipment and space for calibrating applicable equipment.

319 40 RANGE OPERATIONS AND INSTRUMENTATION LABORATORY (SF)

FAC: 3191
BFR Required: Y

31940-1 **DEFINITION.** This facility is used in support of research, development, test and evaluation of range operations to include command center, communications, surveillance, instrumentation, data collection/reduction/display, etc.

320 UNDERWATER EQUIPMENT

320 10 UNDERWATER EQUIPMENT LABORATORY (SF)

FAC: 3201
BFR Required: Y

32010-1 This facility is used in conducting research development, test and evaluation of underwater acoustics, ship vibrations and various types of underwater devices to increase man's capabilities in the ocean.

32010-2 The facility is also used to support RDT&E in hydro-acoustics, structural acoustics, mechanical vibration and signal processing, and conducting acoustic and vibration trials and instrumentation devices for sound and vibration attenuation, the RDT&E of deep ocean tools, equipment and work systems as well as support equipment for divers, submersibles and marine systems of all types.

32010-3 This building supports the RDT&E of undersea navigational systems and related equipment. This would include component design, error diagnosis, and performance analysis for location sensing, direction control, and depth control for undersea vessels. It would include devices for manned and unmanned vehicles as well as divers’ navigational equipment.

320 20 UNDERWATER SYSTEMS INTEGRATION LABORATORY (SF)

FAC: 3201
BFR Required: Y

32020-1 This facility will be used for research, development, test and evaluation of various interacting underwater systems, equipment, tools, techniques and operators working together in an underwater environment. The integration of several systems to accomplish a greater total effort will be accomplished in this facility.

321 TECHNICAL SERVICES

321 10 TECHNICAL SERVICES LABORATORY (SF)

FAC: 3211
BFR Required: Y

32110-1 Buildings used directly in RD&T manufacturing or reverse engineering of one-of-a-kind models and parts for systems or subsystems from wood, plastic, fiberglass and other materials by molding, casting, extruding and machining.

371 RANGE FACILITIES

371-1 Structures used directly in research, development and testing of small arms, artillery, weapons systems, avionics, protection equipment, shelters, etc.

371 10 SCIENCE SYSTEMS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37110-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 310.

371 11 AIRCRAFT SYSTEMS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37111-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 311.

371 12 MISSILE AND SPACE SYSTEMS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37112-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 312.

371 13 SHIPS AND MARINE SYSTEMS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37113-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 313.

371 14 TANK AND AUTOMOTIVE SYSTEMS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37114-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 314.

371 15 WEAPONS AND WEAPON SYSTEMS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37115-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 315.

371 16 AMMUNITION, EXPLOSIVES AND TOXICS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37116-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 316.

371 17 ELECTRONIC, COMMUNICATION AND ELECTRICAL SYSTEMS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37117-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 317.

371 18 PROPULSION SYSTEMS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37118-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 318.

371 19 MISCELLANEOUS ITEMS AND EQUIPMENT RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37119-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 319.

371 20 UNDERWATER SYSTEMS RANGE FACILITY (EA)

FAC: 3712
BFR Required: N

37120-1 Facilities used in the conduct of tests and evaluations of items identified under Category Code series 320.

390 RDT&E OTHER THAN BUILDINGS AND RANGE FACILITIES

390-1 Scientific structures and facilities other than buildings used directly in theoretical or applied research, development, and test operations related to such items as test tracks, wind tunnels, etc. Do not include structures and buildings used for normal maintenance, repair, and overhaul purposes.

390 10 SCIENCE SYSTEMS FACILITY (EA)

FAC: 3901
BFR Required: N

39010-1 Facilities used in the conduct of research, development, test and evaluation of items identified under Category Code series 310.

390 11 AIRCRAFT SYSTEMS FACILITY (EA)

FAC: 3901
BFR Required: N

39011-1 Facilities used in the conduct of research, development, test and evaluation of items identified under Category Code series 311.

390 12 MISSILE AND SPACE SYSTEMS FACILITY (EA)

FAC: 3901
BFR Required: N

39012-1 Facilities used in the conduct of research, development, test and evaluation of items identified under Category Code series 312.

390 13 SHIPS AND MARINE SYSTEMS FACILITY (EA)

FAC: 3901
BFR Required: N

39013-1 Facilities used in the conduct of research, development, test and evaluation of items identified under Category Code series 313.

390 14 TANK AND AUTOMOTIVE SYSTEMS FACILITY (EA)

FAC: 3901
BFR Required: N

39014-1 Facilities used in the conduct of research, development, test and evaluation of items identified under Category Code series 314.

390 15 WEAPONS AND WEAPONS SYSTEMS FACILITY (EA)

FAC: 3901
BFR Required: N

39015-1 Facilities used in the conduct of research, development, test and evaluation of items identified under Category Code series 315.

390 16 AMMUNITION, EXPLOSIVES AND TOXICS FACILITY (EA)

FAC: 3901
BFR Required: N

39016-1 Facilities used in the conduct of research, development, test and evaluation of items identified under Category Code series 316.

390 17 ELECTRONIC, COMMUNICATION AND ELECTRICAL SYSTEMS FACILITY (EA)

FAC: 3901
BFR Required: N

39017-1 Facilities used in the conduct of research, development, test and evaluation of items identified under Category Code series 317.

390 18 PROPULSION SYSTEMS FACILITY (EA)

FAC: 3901
BFR Required: N

39018-1 Facilities used in the conduct of research, development, test and evaluation of items identified under the Category Code series 318.

390 19 MISCELLANEOUS ITEMS AND EQUIPMENT FACILITY (EA)

FAC: 3901
BFR Required: N

39019-1 Facilities used in the conduct of research, development, test and evaluation of items identified under the Category Code series 319.

390 20 UNDERWATER SYSTEMS FACILITY (EA)

FAC: 3901
BFR Required: N

39020-1 Facilities used in the conduct of research, development, test and evaluation of items identified under the Category Code series 320.

Version: 400.20233005

FACILITIES CRITERIA (FC)
FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

Series 400: Supply Facilities

Record of Changes:

Date	CCN #	CCN Title	Description of change
Jan 2017	Section 420	Ammunition Storage	Complete revision of magazine sizing and siting criteria. Implementation of Magazine Storage and Requirements Calculator (MSRC).
Jan 2017	Section 421	Ammunition Storage Depot and Installation	Revisions to magazine category codes within 421 series.
Jan 2017	42112	Fuse And Detonator Magazine	Consolidated into CCN 42122 High Explosive Magazine. CCN deleted from iNFADS.
Jan 2017	42152	Smokeless Powder And Projectile Magazine	Consolidated into CCN 42122 High Explosive Magazine. CCN deleted from iNFADS.
Jan 2017	42172	Missile Magazine	Consolidated into CCN 42122 High Explosive Magazine. CCN deleted from iNFADS.
Jan 2017	NEW-Table 420-1	Various CCNs	Provides new list of CCNs within the UFC 2-000-05N that require explosive safety site approval.
June 2018	42511	Explosive Storage Site Pad	Added new CCN for site pads for non-RP ordnance storage.
Sep 2019	Section 420	Ammunition Storage	Updated to reflect 10-digit CODEX. Added new requirement for ordnance handling loading/offloading area for all new Earth Covered Magazines.
Sep 2019	41160	Liquefied Petroleum Gas Storage	FAC Code changed to 1244
Sep 2019	42182	Submarine Launched Ballistic Missile	FAC Code changed to 4211
July 2020	42510	Open Ammunition Storage Pad	FAC code changed to 8526
July 2020	42511	Explosive Storage Site Pad	FAC code changed to 8526; revised criteria verbiage.

Date	CCN #	CCN Title	Description of change
8 August 2022	421 36	Ammunition Storage Building	1. Corrected Table 420-2 “MSRC Stowage Matrix.” 2. Added Table 420-3 “Magazine Type and Gross Square Footage.” 3. Added Containerized Long Weapons Storage (CLWS) magazine storage matrix and GSF to tables 420-2 and 420-3.
October 3 2022	420	Ammunition Storage	Updated CCN 420 hyperlinks to flankspeed site. Added CLWS Magazines to the storage matrix of Table 420-2. Changed sf for CLWS Magazines in Table 420-3 Added note to 420-10.7 concerning Army MSM magazines being sited by NOSSA.
4 January 2023	420 Series	Ammunition Storage	Updated Section 420-10.7 Estimating Future Magazines to address magazine spacing and continuous earth cover.
2 Mar 2023	400 Series	UFC 2-000-05N	Change UFC 2-000-05N to FC 2-000-05N document due to the fact that this planning criteria is not unified among the other DoD services.
17 Mar 2023	400 Series, Section 411-1	General Requirements	Change URL to access UFC 3-460-01 Petroleum Fuel Facilities.
17 Mar 2023	411-52	Cut and Cover Jet Engine Fuel Storage	Change URL to access UFC 3-460-01 Petroleum Fuel Facilities.
17 Mar 2023	411-60, Section 41160.2	Liquefied Petroleum Gas Storage	Change URL to access UFC 3-460—01 Petroleum Fuel Facilities.
13 Apr 2023	441-30, Section 44130-1	Hazardous and Flammables Storehouse	Replace references MIL-HDBK 1032/2 and UFC 4-442-01N with UFC 4-440-01.
30 May 2023	420 Series	Ammunition Storage	Updated 420-4 Ordnance Handling, Loading and Offloading Area to define paved area as a single continuous plane with a 0.5% min to 2% max slope to allow for proper drainage away from the ECM. Redefined the size of loading area for Box Type C,D,G,H, MSM, and CLWS magazines

400 SERIES
SUPPLY FACILITIES

Table of Contents

411 LIQUID FUEL STORAGE – BULK

411-1 GENERAL REQUIREMENTS

The availability of commercial facilities, intended service, and government resources (available developable area, security and safety of operations, and operation) should be considered as part of the overall planning process. Special care should be noted of site conditions to ensure design criteria can be met. This information can be found in the most current version of Unified Facilities Criteria Design: Petroleum Fuel Facilities (UFC 3-460-01), located on the Whole Building Design Guide (WBDG) website at the following link:

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-460-01

This document also provides information on the ancillary equipment associated with liquid fuel storage (i.e., pumping station, pipelines, etc.). These facilities will typically have separate category codes.

Note that the real property components associated with the category codes having FAC codes of 4111, 4112, and 4113 include the tanks and any containment structures associated with them, such as berms, liners, and monitoring wells. In the case of "cut and cover" type fuel storage under FAC 4113, the integral deep well turbine pumps are also included in the associated category codes and are not to be counted as separate real property assets.

411-2 STORAGE QUANTITIES

The quantities and types of petroleum products to be stored are based on consumption of fuels by the ships, aircraft, vehicles and equipment at the activities served and what type of delivery system that is utilized. Depot fuel storage facilities must be of sufficient capacity to provide an adequate operating and reserve supply of fuel for the activities served. A barrel is the standard 42 U.S. gallon capacity.

411-2.1 **Capacities.** For planning purposes, the capacities of individual tanks should be approximately 25% of the ultimate storage for each type of fuel, subject to the following:

411-2.1.1 The minimum capacity of a tank for fuel depot bulk storage shall not be less than:

- Diesel Fuel 13,500 barrels
- Fuel Oil 27,000 barrels

411-2.1.2 Standard tank sizes should be used.

411-2.1.3 A minimum of two tanks will be provided for each type of fuel. One will serve as the working tank and the other the receiving tank for new deliveries.

411-2.1.4 It is necessary for impurities in MoGas, AvGas and jet fuels to settle prior to the use. The time required for jet fuel to settle is one hour per foot of depth of the fuel in the tank.

411-3 CATEGORY CODES

The category codes in this section include fuel storage tanks of the following classifications: operational; bulk fuel; cut and cover; liquefied petroleum (LP); contaminated; and heating oil. CCNs 411-10 through 411-52 represent the fuel types associated with operational (10,000-100,000 barrel capacity), bulk fuel (greater than 100,000 barrel capacity), and cut and cover storage tanks (earth covered for hostile environments). CCNs 411-60 through 411-84 represent the remaining fuel types associated with this section.

411 10 SHIP FUEL STORAGE 10K-100K (BL)

FAC: 4111
BFR Required: Y

411 11 SHIP FUEL STORAGE > 100K (BL)

FAC: 4112
BFR Required: Y

411 12 CUT AND COVER SHIP FUEL STORAGE (BL)

FAC: 4113
BFR Required: Y

411 20 AVIATION FUEL STORAGE 10K-100K (BL)

FAC: 4111
BFR Required: Y

411 21 AVIATION FUEL STORAGE > 100K (BL)

FAC: 4112
BFR Required: Y

411 22 CUT AND COVER AVIATION FUEL STORAGE (BL)

FAC: 4113
BFR Required: Y

411 30 DIESEL FUEL STORAGE 10K-100K (BL)

FAC: 4111
BFR Required: Y

411 31 DIESEL FUEL STORAGE > 100K (BL)

FAC: 4112
BFR Required: Y

411 32 CUT AND COVER DIESEL FUEL STORAGE (BL)

FAC: 4113
BFR Required: Y

411 40 MOTOR GASOLINE STORAGE 10K-100K (BL)

FAC: 4111
BFR Required: Y

411 41 MOTOR GASOLINE STORAGE >100K (BL)

FAC: 4112
BFR Required: Y

411 42 CUT AND COVER MOTOR GASOLINE STORAGE (BL)

FAC: 4113
BFR Required: Y

411 50 JET ENGINE FUEL STORAGE 10K-100K (BL)

FAC: 4111
BFR Required: Y

411 51 JET ENGINE FUEL STORAGE >100K (BL)

FAC: 4112
BFR Required: Y

411 52 CUT AND COVER JET ENGINE FUEL STORAGE (BL)

FAC: 4113
BFR Required: Y

DEFINITION. The fuel products in these category codes 411-10 through 411-52 are organized into three basic categories: operational fuel storage, bulk fuel storage, and “cut and cover” fuel storage. Operational storage tanks are designed with capacities between 10K and 100K BL; bulk storage tanks are designed with capacities greater than 100K BL; and “cut and cover” storage tanks are designed with capacities typically between 10K and 100K BL (these are operational tanks used in potentially hostile environments). Bulk fuel storage tanks are supplied by pipelines, tank trucks, or rail tanker cars. The bulk tanks in turn, supply operational fuel tanks and “cut and cover” storage tanks, which then supply the various fueling systems at an installation.

The Fleet Fuels Officer, Code N413F, within the US Fleet Forces Command in collaboration with Defense Logistics Agency’s (DLA) Defense Energy Support Center (DESC) Code B (Bulk Fuels) will determine the fuel storage requirement. Design guidance, including safety features, can be found in the most current version of Unified Facilities Criteria Design: Petroleum Fuel Facilities (UFC 3-460-01), located on the Whole Building Design Guide (WBDG) website at the following link:

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-460-01

Note that the real property components associated with the above category codes include the tanks and any containment structures associated with them, such as berms, liners, and monitoring wells. In the case of “cut and cover” type fuel storage, the integral deep well turbine pumps are also included in the associated category codes and are not to be counted as separate real property assets.

411 55 BULK/READY FUEL ADDITIVE STORAGE (BL)

FAC: 4114
BFR Required: Y

411 60 LIQUEFIED PETROLEUM GAS STORAGE (BL)

FAC: 1244
BFR Required: Y

41160-1 **DEFINITION.** The Navy uses liquefied petroleum gas, commonly known as LPG, for heating, metal cutting, brazing, in dental laboratories, aboard ships, and in similar installations. LPG consists predominantly of propane, propylene, with minor amounts of butane, isobutene, and butylene.

41160-2 **REQUIREMENT.** LPG is normally supplied in 100-pound cylinders or delivered by tanker truck or train car. The bulk storage capacity requirements for LPG depend on activity requirements, frequency of deliveries, and dependability of supply as well as lack LPG on base operations. Historical data is a good resource for developing a requirement looking for predictable changes in demand (i.e., loss of metal shop, increase in ship homeporting, increase in local dental operations, etc.). Otherwise, review equipment specifications for consumption rate as well as equipment usage to determine basic requirement. Again, allow for impacts from delivery schedules and dependability. Design guidance, including safety features, can be found in the most current version of Unified Facilities Criteria Design: Petroleum Fuel Facilities (UFC 3-

460-01), located on the Whole Building Design Guide (WBDG) website at the following link:

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-460-01

411 82 CONTAMINATED FUEL STORAGE (BL)

FAC: 4211
BFR Required: Y

41182-1 **DEFINITION.** A fuel storage facility requires temporary storage for off-specification (contaminated) fuel.

41182-2 **REQUIREMENT.** Separate tanks should be provided for each type of fuel stored and consumed in large quantities. Review historical data to determine typical volume of delivery and method and schedule of disposal to determine tank size.

411 84 BULK (DEPOT) HEATING FUEL STORAGE (BL)

FAC: 4111
BFR Required: Y

41184-1 **DEFINITION.** Heating fuel oil storage may include storage tanks for kerosene and several different grades of diesel oil.

41184-2 **REQUIREMENT.** The station’s requirements and mission will determine the quantity of any type of heating fuel oil stored. Some bases may rely on contract deliveries versus depot support. In these instances, depot storage should not be provided.

412 LIQUID STORAGE OTHER THAN WATER, FUEL AND PROPELLANTS

412-1 GENERAL DESCRIPTION

This group includes tank storage, accessories and piping for organic liquids such as cottonseed, linseed or soybean oils and other non-fuel liquids such as lubricants, ballast, or waste oils. Historical data should be available to determine rate of delivery and storage requirement. For waste liquids and oils, methods and schedule of disposals should be considered when determining storage requirement.

412-2 STORAGE QUANTITIES

No specific planning factors for the following category codes are currently available. Historical data may be used to develop the basic requirement including review of delivery schedules and removal of materials. Method of delivery/removal (i.e., pipeline to barge, truck, etc.), maximum quantity delivered/removed (is incoming quantity greater than outgoing quantity) and frequency (how often is material delivered to tanks and how often is material taken from tank) should also be considered.

412-3 CATEGORY CODES

The individual category codes in this group are shown below:

412 15 ROAD OIL STORAGE (GA)

FAC: 4121
BFR Required: N

412 25 LUBRICANT STORAGE (GA)

FAC: 4121
BFR Required: N

412 35 BALLAST AND SLUDGE STORAGE (GA)

FAC: 4121
BFR Required: N

412 40 ORGANIC OIL STORAGE (GA)

FAC: 4121
BFR Required: N

412 45 MISCELLANEOUS LIQUID STORAGE (GA)

FAC: 4121
BFR Required: N

412 50 INDUSTRIAL/POL WASTE STORAGE FACILITY (GA)

FAC: 4121
BFR Required: N

420 AMMUNITION STORAGE

420-1 DEFINITION

Ammunition storage utilizes magazines, general purpose and refrigerated storehouses, tanks, open storage pads and associated stationary equipment for storage of Ammunition, Inert Ammunition Components, Liquid Propellants and Weapon-Related Batteries.

Category groups pertaining to these facilities are as follows:

Code 421 Ammunition Storage (Tables 420-l thru 420-19)

The 421 series category codes have been re-organized to simplify and make category codes more consistent with magazine construction design. 421-22 High Explosive Magazine becomes the primary category code. The following category codes have been eliminated and rolled up under 421-22 High Explosive Magazine:

- **421 12 Fuse and Detonator Magazine**
- **421 52 Smokeless Powder and Projectile Magazine**
- **421 72 Missile Magazine**
- **421 83 High Performance Magazine**

Code 423 Ammunition Storage -Liquid Propellants (Tables 420-20 thru 420-25)
Code 424 Weapon-Related Battery Storage
Code 425 Open Ammunition Storage

NOTE: All planners developing magazine BFRs must have current certification through AMMO-36 Explosives Safety for Naval Facility Planning offered by the Defense Ammunition Center.

420-2 GENERAL STORAGE REQUIREMENTS

Ammunition and bulk explosives should be stored in magazines of approved design, sited and designated for specific purposes. The type and amount of material that may be stored in any magazine is dependent on the quantity-distance requirements and permissible storages as established by the Department of Defense Explosives Safety Board (DDESB) and as approved by the Naval Sea Systems Command. These safety distance requirements are designed to provide the inhabitants of nearby communities, military personnel, and adjacent public and private property reasonable safety from injury or destruction from possible fires or explosions, and to keep to a minimum the loss of valuable ammunition stores through fire or explosions.

420-3 MAGAZINE AREA

The magazine area is the area surrounding a magazine or group of magazines, where personnel movements are restricted in the interest of safety. Magazines must be sufficiently remote from inhabited buildings, passenger railroads, and public highways, including navigable waters, so that the dangers and risks involved in storing explosives and ammunition are confined primarily to the magazine area. In order to insure this safety zone the DDESB has spacing criteria for magazines, based on the type of hazard involved and the quantity of explosives stored. See Naval Sea Systems Command Publication NAVSEA OP-5 Volume 1 (current revision) for Quantity-Distance Requirements. In the case of existing facilities, spacing criteria may limit the amount of explosives stored in a magazine to less than full capacity. In addition, limits have been set on the maximum amount of explosives that can be stored in certain types of magazines. This information is listed in the category code descriptions.

420-4 ORDNANCE HANDLING, LOADING AND OFFLOADING AREA

For new construction of Earth Covered Magazines (ECM), a concrete area will be required in front of the ECM for handling, staging, inspection, loading and offloading ordnance. This paved area will ensure adequate space is available to handle ordnance in accordance with the safety principles and tenets outlined in NAVSEA OP 5 Volume 1, Ammunition and Explosives Safety Ashore. This paved area provides safe turning distances for Material Handling Equipment (MHE) transporting ordnance and for ordnance transportation conveyances while allowing spotters and safety observers a clear view of the operation from a safe distance. The area provides critical space and clearances for ordnance staging, set-down, and maneuvering containerized weapons and pallets to/from flat bed and enclosed commercial conveyances.

For Box Types C, D, G, H, and Containerized Long Weapons Storage (CLWS) Double Bay magazines, the paved area must be approximately 175’ wide centered in front of the magazine and extend 85’ outward from the magazine. For Box Type Modular Storage Magazines (MSM) and CLWS Single Bay magazines, the paved area must be approximately 100’ wide centered in front of the magazine and extent 85’ outward from the magazine.

The paved area must drain away from the ECM in a single continuous plane and the grade must be 0.5 % min with a 2.0 % max slope from the magazine.

The paved area must not be part of an adjacent road, but must connect with the adjacent road with an adequate turning radius or short access road. The paved area must be measured from the face of either, the ECM headwall where there is no loading dock or from the face of the ECM loading dock.

Where the above paved area is not available in front of the ECM, the planner must coordinate with the Local Ordnance Handling Activity and their respective Echelon III command to review and assess the impacts to ordnance handling safety. If the appropriate area is not provided, the Echelon III command must provide written (via email) concurrence of the proposed alternative to ensure all risk management concerns have been addressed or mitigated.

The ordnance handling, loading and offloading area will be recorded under Category Code 852-40.

420-5 SEGREGATION OF MATERIALS

The dangers or hazards involved in the storage of ammunition or explosives are not measured solely by the quantity of explosives stored, but also by its sensitivity - explosives that present similar hazards may generally be stored together. Tables showing compatibility relationships can be found in the NAVSEA OP-5, Vol. I (current revision).

420-6 WEIGHT MEASUREMENT

Net Explosive Weight (hereafter referred to as NEW). This is the weight of explosive material, and is measured in pounds. In items of ammunition with a high explosive main charge, fuses containing ignition explosives, and a propelling charge of smokeless powder, the NEW is calculated in accordance with NAVSEA OP-5 Vol. I, Chapter 5. It is the NEW of ammunition or bulk explosives that is used in application of explosive safety quantity-distance (ESQD) tables.

420-7 SITING REQUIREMENTS

To ensure the prevention of unacceptable damage or injuries in the event of an accidental explosion, siting criteria have been established to define minimum required separation distances between a Potential Explosion Site (PES) and other facilities. Minimum separation distances have also been established to prevent sympathetic detonation between two PESs, and to prevent prompt propagation of an explosives event between two PES's. ESQD minimum separation distances are based upon several factors including, but not limited to:

- The level of protection mandated by the applicable explosive safety standard
- The Exposed Site (ES) type and classification
- The NEW
- The hazard classification of the ammunition and explosives at a PES
- The physical orientation between the PES and the ES
- The presence of effective barricading

Minimum ESQDs are defined in the applicable DoD and service specific explosive safety standards for various applications. These ESQDs are based on maximum levels of risk considered acceptable for various types of ES. Separation distances are not absolute safe distances, but are relative protective or safe distances.

Use greater distances than those shown in the explosive safety standards whenever practicable.

Explosives safety site plans are required for construction projects involving new PESs, new facilities (explosive or non-explosive) within the ESQD arc of existing PES, as well as for the upgrading or renovation of existing facilities (explosive or non-explosive) that might impact the explosives safety criteria applied to these facilities (e.g., removal of hardening for fragmentation that previously allowed the facility to be a lesser distance, change of mission that requires the facility to now be at a greater distance). These site plans are reviewed to ensure explosives safety criteria are being met by the proposed work. DoD requires most explosives safety site plans to be forwarded to the DDESB for review and approval. See NAVSEA explosives safety criteria for more detail on when a site plan is required and what level of site plan review and approval must be accomplished prior to commencing projects.

Table 420-1
CCNs Requiring Site Approval

116-55	148-35	216-10	226-25	226-66	421-22	425-11
116-56	148-40	216-20	226-30	226-70	421-35	
143-20	148-45	216-30	226-35	226-80	421-42	
143-21	151-10	216-40	226-40	226-81	421-48	
143-60	151-70	216-50	226-45	226-82	421-62	
148-20	212-10	216-55	226-50	226-85	421-82	
148-25	212-30	216-77	226-55	226-86	425-10	
148-30	212-50	222-10	226-56	226-88	425-30	

Explosives safety site approvals are required for facilities of the CCNs of Table 420-1. See NAVSEA explosives safety criteria, OP-5 and NAVFACINST 11010.45 (latest rev) for more detail. **The planner preparing the site approval must have current certification through AMMO-36 Explosives Safety for Naval Facility Planning offered by the Defense Ammunition Center**.

420-8 AMMUNITION LOADING

The first step in preparing requirements for ammunition storage is obtaining the authorized ammunition load plan for the installation or command for which the requirement is being prepared. To obtain the authorized load plan, the planner should contact the local or regional representative from Naval Munitions Command (NMC). When an NMC load plan is not available, the planner should contact the tenant command for which the requirement is being developed and request a copy of the Arms, Ammunition, and Explosives (AA&E) loading.

The load plan could be the Global Requirements Based Load Plan (GRBLP) or another site-specific requirement such as the tenant command’s N4 shop providing the Navy Ammunition Logistics Code (NALC) items and the quantity being used, averaged over a one year period. The GRBLP is developed and maintained by Naval Supply Systems Command, Global Logistics Support in Mechanicsburg, PA. The GRBLP will be obtained by NMC from Ordnance Information System (OIS). NMC should adjust the data to properly reflect the added ammunition maintenance load as well as a reduction factor to account for the percentage of the items that need to be stored ashore versus the items deployed afloat. Fleet Commanders Ordnance staff should be consulted for fleet ordnance download requirements from ships. NMC will provide this “adjusted” GRBLP to the planner for use.

420-9 TYPES OF MAGAZINES

The next step the planner should take is to determine the number of existing magazine assets for the installation or command and the exact type and size of each by design. This is contrary to typical requirement calculations made independent of existing facilities. A key component of the updated criteria is an accurate determination of the physical construction type of each magazine.

Earth-Covered Magazines (ECM) typically fall within one of the following categories. Details for these magazine types can be found in DDESB Technical Paper Number 15 (TP 15) Approved Protective Construction and UFC 4-420-01.

- Small “Keyport” or “Fuse & Detonator” magazines – typically smaller than 20’ x 20’
- Arch magazines – typically 25’ wide and varying in depth between 20’ and 80’ (can be standalone or one of three in a triple arch magazine facility).
- Legacy box magazines – Smokeless Powder and Projectile (SP&P), Standard Missile Magazines, Box Types A and B
- Modern box magazines – Box Types C, D, E, F and M
- Modular Storage Magazines (MSM) – 25’ wide and varying in depth between 20’ and 80’

Installations can commonly have several magazines that are modified versions of the types listed above. Both TP 15 and UFC 4-420-01 define magazine designs that are authorized for future construction. For new construction, the following magazines are recommended: Box Type C/D, Modular Storage Magazine (Navy), Modular Storage Magazine (European), Containerized Long Weapons Storage (32’ Single Bay, 50’ Double Bay). The CLWS magazine is currently under development and shall be ready 4th quarter of FY20. If a different magazine than the recommended designs listed above is being considered, the planner shall contact NOSSA to obtain approval for use.

The planner should contact the local NMC Detachment or Naval Ordnance Safety and Security Activity (NOSSA) for information on existing facilities. If this data does not exist, a detailed asset evaluation of the magazines should be conducted to identify the design of each ammunition storage facility. In addition, the planner shall consult the Magazine Design Type Identification Guide, which provides technical and detailed information on the various magazine design types (both legacy, and approved for new construction) used by the Navy and Marine Corps. The magazine type is an identifying feature on the iNFADS Property Record Card. The Magazine Design Type Identification Guide is available on the NAVFAC Criteria Management Portal page: Magazine Guide

420-9.1 MAGAZINE ASSET EVALUATION

When conducting an asset evaluation survey of an ammunition storage magazine, the planner should work with the NMC Detachment representative and have access to the installation's latest Explosives Safety Siting *(*ESS*)* software program. Planners should use the "Magazine Construction Assessment Report" (MCAR) to record the magazine physical characteristics while in the field (link to downloadable form is referenced below).

The planner should physically inspect and record the following data of each magazine:

- Interior Length - The interior measurement (to the nearest inch) of the distance from headwall to back wall.
- Interior Width - The interior measurement (to the nearest inch) of one side to the other. For arch magazines, this measurement is taken at the base of the wall.
- Interior Height - The vertical distance measured from the ground inside to the ceiling (to the nearest linear foot). For box type magazines the ceiling is sloped and the height will vary. The height should be measured at the high and low points.
- Exterior Length – The exterior measurement (to the nearest inch) of the magazine. For earth covered magazines, refer to the Magazine Design Type Identification Guide for specifications.
- Exterior Width – The exterior measurement (to the nearest inch) of the magazine. For earth covered magazines, refer to the Magazine Design Type Identification Guide for specifications.
- Doors - The number of doors, height and width (to the nearest inch), and thickness (to the nearest inch) of the door panel as well as the clear opening and location from center of headwall. Record if the door is single or double leaf design and whether the door is designed to swing open or slide open. If the door has more than one steel plate in thickness (i.e., is the door a built-up section), record details of the various plates and the channels/beams/bracing used to construct the door. Note the bracing and bearing surfaces supporting the door. Specifically, note any corbels on the ceiling or pull-up door stops in the floor.
- Headwall – Measure the thickness (to the nearest inch) of the thinnest part of the head wall. This may not be directly measurable at the door opening. Record any window or other opening in the headwall that is not concrete.
- Columns – Number, width, height and distance between (to the nearest linear half-foot) each column. Note the type and dimensions (width and height to the nearest inch) of the column header at the ceiling. Note if there are multiple

column rows and the number in each row as well as the distance between (side to side).

- Bays – Number of and distance between (front to rear) column bays.
- Miscellaneous – Indicate presence of loading dock, wing walls, IDS, revetment/berm/barricade, mechanical room and crane. Measure the loading dock length, width and total area (square feet). Measure the revetment distance from the headwall (feet). Identify IDS type and access type (rail, pallets, forklift, small missile, large missile, etc.).
- Photographs of each building, facility and structure. Photographs of the interior of the magazine, the head wall from the outside and inside, and the door from the outside and the inside. (NOTE: photographs are subject to security restrictions).
- Note any other structural feature such as HVAC openings, rails in the floor, added walls or racks

This data should be compared against known designs in the Magazine Design Type Identification Guide, available on the NAVFAC Criteria Management portal page to determine the magazine type. Both the MCAR and the Magazine Design Type Identification Guide are available on the Criteria Management portal page (located HERE). Because variations to the standard magazine types do exist at many installations, capturing the key structural features of each facility is essential. In these cases, the planner should consult with structural engineers from NAVFAC Capital Improvements or NOSSA. The CODEX is a 10-digit code which describes magazine type (including variants of the main types), strength (7 Bar, 3 Bar, and Undefined, as well as Flat Roof downgrade, and types of Above Ground Magazines (AGMs)), and exterior features such as barricades, access in/out of the magazine, and if there is or is not Intrusion Detection System (IDS) protection, and the level of security provided by the magazine. The CODEX coupled with the Magazine Construction Assessment Report (MCAR) provides the definition of a magazine which sites physical capabilities, strength and security requirements of ammunition stored. The CODEX consists of a ten-digit number represented by eight data fields in iNFADS. These fields are:

- Facility Type – 1st and 2nd digit
- Facility Sub Type – 3rd and 4th digit
- Strength Designator – 5th digit
- Barrier – 6th digit
- Access Type – 7th digit
- Intrusion Detection System (IDS) – 8th digit
- Mechanical Room – 9th digit
- Bridge Cranes/Monorails – 10th digit

Upon completion of the CODEX for each magazine, the planner shall validate the CODEX with the Installation Explosive Safety Officer (ESO). Once approved, the final MCAR shall be signed by the ESO and uploaded as an attachment to the property record card. In addition to uploading the signed MCAR, the magazine type must be entered for each facility via the “MCAR” tab located under the physical level tab of the iNFADS Facility Module (at the utilization level). The information entered will subsequently appear on the Property Record Card.

Additional data that should be captured includes:

- Maintenance Responsibility UIC
- User UIC
- Presence of a front loading dock or apron. Loading docks shall be classified as a utilization within the magazine's property record card under Category Code 85115 "Load/Unload Ramp."
- Presence of front wing walls. These are concrete walls at ECMs that flank both sides of the headwall.
- Presence of a mechanical room. Mechanical rooms shall be classified as a utilization within the magazine's property record card under Category Code 89009 "Miscellaneous Utility Building."
- Presence of an adjacent, earthen berm or engineered revetment or barricade (typically either a steel or concrete structure). This structure should be recorded under Category Code 14910 "Protective Barricade/Revetment" and each non-contiguous asset should be counted separately on the property record card.
- Where there are multiple Hazard Class/Divisions (HC/D) in a magazine, the utilization of the magazine will be determined by siting the most restrictive HC/D.
- Where there are multiple tenant commands in a magazine, the utilization of the magazine shall be determined by the most restrictive HC/D material being held by the group of tenants.
- NOTE: Prior to changing the utilization Category Code of a magazine, the planner shall contact the Installation Explosive Safety Office and discuss/verify the action is acceptable.
- NOTE: Verify that the "Predominate Design" field in iNFADS aligns with the ESO's Safety Site Approval designation for the facility. This field shall only be changed with ESO approval.

420-10 PLANNING METHOD

A facility requirement is established by comparing the required load plan to the available existing facilities to determine if sufficient space exists or if a deficit exists. The load plan could be the GRBLP or another site-specific requirement. The list of existing facilities is based on the list of explosive storage facilities with current approved site plans.

The methodology used for the comparison and the required level of detail is a factor of the relative size of the installation or area being considered. Two generic size categories are described here. These categories are not rigid and judgment should be used to determine the most effective analysis method.

- Small scenario (manual)–
    - Fewer than 5 storage magazines, or

    - Storage of less than 4 item types, or
    - Storage of a small load plan (less than 100 pallets/footprints) in which the number of pallets/footprints is already defined
- Large scenario –
    - Any scenario with 5 or greater storage magazines, or
    - Storage of 4 or greater item types, or
    - Storage of a large load plan with greater than 100 pallets/footprints, or
    - Any complex load plan of unknown characteristics

NOTE: All planners developing magazine BFRs must have current certification through AMMO-36 Explosives Safety for Naval Facility Planning offered by the Defense Ammunition Center.

The Magazine Storage and Requirements Calculator (MSRC) has been developed to facilitate the planning process. The planner has the option to use the MSRC for either scenario described above, as deemed fit. But the small scenario allows the planner to handle small/simple scenarios without using the MSRC. This tool can be obtained from the NAVFAC Criteria Management portal page along with an instruction manual for its use. The direct link to the tool and all supporting resources is located here, and requires Common Access Card (CAC) access:

Magazine Storage & Requirements Resources

420-10.1 **PLANNING METHODOLOGY**. The general planning process follows the same steps regardless of the approach used. Each of the following steps is described in more detail for each scenario size. Instances in which the MSRC can or should be used are identified.

1. Characterize the load plan.
2. Define the list of existing magazines.
3. Perform a stowage analysis.
4. (Optional in the event of a deficit of magazine space) Identify the preferred magazine type for hypothetical additional magazines and then optimize the storage of the remaining load plan items into this magazine type.
5. Magazines facilities are pre-approved, non-deviation, construction designs. The MSRC will provide the required number of magazines in whole units and if the planner is developing the requirement by hand calculation, the final requirement shall also be in whole units.

420-10.2 **CHARACTERIZE THE LOAD PLAN**. This step translates a load plan of individual items (e.g., bullets and bombs) into a defined number of stowage footprints (e.g., 46 pallets and 12 large bombs) as defined in Table 420-1. The load plan is obtained from NMC or other tenant command and has been previously adjusted by NMC to properly reflect the added maintenance load as well as a reduction factor to account for the percentage of the items that need to be stored ashore. NMC will provide this “adjusted” GRBLP to the NAVFAC planner or contractor for use.

At a minimum, the GRBLP will contain the Navy Ammunition Logistics Code (NALC) and a quantity of individual items for each NALC. The GRBLP may also include an “owner” or other designator, though this is not necessarily required.

The planning process (either using the MSRC or any “manual” process) will translate the load plan into an equivalent number of generalized footprints. The generalized footprint types used in this process are (with nominal storage Length x Width x Height provided in inches):

- Standard Pallet (48x40x34)
- Oversized Pallet (53x47x43)
- Small Bomb (65x36x32)
- Large Bomb (107x41x24)
- Small Missile (127x43x24)
- Medium Missile (159x36x49)
- Large Missile (241x40x41)
- Extra Large Missile (308x40x40)

If the MSRC is used (for either a small or large scenario), the GRBLP is entered into the spreadsheet and the equivalent number of various footprints can be output as a report.

Additional factors including Hazard Class/Division (HC/D), storage Compatibility Group (CG) and NEW of each item are also gathered for each item. If the MSRC is used, these values are obtained automatically from the technical data obtained from OIS based on the NALC for each item.

Where there are multiple Hazard Class/Division (HC/D) ordnance in the load plan, the BFR CCN will be determined by siting the most restrictive HC/D.

420-10.3 **DEFINE THE LIST OF EXISTING MAGAZINES**. In this step, magazines that are acceptable for storage of the load plan are identified with sited NEW quantities. This list should be correlated with iNFADS, NMC and NOSSA for agreement. Magazines typically fall within one of the following categories. Details for these magazine types can be found in TP 15.

- Small “Keyport” or “Fuse & Detonator” magazines – typically smaller than 20’ x 20’
- Arch magazines – typically 25’ wide and varying in depth between 20’ and 80’
- Legacy box magazines – Smokeless Powder and Projectile (SP&P), Standard Missile Magazines, Box Types A and B
- Modern box magazines – Box Types C, D, E, F and M
- Modular Storage Magazines (MSM) – 25’ wide and varying in depth between 20’ and 80’

The NAVFAC planner or contractor obtains the list of magazines from iNFADS and verifies with the local installation. Sited NEW values are obtained from the local Explosives Safety Officer, Installation Planner or NOSSA. The MSRC includes the capability to import a list of magazines generated from the ESS software. See the MSRC User's Manual for details.

Each of the magazines other than the small Keyport and Fuse & Detonator types can be modeled in the MSRC as a standard type. Other types can be modeled as user-defined magazine types in the MSRC.

420-10.4 **ANALYSIS PROCESS**. In this step, the load plan is systematically allocated throughout the existing magazines. This process may be very direct for small scenarios. For larger scenarios, the MSRC has been developed to facilitate this process using methods and requirements approved by NAVFAC, NMC, Fleet and NOSSA. The intended outcome of this step is to show that all munitions in the load plan can be stowed within the list of available magazines while satisfying CG rules, sited NEW limitations and spatial constraints.

The maximum number of footprints within a specific type of magazine can be obtained using the MSRC stowage matrix shown in Table 420-1. Small Keyport and Fuse & Detonator magazines are not accounted for in this table.

This table assumes that all items are stacked 3 containers high. If a given NALC has a different maximum allowable stack height, the values in Table 420-1 would be scaled accordingly. If the number of footprints to be stowed does not entirely fill one or more stacks, empty spaces must be accounted.
Fractions are used to account for mixing of various footprint types. As an example of this, if an 80' Arch contains 58 large bombs (50% of its capacity for large bombs), it could only accept 49 standard pallets (50% of its theoretical max capacity of standard pallets) before it is considered completely full.

The values in this table have been determined by NMC, NAVFAC and NOSSA, and NAVSEAINST 8024.2 (latest revision) and account for all rows and other wall standoff requirements.

Table 420-2
MSRC Stowage Matrix

Magazine Type (depth)	Standard Pallet	Oversized Pallet	Small Bomb	Large Bomb	Small Missile	Medium Missile	Large Missile	Extra Large Missile
Arch (20')	20	--	--	--	--	-	--	--
Arch (25')	26	--	--	--	--	--	--	--
Arch (40')	48	--	--	--	--	--	--	--
Arch (50')	65	30	109	68	--	--	--	--
Arch (80')	98	48	153	116	--	--	--	--

Magazine Type (depth)	Standard Pallet	Oversized Pallet	Small Bomb	Large Bomb	Small Missile	Medium Missile	Large Missile	Extra Large Missile
Triple Arch	294	144	459	348	--	--	--	--
SP&P I	432	216	288	144	192	144	--	--
SP&P IIA	480	396	480	240	264	198	60	--
SP&P IIB	426	276	303	198	224	114	30	--
Box A	426	276	303	198	224	114	30	--
Box B	468	306	338	212	192		36	--
Box C	450	288	324	216	240	126	36	36
Box D	750	432	525	360	400	198	90	60
Box E	450	288	324	216	240	126	36	36
Box F	750	432	525	360	400	198	90	60
Box M *	--	--	--	--	--	--	153	108
Std Missile Mag I	408	286	305	198	182	--	--	--
Std Missile Mag II	430	302	324	225	120	--	--	--
MSM (20')	30					--	--	--
MSM (40')	78	72	108	60	72	15	--	--
MSM (60')	129	108	162	90	108	22	--	--
MSM (80')	180	144	207	120	144	30	--	--
CLWS 32’ x 93.5					84	60	48	36
CLWS 32’ x 117					168	126	60	48
CLWS 50’ x 117 Double Bay					504	336	210	168

* Box M has not been considered for any application other than Large and Extra Large Missiles

420-10.5 **SMALL SCENARIO ANALYSIS**. For a small scenario, it is not necessary to use the MSRC. If the number of equivalent footprints within the load plan has been determined (see Section 420-10.2) and the magazine types have been defined (see Section 420-10.3), the NAVFAC planner or contractor can distribute the load plan throughout the magazines manually. CG mixing rules, sited NEW quantities, as well as any other physical constraints must be considered.

The planner can directly compare the number of generalized footprints to the values shown in Table 420-2 for the available magazine types. Magazines can be filled with a mix of footprint types if necessary. In this case, fractions of a full magazine would be used as described in Section 420-10.4.

The output from this analysis would be a listing of all load plan items stowed, and if applicable, a listing of load plan items not stowed. The magazine(s) used for stowage should be listed for each load plan item. These outputs can be used to populate the BFR report.

420-10.6 **LARGE SCENARIO ANALYSIS**. These scenarios should be analyzed using the MSRC. An iterative process is used to optimize the allocation of the load plan throughout the list of available magazines. The MSRC allows the user to systematically work through the load plan to ensure that required storage constraints are met, and if desired, specific munitions are stowed in compatible magazines. Examples of this include items requiring Intrusion Detection Systems (IDS) are stowed in magazines equipped with IDS, or particular items may be required to be stowed in a specific area of the installation, depending on local guidance and discretion.

Detailed instructions for the use of the MSRC are provided in the MSRC Users' Manual provided with the tool. Here is a direct link to the user manual. Common Access Card (CAC) access is required.

MSRC User's Manual

The MSRC provides many options for output from the analysis beyond generating the BFR. Some of these options include a listing all load plan items stowed. If applicable, a listing of load plan items not stowed and a theoretically stowed items listing in each magazine are also included.

420-10.7 **ESTIMATING FUTURE MAGAZINES**. This section describes the additional magazines planning process, whether they are planned as part of a new installation or to meet an existing storage capacity deficit.

In the event that the load plan cannot be completely stowed within the existing magazines, or in the event that a potential future scenario is being studied, the MSRC can be used to estimate the number of magazines required to store this material. In this scenario, the proposed magazines' sited NEW must be determined or estimated (see Section 420-10.2) to ensure a proper required magazines quantity. The proposed sited NEW estimates may be used in the tool, but must be verified by the Explosive Safety Software (ESS) Planning Tool option prior to using the information in a BFR. To use this methodology, check with the local Explosives Safety Officer, Installation Explosive Safety Planner or NOSSA.

Where multiple magazines are proposed at less than 500,000 pounds NEW, if possible, increase the Intermagazine Distance (IMD) separation distance to 100 ft. both “Side to Side” and “Rear to Rear” and 160 ft. “Front to Rear.” This will support a temporary waiver to increase the magazine’s allowed NEW storage up to 500,000 pounds when events dictate such a waiver.

Where magazines are proposed at a “restrictive land available site” and continuous earth cover is considered, as part of the siting criteria, the following must be met:

a) the Intermagazine Distance (IMD) separation distance both Side to Side, Rear to Rear, Front to Rear and;
b) the two earth covers intersect at or below a point ½ the height of the two structures – i.e. H/2 where H is the height of the structure (at structures highest point).
    a. Example: two Box Type D magazines – 15’-8” (height of interior roof at front of magazine) + 1’6” (roof thickness) = 17’-2”, 17’-2” divided by 2 = 8’-7”. The low point of the earth cover must at or below 8’-7” as measured from finished grade.

If only one or two types of munitions need to be stowed, the MSRC Stowage Matrix can be used directly to estimate the number of required magazines. Compatibility Group mixing rules as well as sited NEW quantities and any other physical constraints must be considered.

The MSRC can be used to estimate required magazines to stow any remaining load plan for an analysis or theoretical scenarios. When using the MSRC, the user will select the preferred magazine type to be constructed. By default, Box Types C, D, CLWS Single Bay, CLWS Double Bay or any size of MSM should be selected for the analysis. Other magazine types are not permitted for new construction.

The following table is from the Whole Building Design Guide:

“Ammunition and Explosive Storage Magazines: ECM Approved For New Construction”

https://www.wbdg.org/building-types/ammunition-explosive-magazines/ecm-approved-new-construction

Table 420-3
Magazine Type and Gross Square Footage

Magazines Approved for New Construction per Department of Defense Explosive Safety Board (DDESB) Test Paper (TP)-15, “Approved Protective Construction”			

Magazine Type	**Drawing Number**	**Number of Doors/"Bays"**	**Gross Square Footage (GSF)**
RC Box Type "C"	14004689-14004720 Rev. 1 (Without Platform)	3	5,920
RC Box Type "C"	14005091-14005122 Rev 1 (With Platform)	3	5,920
RC Box Type "D"	18232899-18232936 (Without Platform)	5	10,057
RC Box Type "D"	18232899-18232978 (With Platform)	5	10,057
Modular Storage Magazine:	Army:421-80-07	1	2,124.22
Modular Storage Magazine:	**NAVY**:14063806-14063858 **ARMY**:421-80-08, 421-80-13	1	
25' w x 20' depth variant		1	894
25' w x 40' depth variant		1	1,438
25' w x 60' depth variant		1	1,978
25' w x 80' depth variant			2,518
CLWS, Single Bay, 32' w x 93'-6" depth	TBD	1	3,706
CLWS, Single Bay, 32' w x 117' depth	TBD	1	4,552
CLWS, Double Bay, 50' w x 117' depth per bay	TBD	2	13,254

Notes:

1. Army ECM, Concrete Oval-Arch, dwg. No. 421-80-09, 25' width x 90' depth is approved for new construction but door width of 8' limits the use of the magazine to Small Bombs, Oversized and Standard Pallets.
2. Army RC Box, Dwg No. 421-80-07, 24' width x 80' depth, are approved for construction but in lieu of sliding doors have two steel doors that are manually opened and there is a 4" lip at base of opening for doors to rest against, causing loading/unloading issues.

3. Army RC Box, Dwg No. 421-80-13, 25’ width x 80 depth is approved for European construction but NOSSA will required modifications to the design drawings to support Lightning and Electrical.
4. Munitionslagerhause (German Deign) magazines, although shown as approved for new construction, will require a review and design update before being avail for NOSSA/DDESB approval for construction.

420-11 CONTAINERIZED AMMUNITION

Implementation of directives for containerizing ammunition for shipment is now underway at certain ordnance activities, initially at coastal POE's. For these activities, category codes and planning factors have been developed to facilitate proper identification and sizing of the facilities that are in support of containerized ammunition shipments. The following category codes and planning factors are established for handling of ammunition by containers. As warranted, additional category codes and planning factors will be developed.

148 35 Container Holding Yard (Loaded)
148 40 Container Transfer Facility
148 45 Rail/Truck Receiving Station
151 70 Ordnance Container Handling Pier
152 70 Ordnance Container Handling Wharf
156 20 Container Operations Building
218 10 Container Repair and Test Building
425 20 Container Holding Yard (Empty)
860 20 Explosive Barricade for Suspect Trucks and Railroad Cars

421 AMMUNITION STORAGE DEPOT AND INSTALLATION

421-1 DEFINITION

Ammunition storage utilizes magazines or other suitable containers to store ammunition for the ultimate user's logistic flexibility at an activity. Planning methods are provided for the following types of ammunition storage facilities:

421 22 High Explosive Magazine
421 32 Inert Storehouse
421 35 Ready Magazine
421 42 Smokedrum Storehouse
421 48 Small Arms/Pyrotechnic Magazine
421 62 Special Weapons Magazine

421 12 FUSE AND DETONATOR MAGAZINE (SF)

FAC: 4211

BFR Required: Y

This category code is no longer in use. Please use 421 22 High Explosive Magazine or 421 48 Small Arms/Pyrotechnic Magazine as appropriate.

421 22 HIGH EXPLOSIVE MAGAZINE (SF)

FAC: 4211
BFR Required: Y

42122-1 **DEFINITION.** A high-explosive magazine is used for the storage of mass- detonating explosives. Bomb, warheads, missiles, naval mines, demolition charges are examples of munitions generally stored in high explosive magazines. Refer to the Magazine Design Type Guide for types of magazines commonly found on installations.

Please refer to Section 420-8 TYPES OF MAGAZINES for details on how to survey existing magazines and DDESB Technical Paper Number 15 (TP 15) Approved Protective Construction and UFC 4-420-01 for descriptions of magazines and those authorized for construction.

Note: The following category codes have been eliminated and rolled up under 421-22 High Explosive Magazine:

- **421 12 Fuse and Detonator Magazine**
- **421 52 Smokeless Powder Projectile Magazine**
- **421 72 Missile Magazine**
- **421 83 High Performance Magazine**

421 32 INERT STOREHOUSE (SF)

FAC: 4211
BFR Required: Y

42132-1 **DEFINITION.** Storehouses for inert material are usually 50 x 200 ft. or 106 x 204 ft. or multiples of these basic dimensions, and are similar to commercial warehouses. These storehouses are used for the storage of such non-explosive items as bomb tails, machine gun links, empty cartridge cases, and packing materials.

Although the height of stowage in these storehouses depends on the type materials, the average stacking height is about 10 feet. Storage space available for storage will meet a minimum criteria of 60 percent of net storage space used for storage operations. The net storage capacity of the 50 x 200 ft. storehouse is approximately 60,000 cubic feet. For planning of installation inert storehouses use only the 50 x 200 ft. storehouse.

421 35 READY MAGAZINE (SF)

FAC: 4221
BFR Required: Y

42135-1 **DEFINITION.** This category code and nomenclature encompasses two specific types of magazines whose requirements are determined by the function performed. The three types of magazines within this category code are identified as:

(a) **Ready Service Magazine.** When shore establishments require certain types of ammunition to be stored in a ready service condition, in order to reduce the arming time, the ammunition may be stored in designated Ready Service Magazines. A 12' x 17' box-type magazine is suitable for performing this function. This facility is usually located at an air station and is used to hold ammunition and/or weapons that are built up from a storage configuration ready for arming an aircraft, or to receive for temporary storage, ammunition and/or weapons from aborted aircraft. These paved areas for loading or unloading ordnance from an aircraft are typically captured under CCN 11656 “Combat Aircraft Loading Area (CALA)”.

(b) **Special Service Magazine**. This type of magazine is provided in or near such facilities as loading plants, filling houses, weapon assembly buildings, ammunition maintenance buildings and Weapon Quality Evaluation Laboratories. The magazine can be a special size and construction, depending upon the material(s) stored therein. However, a 6' x 8' Keyport magazine has been found to be most suitable for this application. The need to provide segregation of non-compatible, open explosives frequently gives rise to a requirement for separate magazine structures, irrespective of any loading factor. Historical data should be used to determine the number of these facilities required which is dependent upon both the amount of explosives stored and the compatibility of the explosives themselves.

Note: Ready Service Lockers (i.e. RSLs, GOLANs, RMAG, NABCOs, CONEXs, etc.) are not Class 2 Real Property and shall not be entered into iNFADS. NAVFAC HQ instruction on RSLs as equipment/non-RP can be found here: NAVFAC HQ RSL Instruction. Concrete pads supporting RSLs shall be recorded under Category Code 425 11. The Pad should be sited for RSL’s NEW limit.

421 42 SMOKEDRUM STOREHOUSE (SF)

FAC: 4211
BFR Required: Y

42142-1 **DEFINITION.** Chemical and smoke mixtures are stored separately in fire- hazard type magazines or in buildings especially designed for such storage. Drums of smoke mixture may be stored in surface buildings with special racks for support, and overhead equipment for handling. Smokedrum storehouses are of the sizes and capacities shown in Table 42142-1.

Table 42142-1
Smokedrum Storehouses

Size Number	Capacity (Drum)	Approximate Bldg Dimensions In Feet				
		W		L		H
1	120	25	x	17	x	14
2	240	25	x	34	x	14
3	360	25	x	51	x	14
4	480	25	x	58	x	14

For more than 480 drums, two or more buildings should be provided.

421 48 SMALL ARMS/PYROTECHNICS MAGAZINE (SF)

FAC: 4211
BFR Required: Y

42148-1 **DEFINITION.** This structure may be used to store Class 1 Division 3 and 4 ammunition. This type of magazine may vary considerably in size and description. The standard earth-covered concrete arch magazine without barricade and the non-earth covered two compartment magazine are commonly used for this purpose. If the land area is limited and there is a large requirement for small arms/pyrotechnics storage space, the large triple arch magazine maybe used. See section 420-9 PLANNING METHOD to calculate requirements. For ammunition class descriptions, see OPNAVINST 8020.8.

421 52 SMOKELESS POWDER PROJECTILE MAGAZINE (SF)

FAC: 4211
BFR Required: Y

This category code is no longer in use. Please use 421 22 High Explosive Magazine or 421 48 Small Arms/Pyrotechnic Magazine as appropriate.

421 62 SPECIAL WEAPONS MAGAZINE (SF)

FAC: 4211
BFR Required: Y

42162-1 **DEFINITION.** The special weapons magazine is the same type of structure as the high explosive magazine and differs only in that it is used for the storage of nuclear weapons. Magazines used for the storage of special weapons are subject to quantity-distance requirements and are limited to the maximum amount of nuclear material that can be stored in any one magazine. This information, along with the sizes and weights of nuclear weapons and security requirements can be obtained from:

- (S) SWOP 20-7, NUCLEAR SAFETY CRITERIA (U)
- (S) SWOP 50-1, NUCLEAR ORDNANCE GENERAL INFORMATION (U)
- (C) OPNAVINST C5510.83 SERIES, CRITERIA AND STANDARDS FOR SAFEGUARDING NUCLEAR WEAPONS (U)

Planning data for Category Code 421 62 related to specific locations will be classified in accordance with cognizant Navy directive.

421 72 MISSILE MAGAZINE (SF)

FAC: 4211
BFR Required: Y

This category code is no longer in use. Please use 421 22 High Explosive Magazine.

421 82 SUBMARINE LAUNCHED BALLISTIC MISSILE STORAGE FACILITY (SF)

FAC: 4211
BFR Required: Y
42182-1 No criteria are currently available for this Category Code.

421 83 HIGH PERFORMANCE MAGAZINE (SF)

FAC: 4212
BFR Required: Y

This category code is no longer in use. Please use 421 22 High Explosive Magazine or 421 48 Small Arms/Pyrotechnic Magazine as appropriate.

423 AMMUNITION STORAGE – LIQUID PROPELLANTS

423-1 DEFINITION

The siting of liquid propellant (energetic liquids) storage facilities and the amount of propellant that can be stored are subject to strict safety criteria due to the fire and/or detonation hazards involved. Factors such as the degree of hazard and the compatibility of propellants stored in close proximity to each other affect the spacing of storage facilities and the amount of propellant that can be stored. NAVSEA OP-5 Vol. 1, Ammunition and Explosives Ashore provides criteria on hazard classification, quantity-distance tables, storage compatibility, and explosive equivalents.

423 10 LIQUID PROPELLANT STORAGE (GA)

FAC: 4231
BFR Required: Y

42310-1 **DEFINITION.** Storage vessel dimensions along with relevant siting requirements can be used to develop facility requirements.

423 20 LIQUID PROPELLANT DISPENSING FACILITY (GM)

FAC: 1221
BFR Required: Y

42320-1 **DEFINITION.** Liquid propellant storage and dispensing facilities shall satisfy the operational requirements of the particular command within whose jurisdiction the facilities are located.

424 WEAPON-RELATED BATTERY STORAGE

424-1 DEFINITION

Weapon-related storage utilizes refrigerated warehouses that are capable of maintaining at least subfreezing temperatures. This code is not to be used for other cold storage facilities.

424 10 WEAPON-RELATED BATTERY STORAGE (SF)

FAC: 4241
BFR Required: Y

42410-1 **DEFINITION.** Storage requirements can be determined from the quantity to be stored and the types of equipment used to rack and stack the batteries.

425 OPEN AMMUNITION STORAGE

425-1 **DEFINITION.** Provides open hardstands (pavements or prepared/stabilized surfaces) for ammunition storage and excludes all other hardstands.

425 10 OPEN AMMUNITION STORAGE PAD (SY)

FAC: 8526
BFR Required: Y

42510-1 **DEFINITION.** Refer to NAVSEAOP-5 Vol. 1 for regulations governing open storage of explosive material. Ordnance open storage is undesirable.

42510-2 **EXPLOSIVE SAFETY SITE APPROVAL.** Explosives safety site approvals are required for facilities of this category code. See NAVSEA explosives safety criteria for more detail. The planner preparing the site approval must have current certification through AMMO-36 Explosives Safety for Naval Facility Planning offered by the Defense Ammunition Center.

425 11 EXPLOSIVE STORAGE SITE PAD (SY)

FAC: 8526
BFR Required: N

42511-1 **DEFINITION.** This category code covers the pad, which must be made of concrete or asphalt, that Ready Service Lockers or reduced Quantity Distance (QD) equipment (i.e. RSLs, GOLANs, RMAG, NABCOs, CONEXs, etc.) are placed on. The site pad must be marked with a permanent facility marker (i.e. concrete monument, bollard, or placard) in accordance with the Installation Appearance Plan. The marker must be of the same level of permanent construction as the site pad.

For a newly constructed site pad, the edges must be constructed such that there is a minimum 1’ offset from any point along the perimeter of the storage equipment. The intent is to provide a 1’ offset on all four sides of rectilinear equipment, or a minimum of a 1’ offset at any point along the perimeter of non-rectilinear equipment.

For site pad areas obtained from existing paved surfaces such as aircraft aprons, etc., the dimensional rules for new pads still apply. In these cases, the dimensional area must be delineated by permanent markings such as road striping, permanent corner markers, or similar permanent markings, such that the dimensions of the site pad area can be validated at any point in the future.

The site pad must be sited for the equipment’s NEW limit and the site pad’s NFA number shall be incorporated into the site approval process, (i.e. NFA 0001, RSL 0001-1 RO 0001-1). The equipment number shall be a follow on number of the structure (i.e. 0001-1 or 0001-A).

The tenant command is responsible for maintenance (i.e. grounding and bonding test, etc.) of the storage equipment (i.e. RSL or other reduced QD equipment) on the site pad. The Installation’s Public Works Department is responsible for maintenance of the site pad (as it is real property).

If the planner is establishing a site pad area on an existing and approved contiguous surface, the planner must subtract the area of the site pad from the property record card of the existing contiguous surface.

42511-2 **EXPLOSIVE SAFETY SITE APPROVAL.** This structure is required to support equipment that stores explosive material. Therefore, explosive safety site approvals are required for equipment placed on this structure. In accordance with NAVSEA OP 5 Volume 1 (latest revision), the facility number for the site approval must reference the structure (site pad). See NOSAAINST 8020.22 (latest revision), NAVSEA OP 5, Volume 1 (latest revision), and NAVFAC Instruction 11010.45 for more detail. The planner preparing the site approval must have current certification through AMMO-36 Explosives Safety for Naval Facility Planning offered by the Defense Ammunition Center.

Note: Ready Service Lockers (i.e. RSLs, GOLANs, RMAG, NABCOs, CONEXs, etc.) are not Class 2 Real Property and shall not be entered into iNFADS. NAVFAC HQ instruction on RSLs as equipment/non-RP can be found here: NAVFAC HQ RSL Instruction. The Pad shall be sited for RSL's NEW limit.

425 20 CONTAINER HOLDING YARD (EMPTY) (SY)

FAC: 4251
BFR Required: Y

42520-1 **DEFINITION.** An empty ISO container-holding yard should be capable of storing at least one full container shipload plus 1/3 more. As the pipeline becomes full of containers, each container ship will discharge one container for each one loaded. Additionally, empty containers awaiting testing, repairs, stuffing or shipment to inland points will be on hand. Assuming a single berth pier/wharf for a 750 container ship, planning for an empty container-holding yard should be for 1,000 empty containers. See Figure 42520.1 for a typical 1,000-container yard layout. Total area of the holding yard is 19,180 SY. Size is predicated on 8' x 8' x 20' containers stacked three high. Containers are handled with container handling equipment or straddle carriers.

Figure 42520.1-Typical 1,000 Container Yard Layout

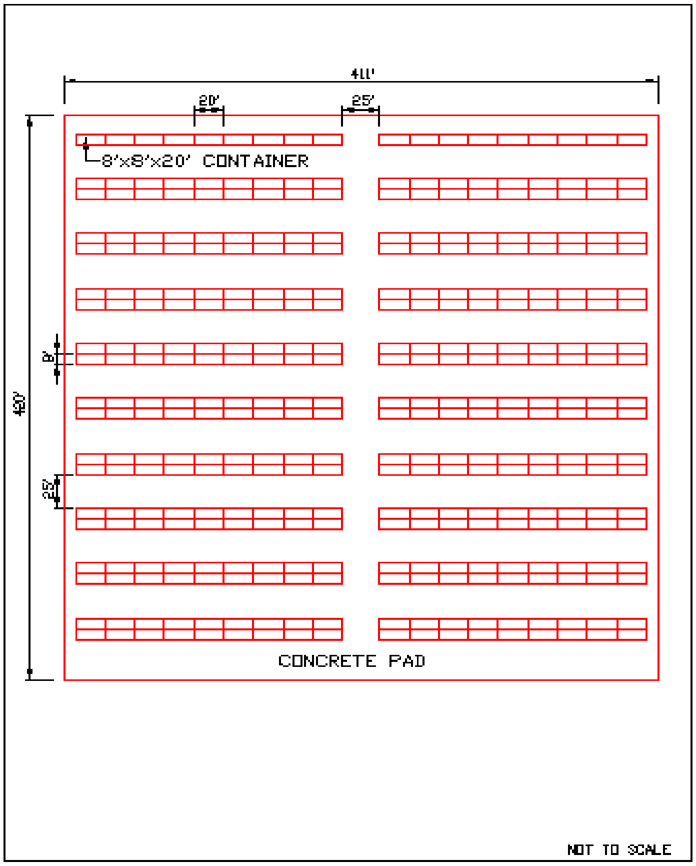


FIGURE 425-20
CONTAINER HOLDING YARD (EMPTY)

425 30 BARRICADED MODULE (SY)

FAC: 4251
BFR Required: Y

42530-1 **DEFINITION.** A barricaded module is a barricaded area comprising of a series of connected cells with hard surface storage pads separated from each other by barricades. A light shed-type metal roof or fire retardant tarpaulin installed in a manner to provide sufficient ventilation between the tarpaulin and the stored ammunition may be used to cover the individual cells. Heavy structures or flammable materials will not be used for this purpose.

The maximum net weight of explosives permitted to be stored within each cell is 250,000 pounds. Storage pads should be hard surfaced, if possible, in order to minimize the effects of earth shock from an accidental explosion. No restrictions are imposed upon the arrangement of cells within a module or upon the arrangement of groups of modules, except that all cell openings will not be faced toward each other unless they are barricaded or meet the standard quantity-distance criteria for un-barricaded above ground magazines. See Figure 42530.1 for typical module layout. See NAVSEA OP-5 for site restrictions and facility design requirements.

Figure 42530.1 Typical Module Layout

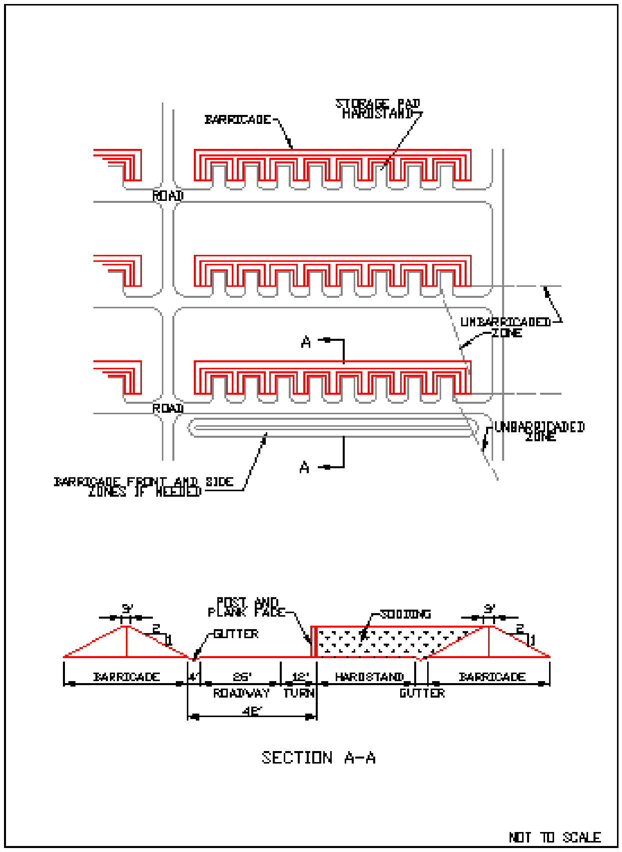


FIGURE 425-30
TYPICAL ARRANGEMENT OF EIGHT-CELL MODULES

42530-2 **EXPLOSIVE SAFETY SITE APPROVAL.** Explosives safety site approvals are required for facilities of this category code. See NAVSEA explosives safety criteria for more detail. The planner preparing the site approval must have current certification through AMMO-36 Explosives Safety for Naval Facility Planning offered by the Defense Ammunition Center.

430 COLD STORAGE

430-1 DEFINITION

Cold storage is planned to provide refrigerated warehouses for storage of General Supply Materials which require temperatures ranging from -10°F to 60°F in the following categories:

- Perishable Substances
- Photosensitized Material

- General Supply Batteries
- Medical and Dental Supplies

430-2 EXCLUSION

Excluded from this category group are cold storage for weapons-related batteries (use Category Code 424 10) and cold storage spaces that are a functional part of another facility such as an open mess, club, hospital, commissary or exchange. These cold storage spaces are planned as part of their respective main facilities and are accommodated within its space allowances.

430-3 OTHER APPLICABLE REQUIREMENTS

In most CONUS locations, Cold Storage Facility requirements have been all but eliminated through changes in supply business processes. Direct Vendor Delivery contracts provide such materials directly to end users in an as needed frequency required to effectively transfer the related warehousing from the public to the private sector vendors. These requirements guidelines are provided for those missions who do require an installation or area storage facility to hold some measure of items requiring cold storage.

430-4 STORAGE OF FARINACEOUS AND HIGH ACID FOOD PRODUCTS

These food products are properly stored in an environment where the temperature is between 50 and 70 degrees Fahrenheit. A cold storage warehouse will be required to provide chill storage at those activities where climatic conditions preclude the use of a general purpose warehouse.

431 10 COLD STORAGE WAREHOUSE (SF)

FAC: 4311
BFR Required: Y

43110-1 **DEFINITION.** A cold storage warehouse is planned to preserve the quality of perishable foods and general supply materials that require refrigeration. The warehouse will include freeze and chill space and normal processing facilities and mechanical areas. The space requirements are applicable to cold storage facilities of all sizes whether built as separate structures or in conjunction with other buildings and are determined by using the criteria furnished in the BFR guidance above. For installations with such requirements, correlated to loading, Table 43110-1 provides a means of estimating cubic feet. The facility requirements are based upon the cubic foot space required per man per 30 days. This method utilizes subsistence consumption requirements for shore facilities and provides for two types of storage requirements.

For additional information, see MIL-HKBK 1032/2.

Table 43110-1
TCF Allowances for Refrigerated
Warehouse Facilities per Man per Month

Total Cu. Ft. (TCF) Allowances for Category Code 431-10:

Type I Requirement: Allows 4 cubic feet (CF) of perishable subsistence per man per month when fresh milk and bread are received monthly.

Type II Requirement: Allows 3 CF of perishable subsistence per man per month when fresh milk and bread are received at least every other day.

Type	Net Cubic Feet Per Man Per Month	Universal Factor**	TCF Allowances Per Man Per Month*		
			Total	Chill	Freeze
I	4	1.96	7.84	4.12	3.72
II	3	1.96	5.88	4.12	1.76

* All allowances represent average values. If historical data are available that differ from these allowances, such data may be used for requirements planning if fully justified/documented.

** See derivation of "Universal Factor" in appendix P 80X. This factor states, “1.96 TCF are required per cubic foot of material to be stored or 78.4 TCF are required per M/T of material to be stored.”

440 GENERAL SUPPLY BUILDING

440-1 DESCRIPTION

This category group consists of supply-oriented covered storage and/or storage support facilities that are assigned to the Supply/Material Department or assigned for storage of operational mount-out stocks. Requirements allowance guidance can be found in the General Supply Planning Guidance under Requirements Determination.

440-2 DETERMINING GENERAL SUPPLY REQUIREMENTS

This section provides information regarding the general methods used to calculate Basic Facilities Requirements (BFRs) for supply facilities.

440-2.1 **Definitions.**

440-2.1.1 **Cubic vs. Square Feet.** Requirements for supply operations and logistics facilities planning are first found in volume and then in the associated area, as opposed to area alone. This initial measure of volume is more commonly in cubic feet (CF) or measurement tons (MT). A MT is a logistics term that is often convenient to express a palletized or material unit load - and is equal to 40 cubic feet. The second general phase of a logistics requirement calculation is the translation of a given volume into area or square feet of facility required. This second phase is wholly dependent on an assumption of facility and storage system configuration as it interjects an available height or stacking height (SH). This is the height available to the storage function. The accommodation of a given volume requirement can vary with that of different stacking heights. That is, a given volume or cubic foot requirement translates into SF – X with SH – X and translates to SF – Y with SH – Y. This height is either that of an existing or planned building and/or system.

440-2.1.2 **BFR Qualification - Existing vs. Planned Facilities.** Supply operations' dependence on available stacking height requires a BFR to carry an assumption of SH that is either based on an existing building and system (status quo), an existing building with system upgrades (modernization) or a new building. It is, therefore, important that the BFR be qualified with the assumptions related to the respective SH (used to translate cubic feet to square feet of facility required).

440-2.2 **Calculation Methods.** BFRs may be calculated using either the analytical/4-step method or an operational space analysis method as the situation dictates.

440-2.2.1 **Analytical or 4-Step Method.** There are four steps required for determining storage space requirements by this method. This method is thought to be the preferred and most practical for use in planning up to and including the activity 1391 level or as needed to feed strategic planning.

Step 1 - Total Cubic Feet. Determine the total cubic feet (TCF) required for the CF or MT of material to be stored.

The first factor in the two part equation is determining a cubic feet (CF) or MT required by the user or user group. This cubic measure can be provided by the user (e.g., via records or expert knowledge of business forecast) or determined via a survey of existing operations coupled with an interview aimed at validating observations and forecasting any changes (i.e., survey observes 1 CF, interview relates 20% forecasted increase, requirement is 1.2 CF). A normal desired forecast for requirements is five years.

The second part of this two-part equation translates the raw volumetric measurement of required material into a CF requirement of the accommodating system or facility. This adjustment or translation accounts for the inherent losses in a storage system due to normal operations (various system and operational space losses). A universal factor has been derived and found to be 1.96 for CF and 78.4 for MT. That means that for 1 CF equates to 1.96 TCF required and 1 MT equates to 78.4 TCF required. This universal loss factor, 1.96, adjusts the raw material cubic measurement for various system and operational space losses. For example, 100 CF of raw material required translates to 196 TCF storage space required.

Step 2 – Stacking Height. Determine a stacking height (SH = available stacking height) value. For an existing facility use the current SH value. For a planned facility suggested SH's are shown in Table 440-1.

Table 440-1 Suggested Stacking Heights for Planned Facilities

Type of Storage	Stacking Height (FT)
Open Storage	4 – 10
MTIS, ILO, Outfitting Facilities	4 (without racks) Up to 12 (if racks are planned)
SERVMARTS	4 feet for display gondolas 7 feet for bin shelving
Covered Storage Facilities (other than above)	12
High-Rise Facility (planned available storage height above 12 feet)	Use the planned available storage height.

Step 3 – Net Square Feet. Determine the projected net square feet or NSF requirement by dividing the projected TCF required by the SH value determined in Steps 1 and 2 above.

Step 4 – Gross Square Feet. A NSF to gross square feet (GSF) multiplier of 2.5 or 2.0 should be applied to adjust for aisle, operational, handling and all spaces within the outer portion of the exterior walls defining the notional facility. Use 2.5 with the more common, large aisle operations that normally utilize sit-down, rider counter-balance material handling equipment and are characterized by the related ten to twelve feet maneuvering aisles. Recommend using 2.0 in facilities with more dense, modern systems referred to as very-narrow aisle. These will be characterized by aisles of less than seven feet and often outfitted with vehicle guidance such as electronic wire or mechanical rail. Where this very-narrow aisle system cannot be verified or confirmed, 2.5 should be used.

Alternative GSF Multiplier. Alternatively to the net to gross factors described above, a more accurate SF to GSF multiplier can be calculated, through a notional facility layout that depicts actual floor space required for the rack or storage footprint (i.e., no aisles or collateral areas) and the resulting total facility. The ratio of total space to racked space is the SF per NSF multiplier. For additional assistance please contact the criteria manager.

Additional Support Space. The net to gross factors listed in this step are intended to accommodate some nominal area for material receiving, processing, staging and shipping areas associated with the operation. As such required support areas can vary widely, additional space may be added to the requirement 'bottom-line' to allow for a more active receipt and shipping operation. This additional space should be supported by and documented from operator input. If such additional processing space is expected to exceed fifteen percent of the total facility, the planner should consider it a separate category code as it may begin to address a transshipment operation that is related to, but additive to, the related storage requirement calculation. In any case it would be a separate and additive calculation to that arrived using the net to gross above. Such transshipment category codes would include 156-10 and 143-55.

440-2.2.2 **Operational Space Analysis Method.** This method for determining the BFR is prescribed as a more accurate process than that developed using the 4-step method. This Operational Space Analysis Method is expected for any BFR project support beyond the activity 1391 level.

440-2.2.2.1 **Total Cubic Feet.** The TCF for the operation would be determined as described in step one of the 4-step method above (paragraph 440-2.2.1.1).

440-2.2.2.2 **Operational Analysis Mapping.** An operational analysis that maps the planned operation within an existing or planned facility should then be used to determine the facility requirements. Using input from the operator, the space analysis should identify and quantify the key operational components such as: administrative, receiving, shipping, storage, aisles. etc. It is expected that the material storage or staging portion of this analysis will include consideration and identification of storage and material handling systems. Note that each of these areas may be comprised of distinguishable components (i.e., storage can be bulk, palletized, rackable and binnable). As actual or planned SH's, aisle spacing, mechanical and miscellaneous spaces are used in this method, no related estimating metrics are required.

440-2.2.2.3 **Gross Area Requirement.** The sum of the planned areas (i.e., areas comprising the operation) form the gross area requirement - the BFR. It is expected that such an analysis would be supported by narrative and graphical documentation sufficient to convey the planned operational construct that has been coordinated with and approved by the user.

440 - 2.3 DISCUSSION OF CUBE RELATIONSHIPS.

440 – 2.3.1 **Material Cube and the Measurement Ton**. The cube of material may be expressed in terms of several units of measure. However, cubic feet and Measurement Tons are the most commonly used in the Navy. A Measurement Ton (M/T) is a volumetric unit of measure defined as 40 cubic feet. An M/T of material can be configured in any shape. It can be visualized, for example, as 40 cubes of material measuring one cubic foot each. The cube of material in bin, rack and bulk storage areas is normally quantified in terms of cubic feet of material or M/Ts of material. The M/T is the preferred unit of measure in the Navy since it is the standard unit of measure used for shipboard cargo.

The following information may prove useful in estimating M/Ts of material in storage when no other data are available. A M/T of material is the appropriate average cube of pallet load of Navy shipment cargo on a standard Navy/DoD 40" x 48" pallet with a load height averaging 36", including pallet. The cube of an average Navy pallet load in storage is typically 0.8 M/Ts or 40" x 48" with a load height averaging 30", including pallet. The maximum pallet load height specified by Military Standard 147 is 54" (including pallet). A pallet load measuring 40" x 48" x 54" high (including pallet) equals 60 cubic feet or 1.5 M/Ts of material. The maximum cargo load size specified by Military Standard 147 on a 40" x 48" pallet (with material overhanging on pallet) is 43" x 52" x 54" high (including pallet). A load measuring 43" x 52"x 30.9" high (including pallet) equals 40 cubic feet or one M/T.

440-2.3.2 **Total Cubic Feet and the Universal Factor.** The Universal Factor provides for the determination of Total Cubic Feet required based on the cubic feet or M/Ts of the material to be stored. The Universal Factor allows 1.96 cubic feet of space for every cubic foot of material that is to be stored, i.e., a ratio factor of 1.96 to 1 applies. This can also be stated as a ratio factor of 78.4 to 40 if both the "1.96" and the "1" are multiplied by 40. The Universal Factor can thus be stated in either one of two ways, i.e., "1.96 TCF are allowed per M/T of material to be stored" or "78.4 TCF are allowed per M/T of material to be stored." The term Universal Factor is used because it applies equally to bin, rack and bulk storage areas. That is, it applies to all TCF in SA Facilities. This is an extremely convenient factor for determining storage space requirements since it means that TCF can be determined, on the basis of M/Ts or cubic feet of material to be stored, without regard to whether bin, rack or bulk facilities are or will be used to satisfy the requirement. Thus, the function of determining the BFR for TCF can be completely separated from the function of facility layout, equipment select ion, comparative cost analysis and integrated systems development.

440-2.4 References.

440-2.4.1 **NAVSUP Publication 529 – Warehouse Modernization & Layout Guide.** This reference is somewhat dated, but the guidance is valid regarding the layout planning related to modernization or new construction of warehousing facilities. This remains a significant publication to that end, but should be used in conjunction with some professional logistics engineering input for any purpose beyond initial activity level 1391 preparation.

440-2.4.2 **DLAM 4145.12 – Joint Services Manual (JSM) for Storage and Materials Handling.** This manual provides detailed guidance on storage and handling of material at DoD installations, by material type. While geared towards operations guidance, this information is critical to some correct planning by providing storage assumptions that impact spatial requirements.

440-2.4.3 **UFC 4-442-01N & MIL-HDBK-1032/2.** The developing UFC and the MIL HDBK which is its primary text, provide guidance on the design of covered storage facilities. It is of particular interest to planners as it provides information that is relevant to any plans (scope) for modernization or construction, including facility and site layout guidance.

440-3 REGIONAL PLANNING FOR SUPPLY

The application of requirements guidance in a regional planning perspective is meant to identify and exploit opportunities for optimizing facility use. This optimization goal of planning analysis is implied in regionalization (i.e. seeking regional economies of scale) and requires the planner to view the sum of all available assets in their aggregate, wherever practical. It is in this aggregate view of assets that a requirements summary in cubic feet is best translated into an optimal configuration in square feet. In other words, the question of a regional planning exercise is: "What is the most efficient accommodation of my cubic foot requirement within the existing or planned square footage (facilities & systems)?" For additional information on applying this criteria in a regional perspective, contact the criteria manager via e-mail.

441 10 GENERAL PURPOSE WAREHOUSE (SF)

FAC: 4421
BFR Required: Y

44110-1 **DESCRIPTION.** This code includes general warehouses with the following characteristics: heated or unheated and with/without heavy-duty (overhead crane) capability, sprinkler systems and/or alarm systems. The purpose of related missions is to provide all or some combination of materials staging or storage, handling and processing, receipt and shipping.

44110-2 **REQUIREMENT.** The general warehouse provides covered space for bulk and in storage, aisle space, space for receiving, packing and crating, office space for direct warehouse supervision (non-administrative) and toilet facilities.

441 11 GENERAL PURPOSE WAREHOUSE, MARINE CORPS DSSC (SF)

FAC: 4421
BFR Required: Y

44111-1 **DESCRIPTION.** This category code includes requirements for Marine Corps ground activities which have been designated by Marine Corps Orders as Direct Support Stock Control activities or which have specialized DSSC functions.

44111-2 **REQUIREMENT.** For new activities, Table 44111-1 may be used for requirements development. The guidance related to 440 series requirements development found in General Supply Planning Guidance under Requirements Determination, is otherwise recommended. If the 10-foot stacking height (SH) used in Table 44111-1 is not applicable, you may reduce the SF proportionate to the increase in SH as a conservative approximation (e.g., if SH is 20 feet vs. 10 feet, 330,000 SF would translate to 165,000 SF). For DSSC mission, include military strength of the base in question plus the military strength of other locally supported units. Non-DSSC activities use only the military strength of the base at which located.

Table 44111-1 Storage Space for DSSC Functions

Installation Military Strength	SF Allowed with SH of 10 feet
Up to 500	7,500
501 to 1,000	14,000
1,001 to 3,000	36,000
3,001 to 5,000	64,000
5,001 to 7,000	96,000
7,001 to 10,000	125,000
10,001 to 15,000	182,000
15,001 to 20,000	216,000
20,001 to 25,000	286,000
25,001 to 30,000	304,400
30,001 to 35,000	333,000

441 12 STORAGE OF AIR OR GROUND ORGANIC UNITS FOR MARINE CORPS (SF)

FAC: 4421
BFR Required: Y

44112-1 **DESCRIPTION.** This category code includes general purpose storage facilities assigned to Marine Corps bases, air installations and Fleet Marine Force (FMF) units for organic requirements to include Division/Wing, Battalion/Group and Company/Squadron storage areas, Special Service storerooms, base shipping and receiving functions and any other organic storage requirements.

441 13 SPECIFIC PURPOSE WAREHOUSE, MARINE CORPS LOGISTICS SUPPORT BASE (SF)

FAC: 4411
BFR Required: Y

44113-1 **DESCRIPTION.** This facility includes general-purpose warehouses designated as storage areas for Marine Corps owned material in support of logistic support base mission as Integrated Material Managers. Also included is the space utilized in support of pre-positioned war reserve stocks.

441 14 SPECIFIC PURPOSE WAREHOUSE, MARINE CORPS SUPPORTED ACTIVITY SUPPLY SYSTEM (SASSY) MANAGEMENT UNIT (SF)

FAC: 4411
BFR Required: Y

44114-1 **DESCRIPTION.** This facility includes general-purpose warehouses designated for support of the Supported Activity Supply System (SASSY) management units to include general and mount out accounts and consolidated issue point assets.

441 20 CONTROLLED HUMIDITY WAREHOUSE (SF)

FAC: 4424
BFR Required: Y

44120-1 **DESCRIPTION.** A Controlled Humidity Warehouse is similar to a General Warehouse (441 10) in every respect except that it is constructed with appropriate vapor barriers and contains humidity control equipment to maintain humidity at desired levels. This warehouse may be a separate building or contiguous with a General Warehouse. See Figure 44120-1 for some examples of requirements that justify a controlled humidity warehouse.

Figure 44120-1. Examples of Justifying Requirements

1. Readiness and immediate issue requirements dictate a low humidity environment for moisture sensitive material.
2. A low humidity environment is required to maintain the condition of material being held in temporary storage while awaiting repair, disposition, preservation or assembly of components.
3. A low humidity environment is required to allow a reduction in reactivation time and/or reactivation cost of moisture sensitive material in storage.

441 30 HAZARDOUS AND FLAMMABLES STOREHOUSE

FAC: 4423
BFR Required: Y

44130-1 **DESCRIPTION.** A hazardous materials warehouse is required for the storage and handling of materials such as flammable and combustible liquids, acids, oxidizers, poisons, water reactive materials, caustics and organic peroxides. As safe storage of such materials lies in their separation from incompatible materials, a hazardous and flammables storehouse is required as much for adequate material separation as for their storage and handling. Such separations are normally accommodated via separate rooms. Incompatible material separation accommodations will also extend to the planning and design of containment of affluent run-off basins (i.e., in case of sprinkler event). A hazardous materials warehouse will also be equipped with fire protection and ventilation (i.e., harmful or flammable gases) in accordance with National Fire Protection Association (NFPA) standards. Site evaluation of a proposed or existing hazardous materials storehouse should be done in careful consideration to compatibility with adjacent properties, facilities or operations. Due to the compartmentalized layout of such facilities, their proper planning or planning related evaluation is sensitive to a working understanding of proper facility layout and design. Information on warehouse design and sample storage segregation layouts can be obtained from UFC 4-440-01 Warehouses and Storage Facilities.

44130-2 **STORAGE OF GAS BOTTLE CYLINDERS AND DRUMMED POL.** Storage of bottle gas cylinders and drummed petroleum, oils and lubricants (POL) are not planned for storage in flammables/hazardous warehouses and should be included in shed space, category code 441 35.

441 35 GENERAL STORAGE SHED

FAC: 4422
BFR Required: Y

44135-1 **DESCRIPTION.** The general shed is a roofed structure without complete side and/or end walls and with or without sprinkler and/or alarm systems. Examples of material stored in sheds include gas cylinders, vehicles, unfinished lumber and other construction material. Considerations for the applicability of such facilities are based on the relative need for protection from expected area weather conditions.

441 40 UNDERGROUND STORAGE (SF)

FAC: 4421
BFR Required: Y

44140-1 **DESCRIPTION.** Where it is necessary, because of potential sabotage or enemy action to protect supplies either by dispersal or protective construction, instead of programming new protective construction, existing mines may be used. Suitable mines for this purpose include: limestone, marble, quartzite, granite, gold, silver, uranium, lead, zinc and copper.

44140-2 **REQUIREMENT.** Only draft-type entries should be considered. Rooms should not be less than 30 feet wide or less than 12 feet high. Optimum dimensions are 500 feet wide and 18 feet high.

441 70 DISPOSAL SALVAGE SCRAP BUILDING (SF)

FAC: 4421
BFR Required: Y

44170-1 **DESCRIPTION.** This facility is primarily to provide covered space for the receipt, processing, staging and issue of material that has been deemed excess to Navy needs and is awaiting some resale or final disposal. To the extent practical, such operations are expected to use efficient storage practice as with a ready issue material warehouse. Where the warehousing analogy is accurate, the requirements development for this category should follow those of 441 10.

441 71 INTEGRATED LOGISTICS OVERHAUL (ILO) AND OUTFITTING BUILDING (SF)

FAC: 4421
BFR Required: Y

44171-1 **DESCRIPTION.** This facility provides covered supply space used for processing materials offloaded from or assembled for loading aboard ships. It includes space required for receiving, sorting, identifying and processing materials off-loaded as well as processing and assembly of outfitting materials to be loaded aboard fleet units.

44171-2 **REQUIREMENT.** Since the performance of this operation is primarily a function of facility floor space and not stacking height (SH), the determination of requirements is not first one of cubic feet. This operation is not characterized by a significant storage requirement and is not, therefore, dependent on a facility height. These operations are, however, dependent on a case specific estimate of peak and average operational tempo, processing times, and the related summary of material and operational floor layout requirements. A requirement should be developed using a related space analysis. If an existing operation is present, its floor space can be used as a ‘baseline’ measure from which to determine requirements through documented interview with the operators. This interview would be designed to forecast operational needs and adjust the baseline accordingly.

441 72 SERVMART (SF)

FAC: 4421
BFR Required: Y

44172-1 **DESCRIPTION.** A SERVMART provides covered supply facilities used for display and sale of supply systems materials for self-service requisitioning by end users. It includes areas used to display items on shelves or gondolas, checkout counters and administrative functions. This category excludes back-up storage areas; requirements for such areas must be based on SH values and are carried under other basic category 441 codes.

44172-2 **REQUIREMENT.** Since the performance of this operation is primarily a function of facility floor space and not stacking height (SH), the determination of requirements is not first one of cubic feet. These operations are, however, dependent on an analysis that accounts for stocked items (i.e. number & type), their stock depth and their retail shelving floor layout. A requirement should be developed using a related space analysis. If an existing operation is present, its floor space can be used as a 'baseline' measure from which to determine requirements through documented interview with the operators. This interview would be designed to forecast operational needs and adjust the baseline accordingly.

441 73 MTIS BUILDING (SF)

FAC: 4421
BFR Required: Y

44173-1 **DESCRIPTION.** A Material Turned Into Store (MTIS) Facility provides covered supply space used for processing materials turned into supply for redistribution or disposal. It includes space used for receipt, screening, identification, assembly and staging for return to storage areas.

44173-2 **REQUIREMENT.** Since the performance of this operation is primarily a function of facility floor space and not stacking height (SH), the determination of requirements is not first one of cubic feet. This operation is not characterized by a significant storage requirement and is not, therefore, dependant on a facility height. These operations are, however, dependent on a case specific estimate of peak and average operational tempo, processing times, and the related summary of material and operational floor layout requirements. A requirement should be developed using a related space analysis. If an existing operation is present, its floor space can be used as a 'baseline' measure from which to determine requirements through documented interview with the operators. This interview would be designed to forecast operational needs and adjust the baseline accordingly.

451 10 OPEN STORAGE AREA (SY)

FAC: 4521
BFR Required: Y

45110-1 **DESCRIPTION.** This category group consists of non-covered storage areas, paved or otherwise established, for storage of General Supply Materials. Several of the excluded types of functions include miscellaneous materials coded under other basic category codes (e.g., ammunition on open pad coded under 425-10 and open storage areas for non-supply oriented functions coded under 425 11).

45110-2 **REQUIREMENT.** Unless known to be otherwise, a stacking height (SH) of 4 feet should be used in accordance with the Basic Facilities Requirement (BFR) 4-step method described in the requirements section of this guidance. An estimation of material requirements, likely lay-down scenario (i.e., how material is stowed on area) and material handling equipment access is also acceptable as a means of determining square foot (SF) requirements via a space analysis.

451 70 EXTRAORDINARY SUPPORT – DISPOSAL - STORAGE AREA (SY)

FAC: 4521
BFR Required: Y

45170-1 **DESCRIPTION.** This code refers to open areas primarily to provide space for the receipt, processing, staging and issue of material that has been deemed excess to Navy needs and is awaiting some resale or final disposal and whose value is not significantly impacted by uncovered exposure to the environment. This code may also be used for such open yards required for staging or storage of items being held for their scrap value to ongoing missions or systems.

45170-2 **REQUIREMENT.** To the extent practical, such operations are expected to use efficient storage practice as with a ready issue operation. There are no metrics that can serve to guide an allowance for this operational requirement. A SH of 4 feet should be used in accordance with the BFR 4-step method described in the requirements section of this guidance. Otherwise, an estimation of material requirements, likely lay-down scenario (i.e., how material is stowed on area) and material handling equipment access may also be used in a space analysis to determine requirements.

500 SERIES
MEDICAL FACILITIES

Table of Contents

500 MEDICAL FACILITIES

500-1 GENERAL

The Office of the Assistant Secretary of Defense Health Affairs (OASD (HA)) has primary responsibility for establishing functional space criteria and standards for medical facility programs necessary to fulfill the Secretary of Defense's responsibilities. The medical program is funded by the Assistant Secretary of Defense, Health Affairs (OASD (HA)); which provides annual programming guidance, performs defense-wide health care facility planning, project programming, reviews and adjusts projects for scope and cost. Using the OASD (HA) criteria, the Office of the Navy Surgeon General (BUMED) programs all medical projects for the Navy. OASD (HA) also presents medical programs to OSD and the Congress for MILCON and UMC approval.

500-2 POLICY

This section provides general guidance for planning of Military Healthcare facilities. All Military Healthcare facilities shall be planned with the Department of Defense (DoD) objective to provide facilities that are responsive to the functional requirements of the using Military Department. Joint utilization of military healthcare facilities and medical resources available in the civilian community must be considered in planning healthcare facilities. All medical facilities including medical and dental treatment facilities (MTF's), medical training facilities, medical research facilities, and veterinary treatment facilities should meet the operating requirement and should provide reasonable flexibility to accommodate future changes. The facility should be functional as well as aesthetically pleasing, while still being economical with a practicable life-cycle-cost. The facility must meet the necessary environmental requirements including applicable federal, state, and local environmental standards and criteria.

The Military Healthcare System space planning has two fundamental objectives. Within each objective, there may be multiple levels of determination. The first objective is to develop specific functional area space based upon environmental inputs. Functional areas are driven from a set of environmental inputs. The environmental inputs are defined to indicate demand for space (e.g. program obligations, activity requirements, staffing and equipment). The four major categories of space criteria are patient care, support of patient care, administration, and support of administration. To determine the Program for Design, the environmental inputs are translated into a set of specific space criteria.

The Bureau of Medicine and Surgery (BUMED), subject to approval of the Assistant Secretary of Defense for Health Affairs (OASD (HA)), is responsible for making the ultimate determination of scope and size of Naval Healthcare facilities to be planned, programmed, and constructed for major and minor projects. The following steps are a guide to Healthcare Planning.

Note: BUMED activities will be the maintenance UIC for all facilities they occupy entirely in direct support of their mission or are the preponderant user. Stand-by/ emergency electrical generation, operational fuel storage of the generators or building heat systems and electrical transformers in direct support of the medical facilities should have the BUMED activity as the User and Maintenance UIC. The BUMED facility is not a complete and useable facility without the inclusion of these directly supporting utility systems.

The Healthcare facility and local planner will coordinate with the BUMED Echelon 3 Commands (NME, NMW, NCA, and NMSC)) to identify projects to BUMED, Director of Facilities (M4B1), Installations and Logistics as potential MILCON or UMC candidates. BUMED will identify projects to TMA as potential MILCON or UMC candidates for approval.

The Healthcare facility Commanding Officer shall coordinate will the Lead Agent and their BUMED Echelon 3 command for the development of a project-specific Concept of Operations and integrated market-driven business plan. The elements of the business plan should include, but are not limited to:

- Delivery of the TRICARE health benefit to the population enrolled to the Military Treatment Facility (MTF)
- Provision of care to selected beneficiaries to maintain readiness skills
- Clinical competencies to maximize the utilization of the facility after the needs of TRICARE Prime enrollees have been satisfied
- Develop and implement joint programs in multi-service market areas
- Identify and develop sharing initiatives with VA
- Manage the care of all MTF Prime enrollees under Revised Financing and a Basic Facility Requirement (BFR)
- Planning tasks related to project identification and formulation will be programmed and funded from other than MILCON appropriations

The BUMED Echelon 3 command Project Officers shall coordinate with the medical activity to develop DD Form 1391 and provide all supporting documentation on the medical requirements at the installation, and assist the medical activities in obtaining project validations. The BUMED Echelon 3 commands will also coordinate with the installation to provide information systems requirements and cost estimates to integrate the information systems with the installation and the activity.

The BUMED Echelon 3 command Project Officers will develop explicit planning documents for future year projects, including a Healthcare Requirements Analyses (HCRA), Economic Analyses (EA), Construction cost analyses, Make-versus-Buy Analysis, and Program for Design. Each medical MILCON project is unique and circumstances may warrant modification to the guidelines provided. The analyses will normally require the assistance of outside contractors. One or all of the listed documentation may be required.

The BUMED Echelon 3 command Project Officer, Medical Consultant, outside contractor or A/E Firm will forward all completed documentation (i.e. Project Book, HCRA EA, and DEFTAB) to BUMED Facilities (M4B1) for review. BUMED will coordinate with M3 Operations Directorate for review. BUMED will then forward the required documentation to OASD (HA) for review and approval. Once approved, OASD (HA) will issue a DA to the Design/Construction Agent (NAVFAC/Army Corps of Engineers) to proceed with the Project.

500-3 FACILITY DESIGN

The following conversion factors shall be used in programming a Navy Healthcare facility. A net to gross conversion ratio for each department shall be calculated separately. The following steps are required to determine the net area for each department:

General Methodology:
1. Apply the specific net/gross ratio specific for each department.
2. Add all the department gross areas together.
3. Add the additional net/gross conversion factors to determine the overall building gross area.

Listed below are the department net/gross conversion ratios:

Table 500-1
Department Net/Gross Ratio

Administration	**Net / Gross Ratio**
General Administration	1.40
Medical and Patient Libraries	1.35
Education and Training	1.35
Information Management	1.35
Patient Administration	1.35
Outpatient Services	
Primary Care/Family Practice	1.35
Pediatrics	1.35
Flight Undersea Medicine and Readiness	1.35
Emergency Services	1.35
Women’s Health	1.35
Wellness Clinic	1.25
Occupational Therapy	1.30
Physical Therapy	1.30
Audiology / Speech	1.35
Specialty Surgical Clinics	1.35
Orthopedics / Podiatry	1.35
Ophthalmology/ Pulmonary Services	1.35
Allergy / Immunization	1.35

Mental Health	1.35
Preventative/Occupational Medicine	1.35
Dental Clinics	1.35
Inpatient Services	
Nursing Units	1.50
Labor and Delivery/ OB Unit	1.50
Nursery	1.45
Surgery	1.60
Support Ancillary Services	
Food Service	1.35
Logistics	1.25
Pathology	1.25
Radiology / Nuclear Medicine	1.50
Pharmacy	1.25
Vet services	1.35
Chapel	1.20
Patient Services	1.35
Clinical Investigation	1.35

After all the department totals are calculated and totaled, the additional net/gross ratios need to be added. Listed below are the building net/gross conversion ratios, based on building type:

Table 500-2
Net To Gross Square Feet Calculations

Allowances/ Categories	Medical/ Dental Clinics	Ambulatory/ Health Care Facility	Station/ Community Hospital	Regional Medical Centers
MECHANICAL SPACE	13.50%	14.5%	15.0%	16%
ELECTR. SPACE	2.0%	2.0%	3.0%	3.0%
CIRCULATION	14.0%	15.0%	15%	16%
HALF AREAS	1.5%	1.5%	1.5%	1.5%

Notes: For addition/alteration projects, up to 15% of the total altered net space may be added to the flexibility allowance to offset physical constraints in the existing facility. This increased allowance must be validated during design.
1. Buildings with multiple floors may need additional circulation ratios for stairs, elevators, etc.
2. For facilities with emergency power systems, other than Hospitals and Regional Medical Centers, increase electrical from 2.0% to 3.0%. Hospitals and Regional Medical Centers have a percentage that already assumes that emergency power systems are required.

3. Communication/network server spaces shall be programmed in Section 2.4: Information Management and throughout all departments.
4. Add 25% to mechanical areas for projects in Germany (requires all floor mounted equipment).
5 Add 8% to circulation areas for projects in Germany (natural daytime lighting requirements).

510 HOSPITAL AND OTHER MEDICAL TREATMENT FACILITIES

510 10 HOSPITAL (BD)
FAC: 5100
BFR Required: Y

51010-1 **GENERAL.** A Healthcare facility that provides general and specialized medical care for authorized personnel, with both inpatient and outpatient services. This facility will also normally contain clinics, such as Medical, surgical, pediatrics, obstetrical, ICU and CCU. The facility will have a Pharmacy, ambulance, and administrative area. This facility will admit for more than 24-hour stay.

510 11 MEDICAL CENTER (SF)
FAC: 5100
BFR Required: Y

51011-1 **GENERAL.** A regional medical center. These facilities support both increased surgical capabilities and a surgical graduate education program, not required in smaller hospitals. Applies to Bethesda, Portsmouth and San Diego (Balboa).

510 12 PRE-POSITIONED FLEET HOSPITAL WAREHOUSE (UNASSEMBLED) (EA)
FAC: 5306
BFR Required: Y

510 15 HOSPITAL BRANCH / ANNEX (BD)
FAC: 5100
BFR Required: Y

510 16 MEDICAL ADMINISTRATION (SF)
FAC: 6100
BFR Required: Y

51016-1 **GENERAL.** A building or space that provides administrative support for medical, dental or veterinary functions that is physically located outside of a defined hospital or clinic facility. Types of functions would include, but not limited to, TRICARE management, resource management, patient administration, medical command personnel. Medical administrative personnel provide essential work for the accomplishment of the medical mission. These individuals do not counsel, diagnosis, examine or treat patients. This category does not serve as headquarters space for command level units. Reference the following for space planning: https://www.wbdg.org/FFC/DOD/MHSSC/ARCHIVES/spaceplanning_healthfac_25_2006.pdf.

510 20 HOSPITAL LAUNDRY (SF)

FAC: 5100
BFR Required: Y

510 77 HOSPITAL MEDICAL STORAGE (SF)

FAC: 5306
BFR Required: Y

530 LABORATORIES

530 10 DISPENSARY AND OUTPATIENT CLINIC (SF)

FAC: 5500
BFR Required: Y

53010-1 **GENERAL.** Free Standing Clinic, outpatient clinic, which occupies a building or part of a building, but is not physically located with a hospital or medical center that provides routine and emergency care to authorized personnel.

530 20 MEDICAL LABORATORY (SF)

FAC: 5302
BFR Required: Y

53020-1 **GENERAL**. A facility, detached from a hospital that provides laboratory support to the hospital and/or other medical activities. The analysis and diagnostic laboratory includes chemistry, diagnostics and microbiology testing sections and a quality assurance and technical support section. Contact the Bureau of Medicine and Surgery (BUMED) or the appropriate BUMED Echelon 3 command when planning this facility.

530 25 PHARMACY (SF)

FAC: 5500
BFR Required: Y

53025-1 **GENERAL.** A pharmacy building or space that dispenses medically prescribed drugs. This category is used for standalone buildings or to delineate functional areas within facilities located outside a defined hospital or clinic facility (for example Exchange, Commissary, etc.). Pharmacy areas within hospitals or clinics will not be separately identified but will carry the same category code as the hospital or clinic. This category does not serve as headquarters space for command level units.

530 30 MORGUE (SF)

FAC: 5303
BFR Required: Y

53030-1 **GENERAL.** A facility, either detached or within a hospital, for the identification, preparation, and holding of human remains.

530 40 VIVARIUM CLINIC (SF)

FAC: 5304
BFR Required: Y

53040-1 **GENERAL.** The vivarium clinic is a medical research laboratory for keeping and raising animals and plants under natural conditions for observation and research. This clinic may also do biological defense and other research for war and peacetime protection. Contact the Bureau of Medicine and Surgery (BUMED) or the BUMED Echelon 3 command when planning this facility.

530 45 VETERINARY TREATMENT FACILITY (SF)

FAC: 5304
BFR Required: Y

53045-1 **GENERAL.** This facility is used to provide food safety and quality assurance, care for government owned animals (working dogs and horses), and animal disease prevention and control. Veterinary services are to examine, immunize and treat for the prevention and control of diseases or conditions that are transmissible to humans or animals, or may constitute a military community health problem. Conditions that are not transmissible from one animal to another or to a human generally are not treated at this facility. A veterinary treatment facility (VTF) is equipped and staffed to perform the entire spectrum of veterinary services required by a military installation. A VTF includes offices for the veterinarian and section chiefs, conference room, library, food inspection room, waiting room, x-ray facilities, pharmacy, clinical laboratory room, inside rabies quarantine kennel rooms, inside-outside kennel area for hospitalized government owned animals, toilets and showers, employee lounge, locker and dressing rooms, linen room and storage space for records, supplies and cleaning equipment. Table 53045-1 provides space allowance for individual components of a Veterinary Treatment Facility. It should be noted that not all components may be required for each Facility.

> **Note: Cat Codes 530-40 and 530-45 should be used when the tenant is an Army Veterinarian conducting food inspections. This is the only instance where it is a BUMED funding responsibility and requires the BUMED Activity as the Tenant / User and Maintenance UIC.**

For a veterinary clinic operated by MWR in support of the base populations' pet animals or for a military working dog (MWD) kennel, please use Category Code 730 76. These are not BUMED activities.

Table 53045-1

Type of Space	Net Square Feet
I. Clinical Spaces	
Exam. Rms.	120
Surgical Suite	200
Clean Utility Room	80
Dirty Utility Room	80
X-ray (incl. processing space)	250
Kennel (quarantine)	80
Pharmacy Store Room	120
Food Inspection Room and Laboratory	470
Clinic Laboratory Area	120
Stray Animal Confinement Kennels	10/40
Utility and Supply Area	150
Rabies Quarantine Kennels	40
Hospitalization Kennels	40
Utility Area for Kennels	140
Kennel Inside and Outside	60
II. Support Spaces	
Chief Veterinarian Office	140
Administrative Support Area	120
Reception Area and Control Area	140
Clinical Records Holding Area	50
Employees' Lounge	140
Patient Handler Waiting Room	200
Conference Room/Library	250

530 50 ENVIRONMENTAL PREVENTATIVE MEDICINE LABORATORY (SF)

FAC: 5302
BFR Required: Y

53050-1 Criteria for this category code are currently being written.

530 60 MEDICAL WAREHOUSE (SF)

FAC: 5306
BFR Required: Y

53060-1 **GENERAL.** A storage facility for medical equipment and supplies that is continuously withdrawn and replenished. Storage of war reserve medical supplies is included in depot storage facilities.

530 70 AMBULANCE SHELTER (SF)
FAC: 5307
BFR Required: Y

53070-1 **GENERAL.** A covered space used to shield the Ambulance, its driver and its patients from exposure to the elements.

540 DENTAL CLINICS

540-1 A dental clinic is an oral health care service facility equipped and staffed to perform dental procedures for general practices, a specialty, or a grouping of specialties. A dental facility will normally include treatment areas, administrative, support and storage areas.

540 10 DENTAL CLINIC (SF)
FAC: 5400
BFR Required: Y

54010-1 **GENERAL.** The Bureau of Medicine and Surgery (BUMED), subject to the approval of the Assistant Secretary of Defense (Health Affairs), is responsible for the determination of scope of dental clinics planned, programmed, and constructed. The following information is provided as a guide to be utilized for planning and preliminary programming purposes.

Step 1: <u>Beneficiary Population</u>. Determine the active duty beneficiary population. On average there will be 1 dental officer per 800 active duty beneficiaries.

Step 2: <u>Staffing</u>. Obtain staffing figures for the planning year from the Authorized Manpower documentation for the military personnel and the authorized positions for the civilian personnel. The planning documents must be submitted via the BUMED Echelon 3 to the BUMED Manpower Division (M1) for confirmation of support for any increased staffing, both military and civilian.

Step 3: <u>Dental Treatment Rooms (DTR's)</u>. Determine the number of required DTR’s from the following criteria.

- 1 DTR for each dentist in training.
- 2 DTR’s for each general duty dentist assigned to clinical dentistry. 2 DTR’s for each Prothsodontist, Periodontist, Endodontist, Oral Surgeon, Pedodontist, and Comprehensive General Dentist assigned to clinical dentistry.
- 3 DTR’s for each Orthodontist.

NOTE: When the total number of dentists is five (5) or less, use a DTR factor of 2 DTR's per dentist Clinics with six (6) dentists will have a minimum of 10 DTR's.

- 1 Oral Hygiene Treatment Room (OHTR) for each oral hygienist or technician functioning as oral hygienist.

Step 4: Clinic Space Required. After calculating the number of DTR's required, consult table 540-10A to determine the gross area required. Interpolation is required. These figures include space allowance for all functions that are in direct support of the dental clinic, such as administration, locker rooms, conference rooms, limited prosthetic laboratory, storage of operating supplies, a central sterile and dental X-ray. This also includes waiting rooms, mechanical spaces, restrooms, circulation, walls and partitions, and consultation rooms. Interpolation, as explained at the front of the 500 series, is necessary.

Table 54010-1
Space Allowances for Dental Clinics

Number of DTR's and OHTR's	Gross Area per DTR and OHTR (sq.m / GSF)
2	93 sq.m. / 1000 GSF
3	93 sq.m. / 1000 GSF
4	84 sq.m. / 900 GSF
6	84 sq.m. / 900 GSF
8	75 sq.m. / 800 GSF
10	75 sq.m. / 800 GSF
12	70 sq.m. / 750 GSF
18	70 sq.m. / 750 GSF
25	70 sq.m. / 750 GSF
30	65 sq.m. / 700 GSF
40	65 sq.m. / 700 GSF
50	65 sq.m. / 700 GSF
100	61 sq.m. / 650 GSF

Step 5: Optional Functions: (must be specifically justified and documented)

A. Dental Equipment Repair. For clinics with equipment repair technicians assigned, determine the number of repair technicians from Manpower Authorization and consult table 54010-2 to determine the gross area required.

Table 54010- 2
Space Allowance for Dental Equipment Repair Technicians

Number of Repair Technicians	Gross Area - sq. m. / GSF
1	25 sq. m./ 270 GSF
2	46 sq. m. / 500 GSF

3	60 sq. m. / 650 GSF

Note: Add 9 sq.m. (100 GSF) more for each additional repair technician.

B. Special Education Functions. Where specifically justified, an education training room can be planned based upon documentation of course title, frequency and duration of courses, and average on board students. A space factor of 2.6 sq.m. (28 GSF) per student will be used to size the facility based upon the average monthly student population that can be justified. Routine classroom/conference room functions are already included in table 54010-1.

C. Full Prosthetic Lab. If authorized and staffed with a full time prosthetic lab technician, additional space may be added for a full prosthetic lab. Consult table 54010-3 for the gross square area required.

Table 54010- 3
Space Allowance for a Full Prosthetic Laboratory

Function	Gross Area - sq. m. / SF
Dental Prosthetic Lab	63 sq.m./ 675 GSF
Ceramic Room	19 sq.m./ 200 GSF
Casting & Grinding	19 sq.m. / 200 GSF
Model Storage	11 sq.m. / 120 GSF
Each technician over 3	**8 sq.m.each 85 GSF**

Table 54010- 4
Space Allowance for Regional Storage

Number of Branch Clinics served	Gross Area – sq. m. / SF
Up to 5	19 sq. m. / 200 GSF
6 to 10	65 sq. m. / 700 GSF
11 to 20 (maximum allowable)	93 sq. m. / 1000 GSF

Step 6: Total Gross Square Footage Required. Add the gross square footage for the clinic obtained in step 4 to the gross square footage of the supported options obtained in step 5. The sum is the total space requirement for category code 540-10 and includes all functions that are normally associated with a Dental Clinic.

Step 7: Parking. Based on the 15 Oct 1991 MIL-HDBK-1191 (DOD Medical and Dental Treatment Facilities Design and Construction Criteria), for clinics with less than 30 DTR's, provide 3 parking spaces per DTR For larger clinics, 2.5 spaces per DTR should be planned. One space per organizational vehicle is also authorized.

Step 8: Site Selection. Site facility convenient to active duty beneficiaries. Collocation of Dental Clinics with Medical clinics is operationally efficient and desired. In site selection, provide a minimum of 25% expansion capability of the facility square meters, as calculated in step 6, & parking requirements, calculated in step 7. Facility should be sited convenient to existing utility support.

550 DISPENSARIES/ CLINICS

550 10 PRIMARY CARE CLINIC (SF)

FAC: 5500
BFR Required: Y

55010-1 **GENERAL.** A primary care clinic may be referred by various names (troop medical clinic, adult clinic, family practice clinic, OCC Health, Outpatient, and others). A primary care clinic provides the office, examination and treatment space for “primary care managers”.

550 20 AMBULATORY CARE CENTER (SF)

FAC: 5501
BFR Required: Y

55020-1 **GENERAL.** A health care facility capable of performing outpatient surgical procedures and other medical treatment, not requiring extensive patient convalescence or overnight observation.

550 30 REHABILITATION CENTER FOR DRUGS AND/OR ALCOHOL (SF)

FAC: 5500
BFR Required: Y

55030-1 This facility will provide the necessary administration, counseling, training, berthing, and recreation for rehabilitation of eligible Navy, Marine Corps and other personnel suffering from alcoholism, drug dependency and/or compulsive overeating.

55030-2 A typical Alcohol Rehabilitation Center (ARC) is composed of three major components which are: Berthing, Administration, and Operational Support area. The berthing requirements for all patients are based upon the criteria for category code 721-14, Bachelor Housing - Class A Student Barracks in order to be compatible and consistent with the Navy's treatment modality of group therapy. Each "group sized" bay or module will accommodate 12 beds and an appropriately shared head/shower. Identical berthing modules for female patients should be provided in a separate and distinct location. The number of modules required varies with patient load. A 120 patient facility requires 12 12-bed modules; the apparent extra modules are required to accommodate female patients, patients awaiting transportation and any group overflow.

55030-3 The Administration requirements are derived by using the criteria established for category code 610-10, Administration, keeping in mind that administration includes both command oriented and patient affairs.

55030-4 The Operational Support Area is composed of all those remaining facilities required for the ARC to accomplish the assigned mission. Included within this area is sufficient space for the following types of functions: group therapy rooms, some with discreet observation capability; multi-purpose room, large enough to accommodate entire facility population; a visitors lounge with some privacy; traditional classrooms with audiovisual capability; library; patients lounge; secure medical exam room and a small laboratory capability; and storage space. A planning factor of 18 square meter (190 gross square feet) per patient is used to provide for these facilities. In the event that no parking is available, the criteria for category code 852-10, Parking Area, is used to determine the parking space requirements for the organizational and non-organizational vehicles.

55030-5 The following example illustrates the methodology used to determine the space requirements for a typical ARC treating 120 patients and having a staff complement of 50 personnel.

Table 55030-1

ARC	**Component**	**Gross Area**	
		Square Meter	**Square Foot**
Berthing—Class A Student (Cat Code 721-14):	120 patients x 7 sq.m. (75.3 sf)/patient =	840	9,307
Net to gross conversion = (Includes lounges, general circulation, mechanical space, etc.)	1.71 X 840 sq.m. (9,037 sf) =	1,436	15,453
Administrative Office (Cat Code 610-10):	14 sq.m. (162.5 gsf) X 50 personnel =	700	8,125
Operational Support Area:	120 patients X 190 gsf per patient =	2,119	22,800
	Total ARC Space	5,095	55,685
Parking	**Component**	**Square Meter**	**Square Yard**
Non-Organizational			
Admin = 50 pn X 60% (factor)	35 spaces		
Patient = 120 pn X 75%	90 spaces		
	Total: 125 spaces @ 33 sq.m. (39.5 sq.yds.) =	4,125	4,933
Organizational			
Vans = 10 pn x 75%	8 spaces @ 33 sq.m. (39.5 sq.yds.) =	264	316
	Total Parking Space	4,389	5,249

NOTE: These planning factors are the maximum space allowances for this type of facility. Smaller areas are permitted as appropriate. However, in all cases, the berthing requirements must conform to the Class A Student space requirement as given in the criteria for category code 721-14, Bachelor Housing.

Version: 600.20230203

FACILITIES CRITERIA (FC)
FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

Series 600: Administrative Facilities

Record of Changes:

Date	CCN #	CCN Title	Change Description
Sept 2013	61010	ADMINISTRATIVE OFFICE	For simple BFRs, a maximum Admin GSF/PN allowance of 162.5 GSF/PN applies. This allowance includes office space, admin support space, break room space, conference/training room space and a net-to-gross factor of 1.25.
July 2019	61010	ADMINISTRATIVE OFFICE	Continue to use a maximum Admin GSF/PN allowance of 162.5 GSF/PN. For simple BFRs, a net-to-gross factor of 1.40 now applies. For project level BFRs, use the Admin BFR Generator to calculate the actual Admin GSF/PN allowance and Net-To-Gross factor.
Feb 2021	61010	ADMINISTRATIVE OFFICE	Section 61010-11 added to account for Telework and Workspace Sharing. Use section 61010-11 in tandem with Admin BFR Generator.
April 2022	61040	LEGAL SERVICES FACILITY	In Table 61040-1 Space Allowance for Legal Services Facilities, change Paralegal square footage per person from 64 NSF to 110 NSF.
May 2022	61010	ADMINISTRATIVE OFFICE	In Table 61010-7.2, update “shower room” justification by including support if access to a fitness center is 5 minutes or greater by walking. Additional justification includes acknowledgement of military integrity and readiness.
28 Jul 2022	61010	ADMINISTERATIVE OFFICE	Admin. BFR Generator in Excel format mad available for download. This includes various updates.
2 Mar 2023	600 Series	UFC 2-000-05N	Change UFC 2-000-05N to FC 2-000-05N document due to the fact that this planning criteria is not unified among the other DoD services.

SERIES 600
ADMINISTRATIVE FACILITIES

Table of Contents

610 ADMINISTRATIVE BUILDINGS

610-1 DEFINITION. A building that contains general office space, administrative support space, break rooms, and conference/training rooms. Other special purpose space types may apply.

610 10 ADMINISTRATIVE OFFICE (SF)

FAC 6100
BFR Required Y

61010-1 **DEFINITION.** An administrative facility is a building or portion of a building in which the administrative affairs of an organization are conducted. It accommodates the executive and staff functions of an installation or tenant organization. Administrative office space provided within non-administrative facilities under other category codes shall conform to the criteria provided herein.

61010-1.1 **BASIC PLANNING FACTORS.** There are two methods to determine administrative space requirements: Simple BFR Calculation and Project Level BFR Calculation.

- For simple Basic Facility Requirement (BFR) calculations, a maximum administrative (Admin) space allowance of 162.5 gross square feet per person (GSF/PN) applies. An Admin GSF/PN allowance includes all administrative workspace, administrative support space, break room space, and conference/training room space. Included in the 162.5 GSF/PN factor is a net-to-gross (NTG) factor of 1.40. This method is for rough order of magnitude estimates.

- For all project level BFR calculations, where multiple factors are considered (e.g. circulation, multiple stories, scale of economy, telework, workspace sharing, etc.), the maximum Admin GSF/PN allowance of 162.5 GSF/PN still applies, however; all space requirements and the NTG factor shall be calculated. Read sections below and use the online Admin BFR Generator to simplify this process.

  Note: The Admin BFR Generator has been tested with Chrome and Internet Explorer. If security settings prevent the link above from working, copy and paste following address into your browser:

Online version:
https://www.wbdg.org/FFC/DOD/UFC/600SERIES/BFR/Admin_BFR_Generator.htm

MS Excel version for download:
https://www.wbdg.org/FFC/DOD/UFC/600SERIES/BFR/Admin_BFR_Generator.xlsx

61010-2 **Admin BFR Generator Quick Start Process.** Space requirements are calculated for administrative functions using the process below.

Process:

1. Begin on 'Activity' tab and input activity data.

2. Input number of personnel that require a private office, workstation type 1 (WST1) and/or workstation type 2 (WST2) space.
   Note 2a. Private office spaces are justified for supervisory personnel.
   Note 2b. WST1 spaces are justified for general staff personnel.
   Note 2c. WST2 spaces are justified for personnel that predominantly telework.

3. Proceed to 'Space Table' tab and input space table fields if required.
   Note 3a. Space types within the General Administrative Space and Basic Allocation Groups are used to calculate an ‘Admin GSF/PN factor’, which has a maximum allowance of 162.5 GSF/PN.
   Note 3b. Space types within the Functional Support Group, Security Group and User Defined Group are used to calculate a ‘Total GSF/PN’ factor, which may exceed 162.5 GSF/PN.

4. Proceed to 'Justification' tab and input justification fields if required.
   Note 4a. Space types within the General Administrative Space Group and Basic Allocation Group do not require justification.
   Note 4b. Space types within the Functional Support Group, Security Group and User Defined Group do require justification.

5. Proceed to 'Net-To-Gross' tab and input net-to-gross fields if required.
   Note 5a. If space loading is less than 50 PN, a Net-To-Gross (NTG) factor of 1.40 is automatically applied.
   Note 5b. If space loading is equal to or greater than 50 PN, the NTG factor is calculated.

6. Proceed to 'Summary' tab, input summary data fields and 'Submit'.
   Note 6a. The ‘Submit’ function checks to ensure all required data fields are populated. Once all required data fields are populated, the BFR is converted to PDF format and sent to the user via email.

7. Optional: Proceed to ‘Telework’ tab, and follow guidance in section 61010-11.
   Note 7a. Requires completed Base Line scenario (steps 1-5 above)
   Note 7b. Requires survey results in proper format, see section 61010-11.

61010-3 **Personnel Loading.** Personnel loading is the sum of all military, civilian and other personnel associated with an organization at a particular planning area and category code. Administrative BFRs shall be based on an official personnel loading source.

61010-3.1. **Official Personnel Loading Sources.**
61010-3.1.1. Activity certified personnel loading document
61010-3.1.2. Activity manning document
61010-3.1.3. Navy Total Force Manpower Management System
61010-3.1.4. Marine Corps Total Force System
61010-3.1.5. Other - If official reports are not available, certification of the personnel loading data used as a basis for BFR development must be provided by a responsible approval authority.
61010-3.1.6. SIMNavy can provide initial personnel loading reports, but must be certified by the tenant activity for accuracy. Website requires Chrome browser and user authentication. https://fres.cnic.navy.mil/SimNAVY/SimNavy.aspx

61010-3.2. **Personnel Loading Year.** Personnel Loading Year refers to a particular fiscal year for which the projected staffing applies. For planning purposes, a five-year projection is applied.

61010-3.3. **Personnel Loading Types.** Personnel loading types include military, civilian and other personnel.
61010-3.3.1. Military personnel include all active duty personnel. Reserve personnel are justified on a case-by-case basis.
61010-3.3.2. Civilian personnel include all direct hire personnel.
61010-3.3.3. Other personnel include all contractor, foreign national and/or other miscellaneous personnel.

61010-4. **Space Loading.** Space loading is the sum of all personnel requiring private office, Workstation Type 1 (WST1) and/or Workstation Type 2 (WST2) space, associated with an organization at a particular planning area and category code. Personnel loading should be equal to space loading.

61010-5. **General Administrative Space.** General Administrative Space types are justified to support administrative or similar functions and include: private office spaces, WST1 spaces, WST2 spaces as well as secondary circulation space. As part of the General Administrative Space group, these space types are based on official personnel loading reports and do not require further justification. Tenant (personnel and/or space) loading reports must be provided as a separate attachment for project level BFRs.

Table 61010-5.1. **General Administrative Group Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Private Office	A private office provides an enclosed space, typically occupied by supervisory personnel or for those personnel whose job duties require privacy. Depending on an organization's telework and workspace sharing policies, this space type may be dedicated or shared. Private office space allocations typically range from 100-120 NSF/PN.	Allocate 120 NSF/PN requiring private office space	• The number of personnel requiring private office space is supported by an official personnel loading report. 
WST1 (WS Type 1)	A WST1 is a modular workstation, typically occupied by general administrative or support staff. Depending on an organization's telework and workspace sharing policies, this space type may be dedicated or shared. WST1 space allocations typically range from 48-64 NSF/PN.	Allocate 64 NSF/PN requiring WST1 space	• The number of personnel requiring WST1space is supported by an official personnel loading report. 
WST2 (WS Type 2)	A WST2 is an optional space type, similar to WST1 modular workstation, but provides an alternate (usually smaller) size. It may serve as contractor space, hoteling space, or swing space during renovation projects. Depending on an organization's telework and workspace sharing policies, this space type may be dedicated or shared. WST2 space allocations typically range from 36-48 NSF/PN.	Allocate 48 NSF/PN requiring WST2 space	• The number of personnel requiring WST2 space is supported by an official personnel loading report. 
Circulation	General administrative space secondary circulation includes the aisles between private office, WST1 and WST2 spaces. This circulation multiplier may range from 0.12 for all enclosed space (private offices) to 0.28 for all open office (workstation spaces)	Allocation is calculated using the Admin BFR Generator	• Space type does not require justification

61010-6. **Net General Administrative Space**. Sum of all space types listed above including secondary circulation.

61010-7. **Special Purpose Space.** Special purpose space groups include:

1. Basic Allowance Group
2. Functional Support Group
3. Security Group
4. User Defined Space Group

61010-7.1. **Special Purpose Space** – **Basic Allowance Group.** As part of the Basic Allowance Group for administrative functions, these space types are based on official personnel loading reports and do not require further justification.

Table 61010-7.1. **Basic Allowance Group Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Administrative Support Space	Admin support space includes: • Group file storage (as opposed to individual file storage provided within modular furniture) • Conference room equipment storage (audio/visual equipment, chairs, lecterns, and room dividers) • Day locker storage (cell phones and other small personnel items) • Lactation room(s) • Office equipment and supply storage • Reception area(s)	Allocate 8 NSF/PN	• Basic Allowance Group space types are based on personnel loading and do not require further justification. • Note: The degree to which administrative support spaces may be applied is dependent on the number of personnel. For small groups (<50 PN), this allocation may only include space for office equipment and supply storage only. For large groups (>100 PN), this allocation may include all of the space types listed in the description.
Break Room w/o Kitchen	A break room w/o kitchen is a staff-only space used for breaks or lunches. It typically includes some or all of the following: coffee bar, microwave oven, MWR drink/snack space, refrigerator and water cooler.	Allocate 2 NSF/PN	• Basic Allowance Group space types are based on personnel loading and do not require further justification.
Conference/Training Rooms	Conference/training rooms provide space for meetings, briefings and training. One overall space allocation is provided for conference/training rooms.	Allocate NSF based on: Conference/Training Room Table below	• Basic Allowance Group space types are based on personnel loading and do not require further justification.

Table 61010-7.1A. **Conference/Training Room Table**

Personnel Loading Ranges		Conf Rooms	Team Mtg/Mini Conf Room (5-10 PN) 15 NSF/PN			Conf Rooms	Conference Room (10 to 49 PN) 20 NSF/PN			Conf Rooms	Conference Room (50+ Persons) 20 NSF/PN plus 150 NSF spkr area			**Total**
LOWER	UPPER	QTY	PN	NSF/PN	NSF	QTY	PN	NSF/PN	NSF	QTY	PN	NSF/PN	NSF	NSF
0	9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	24	1	5	15	75	0	0	0	0	0	0	0	0	75
25	49	0	10	15	0	1	12	20	240	0	0	0	0	240
50	99	1	10	15	150	1	15	20	300	0	0	0	0	450
100	149	1	10	15	150	2	15	20	600	0	0	0	0	750
150	249	2	10	15	300	2	25	20	1,000	0	0	0	0	1,300
250	349	4	10	15	600	2	25	20	1,000	0	0	0	0	1,600
350	449	5	10	15	750	1	15	20	300	1	50	20	1,150	2,200
450	549	6	10	15	900	2	15	20	600	1	50	20	1,150	2,650
550	649	7	10	15	1,050	5	10	20	1,000	1	50	20	1,150	3,200
650	749	8	10	15	1,200	6	10	20	1,200	1	50	20	1,150	3,550
750	849	9	10	15	1,350	7	10	20	1,400	1	50	20	1,150	3,900
850	949	10	10	15	1,500	8	10	20	1,600	1	50	20	1,150	4,250
950	1,049	11	10	15	1,650	9	10	20	1,800	1	50	20	1,150	4,600
1,050	1,149	12	10	15	1,800	10	10	20	2,000	1	50	20	1,150	4,950
1,150	1,249	13	10	15	1,950	11	10	20	2,200	1	50	20	1,150	5,300
1,250	1,349	14	10	15	2,100	12	10	20	2,400	1	50	20	1,150	5,650
1,350	1,449	15	10	15	2,250	13	10	20	2,600	1	50	20	1,150	6,000
1,450	1,549	16	10	15	2,400	14	10	20	2,800	1	50	20	1,150	6,350
1,550	1,649	17	10	15	2,550	15	10	20	3,000	1	50	20	1,150	6,700
1,650	1,749	18	10	15	2,700	16	10	20	3,200	1	50	20	1,150	7,050
1,750	1,849	19	10	15	2,850	17	10	20	3,400	1	50	20	1,150	7,400
1,850	1,949	20	10	15	3,000	18	10	20	3,600	1	50	20	1,150	7,750
1,950	2,049	21	10	15	3,150	19	10	20	3,800	1	50	20	1,150	8,100
2,050	2,149	22	10	15	3,300	20	10	20	4,000	1	50	20	1,150	8,450
2,150	2,249	23	10	15	3,450	21	10	20	4,200	1	50	20	1,150	8,800
2,250	2,349	24	10	15	3,600	22	10	20	4,400	1	50	20	1,150	9,150
2,350	2,449	25	10	15	3,750	23	10	20	4,600	1	50	20	1,150	9,500
2,450	2,549	26	10	15	3,900	24	10	20	4,800	1	50	20	1,150	9,850
2,550	2,649	27	10	15	4,050	25	10	20	5,000	1	50	20	1,150	10,200
2,650	2,749	28	10	15	4,200	26	10	20	5,200	1	50	20	1,150	10,550
2,750	2,849	29	10	15	4,350	27	10	20	5,400	1	50	20	1,150	10,900
2,850	2,949	30	10	15	4,500	28	10	20	5,600	1	50	20	1,150	11,250
2,950	3,049	31	10	15	4,650	29	10	20	5,800	1	50	20	1,150	11,600

61010-7.1.1. **Admin GSF/PN**. The sum of all space types identified above (private offices, workstations, admin support space, break rooms, conference/training rooms and secondary circulation space) multiplied by the NTG factor, make-up the Admin GSF/PN factor. This factor shall not exceed 162.5 GSF/PN.

61010-7.2. **Special Purpose Space** - **Functional Support Group.** These space types are additive to the 162.5 GSF/PN threshold and must be individually justified. The Admin BFR Generator accounts for these space types by calculating a "Total GSF/PN factor". The Total GSF/PN factor may exceed 162.5 GSF/PN where justified.

Table 61010-7.2. **Functional Support Group Space Types**

Space Type:	**Description:**	**Planning Factor:**	**Justification Guidelines:**
Archive Storage Room	An archive storage room provides space for long-term (5+ years) storage of hardcopy files. Storage space may include letter file cabinets, legal file cabinets, flat file cabinets, high density filing systems, etc. Note 1: Archive storage is different from central file storage included within the administrative support space allocations for group working files. Note 2: Archive storage is different from distributed file storage included within a private office or workstation space allocation for individual working files. No planning factors exist for this space type. A space analysis is required.	Allocate NSF requirement based on specific archive storage needs	• Mission or functions performed • Records retention requirements per SECNAV M-5210.1 apply • Records types (legal, personnel, real estate, other) • Other justification
Command Suite, Private Office	A command suite is an office area configuration containing private offices for the command leadership and key staff. Since private offices have already been accounted for in the space loading, this is an additional 80 NSF allocation for Installation Commanding Officers at the 06 level or above, and all flag and/or SES level personnel serving in a supervisory capacity.	Allocate an additional 50 NSF for each SES/O7 or ICO O6.	• Number of SES (Senior Executive Service) personnel identified in loading reports • Number of O7 or higher (Rear Admiral, Brigadier General or higher) personnel identified in loading reports • ICO O6 or higher (Installation Commanding Officer – Navy Captain, Full Colonel or higher) identified in loading reports

Table 61010-7.2. **Functional Support Group Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Hazardous Material Storage Room	A hazardous material storage room provides storage for flammable, reactive, corrosive or toxic materials. This space type is a dedicated room and does not apply to individual free standing or wall-mounted cabinets within other room types. No planning factors exist for this type of space. A space analysis is required.	Allocate NSF requirement based on specific hazardous material storage needs	• Mission or functions performed • Type of hazardous material requiring storage (corrosive, flammable, reactive or toxic) • Supported by space analysis • Other justification
Interview Room	Interview rooms are used to conduct interviews in a private and professional environment, free of distractions. Plan for up to two interview rooms, located adjacent to an observation room.	Allocate up to two interview rooms at 120 NSF each	• Mission or functions performed • Applicable to certain Echelon II IG functions • Applicable to certain NCIS functions • Address feasibility of using CCTV feeds instead of providing an observation room • Other justification (human resource functions, polygraph functions, speech therapy functions, etc.)
Lg Format Production Room	A large format production room provides space for high-quality, large scale copier, printer, plotter and/or scanner equipment. It should include space for material storage such as large format paper rolls and ink cartridges. This space type typically applies to technical or operational functions. It is not intended for traditional office equipment, which is already accounted for in the admin support space allocation. No planning factors exist for this type of space. A space analysis is required.	Allocate NSF requirement based on specific large format production equipment	• Mission or functions performed • Function(s) supported (e.g., architecture, engineering, operational) • Equipment type(s) to be housed (e.g., large scale copiers, printers, plotters, scanners, other) • Other justification

Table 61010-7.2. **Functional Support Group Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Locker Room	A locker room provides temporary storage space for a change in clothing and other personal belongings. • Lockers authorized in support of personnel performing 24-7 operations. Provide one locker per person based on the largest shift. • Lockers authorized in support of physical training requirements for military personnel at remote locations, without access to fitness centers. Provide one locker for every 10 military personnel assigned. • Lockers authorized in support of security personnel. Provide one locker per person based on the largest shift. Use the guidance above to determine the number of lockers required.	Allocate lockers at 8 NSF each	• Mission or functions performed • Access to a fitness center is greater than a 15-minute drive time • Military, civilian and/or contractor personnel may require lockers in support of 24-7 shift or emergency operations • Military personnel may require lockers in support of mandatory physical training requirements • The number of military personnel contributing to this space requirement is supported by an official personnel loading report • Other justification
Mailroom	A mailroom accommodates processing and distribution of a facility’s incoming and outgoing mail and parcels. A mailroom must be individually justified for operational, site specific or other reasons such as large size of organization. Office space for mailroom personnel is already accounted for within the office space loading above.	Allocate 40 NSF for every 50 personnel assigned	• Mission or functions performed • Organization has 200 or more personnel • Access to the central postal facility is greater than a 15-minute drive time. • Security requirements warrant a standalone mailroom • Hours of operation • Other justification

Table 61010-7.2. **Functional Support Group Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Observation Room	An observation room is for monitoring interviews. Located adjacent to one or two interview rooms, it provides sufficient space for a small table, two chairs, and audiovisual recording equipment. One-way glass windows share common walls with the interview room(s). If feasible, consider using CCTV feeds rather than providing space for an observation room.	Allocate one observation room at 100 NSF	• Mission or functions performed • Applicable to certain Echelon II IG functions • Applicable to certain NCIS functions • Address feasibility of using CCTV feeds instead of providing an observation room • Other justification (human resource functions, polygraph functions, speech therapy functions, etc.)
Secure Storage Room	A Secure Storage Room provides a separate lockable room for storage of sensitive or high-value equipment.	Allocate one secure storage room at 100 NSF	• Mission or functions performed • Applicable to certain NCIS functions • Other justification
Shipping / Receiving Area	A shipping/receiving area accommodates loading and unloading of a wide variety of supplies and services necessary for operations. Most items can be stored in racks and stacked up to eight feet in height, while heavy items such as bulk paper supplies must remain on pallets. A shipping/receiving area must be individually justified for operational, site specific or other reasons such as large size of organization.	Allocate 80 NSF for every 50 personnel assigned	• Mission or functions performed • Organization has 200 or more personnel • Access to a central shipping/receiving facility is greater than a 15-minute drive time • Security requirements warrant a standalone shipping/receiving area • Hours of operation • Other justification

Table 61010-7.2. **Functional Support Group Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Shower Room	A shower room provides one or more shower stalls and is typically collocated with a bathroom and/or locker room. • Showers authorized in support of personnel performing 24-7 operations, without access to fitness centers. Provide one shower for every 10 persons of largest shift. • Showers authorized in support of military personnel physical training requirements, without access to fitness centers. Provide one shower for every 20 military personnel assigned. In both cases, a ratio of 80 / 20, male / female (ratio may go up as staffing structure dictates but not lower than 80 / 20), should be used for planning purposes. Use the guidance above to determine the number of showers required.	Allocate showers at 20 NSF each	• Mission or functions performed • Access to a fitness center by walking is 5 minutes or greater or a 15-minute drive time. • Military, civilian and/or contractor personnel may require showers in support of 24-7 shift or emergency operations • Military personnel may require showers in support of mandatory physical fitness requirements • The number of military personnel contributing to this space requirement is supported by an official personnel loading report. • Other justification is acceptable, particularly as it applies to mission integrity and readiness.
Technical Equipment Area	A technical equipment area is used for check-in /check-out and charging of government issued equipment (cell phones, ELMRS radios, laptops, etc.)	Allocate one technical equipment area at 100 NSF	• Mission or functions performed • Applies to CCN 89051 • Other justification

Table 61010-7.2. **Functional Support Group Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Technical Publications Library	A technical publications library provides ready access to technical manuals, handbooks, and other guidance. Note that the need for this space type has diminished, as many resources are now readily available online. As a space saving measure, consider combining technical libraries within other spaces such as small conference/training rooms, rather than providing a separate allocation. No planning factors exist for this type of space. A space analysis is required.	Allocate NSF space requirement based on specific technical publications library needs of organization	• Mission or functions performed • Function(s) supported (e.g., architecture, engineering, legal, other) • Number and size of technical libraries required. • Other justification
Vault Room	A vault room is a secured area for handling classified material. It typically includes a worktable area and access to one or more shared SIPRNet workstations. Assume 48 NSF per workstation plus an additional 16 NSF per workstation to account for a central worktable area. The basic allocation factor becomes 64 NSF per workstation. The number of workstations required is provided/verified by the special security officer (SSO) or security manager.	Allocate 64 NSF per workstation	• Mission or functions performed • Number of workstations required. • Number and size of vaults required if more than one. • Other justification
Other Functional Support Space	This is a user-defined, functional support space type and allocation. It is intended for “one-off” space types not included above.	Allocate NSF for this user-defined space type	Provide justification for this user defined space requirement

61010-7.3. **Special Purpose Space - Security Group**. These space types must be individually justified in support of specific missions or functions.

Table 61010-7.3. **Security Group Space Types**

Space Type:	**Description:**	**Planning Factor:**	**Justification Guidelines:**
Entry Control Area	An entry control area may be authorized for secure facilities allowing for orderly check-in and checkout. The entry control area provides for one entry and one exit channel adjacent to one or more security watch stations. This area includes an additional 20 NSF for every 50 personnel assigned to the organization to accommodate transit of building personnel though the entry control area. Security watch station(s) are a separate allocation (see below).	Allocate one entry control area at 100 NSF plus 20 NSF for every 50 personnel assigned	• Mission or functions performed. • Applicable to certain operational functions. See 131 series justification guidelines. • Other justification
Secure Visitor Waiting Area	A secure visitor waiting area may be authorized for secure facilities. This space type may also apply to NCIS functions and certain Echelon II Inspector General functions. In this capacity, it separates individuals under investigation or awaiting interview from other visitors and ongoing investigations. This separate waiting area helps to maintain security, protect the integrity of investigations, and avoid compromising the facts and circumstances surrounding a criminal inquiry.	Allocate one secure visitor waiting area at 120 NSF	• Mission or functions performed • Applicable to certain operational functions. See 131 series justification guidelines. • Applicable to certain Echelon II IG functions and NCIS functions • Other justification
Security Watch Station	A security watch station provides space to house a security officer and security system monitoring equipment. A security watch stations is typically located adjacent to a lobby or quarterdeck area to control building ingress and egress.	Allocate NSF based on specific security office requirements	• Mission - Organization's mission requires security beyond that provided by the host installation • Size – Organization's size requires security beyond that provided by the host installation • Location – Organization's location is geographically separated from the host installation • Other justification

Table 61010-7.3. **Security Group Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Special Security Officer Suite	A special security officer (SSO) suite is a multifunctional area containing, but not limited to, a reception area, indoctrination area, photography area, vault space, and office space for the SSO. An SSO suite may be required depending on the TS/SCI classification level and where SCIF or SAP facilities are present.	Allocate NSF based on 131 series space planning factors	• Mission or functions performed • See 131 series justification guidelines • Other justification
Weapons Vestibule and Vault	A weapons vestibule and vault are for the secure storage of weapons. The vestibule and vault are actually two separate rooms. The vestibule is equipped with individual lockers for each issued weapon, a cleaning counter with proper ventilation, and a safety loading/unloading barrel. Include a hazardous materials storage cabinet for solvent and cleaning materials. The vault is equipped with racks.	Allocate one weapons vestibule and vault at 120 NSF	• Mission or functions performed • Applicable to certain operational functions • Applicable to certain NCIS functions • Applicable to certain security functions • Other justification
Other Security Space	This is a user-defined, security space type and allocation. It is intended for "one-off" space types not included above.	Allocate NSF for this user-defined space type	• Provide justification for this user defined space requirement

61010-7.4. **Net Special Purpose Space Subtotal.** Sum of all special purpose space types.

61010-7.5. **Special Purpose Space Secondary Circulation.**

Circulation	All special purpose spaces are assumed to be enclosed. A circulation multiplier of 0.12 is multiplied by the net special purpose space subtotal.	Allocate NSF based on: (0.12) (net special purpose space subtotal)	• Space type does not require justification

61010-7.6. **Net Special Purpose Space.** Sum of all special purpose space types, *including* secondary circulation.

61010-8. **Net Building Area**. Net Building Area is the sum of net general administrative space and net special purpose space.

61010-9. **Net-to-Gross Space**. Net-To-Gross (NTG) space types are used to calculate an overall NTG area and NTG factor on a case-by-case basis.

Table 61010-9. **Net-To-Gross Space Types**

Space Type:	**Description:**	**Planning Factor:**	**Justification Guidelines:**
Adjust Building Height (option)	By default, the "Adjust Building Height" option is not applied (not checked), allowing the Admin BFR Generator to optimize the number of above ground floors (stories). If preparing BFR for an entire organization, use the default option. If preparing project level BFR and the number of stories is known, apply this option and adjust the number of floors accordingly. If preparing BFR for an individual component of an organization with less than 100 personnel, apply this option and adjust the number of floors to one.	Number of above ground floors is variable	• This option does not require justification Note: Once the number of above ground floors is established, a "net average floor area" is calculated for use in follow-on calculations.
Bathrooms	The number of toilet fixtures is based on UFC 3-420-01, Plumbing Systems. Bathrooms are assumed to be located on each floor. For planning purposes, bathrooms allocations are based on standardized modules and the number of persons per floor.	Allocate NSF based on: See Bathroom Allocations table	• Space type does not require justification

Table 61010-9. **Net-To-Gross Space Types**

Space Type:	**Description:**	**Planning Factor:**	**Justification Guidelines:**
Electrical Space	An electrical room houses electrical equipment for power distribution to other areas of a building. Multi-story buildings will have at least one electrical room per floor. The total allocation is equivalent to 60% of central mechanical room allocation.	Allocate NSF based on: $x = (y/69.2)^{1.053} (0.6)$, where x = electrical space, y= net bldg.. area	• Space type does not require justification
Elevator Hoistway	An elevator used for the movement of personnel must be designed as a passenger elevator. Passenger elevators may be used for general freight loading by using a heavy-duty interior to resist damage from hand trucks. For planning purposes, assume elevator must be able to accommodate an ambulance type stretcher (84" X 24") and a 4,000-pound load capacity.	For 2 to 4 stories, allocate one hydraulic elevator per 10,000 NSF of avg. floor area at 82 NSF each x no. of floors For 5 to 10 stories, allocate one traction elevator per 10,000 NSF of avg. floor area at 91 NSF each x no. of floors	• Space type does not require justification

Table 61010-9. **Net-To-Gross Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Elevator Machine Room	An elevator machine room contains the elevator machine equipment and controller. One elevator machine room is allocated for each elevator.	For 2 to 4 story buildings, allocate one machine room per elevator per 10,000 NSF of ground floor area at 72 NSF each. For 5 to 10 story buildings, allocate one machine room per elevator per 10,000 NSF of ground floor area at 152 NSF each.	• Space type does not require justification Note: Net ground floor area is equal to net average floor area.
Janitor's Closet	A janitor's closet accommodates all equipment and supplies to include a 24-inch square mop basin, a wall-mounted mop rack, and three feet of 10-inch wide wall shelving.	Allocate NSF based on: (one per 10,000 NSF of avg. floor area) (20 NSF/each) (# floors)	• Space type does not require justification

Table 61010-9. **Net-To-Gross Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Mechanical Space	For planning purposes, assume a variable air volume system is used with a central (primary) mechanical room located on the ground floor and one or more distributed (secondary) fan rooms located on each floor. The following equation estimates the central mechanical room area for an office building: • $x=(y/69.2)^{1.053}$, where x = size of mechanical room (NSF) and y = net building area (NSF) The following equation estimates the area for all fan rooms: • $x=(y/58)^{1.087}$, where x = size of fan rooms (NSF) and y = net building area (NSF).	Allocate NSF based on: $x = (y/69.2)^{1.053} + (y/58)^{1.087}$ where x = sum of mechanical spaces and y = net building area	• Space type does not require justification
Primary Circulation Multiplier	Primary circulation consists of the main circulation routes (hallways) connecting to the building core and common spaces (elevators, stairwells). This multiplier accounts for lobby / quarterdeck areas, but not the entry control area, security watch stations or secure visitor waiting areas listed above. Primary circulation is associated with net-to-gross space, unlike secondary circulation space, which is associated with the “net building area”.	Allocate NSF based on: (primary circulation multiplier) (net building area - secondary circulation areas)	• Space type does not require justification
Stairwell	A vertical penetration in a multi-floor building for personnel egress. For planning purposes, one story is assumed to be 12 feet in height.	Allocate NSF based on: (one per 10,000 NSF of avg. floor area) (200 NSF/each) (# floors)	• Space type does not require justification

Table 61010-9. **Net-To-Gross Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Telecom Room	Telecommunication rooms enable telephone and computer connectivity throughout a building, providing space for telephone switches and rack-mounted computer equipment.	Allocate NSF based on: (one per 10,000 NSF of avg. floor area) (110 NSF/each) (# floors)	• Space type does not require justification
Vestibule	A building entrance vestibule serves a dual purpose. First, it helps mitigate temperature differences between the indoor and outdoor environment and secondly, provides an area where people entering the building can wipe their feet on an appropriate surface.	Allocate NSF based on: (one per 10,000 NSF of ground floor area) (60 NSF/ each)	• Space type does not require justification Note: Net ground floor area is equal to net average floor area.
Other NTG Space1	This is a user-defined NTG space type and allocation. It is intended for “one-off” space types not included above.	Allocate NSF requirement for this user-defined space type.	• Provide justification for this user defined space type
Other NTG Space2	This is a second user-defined NTG space type and allocation. It is intended for “one-off” space types not included above.	Allocate NSF requirement for this user-defined space type.	• Provide justification for this user defined space type
Adjust Building Width (option)	By default, this option is not applied (not checked) and the Admin BFR Generator assumes a square footprint. Using the checkbox option allows the user to adjust the width of the building. The building width slider ranges from 30 feet wide to 210 feet wide. Building width affects the building perimeter and is used to calculate the area associated with exterior walls.	Building width and length are variable	• This option does not require justification but should only be applied if site specific project requirements are known. • Note: Daylighting and natural ventilation cooling can be important energy-saving strategies, and both require one dimension of the building to be relatively narrow, in the order of 45 to 60 ft.

Table 61010-9. **Net-To-Gross Space Types**

Space Type:	Description:	Planning Factor:	Justification Guidelines:
Exterior Wall Thickness Area	Accounts for the square footage associated with exterior walls. Exterior wall thickness is assumed to be 16 inches (1.33 feet) thick. By default, the Admin BFR Generator applies this space type.	Allocate NSF based on: (average net floor area perimeter) (wall thickness) (# floors)	• Space type does not require justification

61010-9.1. **NTG Space Total.** The NTG Space Total is the sum of all NTG space types above.

61010-9.2. **NTG Factor.**

NTG Factor	Once the net building area and net-to-gross space total have been established, the Net-To-Gross (NTG) factor can be calculated.	NTG factor = (net bldg area + NTG space total) / (net bldg area)	Justification Guidelines: • Not applicable

61010-9.3. **NTG Factor Override.**

NTG Factor Override	The NTG Factor Override function is provided within the Admin BFR Generator for situations in which an alternative NTG gross factor is required. By default, this function is not applied (not checked).	NTG factor is variable	Justification Guidelines: • Admin space within another category code that has a higher or lower NTG factor • Admin buildings must conform to host nation construction standards, which may dictate a higher NTG factor • Other justification

61010-10 **Gross Building Area**. Gross Building Area accounts for a building's above-ground stories measured to the outside wall surfaces. Gross Building Area is calculated by multiplying the Net Building Area by the Net-To-Gross Factor (or NTG Factor Override). Gross Building Area represents the overall Basic Facility Requirement (BFR).

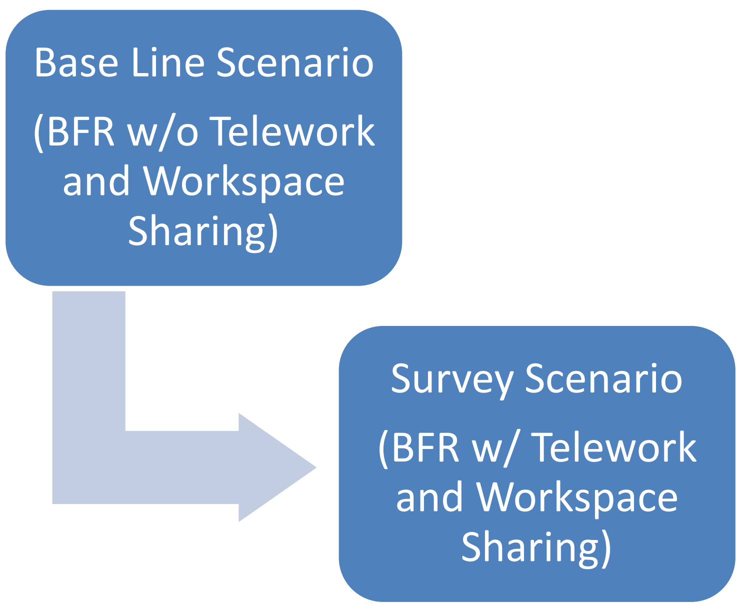
61010 -11 Telework and Workspace Sharing

61010-11.1 Introduction

Using building blocks of the existing criteria for Administrative Office and the Admin BFR Generator, this section defines the process for developing a reduced Basic Facility Requirement (BFR) that accounts for a robust telework and workspace sharing program. Individual organizations are responsible for updating telework and workspace sharing policies to meet their specific needs. The process defined here allows flexibility for consultants tasked with layout and implementation.[1]

Various federal agencies have successfully implemented reduced space requirements through the use of telework and workspace sharing. At the time of this writing, February 2021, the long-term impacts of robust and sustained telework usage for DoD organizations are unclear. Numerous DoD organizations are concurrently developing space reduction and implementation plans. It is anticipated that there will be some lessons learned from these concurrent efforts, therefore, this update provides initial guidance that will likely undergo incremental updates as part of an iterative process.

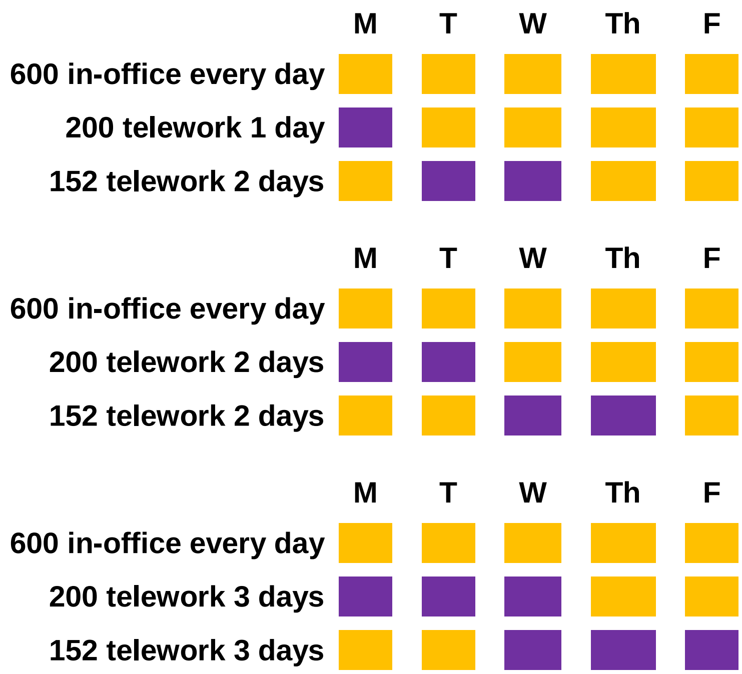
61010-11.2 Process



[1] Additional savings may be realized by accounting for employee work patterns and are best realized by consultant tasked with layout and implementation. These smaller space savings are not accounted for within this guidance.

61010-11.3 TW6+ Rationale

Savings on office space and related costs may be achieved if enough employees telework often enough. The graphic below provides three scenarios; each for an organization with 600 employees where 248 (41%) do not telework and 352 (59%) do.



In the first scenario, 200 employees telework 1 day a week and 152 telework 2 days a week. No matter how you arrange schedules, there will always be at least 2 days a week when you need space for all 600 employees.

In the second scenario, where all teleworkers work 2 days a week from home, there is still one day a week when you need space for everyone.

The third scenario identifies a minimum of 352 workspace sharing opportunities every day. Assuming schedules are arranged accordingly, a 2:1 (2 persons:1 seat) sharing ratio results in a reduction of 176 workspaces. This diagram points out the obvious fact that the more teleworkers you have working three or more days a week from home, the greater the chance of freeing up office space.

So, while an organization may start small, there is real incentive to ramp up so that a significant amount of work is home-based. This emphasizes the need for good telework managers and technology that allows workers to do any work at home that they could do in the office.

As a rule of thumb, the threshold for freeing up space is when employees are allowed to telework three or more days a week, or as with the case of the federal government, when employees are allowed to telework six or more days a pay period (*TW6+*).

The scenarios presented above are generalized to make a point, but do not consider specifics such as the type of space being shared, whether it be private office or workstation space. Guidance provided in remainder of this section does consider the specific space types and applies sizing standards.

61010-11.4 Space Sizing Standards[2]

Private Office

A private office provides an enclosed space and is typically occupied by supervisory personnel or for those personnel whose job duties require privacy. Depending on an organization's telework and workspace sharing policies, this space type may be dedicated or shared. Private office space allocations typically range from 100-120 NSF/PN.

WST1

A WST1 (WS Type 1) is a modular workstation, typically occupied by general administrative or support staff. Depending on an organization's telework and workspace sharing policies, this space type may be dedicated or shared. WST1 space allocations typically range from 48-64 NSF/PN.

WST2

A WST2 (WS Type 2) is an optional space type, similar to WST1 modular workstation, but provides an alternate (usually smaller) size. It may serve as contractor space, hoteling space, or swing space during renovation projects. Depending on an organization's telework and workspace sharing policies, this space type may be dedicated or shared. WST2 space allocations typically range from 36-48 NSF/PN.

[2] The Admin BFR Generator accounts for three standard space sizes (Office, WST1, and WST2 space). “Workspace Size Overrides” may be applied in the Activity tab if default values are not applicable.

61010-11.5 Sharing Ratios

Sharing ratios may be applied from 1:1 (no sharing) to 5:1 (maximum sharing). Sharing ratios indicate the number of persons per seat, for example, 2:1 indicates “2 persons:1 seat”. If shared WST1 spaces have a 3:1 or greater sharing ratio, they are automatically converted to WST2 space. Sharing ratios reduce the overall number of personnel in-office, but contribute to greater collaboration space allocations at the same time.

61010-11.6 Special Purpose Space

Special purpose space can impact an organizations ability to reduce space. Those that are not based on the number of personnel will invariably increase the GSF/PN factor, even as the “in-office” number of personnel decreases from workspace sharing. For instance, an Echelon II Headquarters Command will require some form of Operations Center. While specific space requirements for an operations center would be based on ‘CCN 14365 – Regional/Installation Operations Center’ criteria, the NSF results can be captured in the Admin BFR Generator via a “user defined field”.

61010-11.7 Collaboration Space

Collaboration space is another type of special purpose space, but only applies if workspace sharing is utilized. Collaboration spaces are typically enclosed and provide users with a variety of the modern technology capabilities. Collaboration space is allocated at 16 NSF/PN for each person reduced from the Base Line personnel total. This value is calculated automatically in the Admin BFR Generator. Note that collaboration space allocations are in addition to basic allowances for admin support space, break rooms and conference rooms.

61010-11.8 Sample Scenario

An organization has 614 personnel

- 111 PN occupy private office space
- 503 PN occupy WST1 space
- 0 PN occupy WST2 space

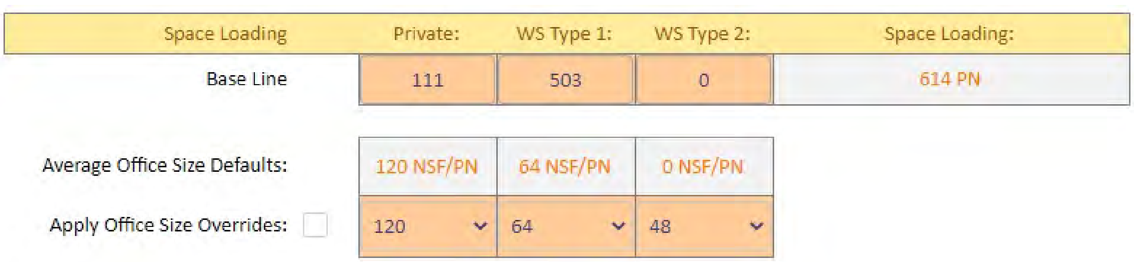
Based on a workplace survey, it is determined that:

- 65 PN require a dedicated private office space and 46 PN require shared private office space
- 143 PN require a dedicated WST1 space and 360 PN require shared WST1 space
- WST2 space is not applicable in this scenario

Sharing Ratios

- Workspace sharing ratio for private office space is 4:1
- Workspace sharing ratio for WST1 spaces is 5:1
- WST2 space is not applicable in this scenario

61010-11.9 Establishing a Base Line Scenario[3]



Base Line Scenario	Private	WST1	WST2	Space Loading
Total Persons	111	503	0	614

[3] Base Line Scenario space loading is entered in "Activity" tab of Admin BFR Generator. Workspace sizes may be adjusted in "Activity" tab.

61010-11.10 Establishing a Survey Scenario[4]

Establish a 'Survey' Scenario based on survey results that accounts for telework and workspace sharing. Note that a Base Line Scenario must be established prior to establishing a Survey Scenario. For space planning purposes, personnel will fall into one of two categories:

1. Employees that telework 0-5 days a pay period require a **dedicated** workspace

2. Employees that telework 6-10 days a pay period (TW6+) require a **shared** workspace

A Telework/Workspace Sharing Survey must be able to answer the following questions:

1. How many persons require a dedicated private office?

2. How many persons require a dedicated WST1 (WS Type 1) space?

3. How many persons require a dedicated WST2 (WS Type 2) space?

4. How many persons require a private office but are eligible and willing to share space in exchange for flexibility to telework six or more days a pay period?

5. How many persons require a WST1 space but are eligible and willing to share space in exchange for flexibility to telework six or more days a pay period?

6. How many persons require a WST2 space but are eligible and willing to share space in exchange for flexibility to telework six or more days a pay period?

[4] Base Line Scenario must be established prior to establishing Survey Scenario

Sample Survey Results:

Survey		Office Based			Telework Based		
Business / Support Line	Employees	Dedicated Private Office	Dedicated WS Type 1 Space	Dedicated WS Type 2 Space	Shared Private Office	Shared WS Type 1 Space	Shared WS Type 2 Space
AM	**73**	2	11	0	10	50	0
BD	**88**	10	32	0	1	45	0
CIO	**66**	2	4	0	7	53	0
ACQ	**10**	1	0	0	3	6	0
Counsel	**10**	6	0	0	3	1	0
DC	**60**	12	22	0	4	22	0
EV	**35**	5	10	0	1	19	0
EXBL	**40**	3	2	0	6	29	0
EXPO	**49**	3	15	0	0	31	0
CIOFP (EXWC)	**34**	2	5	0	1	26	0
FM	**40**	5	21	0	0	14	0
Front Office	**13**	6	6	0	1	0	0
IG	**5**	2	0	0	0	3	0
OPS	**16**	2	5	0	0	9	0
PW	**60**	2	2	0	9	47	0
Safety	**6**	1	5	0	0	0	0
SIOP	**7**	0	3	0	0	4	0
Small Business	**2**	1	0	0	0	1	0
Validated Totals:	**614**	**65**	**143**	**0**	**46**	**360**	**0**

Summarize sample survey results as shown below[5]

Survey Scenario	Private:	WS Type 1:	WS Type 2:	Space Loading:	Survey TW6+
Dedicated	65	143	0	208 PN	66.12%
Shared	46	360	0	406 PN	
Total	111 PN	503 PN	0 PN	614 PN	

Survey Scenario	Private	WST1	WST2	Space Loading
Dedicated	65	143	0	208
TW6+ Shared	46	360	0	406
Total Persons	*111*	*503*	*0*	*614*

Important! Survey Scenario totals must equal Base Line Scenario totals.

Base Line Scenario	*Private*	*WST1*	*WST2*	*Space Loading*
Total Persons	*111*	*503*	*0*	*614*

All necessary information is now available to establish a Survey Scenario using Admin BFR Generator and following the process below

1. Select Telework tab
2. Select ‘Base Line’ from picklist
3. Set 'GSF w/o Telework' equal to 'Gross Bldg Area' for Base Line
4. Select ‘Survey’ from picklist
5. Enter 'Survey' results
6. Apply 'Sharing Ratios'

[5] Survey Scenario space loading is entered in “Telework” tab of Admin BFR Generator

Sample Survey Scenario Output

Activity | Space_Table | Justification | Net_To_Gross | Summary | Telework

Telework

Activity Data:	
Installation:	N68469 - NSA WASHINGTON
Planning Area:	MAIN SITE - WASHINGTON NAVY YARD
Activity:	N00025 - NAVFACSYSCOM WASH DC
Category Code:	61010 - ADMINISTRATIVE OFFICE

Process:
1 Select 'Base Line' from picklist below
2 Set 'GSF w/o TW' equal to 'Gross Bldg Area'
3 Select 'Survey' from picklist
4 Enter TW/Workspace Sharing Survey results
5 Enter 'Sharing Ratios' with stepper
6 Set 'Survey BFR' equal to 'Gross Bldg Area'

Current Scenario Type* : Survey

Running Totals:

Private:	76 PN
WS Type 1:	143 PN
WS Type 2:	72 PN
Space Loading:	291 PN
Net Admin:	21,095 NSF
Net Special:	10,839 NSF
Net Bldg Area:	31,934 NSF
Admin NSF/PN:	92 NSF/PN
Est. Floors:	2 FL
Est. Width:	152 FT
Est. Length:	152 FT
NTG Area:	14,341 NSF
NTG Factor:	1.45 NTG
Gross Bldg Area:	46,276 GSF
Avg Floor Area:	23,138 GSF
Admin GSF/PN:	133 GSF/PN
Total GSF/PN:	159 GSF/PN

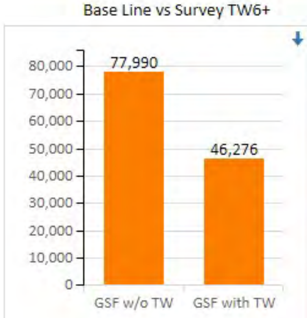
Base Line Scenario	Private:	WS Type 1:	WS Type 2:	Space Loading:	GSF w/o TW
Base Line Scenario	111 PN	503 PN	0 PN	614 PN	77,990

Survey Scenario	Private:	WS Type 1:	WS Type 2:	Space Loading:	Survey TW6+
Dedicated	65	143	0	208 PN	66.12%
Shared	46	360	0	406 PN	
Total	111 PN	503 PN	0 PN	614 PN	

Sharing Ratios*	Shared Pool	Sharing	Ratio	Shared
Private Office:	46 PN	− 4 +	4:1	11 PN
WS Type 1:	360 PN	− 5 +	5:1	0 PN
WS Type 2:	0 PN	− 1 +	1:1	72 PN

TW6+ Survey Scenario	Private:	WS Type 1:	WS Type 2:	Space Loading:	GSF with TW
Survey Scenario	76 PN	143 PN	72 PN	291 PN	46,276 GSF

Base Line vs Survey TW6+



Sharing Ratios	
Private:	4:1
WS Type 1:	5:1
WS Type 2:	1:1

GSF w/o TW	77,990
GSF with TW	46,276
GSF Delta	31,714

Survey BFR: 46,276 GSF

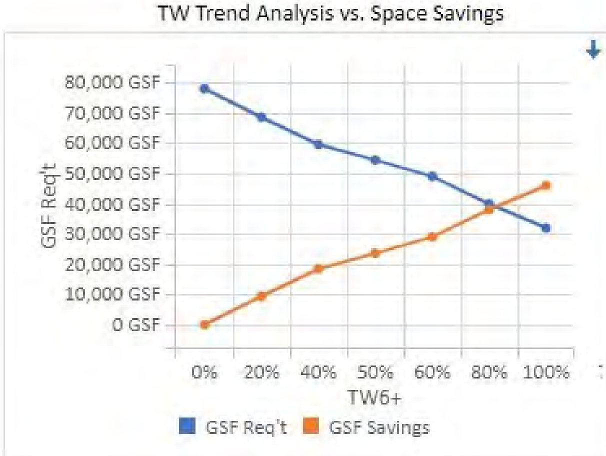
61010-11.11 Establishing a Trend Analysis[6]

The trend analysis is optional. Process steps are provided in the “Telework” tab after selecting “Trend” from picklist. This process prorates the Survey Scenario personnel loading between 0-100% and re-computes GSF space requirements at 20% intervals to generate a chart. This table and chart are useful for associating with a project timeline to show incremental space savings over time.

Sample Trend Analysis Output

TW6+	GSF Req't	GSF Savings	Savings (%)	Space Loading
0%	77,990	0	0%	614
20%	68,573	9,417	12%	517
40%	59,555	18,435	24%	419
50%	54,408	23,582	30%	370
60%	49,026	28,964	37%	322
80%	39,950	38,040	49%	224
100%	31,987	46,003	59%	159

TW Trend Analysis vs. Space Savings



Sharing Ratios

Private:	4:1
WS Type 1:	5:1
WS Type 2:	1:1

[6] The ‘Trend’ Analysis is optional. It requires that the Base Line and Survey Scenarios are established.

Conclusion

While significant space savings may be realized on paper, it is important to consider impacts of over-consolidation, future growth or surge requirements. Many Navy and Marine Corps administrative functions were able to adapt almost seamlessly from primarily working in an office environment to primarily working in a home environment as a result of the COVID-19 pandemic. A Center for Naval Analysis Study from December 2020 indicated that, “current productivity from remote working actually may be the result of previous **teamwork capital** created over time by in-person collaboration.”[7] Keep this in mind as you apply guidance contained here in Section 61010-11. It is better to err on the conservative side and let a layout and implementation consultant identify additional space savings.

Helpful Tips

If using the Admin BFR Generator and results look suspect, check if:

1. Base Line space loading fields are entered in the Activity tab
2. "Office Size Overrides" are applied in the Activity tab
3. Special purpose space allocations are hidden by using checkbox to “Show all special space types” at top of Space Table tab
4. Correct "Scenario Type" is applied in the Telework tab.
5. Value manually entered for ‘GSF w/o TW’ is correct
6. Value manually entered for ‘GSF with TW’ is correct
7. If you leave scenario picklist set to “Trend” it no longer shows the “Survey” scenario output and associated reduced BFR value. The Trend analysis is an option that shows a scenario specific linear relationship between teleworking and workspace sharing. It is recommended to set “Current Scenario Type” to “Survey” before using “Submit” function

610 30 CLASSIFIED MATTER INCINERATOR/SHREDDER AND BLDG. (SF)

FAC 6100
BFR Required Y

61030-1 No planning factors are available. Provide facilities as required.

[7] CNA Study, December 2020, Increased Teleworking: Potential Facility Savings and Policy Considerations

610 40 LEGAL SERVICES FACILITY (SF)

FAC 6100
BFR Required Y

61040-1 **DESCRIPTION.** Defense Service Offices (DSO), Regional Legal Service Offices (RLSO), Judiciary Offices, and Claims Centers provide comprehensive legal services to command and individual clients. These services include safe and secure trials by court-martial, administrative discharge proceedings and other personnel actions, adjudication of claims, legal assistance, and command advice. Properly designed and constructed, DSO/RLSO/Judiciary/Claims facilities emphasize the Navy's commitment to the administration of local, state, federal, and international law, improve the client's perception of the services provided by Navy legal personnel and allow for the most efficient provision of legal services.

61040-2 Generally, the space requirements for a DSO/RLSO/Judiciary Office/Claims Office relate to the following six functions:

1. Military Justice
2. Command Services
3. Claims
4. Legal Assistance
5. Unit Administration
6. Law Library

61040-3 Some of the space requirements can be derived from administrative space criteria, Category Code 610-10. DSOs/RLSOs/Judiciary Offices/Claims Offices, however, present a unique set of spatial constraints that must be recognized during the facility planning and design stages. These constraints include:

61040-3.1 The physical separation of the RLSO/trial counsel (prosecution, including appellate counsel), DSO/defense counsel (including appellate counsel), and judiciary (judge) spaces;

61040-3.2 Separate waiting areas for individuals waiting to be interviewed by trial and defense counsel and other clients not involved in military justice matters;

61040-3.3 Private offices for attorneys who must form attorney-client relationships that involve protected communications;

61040-3.4 Safe and secure courtrooms/courthouses where highly charged military justice proceedings routinely occur, the potential for violence is great, and the deterrence, detection and limitation of risk are paramount. Courtroom spaces must be designed to include metal detection equipment, private points of entry for various personnel, and other security measures addressed in COMNAVLEGSVCCOMINST 5530.2;

61040-3.3 Sufficient library space to allow for the continuous expansion of bound legal precedents and other legal materials.

61040-4 Table 61040-1 below delineates the functional elements of a DSO/ RLSO/Judiciary Office/Claims Office, provides planning factors, and comments on special requirements applicable to the individual elements. For the convenience of facility planners, Table 61040-1 has been designed to reflect the entire DSO/ RLSO/Judiciary Office/Claims Office operation. It may be used to calculate space requirements for the entire operation or for any of the individual components. DSO/RLSO/Judiciary Office/Claims Office facilities are planned and reported under Category Code 610 40.

Table 61040-1. Space Allowance for Legal Services Facilities

Type of Space	Allowances in NET SF (NSF)	Note
1. Unit Administration		
CO, XO, Senior Enlisted Advisor		1
Secretarial Staff	Use 610-10 Criteria	
Administrative Staff		2
Conference/Training Room	Small Activity-------1 ea 500 NSF Medium Activity----2 ea 500 NSF Large Activity-------1 ea 500 NSF + 1 ea 900 NSF	
Data Processing Space	Based upon equipment sizes	
2. Legal Assistance		
Legal Officers	120 NSF per counsel	1
Paralegals	110 NSF per person	
Staff	Use 610-10 Criteria	2
Waiting Room	9 NSF per occupant	3
Will Execution Room	100 NSF	8
3. Claims		
Legal Officers	120 NSF per counsel	1
Paralegals	64 NSF per person	
Staff	Use 610-10 Criteria	
Files	7 NSF per legal cabinet	
Archives	Small Activity-------150 NSF Medium Activity----200 NSF Large Activity-------400 NSF	
4. Law Library		
Stack Area	6.6 NSF per 100 volumes	
Work Area	25 NSF per person	
Staff	10% of stack plus reading areas	

Type of Space	Allowances in NET SF (NSF)	Note
Expansion	120 NSF	
5. Military Justice		
Courtrooms		
Trial by Court Members	1,500 NSF	4
Trial by Judge	900 NSF	4
6. Support Spaces		
Judges Chamber	250 NSF (one per judge)	
Deliberation Room	300 NSF	5
Witness Room	100 NSF (two per courtroom)	
Trial Counsel Spaces	150 NSF per Counsel	1, 6
Trial Counsel Waiting Area	9 NSF per Occupant	6
Defense Counsel Spaces	150 NSF per Counsel	1,6
Defense Counsel Waiting Area	9 NSF per Occupant	6
Detention Room	48 NSF (with W/C and Lavatory)	6
Court Reporter	150 NSF	1 , 7
Paralegals	64 NSF	
Clerks	60 NSF	
ACDUTRA Counsel/IMC Spaces	64 NSF per Counsel	
Secure Storage	100 NSF	

NOTES:

1. Private offices required
2. Private offices for staff must be individually justified.
3. Locate waiting room to serve both legal assistance and claims sections
4. Provide one courtroom for each judge, if only one courtroom is required, plan for trial by court member. If two or more are required, plan for a 1 to 1 mix of courtroom types. Provide space for 40 to 50 spectators for trial by court member type courtroom and 20 to 25 spectators for trail by judge type.
5. Provide one deliberation room with separate and integral toilet facilities for each trail by court member courtroom.
6. Plan for a minimum of two defense and trail counsel offices with separate waiting rooms and detention room as part of defense counsel spaces. It is mandatory that defense and trail counsel spaces are separated to insure confidentiality of internal proceedings.
7. If space for more than one recorder or transcriber is required, plan for general office space with acoustically treated partitioning.
8. Provide for medium and large facility.

61040-5 To obtain gross floor area, add net areas and multiply by 1.50.

61040-6 As a general rule, legal service facilities will be categorized in one of three types: small facility (with approximately 30 personnel), medium facility (approximately 45 personnel), or large facility (approximately 135 personnel).

MARINE CORPS FACILITIES

61040-7 The Marine Corps has specific requirements for courtroom facilities at certain locations. This facility provides space for the courtroom and immediately adjacent space for trial proceedings. The basic allowance provides for the following: courtroom proper, prosecution counsel, prosecution witness, defense counsel, defense witness, court reporter, judge's office, holding room, lobby, janitor, men's toilet, women's toilet and a single occupancy toilet.

61040-8 There are two facility types:

- **Type A** (large facility) - 4,440 gross sq. ft. (60' x 74'). The courtroom proper is 1,512 net sq. ft. (42' x 36') with provisions for trial by trial board members. In addition to the basic functional elements it includes a deliberation room.

- **Type B** (small facility) - 3,213 gross sq. ft. (51' x 63'). The courtroom proper is 825 net sq. ft. (30' x 27.5') with the basic functional elements as described above.

Table 61040-2. Marine Corps Requirements

Type of Function	Number of Type A Facilities	Number of Type B Facilities	Remarks
M.C.B.	1	1	Camp Pendleton requires two Type B facilities.
M.C.R.D.	1	1	
M.C.L.B.	1	1	
M.C.A.S.	1	0	New River requires a Type A facility. None at Tustin. 1st Mar Brig is serviced by M.C.A.S. Kaneohe.
COMCABS EAST/WEST	1	1	3rd Div. Requires 3 type A and 3 type B facilities
FMF (Div.)	1	2	
FMF (Wing)	1	1	
Force Troops	1	1	Force Service Support Group (F55G) is serviced by the Marine Corps air Ground Combat Center (MCAGCC).

610 50 AUSTERE ADMINISTRATIVE FACILITY (SF)

Facility planning criteria related to Austere Administrative Facilities can be found in FC 2-000-05N - Appendix F “Austere Facilities (Navy).”

610 70 DIVISION/WING HEADQUARTERS, MARINE CORPS (SF)

FAC 6100
BFR Required Y

61070-1 This category code is for a Fleet Marine Force (FMF) facility and provides the necessary administrative space to conduct the day-to-day operations of a Marine Division Headquarters or a Marine Aircraft Wing Headquarters. Determine requirements using the criteria for Category Code 610-10.

610 71 REGIMENTAL/GROUP HEADQUARTERS, MARINE CORPS (SF)

FAC 6102
BFR Required Y

61071-1 This category code is for a Fleet Marine Force (FMF) facility and provides the necessary administrative space to conduct the day-to-day operations of a Marine Regimental Headquarters or a Marine Aircraft Group Headquarters. Determine requirements using the criteria for Category Code 610-10.

610 72 BATTALION/SQUADRON HEADQUARTERS, MARINE CORPS (SF)

FAC 6102
BFR Required Y

61072-1 This category code is for a Fleet Marine Force (FMF) facility and provides the necessary administrative space to conduct the day-to-day operations of a Marine Battalion or a Squadron Headquarters. Squadron administrative facilities are often provided within the organizational maintenance hangar (Category Code 211 05) and in such cases, are not authorized under this category code. Determine requirements using the criteria for Category Code 610-10.

610 73 COMPANY/BATTERY HEADQUARTERS, MARINE CORPS (SF)

FAC 6101
BFR Required Y

61073-1 The category code is for a Fleet Marine Force (FMF) facility and is intended for those FMF units of company or battery size which require separate administrative facilities. Requirements for company or battery administrative functions are often included as part of other facilities such as bachelor enlisted quarters. Determine requirements using the criteria for Category Code 610-10.

610 74 GARRISON AID STATION, MARINE CORPS (SF)

FAC 6102
BFR Required Y

61074-1 DEFINITION. A Garrison Aid Station provides medical care at the local level for the Marine Corps and will generally be collocated with the Battalion and Regimental Headquarters facilities. The functions performed in this facility are both administrative and clinical in nature, which requires work space for the medical personnel assigned at the battalion, squadron, group, and regimental levels and space for medical file storage. Due to the functions performed at a Garrison Aid Station, it is vital to distinguish these areas from the rest of the Battalion/Squadron and Regimental/Group Headquarters facilities. This will allow for proper reporting and oversight of these facilities.

It should be noted that Garrison Aid Stations do not take the place of clinics maintained by BUMED, but rather provide the first echelon of basic medical care in a fixed facility. Access to higher echelons of care (including laboratory, radiological, or surgical services) shall be provided at BUMED facilities rather than the facility detailed here.

The Garrison Aid Station spaces may be divided up into four basic categories:

- Reception Area/Admin Area/Medical Records & Medical History Area
- Patient Areas
- Clinic Support
- Deployment Storage

61074-2 REQUIREMENTS COMPUTATION. Table 61074-1 provides space allowances or other planning guidance to calculate the facility requirements for the above components of a Garrison Aid Station.

Table 61074-1. Space Allowances for Garrison Aid Stations

Type of Space	Allowances	Notes
Reception Area/Admin Area/Medical Records & Medical History Area		
Reception Desk	64 NSF per workspace	
Waiting & Form Writing	10 NSF per patient	
History Station	40 NSF per station	
Medical Officer (MO) Office	100 NSF per workspace	1
Independent Duty Corpsman Office (IDC)	65 NSF per workspace	

Type of Space	Allowances	Notes
Administrative Support Space:		
Office Equipment (Xerox, Fax, etc.)	45 NSF average	2
Computer Support	60 NSF average	2
Records Storage, Movable	25 NSF average	2
Records Workroom	• 200 NSF for up to a battalion of 800 Marines • 25 NSF for up to an additional 100 Marines	
Reference Bookshelves	8 NSF per bookshelf	
Restrooms	25 NSF per Exam Room	3
Patient Areas		
Exam Room	100 NSF per physician	4
Treatment Room	150 NSF	5
Nourishment Center	100 NSF	5
Clinic Support		
Clean Utility	120 NSF	
Soiled Utility	90 NSF	
Equipment Storage (blood pressure cuffs, carts, monitors, spare exam items, sterilizer, open boxes of supplies, etc.)	100 NSF average	2
Janitor closet	50 NSF	
Low Volume Pharmacy	50 NSF	6
Deployment Storage		
Deployment Storage	1,000 NSF	

NOTES:

1. The MO office should be a private office. The IDC workspaces should be shared semiprivate office spaces.
2. The NSF given is an average. If the actual equipment or amount of space required is known and approved for use within the General Administrative Space, then use the actual space requirements. Medical records must be stored in locked containers and the record room must be secured by lock. Computer access to the network is required; use network support spaces of 60 NSF when needed.
3. A minimum of two private restrooms (25 NSF each) to include toilet, sink, with an additional 25 NSF restroom space for each exam room above two. Sinks shall have hot and cold running water.
4. An exam room is built for privacy and consists of an exam table, exam table paper, wall mounted ophthalmoscope, exam light, supply cabinet, exam stool, exam room desk, and access to an additional sink with hot & cold running water. The additional sink is needed to provide the clinic staff with proper hand cleansing facilities following exposure to "dirty" procedures.

5. A treatment room is used for first aid performed by support staff. A Nourishment Center provides treatment for dehydration or blood-sugar treatment.
6. The low volume pharmacy includes both dispensing and storage functions. Controlled substances must be stored within a locked storage container and the pharmacy room must be secured by a lock.

61074-3 GROSS FLOOR AREA. To compute gross floor area, the net floor area should be multiplied by an adjustment factor to compensate for common circulation, Americans with Disabilities Act (ADA) requirements, mechanical equipment spaces, NMCI equipment racks, and wall thicknesses. Apply a Net-To-Gross adjustment factor of 1.35 to determine gross floor area. Floors shall be durable and easily cleaned to maintain sanitary conditions—do not use carpeting in patient areas.

610 77 ADMIN STORAGE (READY ISSUE/SHOP STORES/MISC.) (SF)

FAC 6100
BFR Required Y

61077-1 Storage facilities for miscellaneous equipment or goods related to administrative facility support will be provided only where it can be individually justified. There are no criteria for this type of facility. General information on normal stacking heights, SF per measurement ton requirements, and other parameters are provided in Category Code 440 series.

620 ADMINISTRATIVE FACILITIES – UNDERGROUND

Criteria for the 620 series category codes are identical to Category Codes 61010 and 61077, respectively. Plan only where authorized by higher headquarters.

620 10 UNDERGROUND ADMINISTRATIVE FACILITY (SF)

FAC 6200
BFR Required Y

620 77 UNDERGROUND ADMIN STORAGE (READY ISSUE/SHOP STORES/MISC.) (SF)

FAC 6200
BFR Required Y

690 OTHER ADMINISTRATIVE FACILITIES

No planning factors are available for the 690 series. Provide facilities as required.

690 10 FLAGPOLE / MARKER (EA)

FAC 6900
BFR Required N

690 15 SALUTING BATTERY GUN MOUNT (EA)

FAC 6900
BFR Required N

690 25 REVIEWING STAND (EA)

FAC 6900
BFR Required N

690 30 CLASSIFIED MATERIAL INCINERATOR / SHREDDER (NO BUILDING) (EA)

FAC 6900
BFR Required N

Version: 700.20252703

FACILITIES CRITERIA (FC)
FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

Series 700: Housing and Community Facilities

Record of Changes:

Date	CCN #	CCN Title	Description of Change
30 Sept 2016	740 82	Golf Storage/Maintenance Facility	Added new Category Code for Golf storage and maintenance facilities
30 Sept 2016	740 80	Golf Clubhouse	Revised category code to reflect new category code 740 82
8 Feb 2018	711 20	Wherry Housing - Enlisted	Renamed Title to WHERRY HOUSING and consolidated 711 21-24 into 711 20, deleted 711 21-24
8 Feb 2018	711 25	Capehart Housing	Renamed title to CAPEHART HOUSING THRU O6, consolidated 711 26-28 into 711-25, deleted 711 26-28
8 Feb 2018	711 30	Fund Housing 1950-Thru-1969-Enlisted	Renamed Title to FAMILY HOUSING-ENLISTED-THRU-O6, consolidated 711 31-33 into 711 30, deleted 711 31-33
8 Feb 2018	711 34	Fund Housing 1950-Thru-1969 - O7-Thru-O10	Renamed title to FAMILY HOUSING-O7-THRU-O10
8 Feb 2018	711 35	Leased Housing - Enlisted	Renamed title to LEASED HOUSING THRU O6, consolidated 711 36-38 into 711 35, deleted 711 36-38
8 Feb 2018	711 40-43	Fund Housing	Consolidated into 711 30 and deleted
8 Feb 2018	711 44	Fund Housing Before-1950 -O7-Thru-O10	Consolidated into 711 34 and deleted
8 Feb 2018	711 45	Relocatable Housing - Enlisted	Renamed title to RELOCATABLE HOUSING
8 Feb 2018	711 46-49	Relocatable Housing (Various)	Consolidated into 711 45 and deleted
8 Feb 2018	711 50	Surplus-Commodity Housing - Enlisted	Renamed title to SURPLUS-COMMODITY HOUSING
8 Feb 2018	711 54	Surplus-Commodity Housing - O7-Thru-O10	Consolidated into 711 50 and deleted

Date	CCN #	CCN Title	Description of Change
8 Feb 2018	711 56-58	Foreign Source Housing, (Various)	Consolidated into 7C1 55 and deleted
8 Feb 2018	711 60	Inadequate Lanham Housing - P.L. 85-241	Consolidated into 711 30
8 Feb 2018	711 60-63	Inadequate Housing – (Various)	Deleted
8 Feb 2018	711 64	Wherry Housing – Un-acquired	Deleted
8 Feb 2018	711 65	Rental-Guarantee Housing	Consolidated into 711 30 and deleted
8 Feb 2018	711 70-73	Fund Housing (Various)	Consolidated into 711 30 and deleted
8 Feb 2018	711 74	Fund Housing After-1969 -O7-Thru-O10	Consolidated into 711 34 and deleted
8 Feb 2018	711 75-76	Manufactured Housing, Enlisted, Officer	Consolidated into 711 30 and deleted
8 Feb 2018	711 78	Family Housing-Base Operating Support Contractor	Consolidated into 711 30 and deleted
8 Feb 2018	713 10	Trailer-Sites -For Gov't Owned Trailers	Deleted
8 Feb 2018	714 77	Housing - Detached Miscellaneous Storage	Renamed title HOUSING - MISCELLANEOUS STORAGE
8 Feb 2018	721 11	Bachelor Enlisted Quarters E1/ E4	Renamed title UNACCOMPANIED ENLISTED HOUSING
8 Feb 2018	721 12-13	Bachelor Enlisted Quarters (Various)	Consolidated into 721 11 and deleted
8 Feb 2018	721 14	Class A Student Barracks	Renamed title STUDENT HOUSING
8 Feb 2018	721 15	Recruit Type Barracks	Renamed title RECRUIT BARRACKS
8 Feb 2018	721 17	Officer Candidate School (OCS)	Consolidated into 721 14 and deleted
8 Feb 2018	721 18	Naval Academy Preparatory School (Naps)	Consolidated into 721 14 and deleted
8 Feb 2018	721 19	Broadened Opportunity For Officer Selection Training (Boost)	Consolidated into 721 14 and deleted

Date	CCN #	CCN Title	Description of Change
8 Feb 2018	721 21	Transient Quarters - Mission Essential	Consolidated into 740 95 and deleted
8 Feb 2018	721 24-26	Bachelor Enlisted Quarters – Marines (Various)	Consolidated into 721 11 and deleted
8 Feb 2018	721 30	Civilian Barracks - Gs01/ Gs06	Consolidated into 721 11 and deleted
8 Feb 2018	721 31	Civilian Barracks - Base Operating Support Contractor	Consolidated into 721 11 and deleted
8 Feb 2018	721 40	Disciplinary Barracks	Renamed title DISCIPLINARY HOUSING
8 Feb 2018	721 41	Marine Corps UDP Barracks (Enlisted,) BH Mobilization	Renamed title UNIT DEPLOYED PERSONNEL (UDP) – MISSION ESSENTIAL (ENLISTED)
8 Feb 2018	721 45	Dining Facility Built-In / Attached	Renamed title to GALLEY/MESS HALL BUILT-IN/ATTACHED
8 Feb 2018	721 46	Berthing - Naval Home	Renamed title to RESIDENTIAL CARE FACILITY
8 Feb 2018	721 51-53	Transient Personnel Unit Barracks (Various)	Consolidated into 721 11 and deleted
8 Feb 2018	722 10	Enlisted Dining Facility	Renamed title to GALLEY/MESS HALL
8 Feb 2018	722 31	Dining Facility Detached - Civilian Personnel	Consolidated into 722 10 and deleted
8 Feb 2018	722 35	Austere Dining Facility	Renamed title to AUSTERE GALLEY
8 Feb 2018	722 41	Dining Facility Detached - Commissioned Personnel	Consolidated into 722 10 and deleted
8 Feb 2018	722 50	Cold Storage Detached From Galley	Renamed title to COLD STORAGE DETACHED FROM GALLEY/MESS HALL
8 Feb 2018	722 60	Conference Center - Bachelor Housing Operated	Renamed title to CONFERENCE CENTER
8 Feb 2018	723 40	Garage Detached - Bachelor Housing	Renamed Title To GARAGE DETACHED - UNACCOMPANIED HOUSING
8 Feb 2018	724 11	Bachelor Officers Quarters Permanent Party W1/W2 & 01/02	Renamed title to UNACCOMPANIED OFFICER HOUSING
8 Feb 2018	724 12	Bachelor Officers Quarters Permanent Party W3-W5 & 03up	Consolidated into 724 11 and deleted

Date	CCN #	CCN Title	Description of Change
8 Feb 2018	724 13-14	Bachelor Officers Quarters Transient (Various Ranks)	Consolidated into 740 94 and deleted
8 Feb 2018	724 15	Marine Corps UDP Barracks (Officer,) BH Mobilization	Renamed title to UNIT DEPLOYED PERSONNEL (UDP) – MISSION ESSENTIAL (OFFICER)
8 Feb 2018	724 22-23	Civilian Quarters (Various)	Consolidated into 724 11 and deleted
8 Feb 2018	724 24	Officer Indoctrination School (OIS)	Consolidated into 721 14 and deleted
8 Feb 2018	724 30	Commissioned Officers Mess - Closed (Built-In/Attached)	Consolidated into 722 10 and deleted
8 Feb 2018	740 20	Temporary Lodging Facilities (Navy Lodge)	Renamed title to PCS OFFICIAL LODGING
8 Feb 2018	740 22	Transient Housing	Consolidated into 740 94 and deleted
8 Feb 2018	740 81	MWR Rental Accommodation	Renamed title to MWR RENTAL ACCOMMODATIONS
8 Feb 2018	740 94	Visitor's Quarters (NGIS Single Mission Support Rooms)	Renamed title to TDY OFFICIAL LODGING
8 Feb 2018	740 95	Visitor's Quarters (NGIS Mission Support Suites)	Renamed title to LIMITED SERVICE OFFICIAL LODGING
13 June 2018	752 40	Athletic Stadium	CCN added
13 June 2018	735 40	School Playground	CCN deleted and assets remapped to CCN 75110 due to deletion of FAC code 7354 from RPCS by OSD.
13 June 2018	751 10	Playground	CCN name changed from “Community Playgrounds” to “Playground”.
28 May 2019	730 85	Post Office	Clarified verbiage in the “notes” section to better define population used to calculate SF allowance
14 August 2019	730 22	NCIS Field Office	Added new category code.
14 August 2019	740 58	MWR Operated catering facility	Change title to MWR Catering Facility.
14 August 2019	750 33	Pool/pump/filter/treatment facility- remote	Change title to: Pool/pump/filter/treatment facility
14 August 2019	723 50	Wash Rack-Detached	Changed FAC code and UM

Date	CCN #	CCN Title	Description of Change
14 August 2019	730 22	NCIS Field Office	CCN added.
14 August 2019	740 26	Installation Restaurant (MWR)	Consolidated into 740 04 and deleted.
14 August 2019	740 58	MWR Operated Catering Facility	Change title to MWR Operated Catering and Conference Center.
14 August 2019	744 80	Golf Storage/Maintenance Facility	CCN added.
14 August 2019	750 33	Pool/pump/filter/treatment facility- remote	Change title to: Pool/Pump/Filter/Treatment Facility
23 July 2020	Table 710.2	Navy and Marine Corps Personnel Averages (1992 Data)	Table deleted.
23 July 2020	711 45	Relocatable Housing	CCN deleted as Real Property but remains in iNFADS for inventory purposes for USMC.
23 July 2020	721 45	Galley/Mess Hall Built-In / Attached	Consolidated into 722 10 and deleted.
23 July 2020	730 45	Dependent School-Nursery School	Consolidated into 730 61 and deleted.
23 July 2020	722 10	Galley/Mess Hall	Added section 72210-4.7 which provides criteria for planning facilities of more than 2500 PN
23 July 2020	740 28	Amusement Center / Recreation Mall	Consolidated into 740 42 and deleted.
23 July 2020	740 33	Car Wash Structure	CCN added.
23 July 2020	740 52	Gun / Skeet And / Or Trap Building	Consolidated into 74090 and deleted.
23 July 2020	740 42	Community Recreation Center	Title changed from “Fleet Recreation Center”
23 July 2020	740 54	MWR/Military Recreation Center (Single Sailor/Marine Ctr.)	Consolidated into 740 42 and deleted.
23 July 2020	740 91	MWR Operated Car Wash	Consolidated into either 740 32 (building) or 740 33 (structure) and deleted.
23 July 2020	741 40	Private/Organization Club Building	CCN added.
23 July 2020	750 34	Wading Pool/Splash Pool	Consolidated into 750 30 and deleted.

Date	CCN #	CCN Title	Description of Change
23 July 2020	750 58	Recreational Campground-Tent	Consolidated into 750 59 and deleted.
23 July 2020	750 59	Recreational Campground-RV	Title changed from Recreational Campground-RV to Recreational Campground.
30 Sep 2020	750 59	Recreational Campground	Changed UM to acres (AC)
30 Sep 2020	730 22	NCIS Field Office	Criteria developed for CCN 73022. NCIS references removed from 730 20.
27 August 2021	740 54	MWR/Military Recreation Center (Single Sailor/Marine Center)	Category Code 740 54, MWR Military Recreation Center, is deleted. Data in CCN 740 54 is consolidated into CCN 740 42, Community Recreation Center.
3 November 2021	730 76	Military Working Dog Kennel	Changed title from “Kennel - Military Working Dog Kennel” to “Military Working Dog Kennel”.
3 November 2021	740 32	Car Wash Building	Changed title to “Car Wash Building”.
13 December 2021	730 66	Miscellaneous Personnel Weather	Changed BFR Required to N.
13 December 2021	730 75	Public Toilet	Changed BFR Required to N.
3 March 2022	730 22	NCIS Field Office	Exception rule added for evidence storage space types.
18 May 2022	721 11	Unaccompanied Enlisted Housing	The criteria was updated commensurate with the March 2022 update of design UFC 4-721-10N.
17 August 2022	711-56	Family Housing High Rise	Add new category code.
17 August 2022	723-31	Standalone Kitchen	Add new category code.
17 August 2022	724-20	USNA Unaccompanied Housing	Add new category code.
17 August 2022	740-31	POV Filling Station	Add new category code.

Date	CCN #	CCN Title	Description of Change
17 August 2022	730-76	Military Working Dog Kennel	Change title from Military Working Dogs to Military Working Dog Kennel.
2 Mar 2023	700 Series	UFC 2-000-05N	Change UFC 2-000-05N to FC 2-000-05N document due to the fact that this planning criteria is not unified among the other DoD services.
17 Mar 2023	722-35	Austere Galley	Change URL to access Appendix FC 2-000-05N Appendix F.
17 Mar 2023	730-10	Fire Station	Change URF to access Fire Station Space Program spreadsheet and FC 4-730-10N Navy and Marine Corps Fire Stations.
17 Mar 2023	730-10, Section 73010-8	Fire Station	Change URL to access Space Planning Spreadsheet.
17 Mar 2023	740 Series, Section 740-1.4	Community Facilities	Change URL to access Navy Minimum Standards for AT/FP.
17 Mar 2023	740-25 and Section 74025-4.4	Family Services Center	Change URL to Access Design Criteria UFC 4-730-01. Change URL to access to UFC 4-730-03.
17 Mar 2023	740-37	MWR Outdoor Recreation Center	Change URL to access UFC 4-740-03.
17 Mar 2023	740-44 and Section 74044-5	Indoor Physical Fitness Center	Change URL to access Design UFC 4-740-02 and Fitness Program Spreadsheet.
17 Mar 2023	740-49	Austere Indoor Physical Fitness Center (Gym)	Change URL to access Appendix F Austere Facilities (Navy).
17 Mar 2023	740-53-2.2	Swimming Pool – Indoor (Including Poolside Deck)	Change URF to access design criteria on swimming pools.
17 Mar 2023	740-55 and Section 74055-5	Youth and School Age Care Center	Change URL to access UFC 4-740-06. Change URL to access Space Program Spreadsheet.
17 Mar 2023	740-74 and Section 74074-3	Child Development Center	Change URL to access Child Development Center Space Program Spreadsheet. Change URL to access FC 4-740-14N. Change URL to access Child Development Center Space Program Spreadsheet.
1 Dec 2023	740-04	Exchange Food Service	Modify title and description.
1 Dec 2023	740-32	NEX Car Wash Building	Modify title and description

Date	CCN #	CCN Title	Description of Change
1 Dec 2023	740-33	MWR Car Wash Structure	Modify title and description.
1 Dec 2023	750-36	Copper COAX CCTV and CATV Lines	Modify title and description.
1 Dec 2023	740-82	Golf Storage / Maintenance Facility	Delete Category Code. This function is captured in Category Code 74480 – Golf Storage Maintenance Facility.
1 Dec 2023	730-76	Military Working Dog Kennel	Complete update of space requirements.
15 Jan 2024	740-06	Non-Exchange Installation Restaurant (MWR)	Add new category code.
23 Dec 2024	744 80	Golf Storage Maintenance Facility	Remove Figures 74480-1 and 74480-2 from the Table of Contents. Maintain these tables in the Space Allowance section of the Category Code.
27 Mar 2025	722 10	Galley / Mess Hall	Delete the reference FC 4-722-01F and add the reference UFC 4-722-01.
27 Mar 2025	740 55	Youth and School Age Care Center	In section 74055-5, Space Program, delete existing link and add direct link to UFC4-740-06 to access the Youth Center Space Program spreadsheets.
27 Mar 2025	730 61	Dependent School - Consolidated	Rewrite criteria definition

700 SERIES
HOUSING AND COMMUNITY FACILITIES

Table of Contents

710 FAMILY HOUSING

For Design Criteria, refer to UFC 4-711-01 “Family Housing”

710-1 DESCRIPTION

A family housing requirement exists for all Navy and Marine Corps military and key civilian personnel with dependents. Housing will not be programmed where the local housing market has the capacity to provide suitable rental housing for military facilities.

710-2 BASIC CATEGORY GROUPS

The basic categories of facilities included in the 710 Family Housing group are shown in Table 710-1.

Table 710-1 Basic Categories of Facilities in the 710 Group

Group Code	Description
711	Family Housing – Dwellings and Attached Garages
712	Family Housing – Mobile Homes (Substandard)
713	Family Housing – Mobile Home Parks
714	Family Housing – Detached Facilities

710-3 GROSS HOUSING REQUIREMENT

The gross housing requirement for a naval installation is based on the number of eligible personnel with dependents. Eligible personnel are commissioned officers, warrant officers, or enlisted members and key civilian employees. Students in these categories are included if they are on permanent change of station orders for courses of 20 or more weeks. The gross housing figure for a base may be developed from its planned personnel strength projected as far as reliable estimates are available, or from a study of the base table of organization, utilizing the marriage factors developed from an actual survey of personnel assigned to a similar installation.

711 FAMILY HOUSING - DWELLINGS AND ATTACHED GARAGES

Design Criteria: refer to UFC 4-711-01 “Family Housing” for Detailed Guidance, Sample Calculations & Tables of acceptable Land Use Intensity Ratios.

71120 Through 71176-1 REQUIREMENTS. Public quarters for eligible military personnel will be planned as indicated in section 710. Housing for key civilian personnel with dependents will be planned on an individual basis. Government-owned or controlled housing will be provided for all eligible personnel required to reside on-station by reason of military necessity, and for other eligible personnel for whom it is impracticable to obtain adequate private housing at reasonable rentals and locations.

71120 Through 71176-1.1 Net Housing Requirements. In computing net housing requirements, existing housing in the following category codes will be considered as assets against gross requirements:

1. Wherry housing un-acquired.
2. All adequate public quarters.
3. All private housing leased for use as public quarters.
4. All rental guaranty housing (in foreign countries).
5. All public quarters under construction or authorized and approved for construction.
6. Private units approved for leasing but not yet under contract.
7. Rental guaranty units under the contract or approved for development.

71120 through 71176-1.1.1 Non-Federal Government Rental Housing. In addition, existing private and local government rental housing (including mobile homes) in which military personnel are accepted as tenants, will be considered as suitable community support and will be charged as assets against requirements in all cases where it is classed as satisfactory by the occupant. If not classed as satisfactory by the occupant, or if vacant, it will be considered suitable provided it meets the following criteria:

71120 through 71176-1.1.1.1 Location. The distance from the administrative area of the installation can be traversed by privately-owned vehicle in one hour or less during rush hours.

71120 through 71176-1.1.1.2 Cost. Rent plus utilities (except telephone) does not exceed 115% of the member's Basic Allowance for Quarters (BAQ) plus Variable Housing Allowance (VHA).

71120 through 71176-1.1.1.3 Condition. Must be complete dwelling unit with private entrance with bath and kitchen for sole use of occupant and so arranged that both kitchen and bathrooms can be entered without passing through bedrooms. The units must be well constructed and in good condition of repair with heating (if required) and kitchen equipment provided. It must be in a residential area not subject to offensive fumes, industrial noises, and other objectionable features.

71120 through 71176-2 Land Use Intensity. The optimum land use intensity for family housing has been established by the Department of Defense. The following parameters are to be considered in determining the land use intensity ratio for a particular site:

1. Floor area
2. Living space
3. Recreation space
4. Open space

711 20 WHERRY HOUSING (SF)
FAC: 7110
BFR Required: N

711 25 CAPEHART HOUSING (SF)
FAC: 7110
BFR Required: N

711 29 CAPEHART HOUSING – O7 THROUGH O10 (SF)
FAC: 7110
BFR Required: N

711 30 FAMILY HOUSING (SF)
FAC: 7110
BFR Required: N

711 34 FAMILY HOUSING– O7 THROUGH O10 (SF)
FAC: 7110
BFR Required: N

711 35 LEASED HOUSING (SF)
FAC: 7110
BFR Required: N

711 39 LEASED HOUSING – O7 THROUGH O10 (SF)
FAC: 7110
BFR Required: N

711 50 SURPLUS-COMMODITY HOUSING (SF)
FAC: 7110
BFR Required: N

711 55 FOREIGN-SOURCE HOUSING (SF)
FAC: 7110
BFR Required: N

711 56 FAMILY HOUSING HIGH RISE (SF)
FAC: 7113
BFR Required: N

71156-1 **DESCRIPTION.** This type of facility is a building equal to or greater in height than 7 stories above ground level, which contains family housing units/apartments. Associated space may include lobby, multipurpose room, restrooms, elevator banks, utility/control rooms, and emergency generators.

711 59 FOREIGN-SOURCE HOUSING – O7 THROUGH O10 (SF)
FAC: 7110
BFR Required: N

713 FAMILY HOUSING – MOBILE HOME PARKS

713-1 **DESCRIPTION.** This group includes single and/or double wide manufactured housing parking sites with appurtenant utility connections; roads; walks; storage sheds; laundry and community buildings; and recreational facilities.
71310-1 The use of government-owned trailers for the purposes of Family Housing is not authorized. No criteria are available.

713 11 MOBILE HOME PARK (SY)
FAC: 7130
BFR Required: N

71311-1 **DESCRIPTION.** This group includes single and/or double wide manufactured housing parking sites with appurtenant utility connections; roads; walks; storage sheds; laundry and community buildings; and recreational facilities.

71311-2 **REQUIREMENTS.** The number of trailer sites is computed from a specific study and are provided only when private facilities are not available. The sites are self-supporting – tenants supply their own trailers, pay site rent, and receive BAQ.

714 FAMILY HOUSING – DETACHED FACILITIES

714-1 **DESCRIPTION.** Detached facilities are structures separated from family quarters, but available to the occupants.

714 10 DETACHED GARAGES (SF)
FAC: 7141
BFR Required: N

Design Criteria: See UFC 4-711-01 “Family Housing”

71410-1 **REQUIREMENTS.** Detached garages are planned on the basis of one per living unit and a space allowance of one vehicle per garage at those locations subject to temperatures of -10º Fahrenheit and below or where extreme winds, salt air, or sandstorms require garages. See UFC 4-711-01 “Family Housing” for detailed guidance.

714 20 DETACHED CARPORTS (SF)
FAC: 7141
BFR Required: N

Design Criteria: See UFC 4-711-01 “Family Housing”

71420-1 **REQUIREMENTS.** Detached carports are also provided on the basis of one per living unit and a space allowance of one vehicle per carport. See UFC 4-711-01 “Family Housing” for detailed guidance.

714 30 FAMILY HOUSING - OTHER DETACHED BUILDINGS (SF)
FAC: 7143
BFR Required: N

714 31 FAMILY HOUSING - OTHER DETACHED FACILITIES (EA)
FAC: 7143
BFR Required: N

71430/71431-1 **DESCRIPTION.** These codes are for inventory purposes only and are to be used for minor detached buildings and facilities directly relating to a particular family dwelling.

714 32 COMMUNITY CENTER (SF)
FAC: 7143
BFR Required: N

Design Criteria: See UFC 4-711-01 "Family Housing" for specific criteria and procedures for planning FHCC's.

71432-1 **DESCRIPTION**. A Family Housing Community Center (FHCC) provides space for social and recreational programs at family housing projects where comparable Navy or non-navy facilities are not reasonably accessible.

71432-2 **ESTABLISHING AN FHCC**.

71432-2.1 Authorization - The establishment of an FHCC must be authorized by NAVFAC Assistant Commander for Family Housing (FAC 08) or Commandant of the Marine Corps (LFL).

71432-2.2 Justification: Normally the establishment of an FHCC should be considered only for housing projects with 250 or more family units. FHCC in support of smaller projects at isolated locations will be considered on a case by case basis.

71432-3 **REQUIREMENTS.** A typical FHCC may provide spaces for assemblies, games, hobbies and crafts, conferences, and other functions in direct support of the FHCC operation. The design emphasis will be placed on flexible space arrangements and multipurpose space utilization. Also consider indoor-outdoor function interrelationships. The size of the facility is determined by user requirements.

714 33 HOUSING WELCOME CENTER (SF)
FAC: 7143
BFR Required: N

71433-1 **DESCRIPTION.** A Family Housing Welcome Center (HWC) provides space for administrative and service functions associated with the provisions of Government and private sector housing. The establishment of a HWC must be authorized by NAVFAC Assistant Commander for Family Housing (FAC 08) or Commandant of the Marine Corps (LFF-3).

71433-2 **REQUIREMENTS.** When authorized, the size of a HWC is based upon user requirements using 610-10 criteria.

714 77 HOUSING MISCELLANEOUS STORAGE (SF)
FAC: 7142
BFR Required: Y

71477-1 **REQUIREMENTS.** Detached storage facilities in support of family housing will be provided only where it can be individually justified. There are no criteria for this type of facility. General information on normal stacking height, SF per measurement ton requirements, and other parameters are provided in category code 440 series.

71477-2 **MARINE CORPS.** This category code is not intended for Marine Corps use.

720 UNACCOMPANIED PERSONNEL HOUSING

721 ENLISTED UNACCOMPANIED PERSONNEL HOUSING (PN)

See FC 4-721-10 for design criteria.

721-1 Enlisted Unaccompanied Personnel Housing encompasses bachelor quarters for Permanent Party Enlisted Navy and Marine Corps personnel and Transient Enlisted Navy and Marine Corps personnel. Unaccompanied housing for civilian personnel shall be provided at remote installations located away from municipal areas.

721-2 Unaccompanied Enlisted Housing (UEH) for the Navy refers to apartment style, hotel style, dormitory style living quarters, and open bay barracks for recruits. If messing facilities are attached to unaccompanied personnel housing, use category code 721-45 to delineate the mess hall portion. For detached mess halls, use category group 722.

GENERAL NAVY UEH POLICY

721-2 The Enlisted Unaccompanied Personnel Housing programming requirements are derived from the Unaccompanied Housing Requirements Determination Report (R19). The R19 delineates the Effective Permanent Party Program Requirements on line 15 through analysis of personnel base loading against the projected housing inventory. At Marine Corps installations, use the Facilities Support Requirement (FSR) document issued annually by HQMC. For broad planning and programming purposes where survey figures are not available, the quarter requirements may be determined by contacting the Unaccompanied Housing Program Management Office.

The following policy outlines housing for single enlisted military personnel:

- Provide open-bay housing on the installation for recruits at the Regional Training Centers such as Great Lakes.

- House all E1-E3 single sailors on the installation.

- When in homeport, all single sailors with the rank of E1-E3 and sailors with the rank of E4 with less than 4 years of service are to be housed on the installation.

- One resident advisor per 20 E1-E3 sailors housed is authorized.

- Sailors with the rank of E4 with more than 4 years of service will be accommodated with housing on the installation where adequate quarters are available.

- Provide housing on the installation for military personnel for reasons of training and military necessities, acknowledged as “must house” on the installation.

DEFINITION OF TERMS

The following definitions are included to clarify important terminology for developing Basic Facilities Requirements (BFRs) and UH projects.

Bedroom - Sleeping area in net square feet per person; excludes the closets, kitchen, food preparation area, and bathroom area.

UH 2+0 Unit - Includes double occupancy living/sleeping area, two personal closets, a separated toilet and shower compartment, and a single bowl lavatory/vanity in the service area.

UH 1+1E Unit- Includes two occupancy living/sleeping area, four personal closets, a separated toilet and bath compartment, a double bowl lavatory/vanity, and a kitchenette.

Market Style Unit - Two bedroom/two bath apartment with living/dining room, full kitchen, laundry, and two personal closets per bedroom. One bedroom/one bathroom apartment with living/dining room, full kitchen, laundry, and two personal closets per bedroom for remote locations only when authorized.

Navy (NETC) 2+0 Dormitory Unit- Includes double occupancy living/sleeping area, two personal closets, shared toilet with a separated shower compartment, and a single bowl lavatory in the service area.

Military Necessity

1. Augmented military personnel; military personnel assigned to transient personnel units while awaiting ship’s movement or separation from Navy service;

2. Military personnel on temporary duty (TDY) regarding duty for further assignment (TEMDUFURAS) orders, waiting for medical boards;

3. Military personnel on orders for executing limited duty, or sailors under direction from the command to be housed temporarily in unaccompanied housing (UH) due to restricted duty; military protective orders; cool down, etc.

Mission Essential Housing – Housing that supports rotational / mobilized sailors outside of their homeport and crewmembers of uninhabitable ships / submarines at their normal homeport, and rotational units outside of their normal homeport.

Officer Accessions – Any of several programs that provide personnel to assume positions as commissioned officers.

Permanent Party Sailors

1. Military personnel who executed orders for permanent change of station to an installation or to units supported by the installation to include units designated as unusually arduous sea duty for purposes of housing allowances in homeport;

2. Crew members of uninhabitable ships /submarines at their normal homeport, and rotational units (air squadrons, mobile training units, Seabees, etc.) in homeport.

Recruits - Personnel undergoing basic military training who have no continuous prior enlisted service (active or reserve).

Resident Advisors - Personnel who have volunteered and been selected, because of their maturity, to live in unaccompanied housing to assist in maintaining good order and discipline and to act as mentors to E1-E3 personnel..

Rotational/Mobilized Sailors- Sailors attached to units that are "Sea Duty for rotational purposes" (air squadrons, mobile training units, Seabees, etc.) on orders as a unit to duty outside their homeport, individuals on orders to a combat zone or crewmembers of uninhabitable ships/submarines outside their normal homeport.

Training Necessity - Training programs including officer accessions (OTC) and enlisted initial skills training ("A" schools, accessions pipeline schools, etc.) where student housing is part of the training mission and separate from other unaccompanied housing, and students are considered "must house" on the installation.

721 11 ENLISTED UNACCOMPANIED PERSONNEL HOUSING

FAC: 7210
BFR Required: Y

As of Feb 2018, this CCN also includes the consolidation of the following related housing CCNs:

- **721 12, 721 13 Bachelor Enlisted Quarters (Various). See section 72111-1**
- **721 24, 721 25, 721 26 Bachelor Enlisted Quarters – Marines (Various). See section 72111-2**
- **721 30 Civilian Barracks - GS01/ GS06. See section 72111-3.**

- **721 31 Civilian Barracks - Base Operating Support Contractor. See section 72111-4.**
- **721 51, 721 52, 721 53 Transient Personnel Unit Barracks (Various). See section 72111-5.**

The aforementioned CCNs have been deleted from this document and from iNFADS.

72111-1 Navy Assignment Standards

Permanent Party Unaccompanied Housing for enlisted Navy personnel applies to E1-E4<4 (E4 with less than 4 years of service), E4>4 years-E6, and E7-E9 rank designations.

Important Note: Permanent Party Unaccompanied Housing shall be identified on all property records in the internet Assets Facility Data Store (iNFADS) based on Navy military enlisted rank as follows;

- 721-11 E1-E4<4 years of service
- 721-11 E4>4years of service-E6
- 721-11 E7-E9

See FC 4-721-10 for design criteria.

Permanent Party
The market style unit applies to this category. Each unit includes shared living/dining area and kitchen/laundry area. For E1-E3 sailors and E4 sailors with less than 4 years' service, provide a two bedroom/two bath unit to accommodate four persons with each bedroom/bathroom to be shared by sailors.

Mission Essential Housing – Housing that supports rotational / mobilized sailors outside of their homeport and crewmembers of uninhabitable ships / submarines at their normal homeport, and rotational units outside of their normal homeport.

<u>Mission Essential/Military Necessity</u>

The Navy Shared Mobilization Unit (formerly referred to as Navy 2+0) applies to this category. Each unit includes one bedroom, one full bathroom, one kitchenette/service area and two closets. The unit accommodates either two E1-E6 sailors or one E7-E9 sailor.

Reference Requirements

Table 72111-A includes space planning guidelines per housing unit.

TABLE 72111-A
PLANNING LEVEL METRICS per UNIT/PLAN

UNIT/PLAN	MAXIMUM ALLOWABLE GROSS BUILDING AREA Ft^2 (m^2)
Navy Market Unit 2-Bed/2-Bath	606 ft^2 (56.3 m^2) per bedroom, based on a two-bedroom unit. This maximum is not applicable for one-bedroom units.
Navy Market Unit 1-Bed/1-Bath 730 76	1,028 ft^2 (95.5 m^2) per bedroom, based on a one-bedroom unit.
Navy NETC 2+0 Dormitory Unit / Navy 2+0 Unit	595 ft^2 (55.3 m^2) per plan
Marine Corps 1+1E Room (OCONUS Japan)	817 ft^2(76 m^2) per plan
Marine Corps 2+0 Room	595 ft^2 (55.3 m^2) per plan
Marine Corps Officer Plan	855 ft^2 (79.4 m$^{2)}$ per plan
Open Bay Plans	140 ft^2 (13 m^2) per person housed

Refer to Tables 72111-B and 72111-C for assignment policy. All construction projects shall identify maximum occupancy or the number of E1-E4<4 personnel that can occupy the quarters and the intended use capacity. The intended use capacity cannot exceed the number from the Unaccompanied Housing Requirements Determination (R-19) report except for rounding purposes. Activities in CONUS, where facilities include an architectural style that is prominent balcony access, may request a waiver from the interior corridor style from NAVFACHQ BHPO. **In these cases where the balconies serve as the primary circulation (i.e., serving exterior room entrances), they count towards building gross area at 100%.** For high threat areas OCONUS, consider secure barracks design concepts such as locating all UH rooms toward base interior with single-loaded exterior corridors located toward the base perimeter.

NAVY PLANNING CRITERIA FOR NEW CONSTRUCTION AND RENOVATION

Example Shared Mobilization Unit (Formerly Navy 2+0 unit)	3 Stories or less	Above 3 stories**
Maximum Allowable Gross Building Area per Unit	55.3 m^2	57.3 m^2

** For construction over 3 stories, 2 additional square meters per unit is allowed. The additional 2 square meters must be identified as a separate line item on the DD1391. This also applies to special design requirements for historical preservation, etc.

Example Market Style Unit	3 Stories or less	Above 3 stories**
Maximum Allowable Gross Building Area per Bedroom / Bathroom based on a Two-Bedroom Unit	56.3 m^2	58.3 m^2

** For construction over 3 stories 2 additional square meters per bedroom/bathroom is allowed. The additional 2 square meters per bedroom/bathroom must be identified as a separate line item on the DD1391. Also applies to special design requirements for historical preservation, etc.

MARKET UNIT BUILDING COMMON AREAS (See FC 4-721-10N for specific details)

- Corridors
- Interior Stairways
- Elevators (optional/per local building code requirements)
- Mechanical, Electrical, and Telecommunications Rooms
- Building Mechanical/Electrical room and Telecommunications room
- Trash Chute Area
- Janitorial Room
- Vestibule and Lobby Areas
- Reception/Front Desk Area
- Storage Room(s)
- Public Make and Female Restrooms
- General Maintenance Room
- Multi-Purpose Room(s)
- Vending Area
- Linen/Housekeeping Room

TABLE 72111-B
NAVY PERMANENT PARTY – MARKET STYLE UNACCOMPANIED HOUSING

RANK/RATE	UNIT TYPE	OSD MINIMUM STANDARDS OF ACCEPTABILITY*	PLANNING CRITERIA FOR NEW CONSTRUCTION
E7 - E9 (721-13)	Market Style one bedroom/one bath Housing accommodation in remote locations	Private unit with one bedroom/one bath, living/dining area, and kitchen/laundry area, shall be provided in remote locations. Provide a minimum of 13.4 net m^2 (144 nsf) per bedroom area.	One bedroom/one bath, one closet, one living/dining area, and one kitchen/laundry occupied by one person. Maximum allowable gross building area for one bedroom/bathroom Market Style Unit is 95.5 m^2 (1,028 gsf).
E4>4 - E6 (721-12)	Market Style two bedroom/two bath	Shared unit with two bedrooms/two baths, living/dining area, and kitchen/laundry area. Provide a minimum of 13.4 net m^2 (144 nsf) per bedroom area.	Two bedrooms/two baths each occupied by one person with shared living/dining area and kitchen/laundry area. Maximum allowable gross building area for two-bedroom Maximum allowable gross building

RANK/RATE	UNIT TYPE	OSD MINIMUM STANDARDS OF ACCEPTABILITY*	PLANNING CRITERIA FOR NEW CONSTRUCTION
			area per 2-bedroom unit or 620 gsf.
E1-E3 – E4<4 (721-11)	Market Style two bedroom/ two bath	Shared unit with two bedrooms/two baths, living/dining area, and kitchen/laundry area. Provide a minimum of 13.4 net m^2 (144 nsf) per bedroom area. Provide one resident advisor per 20 E1-E3 military personnel.	Two bedrooms/two baths each occupied by two persons with shared living/dining area and kitchen/laundry area. Maximum allowable gross building area per 2-bedroom unit or 620 gsf.

* OSD minimum standards of acceptability apply to billeting management rather than to facility condition for NFADB reporting purposes.

TABLE 72111-C
NAVY MISSION ESSENTIAL OR MILITARY NECESSITY - SHARED MOBILIZATION UNACCOMPANIED HOUSING (NAVY 2+0)

RANK/RATE	UNIT TYPE	OSD MINIMUM STANDARDS OF ACCEPTABILITY*	PLANNING CRITERIA FOR NEW CONSTRUCTION
E7 - E9 (721-13)	Shared Mobilization/Navy 2+0 Unit - one bedroom and one bath	Private unit with one bedroom, service area with kitchenette, bathroom vanity compartment and separate toilet/shower compartment. Provide a minimum of 16.7 net m^2 (180 nsf) per bedroom area.	One sleeping room and one bath, 55.3 gross m^2 (595 gsf) per unit, includes closets and service area/kitchenette for one occupant.
E4 - E6 (721-12)	Shared Mobilization/Navy 2+0 Unit- one bedroom and one bath	Shared unit with one bedroom, service area with kitchenette, bathroom vanity compartment and separate toilet/shower compartment to accommodate two persons. Provide a minimum of 16.7 net m^2 (180 nsf) per bedroom area.	One sleeping room and one bath, 55.3 gross m^2 (595 gsf) per unit, includes closets and service area/kitchenette for two occupants.
E1 - E3 (721-11)	Shared Mobilization/Navy 2+0 Unit - one bedroom and one bath	Shared unit with one bedroom, service area with kitchenette, bathroom vanity compartment and separate toilet/shower compartment to accommodate two persons. Provide 16.7 net m^2 (180 nsf) per room.	One sleeping room and one bath, 55.3 gross m^2 595 gsf) per unit, includes closets and service area/kitchenette for two occupants.

* OSD minimum standards of acceptability apply to billeting management rather than to facility condition for NFADB reporting purposes.

RELATED FACILITIES

Unaccompanied Housing should be collocated with an unaccompanied housing check-in center. Consideration should also be given to collocating UH with single sailor service centers, food service facilities, fitness facilities and other MWR facilities. One car wash area with a water source and an oil separator will also be provided when these type facilities are not available within a reasonable commuting distance. The car wash and supporting features must be captured under CCN 72350 “Wash Rack-Detached”.

PARKING FOR NAVY PERMANENT PARTY PERSONNEL

See CCN 852-10 for parking requirements.

Note: Some Activities may have unique circumstances that require less parking. In these cases, parking will be based on a parking survey of current residents.

OUTSIDE RECREATION

Provide one full outdoor basketball court per 300 residents if not available within 1/2 km. Similar outdoor recreation facilities can be substituted. Picnic areas and barbecue areas are required for all Unaccompanied Housing.

RESTORATION – MODERNIZATION PROJECT GUIDANCE

All deficiencies within existing facilities regarding “condition and configuration,” including Quality of Life (QOL) deficiencies defined by the Unaccompanied Housing Assessment Program (UHAP) shall be identified and addressed on restoration and modernization projects. Design projects for modernization and restoration projects shall comply with OPNAVINST 11010.20H, Navy Facilities Projects, which stipulates major policy guidance. Restoration and Modernization projects shall comply in accordance with the following:

- Perform an economic analysis and/or business case analysis to determine the feasibility of whether renovation or new construction is more cost effective.

- Do not plan projects exclusive to meet new construction criteria, except where the condition and/or configuration of an existing facility is too deficient to economically correct.

- Redesigns shall adjust unit designs to work within existing structural constraints to maximize building area while minimizing investment costs.

- Freestanding columns are allowed in redesigned units, provided that they do not interfere with a functional area or use.

REPAIR STANDARDS

Repair work may be limited to original standards used for the existing buildings. Consult OPNAVINST 11010.20H, Naval Facilities Projects, for additional guidance on repair projects.

72111-2 Marine Corps Assignment Standards

Permanent Party Unaccompanied Housing for enlisted Marine Corps personnel applies to E1-E4, E5, and E6-E9 rank designations.

Important Note: Permanent Party Unaccompanied Housing shall be identified on all property records in the internet Assets Facility Data Store (iNFADS) based on Marine Corps military enlisted rank as follows;

- 721-11 E1-E4
- 721-11 E5
- 721-11 E6-E9

Permanent Party 2+0 Standard

The 2+0 room consists of one room with a bath and is sized for two enlisted E1-E3 or one enlisted E4-E9. Refer to Table 72111-D. There are two basic entry styles for the 2+0 style hotels: exterior corridor style and interior corridor style. All construction projects will identify maximum occupancy or the number of E1-E3 personnel that can occupy the quarters and the intended use capacity. The intended use capacity cannot exceed the number from the FSR except for rounding purposes. See FC 4-721-10 for design criteria.

The Marine Corps may only use the 1+1 module design when individually approved by the CMC.

MARINE CORPS PLANNING CRITERIA FOR NEW CONSTRUCTION AND RENOVATION

2+0 Room	3 Stories or less	Above 3 stories or more**
Maximum Allowable Gross Building Area per Unit	55.3 m^2	57.3 m^2

** For construction over 3 stories 2 additional square meters per bedroom/bathroom is allowed. The additional 2 square meters per bedroom/bathroom must be identified as a separate line item on the DD1391. Also applies to special design requirements for historical preservation, etc.

BUILDING COMMON SPACE OUTSIDE OF THE ROOM

The typical shared common space to be provided for all 2+0 standard plans is shown below. Required common spaces are to be provided except when similar facilities are already available within walking distance of the project. Services should not be duplicated.

REQUIRED BUILDING AREAS (See FC 4-721-10N for specific details)

- Circulation, corridors and/or balcony access
- Multi-Purpose Room
- Duty Office
- Duty Bunk
- Laundry facilities
- Building utility room
- Entry Vestibule
- Unisex Rooms
- Elevators
- Janitor Closets
- Mechanical and Electrical Equipment Room(s)
- Corridors and Breezeways
- Stair Towers

Optional Common Spaces (See FC 4-721-10N for specific details)

- Administrative/Office Space
- Vending
- Game Rooms
- Resident bulk storage, as required
- Centralized Kitchen
- Balconies are optional

TABLE 72111-D
MARINE CORPS UNACCOMPANIED HOUSING
2+0 ROOM

RANK/RATE	OSD MINIMUM STANDARDS OF ACCEPTABILITY*	PLANNING CRITERIA FOR NEW CONSTRUCTION (Permanent Party)
USMC E6 - E9 (721-26)	Private bedroom and bath. Minimum bedroom area is 151 ft^2 (56 m^2).	Private room and bath, living room, and kitchen areas, and one closet at $2m^2$. Bedroom net area is 151 ft^2. Gross room area is 603 ft^2 (56 m^2). New construction of SNCO barracks will be considered on a case-by-case basis.
USMC E4-E5 (721-25)	Private room and a bath shared with not more than two to a room. Minimum 16.7 m^2 (180 SF) net living area per bedroom.	Private room and bath plus service area at 180 ft^2 (16.7 m^2) net sleeping/ living area plus bath and two closets at 2 m^2 net area each. Gross room area is 387.5 ft^2 (36 $m^{2)}$.
USMC E1–E3 (721-24)	Not more than two to a room. Minimum of 16.7 m^2 (180 SF) net living area per bedroom.	Shared room and bath plus service area occupied by two persons at 180 ft^2 (16.7 m^2) net sleeping/ living area plus shared bath and two closets at 2 m^2 net area each. Gross room area is 387.5 ft^2 (36 m^2).

* OSD minimum standards of acceptability apply to billeting management rather than to facility condition for NFADB reporting purposes.

PARKING FOR MARINE CORPS PERMANENT PARTY PERSONNEL

See CCN 852-10 for parking requirements.

Note: Some overseas or CONUS Activities may have unique circumstances that require less parking. In these cases, parking will be based on a parking survey of current residents.

OUTSIDE RECREATION

Provide one sand-volleyball court and one full outdoor basketball court per 300 residents if not available within 1/2 km. Similar outdoor recreation facilities can be substituted. Picnic areas and barbecue areas are required for all unaccompanied personnel housing.

OUTSIDE INDIVIDUAL MILITARY WASH AREA (USMC)

Provide outdoor equipment wash facilities (when required) at USMC unaccompanied personnel housing. The number of faucets/wash outlets shall be determined by the installation commander/resident FMF unit.

72111-3 Civilian Barracks – GS01/GS06 (PN)

72111-3.1 **DESCRIPTION** Quarters and messing facilities for civilian grades GS-6 and below will be provided only at installations that are remote from municipal areas or where civilians are required to be housed on station for security reasons.

72111-3.2 **REQUIREMENTS** Facilities planning for civilians will be the same as for military personnel of equivalent rank. Table 72111-E provides the military and civilian schedule of equivalent grades as established by the Department of Defense.

Important Note: Permanent Party Unaccompanied Housing shall be identified on all property records in the internet Assets Facility Data Store (iNFADS) based on Marine Corps military enlisted rank as follows;

TABLE 72111-E
MILITARY AND CIVILIAN EQUIVALENT GRADE SCHEDULE

Military Grade Group	Civilian Grade Group	
Rank	General Schedule	Wage Grade System
E-7 to E-9	GS-6	WS-1 through WS-7 WL-1 through WL-5 WG-9 through WG-11
E-5 to E-6	GS-5	
E4	GS-4	WG-1 through WG-8
E1 to E-3	GS-1 to GS-3	

72111-4 Civilian Barracks – Base Operating Support Contractor (PN)

There is no criteria currently available for this type of facility. Contact NAVFAC Atlantic Design and Construction business line for current information.

72111-5 Transient Personnel Units Assignment Standard (Inventory Purpose)

Transient housing for enlisted Navy and Marine Corps applies to E1-E4, E5-E6, and E7-E9 rank designations.

Important Note: This category of facilities is for inventory purposes and has no separate criteria. Transient Unaccompanied Housing where applicable shall be identified on all property records in iNFADS based on enlisted Navy and Marine Corps military rank as follows.

- 721-11 E1-E4
- 721-11 E5-E6
- 721-11 E7-E9

Hotels for Transient Personnel Units (TPU) are covered under Transient Unaccompanied Housing. TPUs may be used for operational reasons such as medical holds, transfers, disciplinary problems, etc. Refer to Category Codes 740-95 (Limited Service Official Lodging-Mission) for planning criteria.

721 14 STUDENT HOUSING (PN)
FAC: 7213
BFR Required: Y

Design Criteria: refer to FC 4-721-10N

72114-1 **REQUIREMENTS:** The requirements support housing students in a Naval Education and Training Command (NETC) 2+0 Dormitory Unit. The unit provides double occupancy living/sleeping area, two closets for personnel, a share toilet with a separate shower compartment, and a single bowl lavatory. All construction projects will identify the maximum occupancy or occupancy according to E1-E3, E4-E6, and E7-E9 enlisted personnel rank.

72114-2 **NAVY NETC 2+0 DORMITORY UNIT**

2+0 module	3 Stories or less	Above 3 stories or more**
Maximum Allowable Gross Building Area per Unit	55.3 m^2	57.3 m^2

** For construction over 3 stories, 2 additional square meters per bedroom/bathroom is allowed. The additional 2 square meters per bedroom/bathroom must be identified as a separate line item on the DD1391. Also applies to special design requirements for historical preservation, etc.

72114-3 **PARKING** Automobile parking for the residents at Navy ‘A’ Schools and USMC School of Infantry must be provided. Parking criteria can be found in category code 852 10. In addition, provide motorcycle parking spaces and bicycle parking spaces as required in accordance with historical use quantities. Provide visitor parking for 1% of the residents.

72114-4 **BUILDING COMMON SPACE OUTSIDE OF THE MODULE** For each project, all shared spaces must be individually scoped and justified from the list below. Elevators will not be provided. Items to be counted as one-half scope include stairs and stairwells, enclosed or unenclosed; and vertical chases.

- Office Areas: Admin/Reception (9.3 m^2 typical), Master at Arms (9.3 m^2 typical)
- Communal Areas: Vestibule, lobby, large screen TV lounge, vending room, gang kitchen, gang laundry, public telephone alcove, public toilets, resident bulk storage
- Corridor circulation, mechanical/electrical rooms (5-10% of gross building size), janitor closets (each floor), housekeeping/linen, utility storage room

72114-5 **PARKING FOR RECRUITS AND USMC SCHOOL OF INFANTRY** Resident parking at USMC and Navy recruit barracks is not required. Provide 1% visitor parking at USMC and Navy recruit barracks, however handicapped spaces are not required.

721 15 RECRUIT BARRACKS (PN)
FAC: 7218
BFR Required: Y

Design Criteria: refer to FC 4-721-10N

72115-1 **DESCRIPTION** Recruit quarters are open bay, central head facilities with net living area sized as one equal share of the open bay sleeping area. Typical sizes are 60 people per bay. Open bay designs will be constructed only for recruits, receiving barracks, and USMC School of Infantry.

72115-2 **PLANNING CRITERIA FOR NEW CONSTRUCTION FOR 721 15**

Open Bay

Net Sleeping Area	6.7 m^2
Common Area / Circulation / MEC	6.3 m^2
Building gross m^2 per module	13.0 m^2

Also, see Table 72115-A.

Table 72115-A
Recruit Barracks

RANK/RATE	OSD MINIMUM STANDARDS OF ACCEPTABILITY*	PLANNING CRITERIA FOR NEW CONSTRUCTION
Recruit & Receiving Barracks, and USMC School of Infantry	Open bay; central bath. Minimum 6.7 net m^2 (72 SF) net living area per person.	Open bay with individual armories in lieu of closets; central bath. Minimum 6.7 net m^2 (72 SF) net sleeping area.

721 21 TRANSIENT QUARTERS – MISSION ESSENTIAL

This CCN has been consolidated into CCN 740 95 for legacy facilities. All new transient facilities are captured under CCN 74094. CCN 721 21 has been deleted.

721 40 DISCIPLINARY HOUSING (PN)
FAC: 7312
BFR Required: Y

72140-1 **DESCRIPTION** This Facility is to be used for berthing personnel in disciplinary holding of restricted status. The Disciplinary/Restricted Barracks may be an area within a regular enlisted or transient personnel quarters that is designated by the commanding officer for use as:

> 72140-1.1 Disciplinary Holding Barracks. Berthing facilities for personnel in a holding status pending legal or administrative action or when assigned extra duty status.
>
> 72140-1.2 Restricted Barracks. Berthing for personnel undergoing punitive restriction or restriction in lieu of arrest. Personnel under punitive restriction will not be co-mingled with personnel restricted in lieu of arrest.

72140-2 **REQUIREMENTS** OPNAVINST 1626 provides detailed policy and description of security features utilized in Disciplinary/Restricted Barracks. Berthing space will be in open bay with a minimum of 72 SF net living area per person. The facility is not located within an approved place of confinement (Brig).

721 41 UNIT DEPLOYED PERSONNEL (UDP) MISSION ESSENTIAL (ENLISTED), (SF)
FAC: 7214
BFR Required: Y

72141-1 **DESCRIPTIO**N: These facilities are used for housing enlisted Marine Corps Unit Deployment Program (UDP) personnel (for officer UDP housing, see CCN 72415). Criteria is being developed for this CCN. Consult with the Marine Corps Housing Command Director (GF-3) for interim requirements for BFR purposes.

721 45 GALLEY/MESS HALL BUILT-IN / ATTACHED (SF)

This CCN has been deleted. All existing assets should be reassigned to CCN 72210 GALLEY/MESS HALL

721 46 RESIDENTIAL CARE FACILITY (SF)
FAC: 7210
BFR Required: Y

There is no criteria currently available for this type of facility. Contact NAVFAC Atlantic Design and Construction business line for current information.

721 47 UNACCOMPANIED HOUSING FOR WOUNDED WARRIORS (SF)
FAC: 7215
BFR Required: Y

72147-1 No criteria for this facility type are currently available.

72151/52/53-1 **DESCRIPTION** Hotels for Transient Personnel Units (TPU) are covered under category code numbers 721-51/52/53. TPUs may be used for operational reasons such as medical holds, transfers, disciplinary problems, etc. Refer to Category Codes 721-21/22/23 for planning criteria. This category code is for inventory purposes and has no separate criteria.

722 UNACOMMPANIED HOUSING – MESS AND CONFERENCE FACILITIES

722-1 **DESCRIPTION** This group includes dining facilities for unaccompanied personnel and conference centers operated by Unaccompanied Housing that are located in, or adjacent to, Unaccompanied Housing facilities. For clubs and open mess facilities, see the appropriate codes in 740 series. For additional information, refer to the design criteria found in FC 4-722-01N “Navy and Marine Corps Dining Facilities”.

722 10 GALLEY / MESS HALL (PN)
FAC: 7220
BFR Required: Y

Design Criteria: Refer to UFC 4-722-01 Design: Dining Facilities

72210-1 **DESCRIPTION**. Dining facilities for enlisted personnel provide the functional space necessary to offer efficient and aesthetically pleasing food service facilities that improve the quality of life for military personnel living and working on military installations worldwide.

72210-2 **REVIEW**. The Basic Facility Requirements and project documentation related to the planning for new or renovation of existing Dining Facilities are subject to review by Commander, Navy Installations Command (CNIC) Code N925 for Navy projects, or Headquarters Marine Corps, Logistics Food Service (LFS-4) for USMC projects.

72210-3 **REQUIREMENT**. Planning for a dining facility requires a determination of the number of personnel to be served; the meal schedule, duration and turnover to establish the required seating capacity, and any additional functions (such as a Flight Kitchen) which will be accommodated and require space in the facility. These requirements are generated by following three basic steps:

Step 1) determination of the authorized population which must be served by a dining facility (refer to Chapter 1 of this publication for additional guidance),

Step 2) analysis of existing adequate dining facilities within an acceptable travel distance to supplement the dining requirement, and

Step 3) determination of the space allocation requirement for the population not served by existing facilities.

72210-3.1 Step 1 – Determination of Population Served.

The number of enlisted personnel to be served during a meal period shall be determined by multiplying the projected maximum unaccompanied housing occupancy by the mission utilization factor(s), as provided in Table 72210-A.

The population count may include the average number of shipboard sailors entitled to rations-in-kind while shipboard galley facilities are out of service.

Do not include personnel on separate rations in the serving requirements when planning new dining facilities, or retaining and modernizing permanent facilities.

Officers and civilians shall only be included in the projected occupancy in overseas or remote locations where support is required.

72210-3.2 Step 2 - Analysis of Existing Facilities

New dining facilities shall be justified based on the ability to show that the existing dining facilities are inadequate to provide the serving requirement for the utilizing population established in Step 1.

The BFR for dining facilities requires an evaluation of the capacity, age, condition, and location of existing dining facilities relative to work centers and housing areas.

New dining facilities are not justified solely to support the construction of an additional unaccompanied personnel housing increment. It is necessary to determine that existing dining facilities do not adequately support the mission.

Recent changes in food service operations have made it necessary to re-evaluate the capacities of existing dining facilities which were constructed utilizing earlier criteria. While overall square foot authorization for new facilities is generally applicable to the determination of capacities of existing facilities, there are many independent factors which will limit capacity and must be taken into account. Common examples of these limiting parameters are:

- Storage Capacity include dry foods, refrigerated and frozen foods, consumables, and other non-food goods.
- Service Capacity – The ability to sustain a service rate suitable for the population to be served within the service period.
- Equipment Capacity
- Seating Capacity
- Meal Periods – The amount of time that the dining facility is open.
- Service Period – The amount of time that meal lines are open.

72210-3.3 Step 3 – Determination of Space Requirements

Based on the population to be served (as established in Step 1), and deducting any excess service capacity in existing dining facilities (as determined in Step 2), the required space allowance is determined from the remaining unserved population using the guidance provided in paragraph 72210-4.

Table 72210-A
Mission Utilization Factors for Dining Facilities

Mission	Utilization Factor
Training	
Basic and/or Recruit Training	95 %
Service Schools	85 %
Permanent Party	
Construction Battalions	70 %
Naval Stations	70 %
Personnel Transfer and Overseas Processing Centers	50 %
Remote Locations (1)	90 %

Mission	Utilization Factor
Shipyards	70 %
Weapon Stations	70 %
Brig	100 %

(1) Defined as a location with minimal available other feeding sources, on- or off-installation

72210-4 **SPACE PLANNING ALLOWANCES**. The space allowance for dining facilities is provided in Table 72210-C, based on the population established in paragraph 72210-3.

72210-4.1 Assumptions. The data contained in Table 72210-C is based on the following assumptions:

- Preparation method is conventional cook-serve.
- Mission is basic or recruit training.
- Seating is based on 15 SF (1.4 SM) per seat.
- Lobby queuing, and circulation space is minimized.
- One serving line is needed for every 200 seats, with minimum of 2 lines.
- Baking operations are minimized and reflect minimum bake-off of pre-prepared dough or other items.
- Three meals per day are served, seven days per week.
- Dishwashing space reflects a rack dish machine.
- Bussing method is self-buss to remote dish room.
- No provisions for catering are allocated, except Field Feeding/Vat Chow.
- Beverages are a free standing self-serve counter.
- Staff toilets do not include showers.

72210-4.2 Net to Gross Area Factor. – The net-to-gross multiplier accounts for mechanical and other utility space, wall thicknesses and other construction requirements. It typically ranges from 15 to 25% of all net areas for dining facilities and is influenced by the demands of the mechanical system, the number of floors, and the overall functional layout of the building. After selecting the appropriate net-to-gross factor, it is then applied to the facility subtotal shown in Table 72210-C.

72210-4.3 Additional Spaces. – Space allocation for vestibules, interconnecting covered walks, enclosed corridors and other architectural devices for climate and comfort are not included in Table 72210-C and must be considered separately on the BFR, if the need is fully justified. Aesthetic embellishments which add space to dining facilities are not justifiable.

72210-4.4 Storage Capacity. – Storage area requirements typically range from 10% to 25% of the dining facility net area (public, preparation, serving and support areas) and include dry foods, refrigerated and frozen foods, consumables, and other non-food goods. Factors that influence the storage requirements are the method of preparation and the inventory period:

- Scratch preparation has different fresh, dry and refrigerated storage requirements from frozen convenience and pre-prepared (cook-chill) preparation. The mix of preparation methods must be known to correctly size and design the storage areas.
- Inventory period is the time between deliveries. It will be influenced by the facility location (CONUS vs. OCONUS and rural/remote vs. urban areas), facility mission, and the vendor location and delivery contract terms. The longer the inventory period, the larger the storage requirements.

Table 72210-B provides a grid of these storage capacity factors and net area requirements associated with different combinations of factors. The appropriate net area gain is then applied to the facility subtotal shown in Table 72210-C.

Table 72210-B
Estimated Storage Requirements

	Food Preparation Factors	
Inventory Period Factors	**Frozen / cook-chill**	**Scratch**
Often (urban)	10-15% of net area	15-20% of net area
Infrequent (rural/remote)	15-20% of net area	20-25% of net area

72210-4.3 Service Capacity – A properly equipped and manned regular meal serving line can sustain a service rate of 8 personnel per minute. A properly equipped and manned short-order to-order serving line can sustain a service rate of 5 personnel per minute.

72210-4.4 Seating Capacity – Seating capacity is determined by the total number of patrons to be served divided by the turnover rate. Turnover rates can vary according to the size of facility and seating capacities.

72210-4.5 Meal Periods – The local command determines the meal period.

72210-4.6 Service Period – For planning purposes the total service time should not be less than 72 minutes or more than 142 minutes.

72210-4.7 Dining facilities that require more space than the maximum shown in Table 72210-C can be determined as follows: Divide the increased (projected) demand/loading capacity by the max of 2200 (personnel) shown in 72210-C. This will yield a multiplier greater than 1. Apply this multiplier to the allowances shown for the specific areas within the different functional components (Public, Serving, Preparation, and Support Areas) for 2200 personnel. Calculate the subtotals for the functional components and finish by using the process given for calculating storage adjustments and computing net-to-gross area as shown in the table. Below is an example:

A new Dining Facility is required to accommodate 3500 personnel (pn).

Divide the 3500 pn capacity requirement by the current Table 72210-C maximum allowance of 2200 pn; the result is a factor of 1.59.

Using the maximum allowances for the functional components of the 2200 pn facility, work through the calculations as follows:

Public Areas:	13,140 nsf x 1.59 = 20,892.6 nsf
Serving Areas:	4,288 nsf x 1.59 = 6,817.9 nsf
Preparation Areas:	4,335 nsf x 1.59 = 6,892.7 nsf
Support Areas:	2,440 nsf x 1.59 = 3,879.6 nsf
Facility Subtotal:	38,482.8 nsf
Multiply by Storage req %:	x1.25%
Subtotal Including Storage:	48,103.5 nsf
Multiply by the facility net-to-gross:	x1.25%
Facility Total Requirement:	60,129.4 gsf

(Note: If a flight kitchen is required, add it to the final facility gsf requirement)

Table 72210-C
Space Criteria for Enlisted Personnel Dining Facilities

	Functional Components	Facility Size Classifications							
		1-80 Personnel Served		81-150 Personnel Served		151-250 Personnel Served		251-400 Personnel Served	
		62 Min.Seats		108 Min.Seats		116 Min Seats		172 Min Seats	
		1.3 Max.Turnover		1.4 Max Turnover		2.2 Max Turnover		2.3 Max Turnover	
		ft.^{2}	m^2	ft.^{2}	m^2	ft.^{2}	m^2	ft.^{2}	m^2
Public Areas	Dining Area and Circulation	935	86.9	1630	151.4	1875	174.2	3000	278.7
	Public Toilets	180	16.7	200	18.6	220	20.4	250	23.2
	Queue	130	12.1	250	23.2	325	30.2	500	46.5
	Sign-in Station	40	3.7	40	3.7	40	3.7	60	5.6
	Subtotal	**1285**	**119.4**	**2120**	**196.9**	**2460**	**228.5**	**3810**	**353.9**
Serving Areas	Regular Food Line	250	23.2	320	29.7		0.0		0.0
	Fast Food Line		0.0		0.0		0.0		0.0
	Combination Food Line		0.0		0.0	420	39.0	620	57.6
	Beverage Line	200	18.6	250	23.2	350	32.5	500	46.5
	Cashier Station	30	2.8	30	2.8	50	4.6	50	4.6
	Dish Washing	180	16.7	250	23.2	320	29.7	380	35.3
	Subtotal	**660**	**61.3**	**850**	**79.0**	**1140**	**105.9**	**1550**	**144.0**
Preparation Areas	Kitchen	650	60.4	800	74.3	600	55.7	845	78.5
	Vegetable Preparation		0.0		0.0	220	20.4	255	23.7
	Meat Preparation		0.0		0.0		0.0		0.0
	Bakery		0.0		0.0		0.0		0.0
	Utensil Wash		0.0		0.0	175	16.3	220	20.4
	Subtotal	**650**	**60.4**	**800**	**74.3**	**995**	**92.4**	**1320**	**122.6**
Support Areas	Offices	230	21.4	310	28.8	400	37.2	580	53.9
	Staff Toilets	260	24.2	260	24.2	260	24.2	260	24.2
	Staff Lockers		0.0		0.0	120	11.1	160	14.9
	Janitor's Closet	25	2.3	25	2.3	25	2.3	50	4.6
	Can Wash	40	3.7	40	3.7	40	3.7	40	3.7
	Loading Dock (at 50%)	200	18.6	200	18.6	200	18.6	230	21.4
	Subtotal	**755**	**70.1**	**835**	**77.6**	**1045**	**97.1**	**1320**	**122.6**
	FACILITY SUBTOTAL	**3,350**	**311.2**	**4,605**	**427.8**	**5,640**	**524.0**	**8,000**	**743.2**
	Storage ranges from 10 to 25% of Facility Subtotal								
	Net-to-Gross ranges from 15 to 25% of Facility Subtotal								
	Flight Kitchen*	**100**	**9.3**	**100**	**9.3**	**100**	**9.3**	**100**	**9.3**
	FACILITY TOTAL	To be determined based on storage and net-to-gross		To be determined based on storage and net-to-gross		To be determined based on storage and net-to-gross		To be determined based on storage and net-to-gross	

* The flight kitchen is a staging area where food products are assembled and packaged for delivery to aircraft. Not all locations will require a flight kitchen.

Table 72210-C (continued)
Space Criteria for Enlisted Personnel Dining Facilities

Functional Components		Facility Size Classifications							
		401-650 Personnel Served		651-1000 Personnel Served		1001-1500 Personnel Served		1501-2200 Personnel Served	
		288 Min Seats		345 Min Seats		460 Min Seats		575 Min Seats	
		2.3 Min Turnover		2.9 Min Turnover		3.3 Min Turnover		3.8 Min Turnover	
		ft.^{2}	m^2	ft.^{2}	m^2	ft.^{2}	m^2	ft.^{2}	m^2
Public Areas	Dining Area and Circulation	4700	436.6	6320	587.1	7565	702.8	11000	1021.9
	Public Toilets	300	27.9	320	29.7	340	31.6	370	34.4
	Queue	750	69.7	1000	92.9	1100	102.2	1650	153.3
	Sign-in Station	80	7.4	100	9.3	120	11.1	120	11.1
	Subtotal	**5830**	**541.6**	**7740**	**719.0**	**9125**	**847.7**	**13140**	**1220.7**
Serving Areas	Regular Food Line	600	55.7	650	60.4	1050	97.5	1300	120.8
	Fast Food Line	600	55.7	650	60.4	650	60.4	650	60.4
	Combination Food Line		0.0		0.0		0.0		0.0
	Beverage Line	650	60.4	700	65.0	810	75.2	1056	98.1
	Cashier Station	100	9.3	150	13.9	200	18.6	250	23.2
	Dish Washing	450	41.8	600	55.7	730	67.8	1032	95.9
	Subtotal	**2400**	**223.0**	**2750**	**255.5**	**3440**	**319.6**	**4288**	**398.4**
Preparation Areas	Kitchen	1000	92.9	1100	102.2	1285	119.4	1600	148.6
	Vegetable Preparation	300	27.9	350	32.5	360	33.4	600	55.7
	Meat Preparation		0.0	240	22.3	300	27.9	500	46.5
	Bakery		0.0	690	64.1	825	76.6	1035	96.2
	Utensil Wash	330	30.7	400	37.2	500	46.5	600	55.7
	Subtotal	**1630**	**151.4**	**2780**	**258.3**	**3270**	**303.8**	**4335**	**402.7**
Support Areas	Offices	700	65.0	700	65.0	700	65.0	900	83.6
	Staff Toilets	360	33.4	430	39.9	450	41.8	500	46.5
	Staff Lockers	260	24.2	380	35.3	380	35.3	480	44.6
	Janitor's Closet	50	4.6	75	7.0	75	7.0	100	9.3
	Can Wash	40	3.7	60	5.6	60	5.6	60	5.6
	Loading Dock (at 50%)	300	27.9	300	27.9	400	37.2	400	37.2
	Subtotal	**1710**	**158.9**	**1945**	**180.7**	**2065**	**191.8**	**2440**	**226.7**
FACILITY SUBTOTAL		**11,570**	**1,074.9**	**15,215**	**1,413.5**	**17,900**	**1,662.9**	**24,203**	**2,248.5**
Storage ranges from 10 to 25% of Facility Subtotal									
Net-to-Gross ranges from 15 to 25% of Facility Subtotal									
Flight Kitchen*		**125**	**11.6**	**125**	**11.6**	**150**	**13.9**	**150**	**13.9**
FACILITY TOTAL		To be determined based on storage and net-to-gross		To be determined based on storage and net-to-gross		To be determined based on storage and net-to-gross		To be determined based on storage and net-to-gross	

* The flight kitchen is a staging area where food products are assembled and packaged for delivery to aircraft. Not all locations will require a flight kitchen.

722 35 AUSTERE GALLEY (SF)

72235-1 Facility planning criteria related to Austere Dining Facilities can be found in FC 2-000-05N - Appendix F "Austere Facilities (Navy)," located at https://www.wbdg.org/FFC/DOD/UFC/fc_2_000_05n_appendixf.pdf.

72241-1 **DESCRIPTION.** The operation of closed messes in support of unaccompanied officers' quarters is being discontinued. New Commissioned Officers' Closed Mess Facilities will not be planned for new or existing quarters.

722 50 COLD STORAGE DETACHED FROM GALLEY / MESS HALL (SF)
FAC: 7233
BFR Required: N

72250-1 **DESCRIPTION.** This code is for inventory purposes only, and applies to situations where cold storage facilities are detached from the galley facility. There is no additional space allowance for galley cold storage, and therefore this space must be provided from within the total allowance authorized for dining facilities.

722 60 CONFERENCE CENTER (SF)
FAC: 6100
BFR Required: N

72260-1 **DESCRIPTION.** This category code is for inventory purposes only, and includes only those conference rooms operated by Unaccompanied Housing. No specific criteria are provided.

72260-2 **CONVERSION OF EXISTING SPACES.** Existing unaccompanied housing may have spaces that are no longer required by current criteria or unaccompanied housing practices, such as lounges and galleys (attached or detached). If these spaces cannot be physically or economically converted to unaccompanied housing rooms, or a surplus of unaccompanied housing rooms exists at the activity and region, these spaces may be converted to conference rooms with the approval of the Regional PM for Unaccompanied Housing.

72260-3 **CONVERSION OF ROOMS.** Conversion of unaccompanied housing rooms into conference centers or meeting rooms is not allowed unless there is a projected surplus of unaccompanied housing rooms. In addition, the requirement for conference centers or meeting rooms cannot be used to justify new Unaccompanied Housing construction.

72260-4 **LOCATION.** Conference rooms should preferably be located in, or adjacent to, transient quarters so conference attendees staying in transient quarters may take advantage of the proximity.

723 UNACCOMPANIED PERSONNEL HOUSING - DETACHED FACILITIES

723 20 LATRINE DETACHED (SF)
FAC: 7234
BFR Required: N

72320-1 **DESCRIPTION.** Latrine facilities are planned as an integral part of new unaccompanied housing. This category code is provided to inventory existing detached facilities only.

723 30 LAUNDRY DETACHED (SF)
FAC: 7231
BFR Required: N

72320/30-1 **DESCRIPTION.** Laundry facilities are planned as an integral part of new unaccompanied housing. This category code is provided to inventory existing detached facilities only.

723 31 STANDALONE KITCHEN (SF)
FAC: 7233
BFR Required: N

72330-1 **DESCRIPTION.** This category code is for inventory purposes only in cases where a kitchen is separate from galley/dining hall or other type of building.

723 40 GARAGE DETACHED - UNACCOMPANIED HOUSING (VE)
FAC: 7232
BFR Required: N

72340-1 **DESCRIPTION.** Individual garages will not be planned in conjunction with troop housing. This category code should be used for inventory purposes only. See CCN 730 80 for parking buildings.

723 50 WASH RACK DETACHED (EA)
FAC: 8526
BFR Required: N

72350-1 **DESCRIPTION.** Wash racks for mess hall garbage containers, and wash racks for unaccompanied housing resident's vehicles are planned as part of dining facilities and unaccompanied housing. This category code should be used for inventory purposes only.

723 60 TROOP HOUSING – OTHER DETACHED BUILDINGS (SF)
FAC: 7231
BFR Required: N

723 61 TROOP HOUSING – OTHER DETACHED FACILITIES (EA)
FAC: 7235
BFR Required: N

72360/61-1 **DESCRIPTION.** These codes are for inventory purposes only and are to be used for minor detached buildings and facilities directly relating to unaccompanied housing functions.

723 77 TROOP HOUSING STORAGE (READY ISSUE/SHOP STORES/MISCELLANEOUS) (SF)
FAC: 7231
BFR Required: Y

72377-1 **DESCRIPTION.** Storage facilities for miscellaneous equipment an/or goods related to unaccompanied housing support will be provided only where it can be individually justified. There are no criteria for this type of facility.

724 UNACCOMPANIED PERSONNEL HOUSING - OFFICER QUARTERS (PN)

724 11 UNACCOMPANIED OFFICER HOUSING
FAC: 7240
BFR Required: Y

Refer to CCN 721-11/12/13 “Permanent Party BEQ” for additional planning criteria.
Design Criteria: Refer to FC 4-721-10N “Unaccompanied Housing” for design criteria.

724-11/12/13/14-1 **DESCRIPTION.** Bachelor Officer Quarters (BOQ) will be planned for personnel in officers' grades who come within the following classifications:

72411/12/13/14-1.1 Permanent Party unaccompanied single
72411/12/13/14-1.2 Permanent Party unaccompanied married (overseas)
72411/12/13/14-1.3 Nurses
72411/12/13/14-1.4 Students
72411/12/13/14-1.5 Transients
72411/12/13/14-1.6 Rotational

72411/12/13/14-2 **REQUIREMENT.** The 1+1E module is sized for one O1-O10, W1-W5 personnel. Refer to Table 72411-1 for assignment policy. The intended capacity cannot exceed the number from the BHRD or Facilities Support Requirement (FSR) document. For CONUS, the only basic entry style for the 1+1E module is interior corridor style. CONUS activities with a predominate BQ architectural style of balcony access may request a waiver from the interior corridor style from NAVFACHQ BHPO. For high threat areas OCONUS, consider secure barracks design concepts such as all BEQ rooms facing base interior with single loaded, exterior corridors facing base perimeter.

Table 72411-1
Navy and Marine Corps Bachelor Officer Quarters

RANK/RATE	OSD MINIMUM STANDARDS*	PLANNING CRITERIA FOR NEW CONSTRUCTION
O-3 - O-10 (724-12 and 724-14)	Private room consisting of a sleeping/living room, private bath, access to kitchen or officer's dining facility. Minimum 38 sq. m (400 NSF) net living area.	Living room and sleeping room occupied by one person, minimum 14.4 m^2 each; plus private bath, service area, approximately 3 net m^2 closets per room (total area). Module is 56.0 gross m^2.
O-1-O-2 W-1-W-5 (724-11 and 724-13)	Private suite consisting of a sleeping/living room, private bath. Minimum 24 sq. m (250 NSF) net living area.	Living room and sleeping room occupied by one person, minimum 14.4 m^2 each; plus private bath, service area, approximately 3 net m^2 closets per room (total area). Module is 56.0 gross m^2.

* OSD minimum standards of acceptability apply to billeting management rather than to facility condition for NFADB reporting purposes.

72411/12/13/14-3 **OUTDOOR INDIVIDUAL MILITARY WASH AREA (USMC).** Provide outdoor equipment wash facilities (when required) at USMC bachelor quarters. The number of faucets/wash outlets shall be determined by the installation commander/resident FMF unit.

724 15 UNIT DEPLOYED PERSONNEL (UDP) – MISSION ESSENTIAL (OFFICER) (SF)
FAC: 7214
BFR Required: Y

72415-1 **DESCRIPTIO**N. These facilities are used for housing Marine Corps Unit Deployment Program (UDP) officers (for enlisted UDP housing, see CCN 72141). Criteria is being developed for this CCN. Consult with the Marine Corps Housing Command Director (GF-3) for interim requirements for BFR purposes.

72415-2 **DESCRIPTION.** Housing and messing facilities for civilian grades comparable to officers will be provided only at installations that are remote from municipal areas or where civilians are required to be housed on-station for security reasons.

72415-3 **REQUIREMENT.** Facilities planning for civilians will be the same as for military personnel of equivalent rank. Table 72415-1 provides the military and civilian schedule of equivalent grades as established by the Department of Defense.

Table 72415-1
Military and Civilian Equivalent Grade Schedule

<table>
<tr><th rowspan="2">Military Grade Group</th><th colspan="3">Civilian Grade Group</th></tr>
<tr><th>General Schedule</th><th>Teachers
(20 U.S.C. 901-907)</th><th>Wage
System</th></tr>
<tr><td>0-7
to
0-10</td><td>GS-16
to
GS-18</td><td>-------</td><td>------</td></tr>
<tr><td>0-6</td><td>GS-15</td><td>____</td><td>____</td></tr>
<tr><td>0-5</td><td>GS-13
and
GS-14</td><td>-------</td><td rowspan="2">WS-14 through WS-19 WL-15 and Production Support Equivalents</td></tr>
<tr><td>0-4</td><td>GS-12</td><td>Class IV and
Class V</td></tr>
<tr><td>0-3</td><td>GS-10
and
GS-11</td><td>Class I, Step 5
Through Step 15
Class II and
Class III</td><td rowspan="2">WS-8 through WS-13
WL-6 through WL-14
WG-12 through WS-15
and Production
Support Equivalents</td></tr>
<tr><td>0-2
W-3
and
W-4</td><td>GS-8
and
GS-9</td><td>Class I, Step 3
and Step 4</td></tr>
</table>

Military Grade Group	Civilian Grade Group		
	General Schedule	Teachers (20 U.S.C. 901-907)	Wage System
0-1 W-1 and W-2	GS-7	Class I, Step 1 and Step 2	

724 20 USNA UNACCOMPANIED HOUSING (SF)
FAC: 7242
BFR Required: Y

72420-1 **DESCRIPTION.** This type of housing is for unaccompanied housing buildings located at the US Naval Academy.

72423-1 No criteria for this facility are currently available.

72424-1 No criteria for this facility are currently available.

72430-1 The operation of closed messes in support of officers' quarters is being discontinued. New Commissioned Officers' Closed Mess dining facilities will not be planned for new or existing BOQ's.

725 UNACCOMPANIED PERSONNEL HOUSING – EMERGENCY HOUSING

725 10 TROOP HOUSING - EMERGENCY BUILDING (PN)
FAC: 7250
BFR Required: Y

725 11 TROOP HOUSING - EMERGENCY FACILITY (EA)
FAC: 7251
BFR Required: N

72510/11-1 **DESCRIPTION.** These may be hutments (Quonsets), tent frames with floors and may be permanent, semi-permanent, or temporary types of facilities. No criteria for these facilities are currently available.

730 COMMUNITY FACILITIES – PERSONNEL SUPPORT AND SERVICES

730 10 FIRE STATION (SF)
FAC: 7311
BFR Required: Y

Refer to https://www.wbdg.org/dod/unified-facilities-space-program-sustainability-spreadsheets for the "Fire Stations Space Program" spreadsheet.

Refer to UFC 4-730-10N "Fire Stations" for design criteria at https://www.wbdg.org/dod/ufc/ufc-4-730-10.

73010-1 **DEFINITION.** This space criteria applies to Installation fire station facilities which provide fire protection for structures, fight brushfires, and support fire prevention education and training.

73010-1.1 When the fire station function is part of a consolidated operations facility (fire/police/safety), this CCN is applicable only to the fire station functions and the planner must consider the appropriate space designation (such as CCN 730 20) for the other facility functions. Identify common support and administrative spaces that can be shared between CCN functional areas.

73010-1.2 This criteria shall be used in combination with CCN141-20 "Aircraft Fire and Rescue Station" when developing the total space allocation for CCN 141-25 "Combined Structural / Aircraft Fire / Rescue Station".

73010-2 **REQUIREMENT.** The number of fire stations required on an Installation will be determined by the necessary response time for the type and function of facilities requiring fire protection. This analysis will be provided by Commander Navy Installations Command (CNIC) N30 or Marine Corps Installations Command (MCICOM) G3.

73010-3 **SCOPE.** To support the firefighters' mission, it is crucial that a fire station accommodates the equipment used at that station, supports the numerous unique functional requirements for that type of station, and fulfills the safety requirements of the firefighting personnel using the station. This is reflected in by the designated type of fire station and the required class of fire station.

73010-4 **STATION TYPES.** Functionally, there are three types of fire stations:

- Structural Stations (CCN 730 10) which provide fire protection to facilities,

- Aircraft Rescue Firefighting (ARFF) Stations (CCN 141 20) which provide fire protection to aircraft and associated equipment, and
- Combination Structural/ARFF Stations (CCN 141 25), providing support for each of the first two requirements.

73010-4.1 Differences between Station Types. Generally, the differences between Structural and ARFF stations are limited to the Apparatus Bay size criteria and the facility location to support its mission.

73010-4.2 Marine Corps Requirements. The Marine Corps program includes two separate organizations—one for Structural and one for ARFF. Unlike the other Services, the Marine Corps rarely combines the stations and requires separate offices for Fire Chiefs and other personnel on their Installations.

73010-5 **STATION CLASSES.** For each type of fire station, there are two class designations which determine some of the functions at that station:

- Headquarters (or Main) stations generally house the Fire Chief and most of the general administrative functions.
- Satellite stations are located throughout the Installation to provide adequate response time coverage.

73010-5.1 Differences between Station Classes. The differences between Headquarters and Satellite stations relate only to the additional administrative functions housed in the Headquarters station.

73010-6 **FUNCTIONS.** The Station Class will primarily determine the number and type of functional spaces required. However, it is important to assess the existing fire station assets available at the Installation, as it may be necessary to provide Satellite stations with some spaces normally reserved for Headquarters stations if they are not adequately available with existing facilities. The Installation representatives, in conjunction with the facility planner, must determine which spaces are necessary and justified. The planner should obtain a Needs Validation Assessment of Installation fire station assets to determine the class and required capacity in terms of personnel and vehicles of the new or renovated station (refer to 73010-2).

73010-7 **FUNCTIONAL AREAS.** Fire stations consist of apparatus bays and support areas, equipment and gear storage areas (for fire extinguishers, self-contained breathing apparatus (SCBA), protective clothing, hoses, firefighting agents, etc.), dispatch office, administrative offices, training facilities, living quarters, recreation and dining facilities, and possibly an emergency operations center and/or apparatus and equipment maintenance areas (if required by Installation mission requirements).

73010-8 **SPACE ALLOWANCE.** Space allowances for fire stations are determined according to the planning criteria calculations which result from using the Space Planning Spreadsheet for Fire Stations, which can be found at https://www.wbdg.org/dod/unified-facilities-space-program-sustainability-spreadsheets.

73010-8.1 Apparatus rooms are sized according to the firefighting apparatus to be housed within the station. For new construction, apparatus bays shall be planned to allow drive-through access for firefighting apparatus.

73010-8.2 Table 73010-1 contains functions that may be included in a fire station with adequate justification. These space allowances are optional selections in the space planning spreadsheet and must be individually justified for inclusion in the BFR development. Any additional apparatus equipment from Table 73010-1 should be included in determining the space allocation for apparatus bays.

Table 73010-1. Validate Requirement for these Functional Areas

FUNCTION	NOTE
Assistant Chief of Fire Prevention Office	(1)
Fire Prevention bureau	(2)
Deputy Chief's Office	(3)
Deputy Chief's Bunkroom	
Emergency Response Center	(4)
Disaster Preparedness Admin	(5)
Disaster Preparedness Storage	
Emergency Medical Services - Ambulance Bay	(6)
Ambulance Admin Space	
Ambulance Storage	
Ambulance Bunks (3 personnel/ambulance)	
Hazardous Waste Vehicle	(7)
Hazardous Waste Storage	
Hazardous Waste Bunks (3 personnel/vehicle)	
Specialized Equipment (foam unit, brush truck, etc.)	(8)
Heavy Rescue Vehicle	
Boat/Trailer Bay	
Boat Equipment Storage (100 NSF/9 NSM)	
Vehicle Maintenance Bay	(9)
Vehicle Maintenance Office	
Vehicle Maintenance Parts and Tools	

Notes:
(1) Authorized where there are more than 4 inspectors.
(2) Not included in Space Planning Spreadsheet. Determine space allowance according to CCN 610-10 criteria.
(3) Authorized where there are 4 or more engine Companies.
(4) Usually only provided in HQ-class stations that are consolidated with Police/Security/EMS functions.
(5) Not included in Space Planning Spreadsheet. Determine space allowance according to CCN 610-10 criteria.
(6) When ambulances are authorized, space must be provided to accommodate the vehicles, equipment, supplies, and crew.
(7) When HazMat response team is authorized, space must be provided to accommodate the vehicles, equipment, supplies, and crew.
(8) Include these specialized vehicles in the bay count section of the spreadsheet.
(9) This space allocation in the spreadsheet is authorized only in cases where fire/rescue vehicles are maintained and/or repaired at the fire station.

730 11 FIRE HOSE DRYING STRUCTURE (EA)
FAC: 7311
BFR Required: N

73011-1 **DEFINITION**. Category Code 730 11 is provided for inventory purposes only in cases where these structures are provided in a separate building or structure. For new facility planning purposes, this requirement shall be included as part of the Fire Station, Code 730 10.

730 12 FIRE CART/HOSE DRYING FACILITY (SF)
FAC: 7311
BFR Required: N

73012-1 **DEFINITION**. Category Code 730 12 is provided for inventory purposes only in cases where these facilities are provided in a separate building or structure. For new facility planning purposes, this requirement shall be included as part of the Fire Station, Code 730 10.

730 13 ISSUE/RETAIL CLOTHING AND UNIFORM CENTER (SF)
FAC: 7343
BFR Required: N

73013-1 **DEFINITION.** This is a retail outlet for military clothing and accessories. This facility is operated by the Navy and Marine Corps Exchange Service. It is integrated with the Exchange Retail Store, CCN 740-01 at most existing and all new stores. This category code is provided for inventory purposes only.

730 15 BRIG (SF)
FAC: 7312
BFR Required: Y

Design Criteria: For Renovations, refer to MIL-HDBK-1037/4.
For New Construction, refer to the American Correctional Facilities Guidelines.

73015-1 **DEFINITION.** This code is to be used for facilities whose primary purpose is the confinement of personnel. A facility with confinement as a secondary use should be coded according to its primary use. For example, a restricted barracks is coded as a facility in the appropriate code of the 721 group.

73015-2 **REQUIREMENTS**. Requirements for brigs may only be established at activities where such facility is authorized by SECNAV. This insures strategic distribution of the facilities. Where planning for a brig is authorized, space allowances are in accordance with Table 73015-1 and Table 73015-2. The prisoner capacity is 0.5% of the total military strength in the area served by the facility. This figure may be adjusted by the Bureau of Naval Personnel to compensate for local variations in projected prisoner population. The adjusted figures are available from the Bureau of Naval Personnel (PERS-84).

Where facilities are to include space for gainful employment, they will be programmed on the basis of identified equipment requirements but not to exceed 7 m^2 (75 gsf) per prisoner.

73015-3 **APPROVAL PROCESS.** A request for approval of the establishment of a brig as a Navy place of confinement shall be submitted to the Secretary of the Navy via the chain of command and the Bureau of Naval Personnel or Commandant of the Marine Corps, as appropriate.

73015-4 **SPACE ALLOWANCES**. The gross area allowances shown include facilities for housing, training, welfare, administration, and recreation. The space for prisoner berthing in dormitories must have a minimum of 7 m^2 (72 ft^2) net sleeping area per prisoner. All cells should be planned for single occupancy and be of 6' x 8' x 8' minimum dimensions.

Table 73015-1. Space Allowances for Correctional Centers

Capacity	Gross Area Per Prisoner	
	sq. m	SF
Up to 25	51	550
50	41	440
150	33	350
250	31	330
400	28	300

73015-5 **SITING.** The brig shall be sited where it is free from safety hazards due to its extended evacuation time. The size of site and its location in relation to other activity facilities shall be agreed between the using activity and PERS-84.

73015-6 **FUNCTION.** The structure and its functional components shall be planned in accordance with the guidelines contained in SECNAVINST 1640.9B (Dec '96 @ http://neds.nebt.daps.mil/1640.htm), the American Correctional Facilities Guidelines (new construction) and MIL-HDBK 1037/4 (renovation).

The following list and Table 73015-2 highlight the components which normally should be considered when planning for a brig. The list is not intended to be all inclusive nor may all components be required at all locations. It should be used only for guidance or as a checklist. Figures shown on Table 73015-2 are net square meter (net square feet) and are intended to be utilized for planning physical layout. The size of the spaces may vary depending on the particular needs of the activity.

73015-6.1 **Administrative Section**. Admin. section; Brig Officer's office; prisoner, visitor and legal visiting rooms.

73015-6.2 **Prisoner Processing**. Receiving and release room; prisoner storage; holding cell.

73015-6.3 **Medical Exam Spaces**. Doctor, Dentist and Psychiatrist.

73015-6.4 **Dining Facilities**. Brigs with 100 prisoners or less should cater food from existing base facilities where practical; Brigs over 100 prisoners use cat. code 722-10 criteria.

73015-6.5 **Prisoners Quarters**. Cells or secure rooms will have single occupancy 6'x8'x8' minimum dimension and the total number shall not exceed 15% of prisoner capacity. Dormitories will berth 85% of prison capacity; maximum 35 prisoners per dormitory and 7 sq.m. (72 SF) net sleeping area per prisoner.

73015-6.6 **Other Miscellaneous Spaces as Required**. Staff lounge, classrooms, vocational shop, laundry, chapel counseling, library and recreation facilities should be planned based upon local needs.

Table 73015-2.
Brig Capacity Number of Prisoners

Type of Space	U/M	50	100	150	200	250	300
Administrative Section	sq. m	151	251	251	269	288	288
	SF	1620	2700	2700	2900	3100	3100
Prisoner Processing	sq. m	67	82	82	93	93	93
	SF	720	880	880	1000	1000	1000
Control Room	sq. m	13	13	13	13	22	22
	SF	140	140	140	140	240	240
Barber Shop	sq. m	17	22	22	22	22	22
	SF	180	240	240	240	240	240
Library	sq. m	19	37	37	74	74	74
	SF	200	400	400	800	800	800
Medical Exam Room	sq. m	17	28	28	28	39	39
	SF	180	300	300	300	420	420
Staff Lounge w. Toilet	sq. m	20	42	42	42	42	42
	SF	220	450	450	450	450	450
Chapel, Auxiliary Multipurpose Classroom, Magistrate	sq. m	46	93	93	139	139	186
	SF	500	1000	1000	1500	1500	2000
Special Quarters and Security Cell (6' x 8'x 2') 1830 x 2440 x 610 mm	EA	8	12	16	22	26	32
Segregation Cell (6'x 8'x 8') 1830 x 2440 x 2440 mm	EA	2	4	6	8	10	12
Mail Office	sq. m	11	11	22	22	33	33
	SF	120	120	240	240	360	360
Counselor's Office Supervisor's Training	Sq. m	26	39	46	46	52	52
	SF	280	420	490	490	560	560
Exchange	Sq. m	11	11	22	22	33	33
	SF	120	120	240	240	360	360
Recreational Equipment Storage	SF	140	140	140	240	240	240

730 20 SECURITY BUILDING (SF)
FAC: 7313
BFR Required: Y

73020-1 **DEFINITION.** A security building housing the shore patrol and military or civilian police forces may vary in use from a standard police station to a large security department. Security buildings are generally located well within the base perimeter, and not adjacent to gatehouses.

73020-2 **STANDARD POLICE STATIONS.** For a police force limited to law enforcement within an installation, with no detention responsibilities, plan on the basis of 5 sq.m. (50 SF) per person employed at the police station. This includes the total of all persons in administrative functions and on patrols, for all shifts.

73020-2.1 The space allowance provides space for all or part of the following: armory; administration; communication; fingerprint room, file space; storage; training and briefing; dayroom; maintenance of official vehicles; miscellaneous related support.

73020-3 **LARGE SECURITY DEPARTMENTS.** For large security departments providing a variety of services, including combined dispatch centers with fire and medical services, individual justification for space requirements is required. Spaces may include: administrative areas, waiting areas, customer service and report writing areas, dispatch centers including consolidated dispatch centers for medical, fire and security, armory, Pass and ID services, package inspection, ready issue communication equipment storage, general supply, and break lounges.

730 21 DEFENSIVE FIGHTING POSITION (SF)
FAC: 1498
BFR Required: Y

73021-1 **DEFINITION** A Defensive Fighting Position (DFP) is an elevated facility that houses operations responsible for the protection of access and/or egress to designated areas or facilities and can serve an installation’s security force or a tenant command requiring secure access within a dedicated area or compound. These are typically used at installation Entry Control Points (ECPs), at Pier Heads, and sometimes at secure areas within an installation. For landside DFP applications, the DFP must be located such that it is near the active vehicle barriers and provides the occupants the ability to oversee response zone traffic and operations at the ID check area. For waterside DFP applications, the DFP must be positioned along the waterfront (typically at the head of the pier) to allow 360 degree observation and employment of both non-lethal and lethal force. The DFP will be utilized as an elevated fighting position and as such will be equipped with gun ports to allow the occupants to respond to threats. The gun ports should be positioned to cover the likely avenues of approach and be constructed to accommodate depression angle requirements of weapons (lethal and non-lethal) employed therein. Objectively, the DFP should facilitate weapons employment throughout the entire threat zone as defined by NTTP 3-07.2.1 and as established in installation Antiterrorism Plan.

Note: Landside DFPs should have a 360 degree field of view but geographic constraints/restraints may preclude this at some locations.

73021-2 **REQUIREMENTS**

73021-2.1 DFPs must provide adequate space within the overwatch for movement of a guard and the use of handguns, shoulder fired weapons, and select non-lethal weapons systems. Gun/weapons ports shall be provided on each face of the overwatch (providing a 360 degree field of view). Note: Gun/weapons ports may not be required on all sides of the DFP if the protection plan into which these positions are being placed accommodates/establishes 360 degree protection to assets contained therein.

73021-2.2 The DFP overwatch shall consist of a 36GSF (maximum) structure as in figure 73021-1.

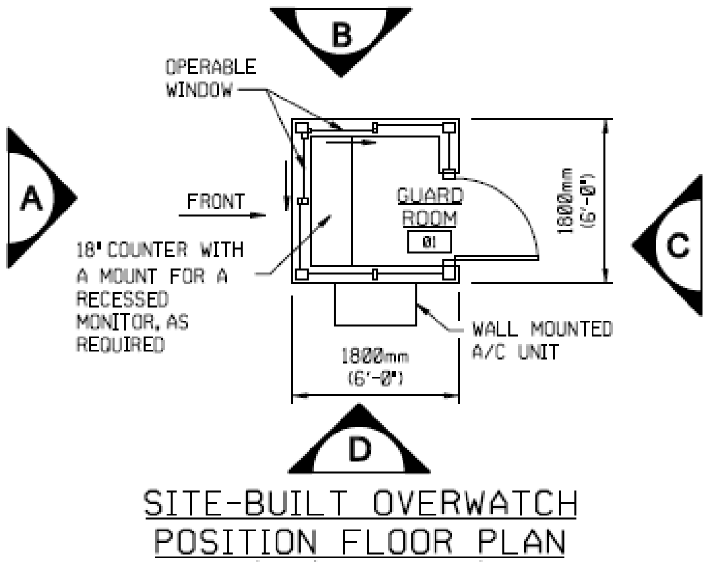
73021-3 The requirements calculation process should begin with consultation with the installation SECO (Security Officer) and ATO (Antiterrorism Officer) to determine how many DFP overwatch positions are needed. For locations within an installation where a tenant command requires a DFP for a dedicated secure area or compound, coordination with the command's OIC may be necessary to obtain requirements.

For the purposes of the BFR, all DFP requirements serving an installation's security force can be captured within a single BFR and based on the installation UIC. If the requirement is for a tenant command for a dedicated secure area or compound within an installation, the BFR should be captured using the tenant command UIC and should be exclusive of the installation's requirements.

For the purposes of identifying assets in iNFADS, use individual property record cards (PRCs) to capture the DFP assets for each landside and waterfront entry control point (ECP) and capture them using the installation UIC. Note their locations on the PRC. If the asset(s) is/are for a specific tenant command for their own secure area(s) or compound(s), use the tenant command UIC to capture all DFPs associated with the command. For the purposes of Asset Evaluations (AEs), if an existing facility is not elevated, note that it is deficient with respect to its functional or space criteria for a building or structure.

Below is a notional diagram of a typical DFP layout. Note that these facilities are typically elevated towers with occupied space on upper floor(s) and an interior stairwell below. The area below the occupied space(s) is not counted as useable area on the property record card.

Figure 73021-1 Model Defensive Fighting Position



73021-4 **SITING CRITERIA.** Several elements must be considered early on in locating the position of a DFP. It is CRITICAL that regional and installation Security Officers (SECO) and Antiterrorism Officers (ATO) be consulted early in the location process. Attention must be given to:

--Topography of the intended location and resulting field of fire.
--More than one may be necessary to adequately cover ECP field of view considerations and different avenues of approach.
-- Safety of the occupant due to firing from gate guards.
-- Safety of general public from downrange fire
--Weapon system to be utilized and its coverage capability.
--DFP should be located behind final denial barrier.
--DFP Should be located a sufficient distance from ECP to allow time for operation of final denial barrier.
-- Waterfront DFPs should be positioned in such a manner to allow for overlapping fields of fire. Objectively, there should be sufficient fields of fire established (i.e. sufficient number of DFPs) that the elimination of any single DFP does not preclude the other DFPs from employing force (lethal/non-lethal) across the entire waterfront. The exact number of DFPs required should be delineated in the installation Antiterrorism plan and/or defined by coverage factor requirements of higher headquarters or both. The number of DFPs required along the waterfront can and should also be influenced by the types/capabilities of weapons (lethal/non-lethal) planned to be employed from therein.

Note: As the urban environment has migrated to the borders of military installations, military operations are being conducted in closer proximity to the general public. Installation public works, security and antiterrorism teams must factor the proximity of the general public into the protective designs of DFPs. Installations shall consider incorporation/application of protective elements such as retaining walls (walls to absorb bullets) into the DFP design (landside application).

73021-5 **USE OF RE-LOCATABLE BUILDINGS** See OPNAVINST 11010.33C for guidance on the use of re-locatable facilities as DFPs. Make-shift facilities created from items such as concrete barricades, box culverts, and similar items are not to be captured as real property DFPs in iNFADS.

730 22 NCIS FIELD OFFICE (SF)

FAC: 7313
BFR Required: Y

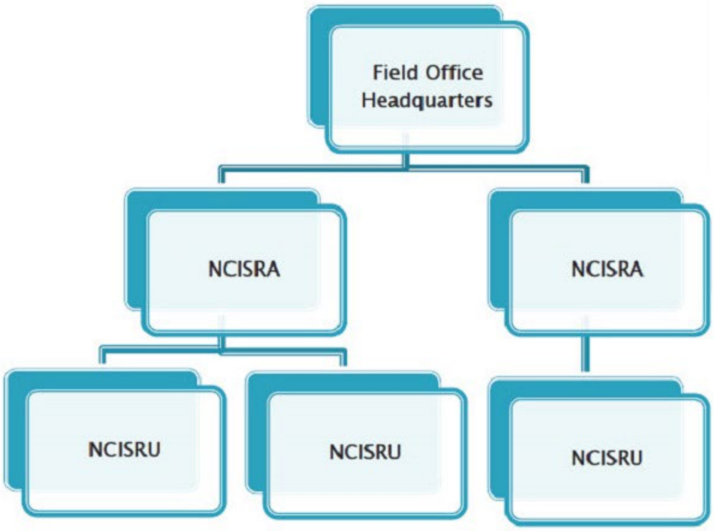
73022-1 **Definition**. A building that houses the command, operation, and administrative functions assigned to the U.S. Naval Criminal Investigative Service (NCIS). NCIS is the primary law enforcement agency of the U.S. Department of the Navy. Its primary functions are to investigate criminal activities involving the U.S. Navy and U.S. Marine Corps, though its broad mandate includes national security, counterintelligence, counterterrorism, cyber warfare, and the protection of U.S. naval assets worldwide. The criteria specifically address NCIS Field Offices, NCIS Resident Activities, NCIS Resident Units and various mission specific components.

73022-2 **Planning Factors**. Review the criteria contained herein and use this information in tandem with the NCIS BFR Template to develop space requirements for NCIS organizations.

Notional Organizational Chart and Staffing Levels

NCIS Field Office (NCISFO)

- Special Agent in Charge (SAC)
- Assistant SACs (ASACs) (Crim, CI)
- Senior Intelligence Officer (SIO)
- Field Operations Support Officer (FOSO)
- Supervisory Program Analyst (SPA)
- Field Computer Specialist (FCS)
- Investigator(s) (1801)
- Intelligence Analyst (s)
- Program Support Assistants (PSAs)



NCIS Resident Agency (NCISRA)

- Can be collocated or geographically separated from field office HQ
- Supervisory Special Agent(s) (SSA)
- Special Agents (SAs)
- PSA(s)

NCIS Resident Unit (NCISRU)

- Geographically separated from NCISRA
- One or more SAs

NCIS Field Office (NCISFO)	25-50 personnel
NCIS Resident Agency (NCISRA)	13-20 personnel
NCIS Resident Unit (NCISRU)	1-5 personnel

73022-3 **Personnel Loading.** Personnel loading must be supported by an official personnel-loading report. See CCN 61010, Sections 61010-3 and 61010-4 for additional information.

73022-4 NCIS BFR Template

When preparing a BFR for NCIS, contact and coordinate with the local NCIS office.

Two levels of approval are required to certify BFR.

1. Mission Approver (NCIS)
2. Activity/PWD Approver (NAVFAC)

The NCIS Engineering Office serves as the "Mission Approver" for all NCIS BFRs. The local installation serves as the "Activity/PWD Approver."

73022-5 General Administrative Space

For Private Office, Open Office, Flex Office and associated Circulation Space, see CCN 61010, Table 61010-5.1. Telework Design criteria is not applied for NCIS entities.

73022-6 **Basic Allowances**

For Admin Support, Break Room and Conference/Training Space, see CCN 61010, Table 61010-7.1.

Note: CCN 61010, Table 61010-7.1A. Conference/Training Room Table provides an overall Conference/Training Room space allocation. For example, if an organization has 112 personnel, an overall conference/training room allocation of 750 NSF is allocated. This overall allocation of 750 NSF can be broken down in any way that best suits the organization, for example it could consist of five conference rooms at 150 NSF each or any variation amounting to 750 NSF. This allocation includes collaboration spaces, teaming rooms, etc.

73022-7 **Functional Support**

73022-7.1 **Case File Storage**: See CCN 61010, Table 61010-7.2 for Archive Storage

Planning Factor: Allocate NSF based on a space analysis

Justification Guidelines: Approved for FO, RA and RU. All require on-site case file storage of active and on-going investigations. NCIS Case Files are "permanent records" as defined by SECNAV M-5210.1 - DON RECORDS MANAGEMENT PROGRAM. A space analysis is required. Multiply the total number of filing cabinets and safes by a planning factor of 7 NSF/EA.

73022-7.2 **Grand Jury Room**: A Grand Jury Room serves as a meeting room for review of ongoing court cases and provides storage room for active litigation documents. Although this space is similar to a conference room, it is additional to the basic conference/training room allocation. This space may require locks or key card entry, but is not necessarily a secure (classified) space.

Planning Factor: Allocate one Grand Jury Room at 150 NSF

Justification Guidelines: Justified for FO if economic crimes component is present. Approved for RA. Not approved for RU.

73022-7.3 **Graphic Workstation:** Shared computer workstation space(s) used to recreate crime scenes, sketch suspects, and develop media presentations. Each workstation requires one NMCI drop and one commercial drop. The purpose of the commercial drop is for the investigation of online evidence that would otherwise be blocked by NMCI, for example, a suspect’s social media. This room is not intended to be the primary workspace for any staff. The number of graphic workstations shall be based on regional requirements as determined by the NCIS Engineering Office.

Planning Factor: Allocate up to four workstations at 64 NSF/WS

Justification Guidelines: Not approved for FO. Approved for RA and RU. Number of graphic workstation(s) based on discussion with NCIS Engineering Office.

73022-7.4 **IT Equipment Storage**: Storage for computer and telecommunication equipment for the using organization. This space type is based on the total number of personnel.

Planning Factor: Allocate 5 NSF/PN, minimum size is 60 NSF

Justification Guidelines: Approved for FO, RA and RU.

73022-7.5 **IT Logistic Support Storage**: A dedicated shipping, receiving, laydown/IT staging, and storage area may be provided to support the IT equipment and parts storage for a NCISFO and that of component NCISRAs and/or NCISRUs. This area is in addition to any maintenance parts and consumables storage requirements that may also exist. The need for IT Logistic Storage Space shall be based on regional requirements as determined by the NCIS Engineering Office.

Planning Factor: See FC 2-000-05N, 131 Series Introduction, Section 131-13.

Justification Guidelines: Justified for FO based on regional requirements. Space analysis is required. Not approved for RA or RU.

73022-7.6 **MCRT Gear Storage**: Provides storage to support a Major Case Response Team's (MCRT) gear storage for special agents. Gear is stored primarily within pelican cases on shelves. Pelican cases are molded plastic containers that seal with an airtight and watertight gasket. Pelican cases for MCRT gear may include but are not limited to: crime scene kits for blood spatter analysis, digital and still camera kits, evidence collection kits, lighting kits for crime scenes and ultra-violet lighting kits for detection of different substances. This space type is based on the number of special agents (SA).

Planning Factor: Allocate 10 NSF/SA, minimum size is 100 NSF

Justification Guidelines: Approved for FO, RA and RU.

73022-7.7 **Secure Conference Room**: Provides space for classified meetings and briefings. This space allocation is in addition to the basic conference/training room allocation above.

Planning Factor:

- Allocate NCISFO secure conference room at 200 NSF
- Allocate NCISRA secure conference room at 120 NSF
- Allocate NCISRU secure conference room at 100 NSF
- Allocate OTHER secure conference room at 120 NSF

Justification Guidelines: Most NCIS organizations operate in secure facilities and have access to secure conference rooms and therefore do not require this space type. If an NCIS organization's primary facility is not secure and only intermittent access to classified briefings are required, a secure conference room is justified.

- Not approved for FO. For FO, apply Mini-MTAC allocation below rather than the secure conference room allocation. The Mini-MTAC is an unmanned, secure space and can also serve as a secure conference room. Ensure that secure conference room and Mini-MTAC are not both allocated at the field office level.

- Justified for NCISRA when only intermittent access to a secure conference room is required. For example, CRIM Agents typically work in an unclassified environment because they require access to their cell phones and require only intermittent access to a secure conference room.

- Approved for NCISRU. NCISRUs are so small (1-5 persons) that they are not authorized a conference room space allocation. However, even if a NCISRU consists of one person, that person must still be able to host a meeting and therefore a basic secure conference room allocation of 100 NSF is approved. Note that at the NCISRU level, the conference room does not necessarily have to be "secure", it can be an ordinary conference room.

73022-7.8 **Secure Terminals**

Note that secure terminals provide secure areas for handling classified material. This space type is not intended to be the primary workspace for any staff. The number of workstations required must be provided by the organization's Security Officer.

Planning Factor: Allocate 64 NSF per workstation

Justification Guidelines: Justified for FO, RA, and RU.

73022-8 **Evidence Storage**

Note: In rare circumstances, an exception to the justification guidelines may be required for evidence storage space types due to site constraints or regional requirements. The NCIS Engineering Office shall provide rationale and responsibility for such an exception in writing.

73022-8.1 **Bulk Evidence Processing**: Room used to process large items of evidence such as, couches, mattresses, washing machines, etc. This space type is based on the number of special agents (SA).

Planning Factor: Allocate 10 NSF/SA, minimum size is 100 NSF

Justification Guidelines: Approved for FO. Justified for RA if drive-time to FO is greater than 60 minutes.

73022-8.2 **Evidence Custodian Station**: Space is required for an evidence custodian station to control and monitor entry to the long-term evidence storage. This overall space is based on a dedicated workstation area of 144 NSF. Since the person manning this space is already accounted for within the General Admin Space allocations at 64 NSF for an open office, this space type is reduced to 80 NSF.

Planning Factor: Allocate one evidence custodian station at 80 NSF

Justification Guidelines: Approved for FO. Justified for RA if drive-time to FO is greater than 60 minutes.

73022-8.3 **Evidence Preparation Area**: This space is used by special agents to prepare evidence for long-term evidence storage.

Planning Factor: Allocate 3 NSF/SA, minimum size is 60 NSF

Justification Guidelines: Approved for FO. Justified for RA if drive-time to FO is greater than 60 minutes.

73022-8.4 **Long-Term Evidence Storage**: Long-term evidence storage is required for securely storing evidence related to ongoing investigations. Space is required primarily for evidence storage shelves and secure storage lockers. A refrigerator is required for the storage of biological evidence. A separate, more secure area is required for storage of firearms, narcotics, currency and/or high-value items. This space type is based on the number of special agents (SA).

Planning Factor: Allocate long-term evidence storage at 30 NSF/SA

Justification Guidelines: Approved for FO. Justified for RA if drive-time to FO is greater than 60 minutes.

73022-8.5 **Temporary Evidence Storage**: This space is for temporary storage of items, awaiting transfer to a long-term, secure evidence storage facility, typically located at nearest NCISFO or NCISRA. Space is required for packaging materials, personal protective equipment, an eyewash station, and a refrigerator for the storage of biological evidence. This space type is based on the number of special agents (SA).

Planning Factor: Allocate temporary evidence storage at 12 NSF/SA

Justification Guidelines: Not approved at FO. Justified for RA if not collocated with FO. Approved for RU.

73022-9 **Fitness**

73022-9.1 **Self Defense Training**: A semi-private room or enclosed area for self-defense training. At a minimum, this space includes easy-to-clean mats that will handle the impact of self-defense training. This space type is based on the number of special agents (SA). A minimum of 10 agents are required to justify this space type.

Planning Factor:

- Allocate 128 NSF for 10-29 special agents
- Allocate 256 NSF for 30 or more special agents

Justification Guidelines: Approved for FO, RA and RU. For security purposes, self-defense training is conducted within NCIS facilities as opposed to a local Installation Fitness Center. A minimum of 10 special agents are required to approve/authorize this space type.

73022-9.2 **Locker Room**: A locker room provides temporary storage lockers for a change in clothing and other personal belongings. This space type is required within NCIS facilities in support of agents working active crime scenes. This space type is based on the number of special agents (SA).

Planning Factor: Allocate one locker at 8 NSF each for every two special agents

Justification Guidelines:
Approved for FO, RA and RU. Agents must be able to shower after conducting a crime scene analysis and therefore require a locker.

73022-9.3 **Shower Room**: A shower room provides one or more shower stalls and is typically collocated with a bathroom and/or locker room. This space type is required within NCIS facilities in support of agents working active crime scenes and self-defense training.

Planning Factor: Allocate one shower at 20 NSF each for every 10 special agents

Justification Guidelines: Approved for FO, RA and RU. While locker and shower rooms do support NCIS Fitness and Self Defense Training functions, the primary requirement for lockers and showers is so agents are able to wash any blood, saliva or unknown substances off their skin with soap and lots of running water after working an active crime scene. A minimum of 10 special agents are required to approve/authorize this space type.

73022-10 **Interviews**

73022-10.1 **Booking & Fingerprinting:** Space used for processing, photographing, and fingerprinting individuals arrested, charged or accused of a crime. This space type is based on the number of special agents (SA).

Planning Factor: Allocate 3 NSF/SA, minimum size is 60 NSF

Justification Guidelines: Approved for FO, RA and RU.

73022-10.2 **Hard Interview Room**: Room used to interview a suspect or criminal. The number of hard interview rooms shall be based on regional requirements as determined by the NCIS Engineering Office.

Planning Factor: Allocate one hard interview room at 100 NSF each

Justification Guidelines: Approved for FO, RA and RU. Hard interview rooms are allocated based on regional requirements.

73022-10.3 **Soft Interview Room**: Room used to interview a victim. Unlike a hard interview room, this space may include comfortable chairs, wall decorations and soft lighting, meant to make victims of traumatic crimes feel more comfortable sharing crime details with investigators. The number of soft interview rooms shall be based on regional requirements as determined by the NCIS Engineering Office.

Planning Factor: Allocate soft interview room at 120 NSF each

Justification Guidelines: Approved for FO, RA and RU. Soft interview rooms are allocated based on regional requirements.

73022-10.4 **Observation Room**: An Interview Observation Room is located between hard interview rooms. One-way glass windows share common walls with the hard interview rooms for monitoring interviews. Consideration should be given to using CCTV feeds rather than providing space for an observation room.

Planning Factor: Allocate one interview observation room at 100 NSF each

Justification Guidelines: Approved for FO, RA and RU. Interview observation rooms are allocated on a case-by-case basis.

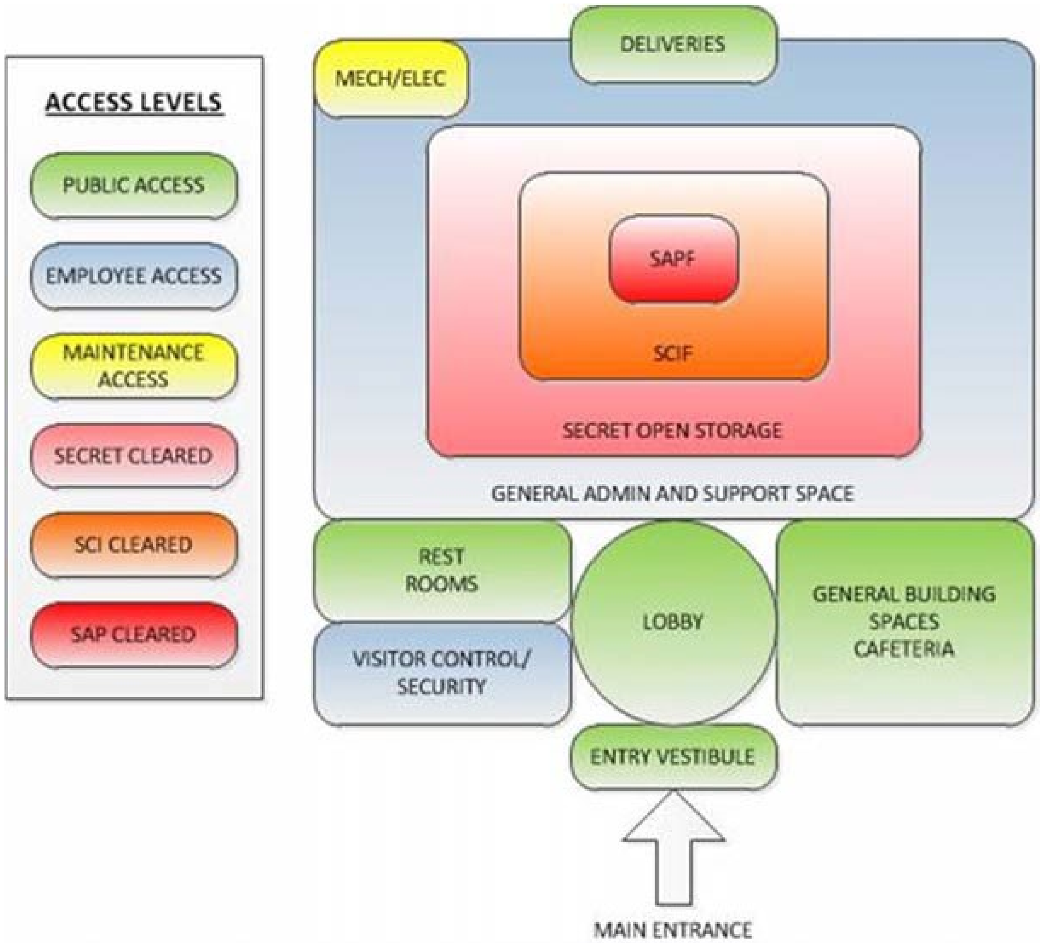
73022-11 **Secure Areas**

These space types are discussed here in general, but are not included in the NCIS BFR Template.

Depending on the mission of an organization, some secure areas may be required, ranging from secure kiosk stations, to Open Secret Storage (OSS) areas, to a Sensitive Compartmented Information Facility (SCIF), to a Special Access Program Facility (SAPF). If a portion of an organization operates at a higher classification than the rest of the facility, the space provided for them is calculated based on the overall requirements set forth in the 131 Series Introduction criteria.

Do not call-out the classification levels of space types in planning or design documents. Refer to these spaces only as “secure spaces”. For NCIS, these space types typically consist of an office space environment with dedicated office spaces. This means the secure spaces do not have to be called out specifically in the BFR, because they have already been accounted for in the office space requirements. This also supports the OPSEC goal of not identifying the level of secure area or the mission in planning or design documents.

Notional Diagram of Secure Space Types



In some cases, one or more analysis workstations may be required and must be called out separately as an "analysis workstation".

- For analysts working in a secure environment:
  - Allocate 90 NSF for an analysis workstation required to monitor up to 4 networks.
  - Allocate 130 NSF for an analysis workstation required to monitor more than 4 networks.
- If using the NCIS BFR Template, an analysis workstation can be included as a "user-defined-space".
- If using the NCIS BFR Template, ancillary secure comms spaces, can also be included as "user-defined-spaces".

73022-12 **Security**

See Table 61010-7.3 for Entry Control Area, Secure Visitor Waiting Area and Weapons Vestibule and Vault.

73022-13 **Watch Center**

73022-13.1 **Mini-MTAC**: The Multiple Threat Alert Center (MTAC) for NCIS Headquarters is a large Watch Center utilizing NCIS' worldwide presence and combination of law enforcement, counterintelligence, intelligence, and security capabilities to identify a wide range of threats to Navy and Marine Corps personnel and assets around the world.

A true Watch Center generally operates on a shift system where personnel oversee multiple systems using multiple shifts to provide coverage up to 24 hours a day. A Watch Center may include the following areas based on mission requirements: Watch Floor (containing Kiosk Workstations, Watch Stander Workstations, and Watch Workstations). Workspaces require an unobstructed view in order to see a centralized display area on a room wall consisting of multiple flat panel screens.

NCIS Field Offices may require portions of a Watch Center in the form of a Mini-MTAC[1]. This is a secure space, but is not permanently manned. At the Field office level, this space type is the equivalent of a secure conference room.

Planning Factor: Allocate Mini-MTAC area at 200 NSF

Justification Guidelines: FO requires portions of a Watch Center in the form of a scaled-down "Multiple Threat Alert Center" (MTAC) referred to here as a "Mini-MTAC". This is a secure space. At the field office level, this space type is the equivalent of a secure conference room, 200 NSF in size. Do not apply secure conference room allocation above, if allocating space for a Mini-MTAC here.

73022-13.2 **Server Room**: A server room is an air-conditioned space, devoted to the continuous operation of computer servers. An entire building or station devoted to this purpose is a data center. For Server Rooms with less than 120 racks, the recommended server room requirements are listed in Table 131-6. For a server room with less than 10 racks, multiply the total number of racks by 45 NSF/Rack.
Planning Factor: See Table 131-6 Equipment Room Requirement by Total Racks and Table 131-7. C5ISR Equipment Factor.

---

[1] The Multiple Threat Alert Center (MTAC) for NCIS Headquarters is a large Watch Center. It is a unique platform in that it merges intelligence from other agencies with information from NCIS source networks and law enforcement activities worldwide to provide the most relevant operational support to Navy and Marine Corps commanders.

Justification Guidelines: FO, RA and RU all may require a secure server room. This space type is intended for NCIS operated servers and does not apply to NMCI operated servers.

Mission Specific Components:

In addition to the NCIS Field Office space requirements identified above, some field offices have specialized component missions and require unique space types. Specialized component missions include:

- Cyber Operations
- Economic Crimes (formerly known as Fraud)
- Forensics Support
- Polygraph Services
- Protective Operations
- Security Training Assistance and Assessment Team (STAAT)
- Technical Services and Technical Surveillance Countermeasures
- Virtual Operations

73022-14 **Cyber Operations**

Cyber Operations conduct cyber investigations, proactive cyber operations, and cyber forensics support for the Department of the Navy (DON). NCIS cyber capabilities disrupt, deter and defend against criminal, terrorist, and foreign intelligence threats against the DON. NCIS Cyber Operations provides full-spectrum criminal, counterintelligence, counterterrorism investigations and operations in the cyber domain; conducts cyber forensics and analysis; coordinates and partners with law enforcement and intelligence in the U.S. and abroad; capitalizes on data by identifying existing and emerging threats to predict future trends and enhance capabilities; collaborates with industry, academia and mission partners.

Unique space types associated with Cyber Operations include:

73022-14.1 **Cyber Forensics Lab**: A shared, unclassified area NCIS agents use to analyze evidence such as recovered cell phones, laptops, desktops, and other electronic storage. This area is unclassified because it may contain cell phones and other unsecured electronic devices.

Planning Factor: Allocate one cyber forensics lab at 300 NSF

Justification Guidelines: Approved if NCISFO has a cyber-operations component.

73022-14.2 **Hard Drive Recovery Room**: A dedicated clean room used to recover data from a hard drive that may have been corrupted, lost or damaged. This space type is designed to avoid particles and contaminates that can settle on sensitive exposed hard drive components as this may affect the recovery process and cause a malfunction or permanent loss of data.

Planning Factor: Allocate one hard drive recovery room at 100 NSF

Justification Guidelines: Approved if NCISFO has a cyber-operations component.

73022-15 **Economic Crimes**

Economic Crimes safeguards DON acquisition programs and enhances fleet readiness and superiority by conducting investigations and proactive operations to identify and reduce economic crimes. Economic Crimes priorities are to identify and reduce product substitution threatening warfighter safety and battlefield superiority, to combat corruption in the acquisition process, and to ensure protection of Navy capital investment in technology. By reducing procurement fraud, defined as bribery, subcontractor kickbacks, conflict of interest, cost mischarging, and product substitution, the DON will realize cost savings and procure products that meet safety standards for the warfighter, ultimately resulting in increased operational readiness.

Unique space types associated with Economic Crimes include:

73022-15.1 **Grand Jury Room**: This space type is defined in the “Special Purpose Space - Functional Support” section above.

Justification Guidelines: Approved if NCISFO has an economic crimes component.

73022-16 **Forensics Support**

Forensics Support provides forensic crime scene support to DON investigations. The Office of Forensic Support is a team of specially trained forensic consultants that assist in the processing of crime scenes. Although all NCIS Special Agents receive basic forensic training, these consultants are experts in crime-scene reconstruction, firearms trajectory, blood spatter analysis, and human remains recovery and examination. Their input is critical to a range of investigations, from deaths to economic crimes and even counterintelligence. Unique space types associated with Forensics Support include:

73022-16.1 **Forensics Lab**: Space used to collect samples and process evidence for further evaluation, including fingerprint analysis, evidence analysis and photography.

This space includes a workstation for a forensic consultant, evidence refrigerator, secure evidence cabinet, sink, standing lab bench, work counters, and fuming/drying chambers. Forensic Support personnel use this space.

Planning Factor: Allocate one forensics lab at 20 NSF/SA

Justification Guidelines: Approved if NCISFO has a forensics support component.

73022-16.2 **Low-Bay Garage**: Space used to collect forensics data (residues, blood, fluids, finger prints, tire prints, bullet trajectories, ID of auto parts and paints). Space is required to accommodate a large SUV or van. A vehicle lift is not required; therefore, this space is not “high-bay”. Space must provide sufficient space between the roof of vehicle and room ceiling for inspection, so this space would not include a dropped ceiling. Allocate up to two vehicles (VE) requiring simultaneous storage based on interview with using activity.

Planning Factor: Allocate up to two vehicles at 375 NSF/VE

Justification Guidelines: Approved if NCISFO has a forensics support component.

73022-16.3 **Vehicle Evidence Parking Area**: A fenced and dedicated parking area for storing evidentiary impounded vehicles. This space requirement is included here for information purposes only. This asset and space requirement are recorded under CCN 85210 - PARKING AREA. The number of vehicles (VE) requiring simultaneous storage is provided by the using activity.

Planning Factor: Allocate one vehicle evidence parking area at 35 SY/VE

Justification Guidelines: Approved if NCISFO has a forensics support component.

73022-17 **Polygraph Services**

Polygraph Services is comprised of highly skilled interviewers who utilize the polygraph to obtain information in support of criminal, counterintelligence, and counterterrorism investigations for NCIS, the Department of the Navy, and the Department of Defense. Additionally, the Polygraph Services Division performs pre-employment polygraphs and administers the DON's Counterintelligence Scope Polygraph Program, helping to ensure that the DON's most sensitive national security programs are protected against the "insider threat."

Unique space types associated with Polygraph Services include:

73022-17.1 **Polygraph Exam Room**: Room used to conduct exams that measures and records physiological indicators while answering a series of questions asked by the Examiner. While the physical requirements are similar to an “Interview Room”, Polygraph Exam Rooms require specialized equipment that would not be found in an

Interview Room; therefore, these spaces cannot be shared as a dual-purpose space. The number of polygraph exam rooms shall be based on regional requirements as determined by the NCIS Engineering Office.

Planning Factor: Allocate one polygraph exam room at 120 NSF each

Justification Guidelines: Approved for NCISFO or NCISRA. Justified at a NCISRU on a case by case basis.

73022-17.2 **Observation Room**: A observation room is for monitoring polygraph exams. Located adjacent to one or more polygraph exam rooms, it provides sufficient space for a small table, two chairs, and audio/visual equipment. Consideration should be given to using CCTV feeds rather than providing space for an observation room.

Planning Factor: Allocate one polygraph observation room at 100 NSF each

Justification Guidelines: Approved for NCISFO or NCISRA. Justified at a NCISRU on a case by case basis.

73022-18 **Protective Operations**

Protective Operations provides and manages full-time protection details on key Department of the Navy personnel. Protective Operations' mission is to prevent terrorist and/or criminal attacks on principals under NCIS executive protection coverage and execute the necessary and appropriate response to a threat and/or attack on a principal. Protective Operations supports DOD/DON High Risk Billets with full or part-time personal security advisors. Protective Operations also provides executive protection to visiting foreign dignitaries and other DOD/USG officials as required by the foreign liaison offices and other DOD/USG agencies. To supplement operational forces, Protective Operations maintains an internal Protective Intelligence Unit to identify potential threats that could affect a principal, understand a principal's level of vulnerability to any given threat, and use available intelligence to mitigate threats and/or risk to a principal.

Unique space types associated with Protective Operations include:

73022-18.1 **(POFO) High Bay Garage**: Protective Operations requires a secure, climate-controlled, high-bay garage for storage of armored Government Owned Vehicles (GOVs). The GOVs are used to provide executive protection to Senior Leadership and visiting foreign dignitaries. Space is required for GOVs, maintenance, cleaning, minor repairs and retrofitting electronic equipment. A high-bay garage is necessary, as at least one vehicle lift is required. These GOVs are large, armored SUVs. The planning factor is based on number of GOVs required at any one time.

Planning Factor: Allocate up to eight vehicles at 375 NSF/VE

Justification Guidelines: Approved for protective operations detachments.

73022-18.2 **Duty/Bunk Room**: A Duty/Bunk Room is required when a mission requires continuous operations, 24 hours a day, 7 days a week. NCIS Protective Operations components meet these requirements. Note: This space type requires approval from the Installation Commanding Officer due to liability issues.

Planning factor: Allocate one duty/bunk room at 130 NSF

Justification Guidelines: Approved for protective operations detachments. Requires additional approval from the Installation Commanding Officer for liability purposes.

73022-19 **Security Training Assistance and Assessment Team (STAAT)**

NCIS Security Training Assistance and Assessment Teams (STAAT) support Navy and Marine Corps components by providing vulnerability assessments and on-site training and assistance to Naval activities worldwide (ashore and afloat) in various law enforcement, physical security, and antiterrorism disciplines. STAAT supervisors and staff work closely with Commanders to determine the level of required support to protect Navy personnel and assets. STAAT also provides support to selected foreign and domestic law enforcement agencies to enhance the protection of U.S. personnel and assets worldwide.

Unique space types associated with a Security Training Assistance and Assessment Team include:

73022-19.1 **Academic Classroom:** This space includes computer-based (laptop) training stations. In addition to STAAT LANT and STAAT PAC, this space type is approved for STAAT Detachments as well. Student loading is provided by the using activity.

Planning Factor: Allocate academic classroom space at 20 NSF/ST

Justification Guidelines: Approved only for STAAT organizations. Does not apply to FO, RA, or RU. In the “Select NCIS Region” dropdown list, select "STAAT" to locate STAAT organizations.

73022-19.2 **Student Lounge:** This space provides a student lounge area during training breaks or lunch. It typically includes some or all of the following: sitting tables, vending machines, microwave oven, and refrigerator.

Planning Factor: Allocate student lounge area at 4 NSF/ST

Justification Guidelines: Approved only for STAAT organizations. Does not apply to FO, RA, or RU. In the “Select NCIS Region” dropdown list, select "STAAT" to locate STAAT organizations.

73022-20 **Technical Services Division (TSD) and Technical Surveillance Countermeasures (TSCM)**

The Technical Services Division (TSD) provides DON technical support for criminal, counterintelligence, and counter-terrorism investigations and operations. Investigative Specialists provide specialized technical capabilities to support NCIS investigations and operations. The technical support provided by these highly trained specialists is often critical to the success of NCIS investigations and operations. Through their efforts, NCIS Special Agents and Technical Enforcement Officers are able conduct authorized interception of telephone communications, employ covert video surveillance, and take advantage of other technical innovations to help meet mission requirements. Technical Services includes Technical Surveillance Countermeasures (TSCM).

Technical Surveillance Countermeasures (TSCM) protects DON classified information and critical infrastructure from being compromised by technical means. NCIS Technical Investigators are responsible for conducting the Navy's Technical Surveillance Countermeasures mission. They conduct investigations to protect the DON's classified information and critical infrastructure from being compromised by technical means (for example, through covert listening devices or other surveillance technology) employed by foreign intelligence or other parties. These NCIS professionals assess vulnerabilities and identify and resolve technical surveillance threats. NCIS Technical Investigators serve in TSCM units at NCIS Headquarters and select NCIS field offices around the world, where they are best positioned to meet the needs of the U.S. Navy commands, they support. TSCM detects, neutralizes, and exploits technical surveillance and associated devices, technologies, and hazards that facilitate the unauthorized or inadvertent access to, removal or theft of DOD information, via technical means at any worldwide facility, ship or aircraft.

Unique space types associated with TSD/TSCM include:

73022-20.1 **(TSCM) High Bay Garage:** This is a vehicle inspection garage, large enough to examine two vehicles the size of a large van or SUV. A high-bay garage is necessary, as at least one vehicle lift is required. This area is for bullet trajectory analysis, installation of GPS tracking equipment and other technical equipment. Technical Services personnel use this space.

Planning Factor: Allocate up to two vehicles at 375 NSF/VE

Justification Guidelines: Approved if NCISFO has a Technical Service or Technical Surveillance Countermeasures (TSCM) component.

73022-20.2 **Equipment Storage:** Large room with shelving for pelican cases used to store investigative and counter-intelligence equipment for TSCM. Pelican cases for TSCM equipment includes, but is not limited to: multiple types of radio frequency detection systems such as cellular or WIFI, portable x-ray systems to look inside a car or wall, network analysis tool sets, crime scene analysis tool sets and more.

This space is similar to the (MCRT) gear storage room used by agents; however, this equipment storage room is typically larger and is used by TSCM personnel. A space analysis is required.

Planning Factor: Allocate NSF based on a space analysis

Justification Guidelines: Approved if NCISFO has a Technical Service or Technical Surveillance Countermeasures (TSCM) component.

73022-20.3 **Equipment Testing & Evaluation Lab:** This space provides for testing and evaluation of field equipment prior to field operation. The space is equipped with a workbench, shelving, and test equipment. Technical Services personnel use this space. A space analysis is required.

Planning Factor: Allocate NSF based on inspection and testing room requirements

Justification Guidelines: Approved if NCISFO has a Technical Service or Technical Surveillance Countermeasures (TSCM) component.

73022-20.4 **Shop Space:** May include a wood shop, metal shop, and/or work benches. Technical Services personnel use this space. Shop Space requirements are developed by a space analysis using the allowances provided in Table 131-4 or an architectural layout. A space analysis is required.

Planning Factor: Allocate NSF based on a space analysis

Justification Guidelines: Approved if NCISFO has a Technical Service or Technical Surveillance Countermeasures (TSCM) component.

73022-21 **Virtual Operations**

Virtual Ops Center (VOC) is a cyber-based operational counterintelligence platform to provide direct support to the DON by; protecting critical naval technologies and programs; conducting operations in the cyber domain; and protecting the DON's technological and warfighting advantage. The VOC’s goal is to detect, identify, neutralize, and exploit attempts of foreign intelligence entities attempting to penetrate the DON and erode its warfighting edge.

Unique space types associated with a Virtual Operations Center include:

73022-21.1 **Virtual Operations Center**: A VOC is a highly specialized facility and may include the following space types: cyber labs with separate IT networks, SAP-F, SCIF, unclassified areas and a watch center. VOC space types must be aligned to either the 131 or 143 Series criteria. Space requirements need to account for the heavy electrical and mechanical loads and associated space requirements. Tier Level (I, II, III) for each function must be identified.

Planning Factor: Allocate NSF based on a space analysis

Justification Guidelines: Approved for NCISFO Virtual Operations Center (VOC).

73022-21.2 **Special Purpose Processing Node**: A Special Purpose Processing Node (SPPN) is a fixed data center or data servers in a fixed facility supporting special purpose functions that cannot or should not be supported by a DoD Core Data Center (CDC) or an Installation Processing Node (IPN) due to its association with mission specific infrastructure or equipment (e.g., Meteorology, Medical, Modeling & Simulation, Test Ranges, Classrooms, RDT&E, etc.). Source: https://dodcio.defense.gov/Portals/0/Documents/DIEA/CDC%20RA%20v1_0_Final_Releaseable%20Version.pdf

Planning Factor: See Table 131-6 and Table 131-7.

Justification Guidelines: Approved for NCISFO Virtual Operations Center (VOC).

73022-22 **Net-To-Gross Factor**

The Net-To-Gross (NTG) factor for CCN 73022 - NCIS Field Office is 1.40.

730 25 GATE/SENTRY HOUSE (SF)
FAC: 1498
BFR Required: Y

73025-1 The gate/sentry house may vary in size from a simple sentry shelter to a building housing a gate guard office, clerical office, and waiting room; or a truck inspection building. See Table 73025-1 for space allowances.

Table 73025-1
Space Allowances for Gate/Sentry Houses

Location	Gross Area allowance
Gate of small activity	6 sq. m or 64 SF
Major gate at medium to large activity	56 sq. m (50 sq. m gate house & 6 sq. m sentry house) or 604 SF (540 SF gate house & 64 SF sentry house)
Secondary gate at medium to large activity	6 sq. m or 64 SF
Truck Inspection Building	Individual justification is required

73025-2 The differentiations between small and medium activities and between major and secondary gates are not given here. A reasonable approach should be taken. If the function requires no more than two guards at a time and no waiting room for persons awaiting clearance, then a sentry house is adequate. Some industrial installations may have an employment office, first aid room, and safety office located at the gate house. Space for these functions are planned and inventoried as Category Code 610 10 using the appropriate planning factors.

730 30 BAKERY (SF)
FAC: 7321
BFR Required: Y

73030-1 **DEFINITION.** The establishment of bakeries is governed by provisions of DoD instruction 4100.33 – Commercial or Industrial Activities – Operation of. Normally a bakery will be authorized where commercial sources are not available. See Table 73030-1 for space allowances. The rated capacities given are for 8-hour per day operation and increase in direct proportion to the increase in hours of operation.

Table 73030-1
Space Allowances for Bakeries

Number of Persons Served	Gross Area SQ. M./SF		Rated Capacity Kilograms/Pounds	
Bread Bakery				
3,000	418	4,500	560	1,500
8,400	483	5,200	1,570	4,200
16,000	762	8,200	3,130	8,400
26,900	929	10,000	5,010	13,425
Pastry Bakery			(servings)	
2,500	167	1,800	5,000	
5,000	274	2,950	10,000	
10,000	311	3,350	20,000	
20,000	451	4,850	40,000	

730 35 LOCKER ROOM (SF)
FAC: 7382
BFR Required: Y

73035-1 **DEFINITION**. This facility provides locker space for the belongings of military personnel who must vacate their quarters for extended periods of time, for those whose allotted storage space is not sufficient, and for other uses as deemed justified by the Commanding Officer. See Table 73035-1 for space allowances. Allowances from Table 73035-1 may be used for planning purposes; however, a detailed space analysis may give a different square footage depending on the function that is being supported. (Do not double count with other CCNs such as gyms, fitness etc.). This category code must be individually justified for Marine Corps activities.

Table 73035-1
Space Allowances for Locker Rooms

Strength Supported	Number of Lockers	Gross Area per Locker	
		sq. m	SF
Up to 500	Strength X 0.285	1.07	11.5
501 to 6,000	Strength X 0.285	0.93	10.0
Over 6,000	Strength X 0.285	0.84	9.0

730 36 LUNCH/LOCKER ROOM (SF)
FAC: 7332
BFR Required: Y

73036-1 This facility is generally provided only to support industrial operations and requires specific justification. No planning factors are available.

730 40 LAUNDRY/DRY CLEANING PLANT (SF)
FAC: 7342
BFR Required: Y

73040-1 **REQUIREMENTS.** The establishment of these facilities is governed by provisions of DOD Instruction 4100.33 - Commercial or Industrial Activities - Operation of. Normally they will be authorized only in locations where commercial facilities are not available. See Table 73040-1 for space allowances. For combination with exchange-operated facilities, see notes in Category Code 740 13 and 740 15.

Table 73040-1
Space Allowances for Laundries And Dry Cleaning Plants

Number of Persons Served	Gross Area (1) Laundry and Dry Cleaning Plants	
	sq. m	SF
0 to 2,000	Not Authorized	Not Authorized
2,001 to 4,000	790	8,500
7,001 to 10,000	1,020	11,000
15,001 to 30,000	4,180	45,000

(1) Does not include boiler plants which are sized as required and are carried under Category Code 821 50.

730 45 DEPENDENT SCHOOL - NURSERY SCHOOL (SF)

This CCN has been deleted. All existing assets should be reassigned to CCN 73061 Dependent School - Consolidated

730 50 DEPENDENT SCHOOL - KINDERGARTEN (SF)

This CCN has been deleted. All existing assets should be reassigned to CCN 73061 Dependent School - Consolidated

730 55 DEPENDENT SCHOOL - GRADE SCHOOL (SF)

This CCN has been deleted. All existing assets should be reassigned to CCN 73061 Dependent School - Consolidated

730 60 DEPENDENT SCHOOL - HIGH SCHOOL (SF)

This CCN has been deleted. All existing assets should be reassigned to CCN 73061 Dependent School - Consolidated

Ref: www.odedodea.edu

73050/55/60-1 The planning and programming for dependent school facilities overseas is currently under the cognizance of Department of Defense Education Activity (DoDEA),. Assistance related to school facility matters may be obtained from DoDEA or their overseas field offices. Each DoDEA region has comprehensive education specifications which should be used in planning dependent school facilities.

The following general notes may be of assistance for preliminary school facilities planning:

73050/55/60-1.1 Dependents school facilities in any overseas area will be planned to accommodate all DoD dependents (Army, Navy, Air Force, and Marine) and dependents of other Federal agencies in the area. In estimating the number of school-age dependents to provide for, the following may prove helpful:

- If an existing school facility is to be expanded, a local survey to determine the average number of school-age children per family may be most accurate.
- If a new school is to be established, the following Navy statistics may serve as a guide: (For Marine overseas the number of accompanied tours is a

function of available housing and is managed by CMC D C/S, manpower. These proportions should be used.)

- Of all officer personnel assigned overseas 62.14% will move families. These families average 1.73 minor dependents per family with 50% of school-age.

- Of all enlisted personnel assigned overseas 31.63% will move families. These families average 1.68 minor dependents per family with 50% school-age.

- The average number of school-age dependents per family may vary from area to area and from mission to mission and may at times exceed one per family. The superintendent/director for dependents' education may provide assistance in this area.

73050/55/60-1.2 In estimating the distribution of dependents by grade, the following average Navy statistics considering all families may help:

Kindergarten	.08 pupils/family
Grade School 1-6	.52 pupils/family
High School 7-12	.26 pupils/family

73050/55/60-1.3 Count all families, with or without children. Again the superintendent/ director for dependent's education in the area may provide assistance.

73050/55/60-2 This scope should be adequate to house the total educational program as developed by the superintendent/director for the area. However, the superintendent/director may wish to alter the utilization of the space to a degree to meet unique requirements of the educational program or the geographic location.

730 61 DEPENDENT SCHOOL – CONSOLIDATED (SF)
FAC: 7352
BFR Required: Y

73061-1 **DEFINITION**. The planning and programming for dependent schools (grades Pre-K or Sure Start program through grade 12) is currently under the cognizance of Department of Defense Education Activity (DoDEA). Assistance related to school facility matters may be obtained from DoDEA HQ which has access to comprehensive education specifications which should be used in planning dependent school facilities.

73061-2 This category code was created to primarily support overseas locations but can be used at any installation where consolidated facilities are recommended. Facilities' sizing and configuration must be completed in consultation with DODEA officials. Prior to project programming, the proposed project must be validated by DoDEA. The point of Contact for DoDEA Schools is:

Headquarters DoDEA/ Facilities Branch
4800 Mark Center Drive
Alexandria, VA. 22350

73061-3 Contact DoDEA HQ at the above address to obtain the “Program for Design” for your school. This document will supply the necessary staffing and size data to complete your BFR calculation spreadsheet.

730 65 FALLOUT SHELTER (SF)
FAC: 7383
BFR Required: N

73065-1 **DEFINITION**. There are two kinds of fallout shelters: dual-purpose and single purpose. A dual-purpose fallout shelter is one which, as a primary purpose, satisfies some other basic requirement such as housing, administrative, storage, etc. and as a secondary purpose, it can provide fallout protection. A single-purpose fallout shelter is a structure or part of a structure whose primary purpose is fallout protection. Dual-purpose shelters are designated in the real property according to their primary purpose. Single-purpose shelters are designated in the inventory as Code 730 65. The construction of single-purpose fallout shelters is not presently authorized. The designation of the number of fallout shelter spaces on existing or new military construction is not presently required.

730 66 MISCELLANEOUS PERSONNEL WEATHER SHELTER (SF)
FAC: 7384
BFR Required: N

73066-1 **DEFINITION**. Shelters may be established at bus stops or other locations as required. Provide 0.5 sq.m. (5 SF) per person.

730 67 BUS STATION (SF)
FAC: 7341
BFR Required: Y

73067-1 A bus station is a terminal with space for a waiting room and ticket sales. It may be planned as required. Provide 2 sq.m. (20 GSF) per person for the expected waiting group.

730 74 KENNEL – MORALE, WELFARE & RECREATION OPERATED (SF)
FAC: 7447
BFR Required: N

73074-1 **DEFINITION**. Use this category code for kennels and quarantine facilities operated as a function of the Morale, Welfare and Recreation (MWR) programs at the Installation. Refer to CCN 730 76 for kennels for military working dogs.

73074-2 **REQUIREMENTS.** The requirements for new kennel facilities are determined by Commander Navy Installation Command (CNIC) Code N9 (Fleet & Family Readiness). The following guidance is used in the project planning for kennel facilities:

73074-2.1 Any proposed new construction must first go through the pre-Internal Needs Validation Study (pre-INVS), full Internal Needs Validation Study (INVS), and Project Validation Assessment (PVA).

73074-2.2 The size of the facility is based upon market analysis and consequent financial projections that must justify programming of the facility.

73074-2.3 Return on Investment (ROI) analysis is based on projected demand, market, revenues, capital investment, and operating and maintenance costs. This type of analysis will determine the financial feasibility of the proposed project and the number and type of units required to ensure a viable outcome. This analysis must follow the requirements of the template developed by CNIC, which is available for download at http://navymwr.org/. This category code is for inventory purposes only.

730 75 PUBLIC TOILET (SF)
FAC: 7385
BFR Required: N

73075-1 Use this code for inventory of all detached comfort stations except for those in the bachelor housing area. Use Category Code 723 20 Latrine for the bachelor housing area.

730 76 MILITARY WORKING DOG KENNEL (SF)
FAC: 1445
BFR Required: Y

73076-1 **DEFINITION**. The Military Working Dog (MWD) Kennel consists of Dog Kennel, Dog Training/Support, and Administrative/Support areas. The following core space designations and rooms for a MWD facility are as follows:

<u>Administration Area</u>

- Kennel Master (with closet)
- Trainers
- Handlers
- Storage

<u>Special Use Areas</u>

- Tack Room
- Food Storage
- Food Preparation
- Exam Room
- Surgery Room

<u>Common Use / Support</u>

- TA-50 Lockers
- Multi-Purpose
- Storage

<u>Kennel</u>

- Dog House
- Interior Kennel
- Exterior Kennel

Support spaces for personnel consists of the following:

- Men's Toilet, Shower, and Locker
- Women's Toilet, Shower, and Locker
- Janitor Closet Area

73076-2 **REQUIREMENTS**. The table below is a space planning tool for developing the core facility space requirements for each area. Use this category code for Military Working Dog (MWD) kennels and quarantine facilities operated by the Installation security department. Activities must consider using existing facilities or consolidating support functions with other activities. Refer to Table 73076-1 for space allowance areas. Refer to CCN 730 74 for kennels operated by Morale, Welfare & Recreation (MWR).

Table 73076-1

Space Allowance for Military Working Dog Kennel

AREA	NO. OF ROOMS REQUIRED	INDIVIDUAL ROOM REQUIREMENTS	NET USER REQUIREMENTS		COMMENTS
		SF	SF	m²	
Kennel Master	1	130	130	12.08	1,4,7
Trainers	1	430	430	39.95	2,4,7
Handlers	1	1,055	1,055	98.01	3,4,7
SUBTOTAL ADMINISTRATION AREA			**1,615**	**150.04**	
SPECIAL USE					
Tack Room	1	370	370	34.37	4
Food Storage and Preparation	1	290	290	26.94	4
Exam Room	1	360	360	33.45	4
Surgery	1	105	105	9.75	4
SUBTOTAL SPECIAL USE AREA			**1,125**	**104.51**	
COMMON USE / SUPPORT					
TA-50 Lockers	1	540	540	50.17	6
Mulit-Purpose Room	1	385	385	35.77	4
SUBTOTAL COMMON USE / SUPPORT			**925**	**85.94**	
KENNEL					
Dog House	10	15	150	13.94	7
Indoor Kennel	10	80	800	74.32	7
Outdoor Kennel	10	80	800	74.32	7
Interior Kennel Corridor (Conditioned)	1	920	920	85.47	7
Exterior Kennel Corridor	2	400	800	74.32	7
Wet Storage	1	90	90	8.36	7
Dry Storage	1	90	90	8.36	7
SUBTOTAL KENNEL AREA			**3,650**	**339.09**	
BUILDING SUPPORT					
Communications Room	1	150	150	13.94	10
Mechanical Room	1	125	125	11.61	10
Electrical Room	1	260	260	24.15	10
SUBTOTAL BUILDING SUPPOPRT AREA			**535**	**49.70**	10

AREA	NO. OF ROOMS REQUIRED	INDIVIDUAL ROOM REQMTS.	NET USER REQUIREMENTS		COMMENTS
		SF	SF	m^2	
TOILET, SHOWER, LOCKER					
Men's Toilet, Shower, Locker	1	320	320	29.73	9
Women's Toilet, Shower, Locker	1	315	315	29.26	9
Janitor	1	50	50	4.65	
SUBTOTAL TOILET, SHOWER, LOCKER AREAS			**685**	**63.64**	
CIRCULATION					5
Administrative Corridor	1	415	415	38.55	
Support Corridor	1	395	395	36.70	
SUBTOTAL CIRCULATION AREAS			**810**	**75.25**	
Outdoor Storage	1	400	400	37.16	8
Dog Break Area	1	200	200	18.58	8
Optional Explosive Storage	1	115	115	10.68	8
Obedience Course	1	11,250	11,250	1,045.13	8
TOTAL FACILITY NET FLOOR AREA			**8,535**	**792.92**	
CIRCULATION MULTIPLIER OF NET FLOOR AREA NET-TO-GROSS MULTIPLIER **TOTAL FGACILITY GROSS AREA (ROUNDED)**	6.5 % 15.0%		9,090 10,455 **10,460**	**972**	11,12,13
COMMENTS					

1 **Kennel Master, one per 10 dogs, user defined.**
2 **Trainers, two per 10 dogs, user defined.**
3 **Handlers, one per 2 dogs, user defined.**
4 **Reference: Standard Design – Air Force Military Working Dog Facility.**
5 **A multiplier of up to 10% may be added to the authorized net facility area to support primary circulation.**
6 **TA-50 storage lockers, one per Kennel Master, Trainer, and Handler, user defined.**
7 **Verify the number of dog kennels for each installation.**
8 **Outdoor Training / Support areas are not included in the facility floor area totals.**
9 **Male/Female ratio of 50/50. See UFC 3-420-01 Plumbing Systems for more details.**
10 **Building Support areas are estimates only. Actual sizes are dependent on climate zone, location, system, etc.**
11 **A net-to-gross multiplier of up to 25% is allowed. A 15% net-to-gross multiplier is used per standard design.**
12 **The area square footage is rounded to the nearest whole number.**
13 **This worksheet plans for a one-bay facility of 10,460 square feet (972 m^2).**

73076-3 **REQUIREMENTS.** Use the following criteria to plan MWD Kennel Facilities:

73076-3.1 Locate the kennel adjacent to or in proximity to an existing military police facility that provides 24 hour observation of the kennel and to eliminate the need for separate exterior lighting and fencing.

73076-3.2 Kennel surfaces must be impervious. Surfaces shall have a liquid glaze applied.

73076-3.3 For planning details, floor plans, and construction criteria, reference Standard Design, Air Force Military Working Dog Facility on the *Whole Building Design Guide* at https://www.wbdg.org/airforce/prototypes-standard-designs.

73076-4 **DEPARTMENT OF THE NAVY PROGRAM MANAGEMENT -** Reference OPNAVINST 5585.2C, *The Department of the Navy Military Working Dog Program dated 7 September 2012,* for policies procedures, and responsibilities for the administration of the Navy's MWD program.

The MWD Program Manager reports to the operational chain of command of U.S. Fleet Forces Command.

73076-5 **USMC PROGRAM MANAGEMENT.** For Marine Corps activities, the project manager for MWD requirements is the Security Branch. Program requirements should be submitted to Headquarters USMC D C/S for Plans, Policies, and Operations.

730 77 PERSONNEL SUPPORT STORAGE (READY ISSUE/SHOP STORES/MISC.) (SF)
FAC: 4421
BFR Required: Y

73077-1 Storage facilities for miscellaneous goods related to personnel support facilities will be provided only where it can be individually justified. There are no criteria for this type of facility. Note: This category code is not applicable for Marine Corps activities.

730 78 DAIRY PLANT (SF)
FAC: 7322
BFR Required: Y

No planning factors are available.

730 82 RECYCLING CENTER (SF)
FAC: 8331
BFR Required: Y

73082-1 This facility serves as a collection, sorting, storage, and shipping center for recyclable materials and products. Recycled materials are forwarded to together government or commercial recycling centers. There are no planning criteria for this facility, each requirement will require individual justification with detailed data on operational methods, equipment required, volume of processed containers and need for enclosed building space.

730 83 RELIGIOUS MINISTRY FACILITIES (SF)
FAC: 7361
BFR Required: Y

Project Review: CNIC HQ Force Chaplain
Design Criteria: Unified Facilities Criteria (UFC) 4-730-02 “Design: Chapels and Religious Education Facilities” dated 16 January 2004

73083-1 **DESCRIPTION.** Department of the Navy policy is that commanders and commanding officers will provide for the free exercise of religion by military personnel and their dependents through Command Religious Programs. Religious Ministry Facility (RMF) is a generic term for facility assets used to support Command Religious Programs. RMFs must therefore accommodate the religious rights and needs of a multi-faith, inter-generational, culturally diverse military population.

73083-2 **REQUIREMENTS SPONSOR -** The Chief of Chaplains (OPNAV N097) is the Director of Religious Ministries for the Department of the Navy under SECNAVINST 1730.7D dated 8 August 2008. The CNIC HQ Force Chaplain, in coordination with N097, will determine the required number of RMFs for an Installation, and validate the size of each RMF, as well as the allocation of space within each RMF. The RMFs located within hospitals are treated as a unique requirement (refer to section 73083-4 for additional guidance).

73083-3 **SPACE CRITERIA** - The space planning requirements for RMFs are determined by four factors:

1) Population for whom ministry will be provided,
2) Environmental factors, including types of religious programming provided,
3) Number of seats in each RMF, and
4) Number of RMF’s at the installation.

73083-3.1 Factor 1: **Installation Population**

73083-3.1.1 **Definition.** Installation population is defined as military strength assigned to the military installation plus their dependents.

73083-3.1.2 **Multiple Installations.** For multiple installations located in the same geographic area, installation population is defined as the military strength, plus their dependents, for which ministry should be provided at the RMF. The Chief of Chaplains will decide which military strength, plus their dependents, will be used to calculate each installation’s space allowance for an RMF (s) when there are multiple installations in the same geographic area. This should be determined when developing the Basic Facilities Requirement (BFR). The same military strength can never be used to justify a space allowance for RMFs at more than one installation. Ministry provided for personnel and their dependents remain the responsibility of the command to which the personnel are attached.

73083-3.1.3 **Training Installations.** For Training installations, a weighted average on board count of students should be included in the military strength.

73083-3.1.4 **Authorized Civilian Personnel.** Authorized civilian personnel, and their dependents, shall be included in the population count when dependent on the military installation for religious support.

73083-3.1.5 **STEP 1: Determine Installation Population.**

- Using the definition above, determine the military strength (and civilian when applicable) for whom ministry will be provided at the RMF (s).

- Determine the number of dependents from actual Family Housing Survey figures. If actual data is unavailable, estimate the number of dependents by first determining the number of military personnel (and civilian when applicable) with dependents. Multiply this number by Navy and Marine Corps service-wide average number of dependents (currently 2.6).

- Add the military strength (civilian when applicable) with the dependents from the steps above to determine the Total Installation Population = ____________ pn.

73083-3.2 Factor 2: **Environmental Adjustment Factors (EAFs)**

73083-3.2.1 **Basis for the EAF**. The EAF is based on the number of major faith group facilities in the surrounding civilian community within 8 km (5 miles) of the installation gate. For this criteria, use only these major faith groups: Baptist/Independent Fundamentalist, Disciples of Christ/ Methodist/ Presbyterian/ United Church of Christ, Episcopalian/ Lutheran/ Pentecostal, and Roman Catholic.

73083-3.2.2 Factors determining Geographical Distribution of Housing

Close **80 %** or more of installation population reside on installation or within a distance of **three kilometers (two miles).**

Normal Less than **80%** of the installation population reside on installation or within a distance of **three kilometers (two miles)** but more than **40%** reside within a distance of **eight kilometers (five miles).**

Distant Less than **40%** of installation population resides on installation or within a distance of **eight kilometers (five miles).**

73083-3.2.3 **STEP 2: Use the EAFs to adjust installation Population**.

- Count the number of **major faith groups** which have at least one facility within **eight kilometer (five miles)** of the installation gate.

- Determine the **housing distribution** from the definition above.

- **Refer to Table 73083-1 below**. Find the number of major denomination churches determined and read across the table to find the **Housing Adjustment**. **Multiply** this **factor** by the **total installation population** (determined in STEP 1) which will give you an **Adjusted Installation population = ________ pn**

Table 73083-1.
Environment Adjustment Factor for RMFs

FAITH GROUPS	HOUSING		
Number of **major faith group facilities** in the surrounding civilian community within **8 kilometers (5 miles)** of the installation gate	CLOSE	NORMAL	DISTANT
0	1.00	0.69	0.46
1	0.84	0.63	0.43
2	0.76	0.58	0.38
3	0.69	0.52	0.35
4	0.61	0.46	0.30
5	0.53	0.40	0.26

73083-3.3 Factor 3: **Number of Seats in each RMF**

73083-3.3.1 **STEP 3: Determine Total Number of Common Assembly Seats below:**

- Use **Adjusted Installation Population** (STEP 2) and **Table 73083-2** to determine the total number of **Common Assembly seats** =_______ for the installation (column 2, Table 73083-2).

Table 73083-2
Number of Seats in Common Assembly Areas at an Installation

Column 1. Adjusted Installation Population	Column 2. Number of Common Assembly Seats
Up to 500	35
501 to 1,000	200
1,001 to 1,500	300
1,501 to 2,000	400
2,001 to 2,500	500
2,501 to 3,000	600
3,001 to 3,500	700
3,501 to 4,000	800
4,001 to 5,000	900
5,001 to 6,000	1,000
6,001 to 7,000	1,100
7,001 to 8,000	1,200
8,001 to 9,000	1,300
9,001 to 10,000	1,400
10,001 to 11,000	1,500
11,001 to 12,000	1,600
12,001 to 13,000	1,700
13,001 to 14,000	1,800
14,001 to 15,000	2,000
13,001 to 14,000	1,800
14,001 to 15,000	2,000
15,001 to 16,000	2,100
16,001 to 17,000	2,100
17,001 to 18,000	2,200
18,001 to 19,000	2,200
19,001 to 20,000	2,300
20,001 to 21,000	2,400
21,001 to 22,000	2,400
22,001 to 23,000	2,500
23,001 to 24,000	2,500
24,001 to 25,000	2,600
25,001 to 26,000	2,700
26,001 to 27,000	2,700
27,001 to 28,000	2,800
28,001 to 29,000	2,900
29,001 to 30,000	3,000
For each add ’l 1,000 add:	100

73083-3.4 Factor 4: **Determine Number of RMFs**

- **STEP 4**: Use the total number of seats in common assembly areas at an installation **(STEP 3)**, the installation's mission, and the types of religious programming required to adequately meet the religious needs and rights of assigned sea service personnel and their dependents, and economical considerations to determine the number of RMFs. RMFs will normally be built in one or a combination of several sizes up to a maximum of 600 seats in common assembly areas, i.e., the sum of the seating in all of the common assembly areas within the RMF should generally not exceed 600 seats. Smaller size RMFs are intended primarily for use at small installations. For example, to satisfy a requirement for 1200 seats, two 600 seat RMFs should be planned rather than three 400 seat RMFs on a typical Navy base; a 1200 seat RMF is more practical at a training center. **Typically, RMFs will be built with the largest common assembly space seating from 250pn to 500pn.** Some installation, such as training centers, may want the convenience of one large RMF assembly area under one roof to accommodate the different congregations in separate areas. Except in unique situations, and with the concurrence of the Chief of Chaplains, the total requirements at an installation will not exceed that authorized by Table 73083-3.

73083-3.5 **Space Allocations for RMFs**

73083-3.5.1 **RMFs** are comprised of six (6) different types of spaces (an approximate percentage of total space is in parentheses): **1. Worship** (35-85%), **2. Religious Education** (10-40%), **3. Pastoral Counseling** (1-12%), **4. Fellowship** (1-20%), **5. Pastoral Administration** (1-20%), and **6. Utility/Support** (1-5%). Adequate and appropriate provisions for all six types should be provided within the criteria. These are contingent on the mission of the installation, religious programming, and needs/rights of assigned personnel and their dependents. **The Chief of Chaplains will decide space allocations within RMFs.**

73083-3.5.2 Within each of the six different types of space, part of the requirement will depend primarily upon the **number of RMFs at an installation** and part of the requirement will depend primarily upon the **adjusted installation population**. Examples of the former include **sacristy, reconciliation room, chancel, reception**, and **kitchen**. Examples of the latter include **religious education spaces, chaplain's offices** and **fellowship halls.** Thus the square foot requirement for each RMF has two separate components each of which must be determined separately.

73083-3.5.3 **STEP 5: Determine Total First Component Requirement Based Primarily upon the Number of RMFs.**

- Use the **number of seats for each RMF** (STEP 4) to determine the **first component** of the gross square foot requirement for the RMF from Column 2 in Table 73083-3. The first component is that portion of the requirement which is primarily dependent upon the number of common assembly seats in the RMF. First component total of **RMF Gross Area Requirement** = _____________ (sum of the first components of RMF Gross Req. for each RMF).

Table 73083-3
First Component of RMF Gross Area Requirement (for each RMF)

Column 1 Number of Assembly Seats	Column 2 First Component RMF Gross Area	
	sq.m.	SF
35	186	2,000
200	604	6,500
300	794	8,550
400	948	10,200
500	1,070	11,500
*600[1]	1,240	13,320
700	1,370	14,700
800	1,490	16,000
900	1,590	17,100
1,000	1,670	18,000
1,100	1,740	18,700
(Maximum for one RMF) 1,200	1,780	19,200

Note 1: When greater than 600 seats, consider the use of multiple RMFs. Use this table to size each one.

73083-3.5.4 **STEP 6: Determine Second Component Requirements Based Primarily upon the Adjusted Installation Population.**

- Use the **adjusted installation population** (STEP 2) to determine the **second component** of the gross square meter (square foot) requirement for RMFs at the installation from the Column 2 of Table 73083-4. The second component is that portion of the requirement which is primarily dependent upon the adjusted installation population. Total second component of **RMF Gross Area Requirement for the installation = __________.**

Table 73083-4
Second Component of RMF Gross Area Requirement

Column 1 Adjusted Installation Population	Column 2 Second Component RMF Gross Area	
	sq.m	SF
Up to 500	93	1,000
501 to 1,000	372	4,000
1,001 to 1,500	411	4,420
1,501 to 2,000	450	4,840
2,001 to 2,500	489	5,260
2,501 to 3,000	528	5,680
3,001 to 3,500	567	6,100
3,501 to 4,000	606	6,520
4,001 to 5,000	684	7,360
5,001 to 6,000	762	8,200
6,001 to 7,000	840	9,040
7,001 to 8,000	918	9,880
8,001 to 9,000	996	10,720
9,001 to 10,000	1,070	11,560
10,001 to 11,000	1,150	12,400
11,001 to 12,000	1,230	13,240
12,001 to 13,000	1,310	14,080
13,001 to 14,000	1,390	14,920
14,001 to 15,000	1,460	15,760
15,001 to 16,000	1,540	16,600
16,001 to 17,000	1,620	17,440
17,001 to 18,000	1,700	18,280
18,001 to 19,000	1,780	19,120
19,001 to 20,000	1,850	19,960
20,001 to 21,000	1,930	20,800
21,001 to 22,000	2,010	21,640
22,001 to 23,000	2,090	22,480
23,001 to 24,000	2,170	23,320
24,001 to 25,000	2,240	24,160
25,001 to 26,000	2,320	25,000
26,001 to 27,000	2,400	25,840
27,001 to 28,000	2,480	26,680
28,001 to 29,000	2,560	27,520
29,001 to 30,000	2,530	28,360
For each additional 1,000 add	78	840

73083-3.5.5 **STEP 7: Allocate Second Component of Gross Area Requirement to each RMF.**

- Apportion the total installation second component Gross Area requirement determined in STEP 6 among each of the RMFs authorized for the installation in STEP 4. Factors to be considered in the apportionment of Gross Area in each RMF are the **Installation's Mission, the Installation's Geography, and Religious Programming**. The Chief of Chaplains shall approve the apportionment.

Examples:

1. *A large installation with a remote family housing may want one RMF in the housing area and another adjacent to the BEQs*
2. *A training command may want on RMF for students and another for permanent population.*

73083-3.5.6 **STEP 8: Determine the Total Gross Area Requirement for each RMF at the installation.**

- To determine the total gross area requirement for each RMF at an installation, add the first component requirement (STEP 5) to the second component (STEP 7) and multiply the sum by a factor of 1.1 (this allows for mechanical, electrical, and communication equipment spaces).

Total Gross Area Requirement for the RMF = (STEP 5 ___ + STEP 7 ___) x (1.1) RMF = ________ Gross Area

73083-3.5.7 **STEP 9: Determine the Total Installation RMF Gross Area Requirement**

- Repeat STEP 8 for each RMF at the installation.

- The **total installation RMF Gross Area Requirement** is the **sum** of the **Gross Area Requirements for each RMF** at the installation (include any RMF within a hospital which is part of the installation).

Total Installation RMF Requirement = ________ Gross Area

73083-4 **HOSPITAL RMFs**.

73083-4.1 To serve patients and staff personnel on duty within composite medical facilities, in-hospital RMFs may be provided. The hospital RMF will be coded as Category Code 730-83. **Space allocated to the hospital RMF is to be included in**

the installation totals computed above. Use Table 73083-5 to compute Hospital RMFs.

Table 73083-5. Space Allocation for Hospital RMFs

Hospital Size (Beds)	Gross Area Note (1)	
	sq.m	SF
26 to 99	34	364
100 to 199	102	1,100
Over 200	130	1,400

(1) Add an additional 5-10% (dependent on local conditions) of the buildings gross area for mechanical, electrical, and communication equipment space (s).

730 85 POST OFFICE
FAC: 7344
BFR Required: Y

73085-1 **CENTRAL POST OFFICE**. Space allowances for central post offices are given in Table 73085-1. These figures represent normal allowances and are given for general guidance. Additional space may be provided if a central post office serves specialized functions on an installation such as:

- Postal directory.
- Nonresident schools
- Major and subordinate headquarters, commands, personnel centers, service schools, major hospitals, air material areas, supply depots.
- Carrier delivery to family housing units.
- Activities generating high volume of accountable mail that requires overnight vault storage.
- Self-service postal units installed within the lobby of the facility.

73085-2 **CONUS INSTALLATIONS.** At CONUS installations (see footnote 4 of Table 73085-1), the determination of specific total requirements and provisions for the specialized functions listed above, shall be coordinated with the U.S. Postal Services Regional Postmaster General. This should be accomplished during the initial planning stage and the DD Form 1391 should be annotated to that effect.

73085-3 **POSTAL SERVICE CENTER.** When justified by specific requirements and approved by the U.S. Postal Services Regional Postmaster General, a postal service center may be provided at which mail may be deposited and picked up by individual post office box holders, as opposed to bulk distribution of mail to the various elements on a military installation. A postal service center may be combined with, or separate from, a central or branch post office. The number of boxes shall not exceed the number of unmarried and unaccompanied married military civilian personnel plus 25% to accommodate specific key personnel and compensate for box reassignment vacancy period. Space allowances per box are given in Table 73085-1.

73085-4 **BRANCH POST OFFICES**. At large installations with personnel concentrations located at such a distance from the central post office that service through the latter is impractical, branch offices, each not exceeding 139 sq.m. (1,500 GSF) may be provided.

73085-5 **FOR BASIC FACILITY REQUIREMENTS PURPOSES**, the total requirement for Code 730 85 is the sum total of central post offices, postal service centers and branch post offices.

Table 73085-1.
Space Allowances for Post Offices

Installation Population (1)	Central Post Office Gross Area (2)		Postal Service Center Gross Area Per Box (3)			
			CONUS (4)		OVERSEAS (5)	
	sq.m	SF	sq.mm	SF	sq.mm	SF
Up to 500	37	400	55700	0.60	55700	0.60
501 to 1,000	56	600	55700	0.60	55700	0.60
1,001 to 2,500	162	1,750	55700	0.60	46500	0.50
2,501 to 4,500	272	2,925	55700	0.60	46500	0.50
4,501 to 7,500	418	4,500	55700	0.60	41800	0.45
7,501 to 11,500	588	6,325	55700	0.60	37200	0.40
11,501 to 16,500	766	8,250	55700	0.60	37200	0.40
16,501 to 22,500	941	10,125	55700	0.60	37200	0.40
22,501 to 28,500	1,160	12,525	55700	0.60	37200	0.40
28,501 to 34,500	1,390	14,925	55700	0.60	37200	0.40
34,501 to 40,500	1,610	17,325	55700	0.60	37200	0.40
40,501 to 46,500	1,830	19,725	55700	0.60	37200	0.40
46,501 to 52,500	2,060	22,125	55700	0.60	37200	0.40
52,501 to 58,500	2,280	24,525	55700	0.60	37200	0.40

Notes:

(1) The space criteria for a military postal facility shall be based on the total population, including: military personnel and approved DoD civilians/dependents and contractors, serviced by the postal facility. Consider a sponsor and

authorized family members as one person. (Department of Defense Postal Manual, DoD 4525.6-M as amended)

(2) Excludes space required for loading platforms.

(3) Allowed only when justified by specific requirements and approved by the U.S. Postal Services Regional Postmaster General. Number of boxes shall not exceed the number of unmarried and unaccompanied married military and civilian personnel plus 25% for key official military and civilian personnel needs.

(4) CONUS include the 50 States and all other geographical areas in which the U.S. Postal Service operates.

(5) Use 55700 sq.mm. (0.60 SF) per box throughout when the postal service center is separated from the central post office. Do not assign a receptacle to more than one person. Consider a sponsor and authorized family members as one person. The square footage of postal service centers is in addition to the central post office. (Department of Defense Postal Manual DoD 4525.6-M as amended)

740 COMMUNITY FACILITIES

740-1 MORALE, WELFARE AND RECREATION (MWR), NAVY EXCHANGE (NEX), AND OTHER SUPPORT FACILITIES (INDOOR)

740-1.1 **General Notes**

740-1.2 **Space Allowances**

740-1.2.1 **Construction Allowances.** These allowances apply to all funding sources and types of construction.

740-1.2.2 **Installation Requirements.** Facilities shall be planned to meet the specific requirements of an installation and not arbitrarily to the maximum allowances indicated. An installation will not automatically qualify for all facilities listed but only for those for which specific requirements exist.

740-1.2.3 **Activities.** Minor exchange facilities operated for the convenience of non-exchange activities that are an integral part of these activities such as barber shops in clubs; food, retail outlets in air terminals, hospitals, schools or large administration buildings; food service in bowling alleys, operations buildings, and service clubs; and snack facilities in theaters are included in the space allowances authorized for the non-exchange activities.

740-1.2.4 **Mechanical Equipment Rooms**. Mechanical equipment room space as required should be added to the gross area in the criteria tables. This space varies from 5-10% of the gross area.

740-1.3 Conversion of Existing Facilities

740-1.3.1 A new facility will be provided only when no existing available structure will satisfy the requirements. When an existing structure is converted for morale, welfare or recreational uses, the space allowances may be increased by not more than 20 percent when necessary to effect economical use of the existing structure. This increase is not allowed in cases where an existing structure is expanded by new construction to accommodate such uses.

740-1.4 Anti-Terrorism / Force Protection (AT/FP) Considerations

740-1.4.1 For High Density facilities, such as many of the 740 series MWR facilities and Exchange facilities, AT/FP must be considered in the planning process. AT/FP siting and setback requirements should be considered early on. Please reference the Navy Minimum Standards for AT/FP for definitions, set back requirements, and additional information. Webpage: https://www.wbdg.org.

740-1.5 Covered/Enclosed Malls and Sidewalks

740-1.5.1 Where elements of a community shopping center, such as the exchange main retail store, snack bar, exchange service outlets, commissary, credit union and a bank, are combined in a common structure and connected by a covered mall, space occupied by the mall will not be charged against (deducted from) space allowances for the respective elements. Likewise, where such elements are in proximity to each other and are connected by a covered walkway, space occupied by the covered walkway will not be charged against space allowances for the respective elements. Entrance canopies should not be counted against the building space allowance.

740-1.6 Construction from Private Funds / PPV Initiatives

740-1.6.1 The construction of exchange facilities on military installations may be accomplished from funds of commercial concerns or private individuals subject to the approval of the Secretary of their cognizant Military Department, when pertinent contracts between commercial concerns or private individuals and the exchange specifies that immediately upon completion title thereto passes to the government and stipulate conditions and restrictions that should prevent any future conflict with military requirements, and eliminate any future obligations against appropriated funds. The requirement for passage of the title should not apply to portable or relocatable buildings.

740-2 MORALE, WELFARE AND RECREATION (INDOOR)

740-2.1 General instructions

740-2.2 Using the criteria

740-2.2.1 **Size to Accommodate Demand.** These criteria provide the current approach to determining allowances for Morale, Welfare and Recreational (MWR) facilities. Facility allowances are sized to accommodate the projected demand for the anticipated functions. This sizing involves a three-step procedure:

740-2.2.1.1 **Estimate Projected Demand.** Calculate the demand for each functional component of the facility using the demand calculation tables. Then apply any special adjustment factors in the criteria.

740-2.2.1.2 **Determine Capacity Requirements.** Derive the number of required functional units by multiplying the demand by the capacity factors in the criteria.

740-2.2.1.3 **Calculate Space Allowances.** Apply the space allocation factors to determine the square footage required for each functional component. Add the areas for all components, plus support area factors indicated in the criteria, to determine the total facility allowance. For each step in this planning process, follow the calculations and instructions provided in the criteria for each facility type. In addition to the criteria stated in *NAVFAC P-80*, attention should be given to relevant planning information in the Base Master Plan, Overview and Functional Regional Plans (RSIPs), UFC Criteria, Design Manuals, Military Handbooks or Instructions for the specific facility type.

740-2.2.2 For **Marine Corps Installations** results of the **MWR Construction Program Patron Survey** will be used to provide Marine Corps specific patron desires. Construction Program Patron Survey data is available from the **Commandant of the Marine Corps**.

740-2.2.3 Space Allowance Flexibility

740-2.2.3.1 **Modular Space Allowances**

For many of these criteria, usage demand, capacity requirements and space allowances are calculated separately for component function-areas of the facility and then totaled to derive overall facility space allowances. This procedure is designed to respond to local variations in the set of activities and spaces provided, and the relative demand for different activities depending on the needs of the installation population. This approach can also accommodate diverse existing facility situations, when considering additions or complementary new facilities.

740-2.2.3.2 **Space Programs versus Facility Allowances**

These criteria are used to determine the total space allowance for a facility. Even though area calculations for functional components of the facility are used in deriving the overall allowance, this does not fix the space sizes of the component program areas of the facility. Local installation decisions, in the space programming and design process, should determine the appropriate allocation of areas for each function-space within the total facility allowance.

740-2.2.3.3 **Local Variation**

Local demand for program activities may depend on a variety of factors, in addition to the overall installation population, including:

- Proportion and relative participation of different user groups among the population.
- Specific program of activities provided.
- Competing on-base and off-base facilities providing similar programs.
- Geographic distribution and accessibility of the user populations.
- Local climate conditions and operating seasons.
- Overseas situations and local customs.

740-2.2.4 Population Basis for Demand Calculations

Chapter 1 of this instruction for information on population definitions and base loading data.

740-3 MWR FACILITIES, GENERAL NOTES

740-3.1 The involvement of MWR representatives in the planning process is required, especially for all Category C business-based projects, to ensure a match between program needs, and the types and sizes of spaces to be provided. See below for a listing of Category A-C facilities as defined by MWR.

740-3.2 MWR programs are funded by a combination of non-appropriated funds (NAFs) and appropriated funds (APFs). MWR activities are divided into three categories following DoD policy on funding and function:

740-3.2.1 **Category A** operations are considered essential in meeting the organizational objectives of the Military Services. They shall be funded almost entirely with APF, with the use of NAF limited to specific instances where APF support is prohibited by law or where the use of NAF is essential for the operation of a facility or program. These facilities do not generate any NAF revenues. Examples are gymnasiums, libraries, and sports programs.

740-3.2.2 **Category B** operations are mission enhancing community support programs that support military members and their families. These programs are primarily supported by APF support but do generate NAF revenues. Examples are outdoor recreation, child development, hobby shops, ITT, community pools, school age care, and youth development programs.

740-3.2.3 **Category C** operations are business-based activities and are authorized minimal APF (such as SRM, environmental compliance, security, and health and safety support; interior renovation and new construction/additions are NAF funded) except at isolated/remote and OCONUS installations where Category C operations are treated the same as Category B operations. Examples are food and beverage operations, bowling centers, cottages, RV parks, slip rental marinas, and golf courses.

For Category B and C facilities an initial market survey and financial analysis or pro forma is required to determine if the facility will be self-sustaining or profitable, in the case of Category C operations. Once the Installation has completed their analysis, the proposal will be submitted via the regional command to NPC (after 1 October 2004, CNIC Field Support Activity) through an Internal Needs Validation Study (INVS). If the project earns sufficient points through the INVS, it will move on to the Project Validation Assessment stage where the demand and scope will be confirmed through independent review.

740-3.3 For overseas activities the net to gross factor (typical net to gross is 1.25 or 25%) will increase as necessary to meet host nation building codes.

740-3.4 **Recreational Planning Context**

Planning for MWR facilities should involve consideration of the individual facility in relationship to a comprehensive recreational program and facilities plan for the installation. Consider the following factors, in addition to those relationships specifically indicated in the criteria for each facility:

- If other MWR facilities serving the same user population provide the same program activities, reduce the allowed capacity of the proposed facility by the capacity provided elsewhere at the installation.

- Consider collocating the facility with other recreational facilities providing complementary programs, to provide the users with the increased convenience and attractiveness of clustered activities, and to take advantage of potential savings in support space requirements and operating costs.

- Size and locate an individual facility appropriately to the target population and geographical area its particular function is designed to serve. Convenient access for users should be considered in balance with the need for efficient facility operation and avoidance of duplicate facilities.

740-4 NAVY EXCHANGE FACILITIES, GENERAL NOTES

740-4.1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535.

740-4.2 The Navy Exchange Service Command, Planning Branch uses a Business Case Analysis model to plan new Navy Exchange facilities. They calculate square footage of new facilities based on sales costs for various product lines and expected sales costs and product lines for new facilities compared to existing facilities. They also incorporate a Market analysis of like facilities in the area. Exchange facilities Navy Facility Category Codes and descriptions are included in this Criteria document; however Navy Planners are instructed to contact the Navy Exchange Service Command for requirements development when a new facility is potentially required. If BFRs are being updated or calculated for existing facilities, in most cases it is reasonable to assume that the requirements are equal to the assets for NEX facilities. Recommend that the Navy facilities planners confirm this determination with NEXCOM prior to setting requirements equal to assets.

740 01 EXCHANGE RETAIL STORE (SF)
FAC: 7346
BFR Required: Y

74001-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74001-2 The exchange retail store is planned as part of an authorized Navy or Marine Corps Exchange. The store includes sales area, immediate back-up stock area, store office, toilets and circulation space. The space allowances for exchange retail stores are determined by the Navy Exchange Services Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452, 757-631-3535. The Patron base for the Main NEX Retail Store is all active duty, retirees and families/dependents. All merchandise categories are included in the Main NEX Retail Store. Some categories may be stronger or weaker according to age or rank classifications or base or command populace.

740 02 LOCATION EXCHANGE (SF)

This category code has been deleted. All existing assets should be reassigned to category code 740 01, Exchange Retail Store.

740 03 EXCHANGE CENTRAL ADMINISTRATION (SF)
FAC: 7387
BFR Required: Y

74003-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74003-2 This is space required for the general administrative effort of an exchange such as accounting, payroll, personnel, purchasing or warehousing. Space required for this facility will be calculated using code 610 10, Administrative Office criteria. Administrative space required for an individual exchange facility, such as office space in warehouses, cafeterias, main retail store or location exchange, shall be provided out of the space authorized for the individual facility.

740 04 EXCHANGE FOOD SERVICE (SF)
FAC: 7331
BFR Required: Y

74004-1 These facilities include: cafeterias, specialty shops similar to deli, fast food and pizza, bake shops, ice cream shops, etc. Non-Exchange food service facilities (standalone) are captured under category code 740 46. Food service facilities operated in and for the sole convenience of non-exchange activities such as bowling alleys, theaters, air terminals and similar functions are already included in the basic space allowance for such activities.

74004-2 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74004-3 MWR Facilities will be coordinated with CNI (N9, N25) and local MWR personnel. See MWR General Notes at the beginning of the 740 Series.

740 06 NON-EXCHANGE INSTALLATION RESTAURANT (MWR) (SF)
FAC: 7332
BFR Required: Y

74006-1 This type of facility includes Category “C” MWR dining facilities, including commercial restaurants. Examples of standalone commercial restaurants are Applebee’s, McDonald’s, etc. For other restaurants found in an Exchange building, or walk-up commercial eateries with common seating areas such as Subway, Taco Bell, Kentucky Fried Chicken (KFC), etc. is covered under category code 740 04, Exchange Food Service.

740 08 EXCHANGE FOOD STORE (GROCERY) (SF)

This CCN has been deleted. All existing assets should be reassigned to CCN 74001 EXCHANGE RETAIL STORE

740 09 EXCHANGE SERVICE OUTLETS (BARBER, UNIFORM, ETC) (SF)
FAC: 7346
BFR Required: Y

74009-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-

5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74009-2 Exchanges are authorized outlets for basic services in conjunction with the retail store, such as Barber Shop, Tailor/Uniform Shop, Radio/TV Repair Shop, Portrait Studio, Watch Repair Shop, Optical Shop, Beauty Salon, and Personal Services. In addition to specific outlets as listed above, special outlets may be authorized for which no distinct space allowances are given. Examples of such outlets are: CONUS and OVERSEAS - taxicab and bus service spaces, toy lands, flower shops, baggage checkpoints; OVERSEAS only - steam-bath facilities, new car sales points, stock investment offices.

740 11 NEX DEPOT (SERVMART) (SF)
FAC: 7346
BFR Required: Y

74011-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74011-2 An NEX Depot may be provided as dictated by NEXCOM. NEX Depots are similar to traditional Navy Servmarts, and offer the same type of inventory, in a more convenient setting.

740 12 RED CROSS/NAVY RELIEF (SF)
FAC: 6100
BFR Required: Y

74012-1 Space for Red Cross and/or Navy Relief functions can be provided within the Family Services Center (Code 740 25) when available. This space however should not be counted against the requirements for Family Services Center. Space may be provided in other facilities on base when available. This space is not counted against Navy requirements.

740 13 EXCHANGE LAUNDRY AND DRY CLEANING FACILITY (SF)
FAC: 7342
BFR Required: Y

74013-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-

5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74013-2 Laundry and dry cleaning plants, which may be operated under the exchange service, normally shall be limited to non-appropriated fund, cleaning and laundering.

740 16 EXCHANGE MAINTENANCE SHOP (SF)
FAC: 7387
BFR Required: Y

74016-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74016-2 An exchange maintenance shop may be provided for the local repair of exchange equipment, fixtures repair of refrigeration equipment and vending machines, and to provide shop space for facility maintenance crews and personnel.

740 18 BANK (SF)
FAC: 7347
BFR Required: Y

74018-1 Banks may be established only when they are authorized by the U.S. Treasury Department. Normally there will be only one banking facility at each installation. Branch banks, providing complete services, shall not be established without prior approval. Space allowances are given in Table 74018-1.

Table 74018-1. Space Allowances For Banks

Personnel Strength (1)	Gross SF
Up to 1,000	1,500
1,001 to 2,000	2,375
2,001 to 3,000	3,250
3,001 to 4,000	3,625
4,001 to 5,000	4,000
5,001 to 6,000	4,375
6,001 to 7,000	4,750

Personnel Strength (1)	Gross SF
7,001 to 9,000	5,560
9,001 to 11,000	6,375
11,001 to 13,000	7,190
13,001 to 15,000	8,000
15,001 to 17,000	10,000
17,001 to 20,000	13,000
Over 20,000	See Note (2)

Notes:

(1) Active duty military personnel assigned to an installation and stationed within a commuting area not served by another military banking office plus civilian employees of the installation.

(2) Determined by Engineering Study.

740 19 CREDIT UNION (SF)
FAC: 7347
BFR Required: Y

74019-1 **DESCRIPTION.** Credit unions are private cooperative savings and loan organizations. Facilities for a properly chartered credit union may be provided to serve military personnel, their dependents, and other personnel as permitted in the bylaws of the credit union. If a credit union on an installation restricts or limits membership of installation personnel, it will be denied free use of installation facilities. In such cases another credit union which meets DOD requirements may be organized and provided with logistic support.

74019-2 **SPACE ALLOWANCE.** Space allowances for credit unions are predicated on size of membership, number of transactions, assets, accounting methods, and number of employees. Each of the variables contributes a number of points, and the total number of points determines the space allowance. The allowance may be increased by 10 percent to accommodate future business expansion. Refer to Table 74019-1 for point values and Table 74019-2 for space allowances.

Table 74019-1. Point Values for Credit Unions

Number of Members	Points Allowed	Point Subtotals
0 to 1,000	2	
1,000 to 2,500	4	
2,501 to 7,500	6	
7,501 to 12,000	8	
12,001 to 20,000	10	
For Each Additional 10,000, add	2	
Accounting	**Points**	
Machines	1	
Manual	2	
Assets (Dollars)	**Points**	
0 to 100,000	1	
100,001 to 500,000	2	
500,001 to 1,500,000	3	
1,500,001 to 5,000,000	4	
Over 5,000,000	5	
Transactions Per Day	**Points**	

Number of Members	Points Allowed	Point Subtotals
0 to 99	1	
100 to 299	2	
300 to 499	3	
500 to 749	4	
750 to 999	5	
For Each Additional 500, add	1	
Number of Employees	**Points**	
2 to 5	1	
6 to 9	2	
10 to 13	3	
14 to 17	4	
18 to 21	5	
22 to 25	6	
For Each Additional 3, add	1	
TOTAL NUMBER OF POINTS =		

Refer to Table 74019-2 for Space Allowance.

Table 74019-2
Space Allowances for Credit Unions

Point Totals	Gross SF
0 to 4	800
5	1,000
6	1,300
7	1,700
8	2,200
10	2,800
12	3,500
14	4,300
16	5,200

Point Totals	Gross SF
18	6,200
19	7,200
20	8,200
21	9,200
22	10,200
23	11,200
24	12,200
25	13,200
For each additional point, add	1,000

740 20 PCS OFFICIAL LODGING (SF)
FAC: 7441
BFR Required: N

74020-1 **REQUIREMENT.** Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series. This category code should not be used to compute a Basic Facility Requirement (BFR).

74020-2 **DESCRIPTION.** These facilities are temporary living accommodations which normally are rented for a service charge for overnight or short term use to authorized personnel such as: official military or civilian visitors to the installation, visitors to installation personnel, transient personnel or families awaiting assignment to quarters. Included are motels, hotels, and apartments. Where such facilities are authorized for new construction, they shall be of motel type with bath and with kitchenettes, if required. Living units with kitchenettes shall contain no more than 450 square feet of living area and those without kitchenettes no more than 425 square feet. Appropriate circulation, administration, mechanical and service space will be provided.

74020-3 **REVIEW.** All leasing, conversion, or construction projects for temporary lodging facilities, regardless of scope and funded by non-appropriated fund activities will be forwarded for review and approval to Assistant Secretary of Defense (I&L).

740 21 VISITOR'S RECEPTION CENTER (RECRUIT TRAINING ONLY) (SF)
FAC: 7440
BFR Required: Y

74021-1 A visitor's reception center is limited to installations performing basic training. It serves as a point of contact between trainees and visiting relatives or friends. Approximate planning factor is 1.5 gross square feet per recruit.

74022-1 **NAVY**

Transient housing is Commander Naval Installations (CNIC)-operated living accommodations rented for a service charge to fleet personnel families of ships undergoing repair. This code is for inventory purposes only and is applicable only to housing units removed from the family housing inventory (Category Group 710) and designated for this purpose by the Chief of Naval Operations.

74022-2 **MARINE CORPS**

These quarters are operated primarily to provide a service to duty transient personnel and TAD students, and to conserve appropriated funds through reduced per diem payments. Guidance is provided in the Marine Corps Order P11000.22.

740 23 COMMISSARY (INCLUDING BACK UP STORAGE) (SF)
FAC: 7349
BFR Required: Y

74023-1 The Navy Commissary Systems were consolidated into the Defense Commissary Agency (DeCA) along with the other services on 1 October 1991. All Commissary construction planning, programming and execution has been transferred to that organization.

74023-2 Questions regarding Commissary construction plans, policies, procedures and sizing should be directed to the Defense Commissary Agency, Directorate of Facilities, Plans and Programs Division, Fort Lee Virginia, 23801-6300. Commercial telephone number is (804) 734-8000 ext. 4-8976.

740 24 COMMISSARY COLD STORAGE (DETACHED) (SF)
FAC: 4321
BFR Required: Y

74024-1 The Navy Commissary Systems were consolidated into the Defense Commissary Agency (DeCA) along with the other services on 1 October 1991. All Commissary construction planning, programming and execution has been transferred to that organization.

74024-2 Questions regarding Commissary construction plans, policies, procedures and sizing should be directed to the Defense Commissary Agency, Directorate of Facilities, Plans and Programs Division, Fort Lee Virginia, 23801-6300. Commercial telephone number is (804) 734-8000 ext. 4-8976.

740 25 FAMILY SERVICES CENTER (SF)
FAC: 7372
BFR Required: Y

Design Criteria: UFC 4-730-01 webpage:
https://www.wbdg.org/dod/ufc/ufc-4-730-01

74025-1 **DEFINITION.** The Family Services Center (FSC) facility supports the programs that provide the information and family services necessary to support qualified single and married Department of Defense (DoD) personnel and their family members in meeting the unique demands of the military lifestyle, as defined by DoD Instruction 1342.22, Family Centers. The program and services provide information to DoD personnel and their family members, improve life skills by fostering competencies and coping skills, encourage self-sufficiency, and offer short-term support and assistance when necessary.

74025-2 **FAMILY SERVICE CENTERS (FSCs)** may be established as required to provide information and referral services, education and training services, and counseling services for the active duty population with services usable to dependents and retirees. The centers require open areas such as visiting rooms and conference areas with the majority of space allotted to individual offices conducive to execution of high quality and confidential service delivery.

74025-3 **SPACE ALLOWANCES.** They provide for baby/toddler play areas, waiting room, record storage, individual counselor offices, administrative areas, and storage areas for hospitality kit, general storage, conference rooms, staff areas, and classroom spaces for training exercises conducted by all FSCs.

74025-4 **LOCATION DETERMINENTS.** Several factors determine the most appropriate and cost effective location for a FSC.

74025-4.1 **Site Size**. Ensure adequate site space for the following elements when selecting the FSC site: criteria for parking space for customers and staff can be found in category code 852-10. Site must also meet Antiterrorism/Force Protection (AT/FP) set-back criteria.

74025-4.2 **Customer Access.** The FSC should be easily accessible both by Military personnel and by Military personnel family members and reservists. The importance of access by civilians or non-active duty personnel must not be overlooked. Consider locations such as near the Installation gate or other high-traffic areas such as the commissary, retail exchange, or medical facilities. As an alternative, consider locating the FSC off-installation like the Installation visitor's center or local high-traffic commercial/retail centers. If the FSC is located off-base, consider the AT/FP impacts to the design of the facility.

74025-4.3 **Capacity**. Capacity shall be determined by actual count of active duty and full time reserve military personnel receiving installation support who are entitled to FSC services. Overseas areas should include the number of DOD employees entitled to services. Justification remains the responsibility of the sponsoring command with requirements based on local needs. Adjust these figures for any projected increase/decrease in military population or mission changes. The population served by the FSC is determined by adding a multiplier to the active duty population. The multiplier varies depending on the location of the proposed FSC.

CONUS: FSC population equals active duty (AD) times **1.6**,

OCONUS: FSC population equals AD population times **2.4**, and
Military (Fleet or Navy) Concentration Areas: FSC population equals AD population times **2.4**.

74025-4.4 **New activities.** Determine the total number of active duty and full time reserve personnel receiving direct installation support.

Table 74025-1
Family Service Center Size Classifications

Size Classification	Population Served
Small	500 to 3,000
Medium	3,001 to 10,000
Large	10,001 to 40,000
Extra Large	40,000 and Up

Table 74025-2
Family Service Center Gross Areas

FSC	Gross Area (sq.m./SF)	Gross Area (sq.m./SF)	Estimated Staffing (PN)	Estimated Staffing (PN)
	Navy	Marine Corps	Navy	Marine Corps
Small	321.96 / 3,466	281.38 / 3,029	6-8	4-8
Medium	667.55 / 7,185	463.31 / 4,987	13-17	5-13
Large	1,160.29 / 12,489	813.14 / 8,753	19-26	6-19
Extra Large	1,763.39 / 18,981	1,310.78 / 14,109	31-36	12-31

Notes for Table 74025-2:
For full space program for the FSC small, medium, large, extra-large please see the UFC 4-730-01 at https://www.wbdg.org/dod/ufc/ufc-4-730-01

1. Many service agencies such as NADSAP, Navy-Marine Corps Relief, American Red Cross and CAA are collocated with FSCs. These areas are not a part of the Family Services Center and should not be counted against the requirements. For Red Cross see CC 740 12.
2. For populations fewer than 500, accommodate the FSC functions in other, non-dedicated facilities.

740 26 INSTALLATION RESTAURANT (MWR) (SF)

This CCN has been deleted. All existing assets should be reassigned to category code 740 04, Exchange Food Service / Restaurant.

740 27 ARMED FORCES RADIO/TV STATION (SF)
FAC: 1441
BFR Required: Y

74027-1 A radio and/or TV station is normally established in overseas locations to provide U.S. installation population with entertainment and news coverage. As a rule, the coverage radius is limited to the installation and immediate vicinity and the facilities are restricted for transmission of prerecorded program material, however if justified, limited studio facilities may be provided. At the present, no space criteria are available for this type of facility. Requirements must be developed on an individual basis.

740 28 AMUSEMENT CENTER / RECREATION MALL (SF)

This category code has been deleted. All existing assets are to be reassigned to category code 740 42 Community Recreation Center.

740 30 EXCHANGE GAS/SERVICE AND AUTO REPAIR STATION (SF)
FAC: 7345
BFR Required: Y

74030-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74030-2 This facility provides space for gasoline and oil sales, automotive parts and accessories sales, emergency service and automotive repair service.

740 31 POV FILLING STATION (OL)
FAC: 1231
BFR Required: Y

74031-1 **DESCRIPTION.** This category code is for fueling stations associated with Personally Owned Vehicles (POVs) at an installation such as those associated with NEXCOM/MCCS facilities or similar.

740 32 NEX CAR WASH BUILDING (SF)
FAC: 7348
BFR Required: Y

74032-1 This facility is associated with the Navy Exchange (NEXCOM) for the washing of vehicles. The surrounding pavement is captured with either FAC 8521 –

Vehicle Parking, Surfaced or FAC 8526 – Miscellaneous Paved Area, depending on the particular situation of usage. For MWR car wash structures, use category code 740 33 - MWR Car Wash Structure.

74032-2 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74032-3 MWR facilities should be programmed through OPNAV N46 Deputy Base Ops and Support, (703) 695-5541.

740 33 MWR CAR WASH STRUCTURE (SF)
FAC: 7350
BFR Required: Y

74033-1 This structure is associated with MWR for the washing of vehicles. The footprint of the structure typically includes a mechanical room, a water separator, wash bays (both covered and uncovered), and pavement area. All other surrounding pavement is captured with either FAC 8521 – Vehicle Parking, Surfaced or FAC 8526 – Miscellaneous Paved Area depending on the particular situation of usage. For NEXCOM car wash buildings, use category code 740 32, NEX Car Wash Building.

74033-2 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head Planning Branch, 757-631-3535. See General Notes for NEX facilities at the beginning of the 740 Series.

74033-3 MWR facilities should be programmed through OPNAV N46 Deputy Base Ops and Support, (703) 695-5541.

740 34 THRIFT SHOP (SF)
FAC: 7340
BFR Required: Y

74034-1 This is a nonprofit facility for the sale and purchase by military personnel of used apparel, furnishings and equipment. See Table 74034-1 for space allowances.

Table 74034-1. Space Allowances for Thrift Shops

Military Strength	Gross SF
Up to 2,000	1,400

Military Strength	Gross SF
2,001 to 4,000	2,000
4,001 to 6,000	2,700
6,001 to 8,000	3,400
8,001 to 10,000	4,000
10,001 to 12,000	4,500
12,001 to 14,000	4,950
Over 14,000	5,350

740 36 HOBBY SHOP – CRAFTECH (SF)
FAC: 7411
BFR Required: N

This CCN is for inventory purposes only.

740 37 MWR OUTDOOR RECREATION CENTER (SF)
FAC: 7446
BFR Required: Y

Design Criteria: UFC 4-740-03
Design: Navy and Marine Corps Outdoor Adventure Centers and Rental Centers

74037-1 **DEFINITION**: There are three categories of outdoor recreation centers included under this category code:

- Outdoor Adventure Centers (OAC),
- Rental Centers (RC), and
- Outdoor Centers & Other Rentals (OCOR).

Generally, these facilities rent and/or sell goods that are associated with Outdoor Recreation Programs (ORP) and other outdoor activities. There is a significant variety in the equipment and goods provided by each of these facility category types, however the general criteria and basic design approach for all three facility categories are similar. The three facility categories are described in paragraphs 74037-1.1, 74037-1.2 and 74037-1.3, and their respective missions are compared in Table 74037-1 with regard to equipment and programs.

74037-1.1 **Outdoor Adventure Centers (OAC)** provide human powered equipment which is specific to outdoor recreation and adventure activities. An OAC supports an Outdoor Recreation Program (ORP). The Marine Corps does not require that OAC or ORP operations be human powered. The activities offered take place in a natural area, front-country, backcountry, or wilderness environment. The name of the operation may reflect anything related to pursuits that fall within the respective Service's ORP. Of the three facilities, the OAC is the preferred option within the Navy Morale Welfare and Recreation's (MWR's) Outdoor Recreation Program Master Plan.

74037-1.2 **Rental Centers (RC)** carry a variety of equipment unrelated to outdoor recreation but may also carry outdoor recreation equipment. Equipment from both categories may include trailers, boats, dunk tanks, home and garden tools, camping gear, athletic equipment, party items, catering items, rental trucks and trailers, etc. While and RC may rent and/or sell goods associated with outdoor and adventure activities, it does not support and ORP, and as such, it differs from and OAC or OCOR. Anything can be in the rental inventory that is appropriate and within the policies or local agreements, for example, agreements between Navy Exchange (NEX) and MWR. Instruction, repairs, and sales related to the equipment are appropriate. The name, image, and theme will be consistent with what is offered.

74037-1.3 **Outdoor Center and Other Rentals (OCOR)** facility is a combination of the first two categories and rents both home and garden type equipment and outdoor adventure activity type equipment that falls with the respective Service's ORP. The two classifications of items must be physically and visually separated into their own unique areas of the facility. They are marketed separately and have specialized employees for each area. An OCOR also supports an Outdoor Recreation Program.

Table 74037-1. Facility Types

Facility Type	Equipment Offered	Support ORP
Outdoor Adventure Center (OAC)	OR	Yes
Rental Center (RC)	H&G and/or OR	No
Outdoor Center & Other Rentals (OCOR)	H&G and OR	Yes

OR= Outdoor Recreation equipment
H&G= Home and Garden equipment/tools
ORP = Outdoor Recreation Program

74037-2 **SIZE CLASSIFICATIONS -** The five facility size classifications and the typical active duty populations they serve are shown in Table 74037-2. The customer base is the primary size determinant. The active duty population directly relates to the potential customer base; however, the customer base may also include active duty family members, youth and teen program participants, and others. Consider all potential users when determining the customer base.

Table 74037-2
MWR Outdoor Recreation Center Facility Size Classifications and Active Duty Populations Served

Size Classification	Active Duty Population Served	Total Building Gross Area	Total Site Support Area
Regional/Extra Large	Greater than 14,000	1,434 m2 / 15,440 ft2	1,060 m2 / 11,410 ft2
Large	7,001 – 14,000	871.59 m2 / 9,382 ft2	788.72 m2 / 8,490 ft2
Medium	3,001 – 7,000	651.39 m2 / 7,012 ft2	579.70 m2 / 6,240 ft2
Small	500 - -3,000	433.88 m2 / 4,670 ft2	373.46 m2 / 4,020 ft2
Extra Small	Less than 500	401.82 m2 / 4,325 ft2	373.46 m2 / 4,020 ft2

74037-3 **LOCATION DETERMINANTS.** Prior to initiating the facility planning of the OAC, RC, or OCOR, perform a space analysis of the existing Installation. This analysis should identify any existing functions which are programmatically considered an essential element of the ORP program. Following that analysis, consider the following factors to determine the location of the facility.

74037-3.1 **Overall Business Viability**: Business viability is the primary location determinant. A location favorable to sustaining a self-sufficient operation is needed. Patron access is one major component of business viability, but the entertainment and adventure elements of the facility must also be considered. The location should be attractive with proximity to natural areas and other retail or recreational services.

74037-3.2 **Existing Program Elements.** On some bases, existing program elements may be clustered in one area. Consider any existing program elements when locating the new facility to take advantage of the population's activity patterns, habits, and knowledge base. This will help with advertising the new facility. This determinant is more important in siting the OAC and OCOR facilities but should also be considered when site planning an RC.

74037-3.3 **Goods Access.** These facilities handle large and cumbersome goods and equipment. The site should offer easy access and room to maneuver the goods and equipment both for delivery and rental.

74037-3.4 **Patron Access.** The facility needs to be visible and easily accessible to the users. Consider locating near other high-visibility areas and related functions. This could be along the pedestrian paths to the existing barracks, existing MWR/NEX/MCCS facilities, and/or the dining facility. To accommodate moving equipment and quick patron access, provide adequate parking (per category code 852-10) as close as possible to the facility, taking into account Antiterrorism/Force Protection (ATFP) requirements.

740 38 MWR AUTO SKILLS CENTER (SF)
FAC: 7412
BFR Required: Y

SECNAV Approved Standards and Metrics are available for this CCN at http://mwr.navy.mil/mwrprgms/programstand.htm.

74038-1 **GENERAL**. See General Notes to 740 series category codes for General Instructions regarding facility allowance planning procedures.

74038-2 **DEFINITION**. The mission of Automotive Skills Center is to provide their customers with a quality, value-based program for the maintenance, repair, modification and improvement of their own vehicles including cars, trucks, trailers, motorcycles, and bicycles. Automotive Skills Centers are not full-service stations, but rather facilities where patron self-help is fostered and automotive skills are learned. Such facilities may also provide space for instructional programs, club meetings, administration, tool issuance, storage and parts sales.

74038-3 **RELATED FACILITIES**. Automotive Skills Centers may be collocated with complementary facilities such as self-service carwashes. Such collocations will have the advantage of drawing more patrons to a single location offering a wider assortment of services.

74038-4 **AUTO BAY DEMAND**. The primary functional component of an Automotive Skills Center is Auto Bays which are sized on the basis of the peak hour demand at each installation as follows:

74038-4.1 Use projected base loading data to determine the population for each significant population category, as listed in Table 74038-1.

74038-4.2 Calculate peak hour demand for Auto Bays by multiplying the population for each category by participation factors found in Table 74038-1. Add the demand for all population categories to derive peak hour Total Demand for Auto Bays.

74038-4.3 Apply the installation mission adjustment factor (divide by 2) for those bases with large numbers of personnel in training schools or on routine deployment.

74038-4.4 Determine the number of indoor or outdoor Auto Bays required to satisfy peak hour demand by dividing the Total Demand by the following capacities per bay per hour and rounding to the nearest whole unit:

- 1.5 users per indoor bay per hour
- 1.0 user per outdoor bay per hour

The split between indoor verses outdoor Auto Bays may be determined at the discretion of the local command. Facility planning considerations based on climatic factors are discussed below under section 4, Space Allowances.

Table 74038-1. Auto Bay Demand Calculation

Note	Population Category	Population (per Base Loading)	x	Participation Factor	=	Peak Hour Demand
(1), (2)	Enlisted	____	x	0.0034	=	____ users
(1), (2)	Officers	____	x	0.0022	=	+ ____ users
(1), (2)	Retirees	____	x	0.0004	=	+ ____ users
(1), (2)	Authorized Civilians	____	x	0.0006	=	+ ____ users
Total Demand (round to the nearest whole unit)						____ users
(3)	Divide by installation mission adjustment (for installations with more than 50 percent of their active-duty personnel in training schools or on routine deployment)					divide by 2.0
Adjusted Total Demand (round to the nearest whole unit)						____ users
(4)	To calculate the number of Indoor Auto Bays divide by the capacity per auto bay					divide by 1.5
Total Demand number of Indoor Auto Bays required to satisfy peak demand (round to the nearest even numbered whole unit)						____ bays
(4)	LOCAL OPTION: If Outdoor Auto B Bays are locally desired, substitute 3 Outdoor Bays for every 2 Indoor Bays					

Notes for Demand Calculation -- Table 74038-1:

(1) Population numbers should be consistent with projected base loading data. Officers are O-1 through O-10 and enlisted are E-1 through E-9. Civilians are authorized DoD employees. Retirees are all military retirees within a 30-minute drive of the installation.

For facility planning purposes at installations with deployable forces, the active duty demand population is comprised of all the non-deployable population, plus two-thirds of the deployable population, to reflect time away on deployment. However, calculation of the deployable population may be adjusted based on the actual deployment experience at individual installations.

(2) Use of facilities by spouses and dependents has been statistically incorporated in the participation factors used in the tables. These participation factors may be revised periodically by NPC, and the most current figures must be used in all demand calculations.

(3) Installation Mission Adjustment Factor
A factor that influences the use of an Automotive Skills Center is the type of installation and it's particular mission. For example, Naval Stations have significant numbers of active-duty personnel routinely deployed, thereby losing potential patronage. Statistics show that even though the automobiles of active-duty personnel are routinely used by spouses and dependents during times of deployment, the skills center facilities are seldom used by these population groups. Likewise, naval installations which have a large percentage of their residents in training schools, with demanding study schedules, suffer declines in the use of Automotive Skills Center since those residents have fewer personally-owned vehicles and/or less leisure time. Therefore, if an installation has a large number of personnel in schools or on routine deployment -- greater than 50 percent of the active-duty population -- the total demand calculation derived in the steps indicated below in Table 74038-1 should be adjusted by dividing by 2.

(4) The number of Indoor versus Outdoor Auto Bays may be determined by the local Command. If Outdoor Auto Bays are provided, they will substitute for Indoor Auto Bays at the rate of 3 Outdoor Bays for every 2 Indoor Bays.

74038-5 **SPACE ALLOWANCE**. The maximum space allowance for an Automotive Skills Center is determined according to the sizing criteria presented in Table 74038-2. For new construction projects, the actual size is determined through a Project Validation Assessment.

74038-5.1 In warm climates, many skills center activities can be performed outdoors or under canopies. Outdoor Auto Bays may, therefore, be used to increase the total work space allowed for an auto skills center located in a warm climate. Such covered outdoor spaces, however, should be properly shielded from climatic conditions such as wind-driven rain or dust and sand.

74038-5.2 Conversely, in very cold climates, care should be exercised with designs which are drafty, uncomfortable and difficult to heat because of the large number of vehicular openings. The number of vehicular openings may be minimized be adopting a layout more common in commercial garages, with interior circulation to auto bays. However, a facility with a limited number of vehicular entrances will require more interior space for maneuvering cars. In such circumstances, an economic analysis of the options is recommended. This analysis should balance the additional cost of constructing extra space for internal vehicular circulation against the reduced operating cost, the possible savings in perimeter walls, and the improved comfort and, therefore, potentially greater use by customers.

74038-5.2.1 Full compliance with all applicable local, state and federal environmental regulations is required in the planning and development of Automotive Skills Centers at all naval installations. All facilities which have the potential for causing environmental contamination, such as, hydraulic lifts, oil tanks, drains, etc. must be appropriately designed with adequate safeguards. Furthermore, to avoid problems related to the safety of patrons and staff, provision of paint booths is not recommended; however, one may be provided if the local installation and patrons agree. The paint booth must be capable of receiving required environmental permits. In many areas of the country, new permits are not being issued in non-attainment areas.

Table 74038-2. Space Allowance for Auto Skills Center

Note	Table	Functional Component	# Units	x	Space Allocation Factor	=	Total NSF	Minimum or Maximum NSF
		ACTIVITY AREAS						
(1)	740 38A	Auto Stalls/Bays	___	X	300 NSF per bay	=	___	
		Machine Shop Workbenches (@ one bench per bay)	___	X	65 NSF per bench	=	+ ___	
		Welding Area			25% total NSF for workbenches	=	+ ___	
		Engine Cages (@ one cage per bay)	___	X	40 NSF per cage	=	+ ___	
		Resale/Tool Issue		X	30 NSF per bay	=	+ ___	
		Classroom Teaching Area	___	X	15 NSF per seat	=	+ ___	225 min./ 450 max.
		Storage Area		X	25% total NSF for classroom	=	+ ___	
					Subtotal Activity Areas (Net Square Feet)	=	_____	
		ACTIVITY SUPPORT						
		Customer Lounge			15% total NSF workbenches	=	___	40 min.
		Patron Support (including lockers, toilets, vending machines)			7-14% X subtotal Activity Areas	=	+ ___	300 min.
		Administration			12-16% X subtotal Activity Areas	=	+ ___	285 min.
					Subtotal Activity Support (Net Square Feet)	=	_____	
		BUILDING SUPPORT						
		Entrance/Lobby/Circulation/ Housekeeping Supplies/Janitor's Closet/ Structure/Partitions			13-17% X subtotal Activity Areas + subtotal Activity Support Areas	=	___	
		Mechanical/Electrical/ Communication Equipment Space			9-13% X subtotal Activity Areas + subtotal Activity Support Areas	=	+ ___	
					TOTAL FACILITY ALLOWANCE (Gross Square Feet)	=	_____	

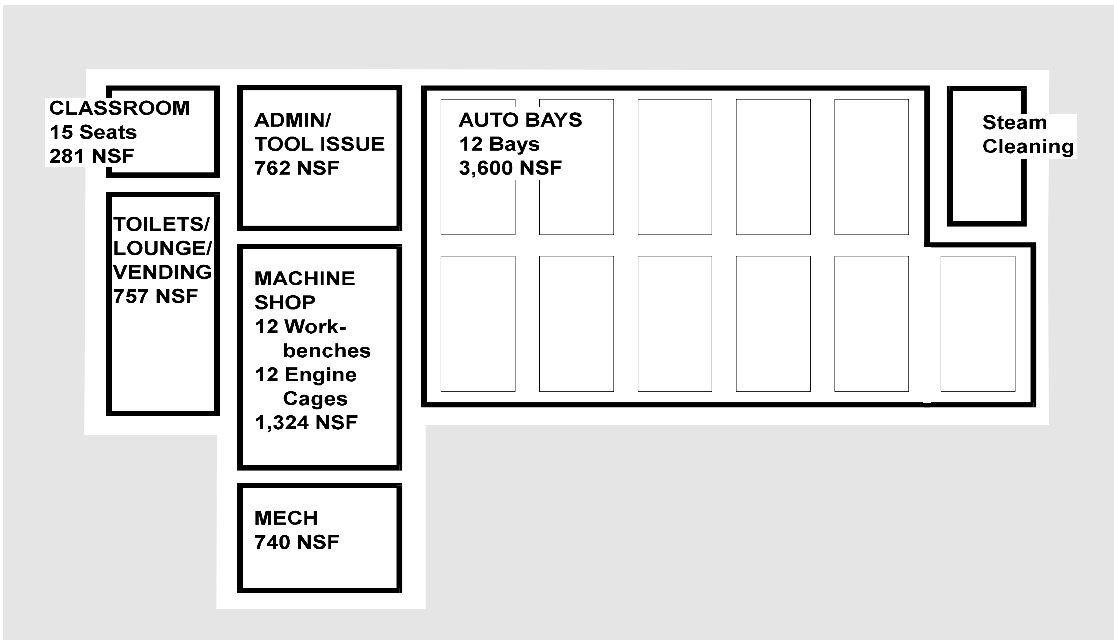
Notes for Space Allowance -- Table 74038-2:

(1) 300 NSF per auto bay is an average figure. Actual bay sizes may vary, ranging from typically, 288 NSF for muffler/tire/lubrication bays to 336 NSF for general repair/bodywork/steam cleaning bays.

NSF = Net Square Feet
GSF = Gross Square Feet
Minimum or Maximum NSF = Minimum or maximum space allowance to be provided for the particular function or activity.

74038-5 **SAMPLE LAYOUT DIAGRAM**. A layout diagram is presented for a medium size Automotive Skills Center. This diagram is an example of the composition of such a facility in terms of its functional components, their respective sizes and adjacencies. The layout diagram is for illustrative purposes only.

Figure 74038-1
Layout Diagram – Automotive Hobby Shop, Medium Size Facility



740 40 BOWLING CENTER (SF)
FAC: 7415
BFR Required: Y

SECNAV Approved Standards and Metrics are available for this CCN at http://mwr.navy.mil/mwrprgms/programstand.htm

74040-1 **GENERAL**. See General Notes to 740 series category codes for General Instructions regarding facility allowance planning procedures.

74040-2 **DEFINITION**. Bowling Centers are recreational facilities which accommodate bowling and related functions, which may include: open bowling, leagues, tournaments, youth bowling, instruction, exhibitions, and support activities such as equipment sales and rental, food and beverage service, electronic and table games, and meetings.

74040-3 **RELATED FACILITIES**. Consideration should be given to collocating the Bowling Center with the following recreational facilities in order to (i) take advantage of potential savings in space requirements and operating costs, and (ii) provide users with the increased convenience of clustered facilities:

- 740 42 Community Recreation Center
- MWR recreational and foodservice facilities, generally

74040-4 **BOWLING DEMAND**. The number of bowling lanes required in a Bowling Center is based on the usage demand at each installation, as follows:

74040-4.1 Use projected base loading data to determine the population for each significant population category, as listed in Table 74040-1.

74040-4.2 Calculate the annual bowling linage demand by multiplying the population for each category by participation factors drawn from the installation's most recent demand survey, and by adjustment factors as indicated in Table 74040-1.

74040-4.3 Find the number of lanes required to accommodate the bowling linage demand in Table 74040-2. These allowances are based on the minimum number of lines required to generate sufficient revenues to meet standard operating expenses.

74040-4.4 Calculate the capacity requirements for foodservice and games components by multiplying the numbers of bowling lanes and of projected non-bowling patrons by the usage factors in Tables 74040-3 through 74040-7. See Section 5, below, for explanation of these Tables.

74040-4.5 Multiply the number of units required for each functional component by the space allocation factors in Table 74040-8. Add the net square footage (NSF) for all components and add support area factors as directed in Table 74040-8, to derive the Total Facility Allowance.

* For **Marine Corps Installations** use historical patron data to determine the participation factor.

Table 74040-1. Bowling Linage Demand Calculation

Note	Population Category	Population (per Base Loading)	x	Participation Factor	x	Adjustment Factor	=	Lines Bowled per Year
(1), (2), (3)	Officers	____	x	___ %	x	111	=	_____
(1), (2), (3)	Enlisted	____	x	___ %	x	17	=	+ _____
(1), (2), (3)	Retirees	____	x	___ %	x	31	=	+ _____
(1), (2), (3)	Family Members	____	x	___ %	x		=	+ _____
(1), (2), (3)	DoD Civilians	____	x	___ %	x		=	+ _____
						Total Lines Bowled per Year	=	
(4)	Add linage for installations in locations with harsh or long winter							+ 32,500
						Adjusted Total Linage Demand	=	_____

Notes for Bowling Linage Demand Calculation:

(1) Population numbers should be consistent with projected base loading data. Officers are O-1 through O-10 and enlisted are E-1 through E-9. Retirees are all military retirees within a 30-minute drive of the installation.
For facility planning purposes at installations with deployable forces, the active duty demand population is comprised of all of the non-deployable population, plus two-thirds of the deployable population, to reflect time away on deployment. However, calculation of the deployable population may be adjusted based on the actual deployment experience at individual installations.

(2) The adjustment factors modify linage demand to reflect differential usage patterns among the different user population categories.

(3) Linage demand for installations in locations with harsh or long winters is adjusted by adding an extra 32,500 lines to the total number of lines bowled per year. This includes all installations located in the following states: Alaska, Colorado, Connecticut, Delaware, Idaho, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin, Wyoming and the District of Columbia.

Table 74040-2. Lane Allowances for Bowling Centers

Note	Lines Bowled per Year	Number of Lanes Authorized CONUS	Number of Lanes Authorized OCONUS
	Fewer than 10,000	0	0
(1)	10,000 - 18,000	2	2
(1)	18,001 - 36,000	4	4
(1)	36,001 - 54,000	6	6
(1)	54,001 - 69,120	8	8
(1)	69,121 - 86,400	10	10
(1)	86,401 - 107,640	12	12
	107,641 - 124,200	14	18
	124,201 - 140,760	16	20

Note	Lines Bowled per Year	Number of Lanes Authorized CONUS	Number of Lanes Authorized OCONUS
	140,761 - 165,600	18	24
	165,601 - 231,840	24	32
	231,841 - 298,080	32	40
	298,081 - 364,320	40	50
	Each incremental increase of 17,280	additional 2	additional 2

Note for Bowling Lane Allowances:

(1) Bowling Centers with 12 lanes or fewer are generally considered uneconomic to operate. Centers of such size can only be approved in exceptional cases, with substantial justification of economic viability.

74040-5 **DEMAND FOR FOODSERVICE AND GAMES**. The numbers of seats in the snack bar and lounge and the numbers of video games and pool/billiards tables required in the Bowling Center should represent the sum of the demand from both bowling patrons and other users -- guests, spectators, and patrons primarily using the food service or games areas of the center. The size of the non-bowling clientele will depend on such local installation factors as the location of the facility, proximity of potential patron populations, competing food service and amusement center facilities, type and attractiveness of food service and games program operations, and historic usage patterns.

74040-5.1 Demand for meeting/function room space must be based on other users than bowling patrons. The seat capacity requirement should be based on the type and size of specific functions for which there is a justifiable local demand.

74040-5.2 Tables 74040-3 through 74040-7 provide usage factors for calculating the demand for the functional components in the foodservice and games areas.

Notes for Foodservice and Games Demand Calculation - Tables 74040-3 through 74040-7:

(1) Use number of bowling lanes as derived in Table 74040-2.

(2) The projected number of non-bowling patrons for each functional component must be determined by the installation and justified based on analysis of specific local experience and requirements. In the absence of local installation data, assume that the numbers of seats required for non-bowling patrons in the foodservice areas, and the numbers of machines and tables for non-bowling patrons in the games area, are equal to those calculated for the bowling patrons.

Table 74040-3. Snack Bar Demand Calculation

Note	# Demand Units	x	Usage Factor	=	Peak Demand
(1)	____ Bowling Lanes	x	0.50 seats per lane	=	____ seats
(2)	____ Non-Bowling Patrons per Peak Hour	x	0.25 seat-hours per patron	=	+ ____ seats
	Total Demand (round to the nearest whole unit)			=	____ seats

Table 74040-4. Lounge Demand Calculation

Note	# Demand Units	x	Usage Factor	=	Peak Demand
(1)	____ Bowling Lanes	x	0.44 seats per lane	=	____ seats
(2)	____ Non-Bowling Patrons per Peak Hour	x	0.50 seat-hours per patron	=	+ ____ seats
	Total Demand (round to the nearest whole unit)			=	____ seats

Table 74040-5. Combined Snack Bar/Lounge Demand Calculation

Note	# Demand Units	x	Usage Factor	=	Peak Demand
(1)	____ Bowling Lanes	x	0.72 seats per lane	=	____ seats
(2)	____ Non-Bowling Patrons per Peak Hour	x	0.33 seat-hours per patron	=	+ ____ seats
	Total Demand (round to the nearest whole unit)			=	____ seats

Table 74040-6. Video Games Demand Calculation

Note	# Demand Units	x	Usage Factor	=	Peak Demand
(1)	____ Bowling Lanes	x	1.0 machines per lane	=	____ machines
(2)	____ Non-Bowling Patrons per Peak Hour	x	1.0 machine-hours per patron	=	+ ____ machines
	Total Demand (round to the nearest whole unit)			=	____ machines

Table 74040-7. Pool/Billiards Demand Calculation

Note	# Demand Units	x	Usage Factor	=	Peak Demand
(1)	____ Bowling Lanes	x	0.22 machines per lane	=	____ tables
(2)	____ Non-Bowling Patrons per Peak Hour	x	0.20 table-hours per patron	=	+ ____ tables
	Total Demand (round to the nearest whole unit)			=	____ tables

74040-6 **SPACE ALLOWANCES**. Space allowances for Bowling Centers are determined according to the planning criteria presented in Table 74040-8 below. The total allowance for a facility is the sum total of the space allowances for each functional component. The number of units of each component required to meet the demand is obtained from the calculations in Tables 74040-1 through 74040-7.

Table 74040-8. Space Allowances for Bowling Centers

Note	Table	Functional Component	# Units	x	Space Allocation Factor	=	Total NSF	Minimum or Maximum NSF
		ACTIVITY AREAS						
		Bowling						
	A, B	Bowling Lanes (incl. pin spotting, settee, promenade, lockers)	___	x	650 NSF per lane	=	___	
	A, B	Workroom	___	x	70 NSF per lane	=	+___	120 NSF min. 840 NSF max.
		Food Service						
	C	Snack Bar (incl. seating, kitchen, serving counter, storage)	___	x	27 NSF per lane	=	+___	
	D	Lounge (incl. seating, bar, storage)	___	x	20 NSF per lane	=	+___	
(1)	E	Combined Snack Bar/Lounge (incl. seating, kitchen, serving counter, bar, storage)	___	x	25 NSF per lane	=	+___	
(2)		Meeting/Function Room	___	x	12 NSF per lane	=	+___	
		Games						
		Video Games	___	x	30 NSF per lane	=	+___	
		Pool/Billiards	___	x	370 NSF per lane	=	+___	
					Subtotal Activity Areas	=	+___	
		ACTIVITY SUPPORT AREAS						
		Toilets			3% x Subtotal Activity Areas	=	+___	
		Administration (incl. pro shop, control counter, storage)			3% x Subtotal Activity Areas	=	+___	1,000 NSF max.
					Subtotal Activity Support Areas	=	+___	
		BUILDING SUPPORT AREAS						
(3)		Lobby/Circulation/Structure/ Partitions/Janitor			4-5% x (Subtotal Activity Areas + Subtotal Activity Support Areas)	=	+___	
		Mechanical/Electrical/ Communication Equip. Space			5-10 % x (Subtotal Activity Areas + Subtotal Activity Support Areas)	=	+___	
					TOTAL FACILITY ALLOWANCE	=	____	GSF

Notes for Space Allowance Table:

(1) Combined snack bar/lounge may be provided as an alternative to separate snack bar and lounge spaces.

(2) Meeting/function room seating capacity should be based on usage by other than bowling patrons. Usage projection must be justified by demand and economic operations analysis, serving local function requirements.

(3) Lobby/circulation/structure/partitions/janitor area -- use 5% factor for centers of 24 lanes or less; 4% for 26 lanes or more.

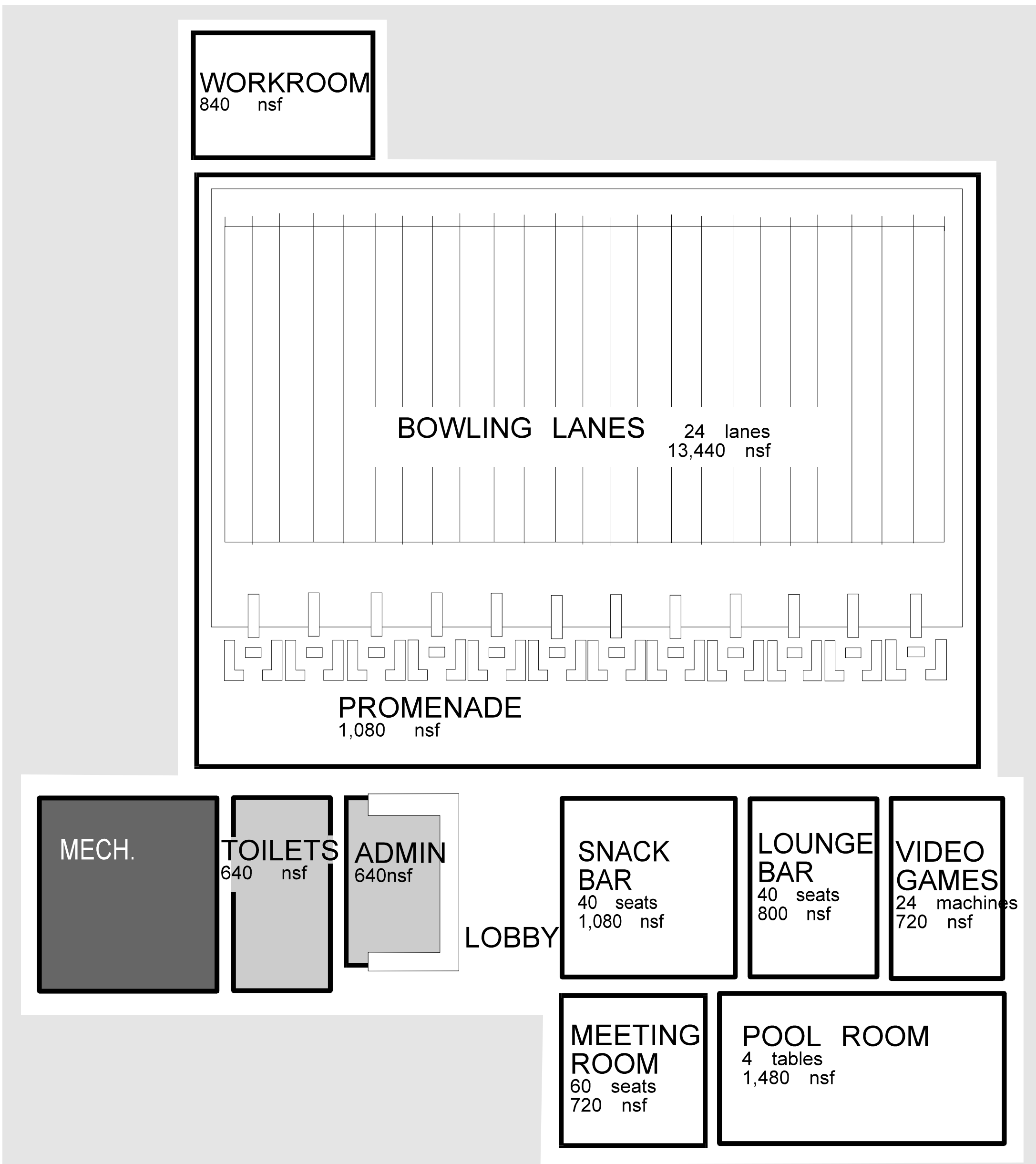
NSF = Net Square Feet

GSF = Gross Square Feet

Minimum or Maximum NSF = Minimum or maximum space allowance to be provided for the particular function or activity.

74040-7 **SAMPLE LAYOUT DIAGRAM**. A layout diagram is presented for a medium-size Bowling Center. This diagram is an example of the composition of such a facility in terms of its functional components, their respective sizes and adjacencies. The layout diagram is for illustrative purposes only.

Figure 74040-1. Bowling Center – Medium Capacity



740 42 COMMUNITY RECREATION CENTER (SF)
FAC: 7417
BFR Required: Y

SECNAV Approved Standards and Metrics are available for this CCN at http://mwr.navy.mil/mwrprgms/programstand.htm

74042-1 **GENERAL**. See General Notes to 740 series category codes for general instructions regarding facility allowance planning procedures.

74042-2 **DEFINITION**. The primary customer for the Community Recreation Center is the ship-based sailor, primarily younger (ages 18-24) enlisted personnel (mostly E1-E6). The mission of a Community Recreation Center is to support fleet readiness and enhance the morale of sailors through a professionally staffed, customer-oriented recreation program that serves the leisure needs of Fleet sailors. The Recreation Center is not for family use, but is intended for active duty personnel. A typical Community Recreation Center is located within convenient walking distance (5-10 minutes) of the piers where Navy vessels are berthed and should be conveniently located within a 5-10 minute walking radius of the majority of BEQ's. Activities accommodated in Community Recreation Centers include: “hanging out”, informal group activities, sports, parties, contests, tournaments, intra-ship competitions, special events, theme activities for holidays, music practice and "jam" sessions, talent shows, movie marathons, game show nights, demonstrations, classes, lectures, board games, card games, television, trivia contests and special programs for women, and other programs structured to meet the special needs of Fleet sailors. Some basic services such as vending and snack bars, laundromats and telephone banks, individual private telephone booths with seats (supervised by a cashier/control desk, and limited space for waiting) may be included for the convenience of patrons.

The local Command has the option of providing the total space allowance as one Recreation Center or distributing the square footage among several smaller facilities. The latter approach may be appropriate on larger bases with multiple concentrations of E1-E6 residential populations.

At installations with smaller populations, Rec. Center functions may be accommodated in a Community Center which serves both younger single sailors and older personnel with families. Facility planning criteria for Community Centers are addressed separately under Category Code 714 32.

Each location where a Navy fleet is based should be individually analyzed to understand its specific situation, and determine the mix of Community Recreation Center functions most appropriate to meet local needs. The space allowance should be based on the development of a justifiable program of functions, capacities and sizes, comparable to the Sample Space Programs contained in this criteria section.

74042-3 **RELATED FACILITIES**. Consideration should be given to collocating Community Recreation Centers with related facilities in order to (i) take advantage of potential savings in space requirements and operating costs (for example, consolidation of administrative and support spaces, site development and staffing), and (ii) provide users with the increased convenience of a clustered recreation complex. These related facilities include:

- 740 40 Bowling Center
- 740 44 Indoor Physical Fitness Center
- 740 53 Swimming Pool
- 740 64 Enlisted Mess, Open.
- Foodservice facilities such as Clubs
- Other MWR indoor and outdoor recreational facilities.

74042-4 **SPACE ALLOWANCE**. The maximum facility allowance for Community Recreation Centers is according to sizing criteria presented in Table 74042-1. The maximum gross square footage indicated in the table is the maximum total allowance per base, and may be used for a single large complex or multiple facilities.

Table 74042-1. Space Allowances for Community Recreation Centers

Ship-based Population (rounded to the nearest thousand)	Max. Gross Square Feet (total allowance per base)	Note
less than 1,500	0 GSF	(1), (2), (3)
2,000 to 5,000	6,600 GSF	(2), (3)
6,000 to 15,000	15,500 GSF	(2), (3)
16,000 and over	31,000 GSF	(2), (3), (4)

Notes for Table 74042-1:
(1) For installations with a ship-based population of 1,500 or less, the base Gymnasium, Bowling Center, Community Center, and other MWR facilities may serve the fleet sailor's recreational needs in lieu of a Community Recreation Center.
(2) Population numbers should be consistent with projected base loading data. For facility planning purposes at installations with deployable forces, the active duty demand population is comprised of all the non-deployable population, plus two-thirds of the deployable population, to reflect time away on deployment. However, calculation of the deployable population may be adjusted based on the actual deployment experience at individual installations.
(3) Round-off population up or down to the nearest thousand.
(4) For extra-large installations, the space allowance should be split up into a minimum of two facilities at separate sites conveniently located within proximity to ship-based population concentrations.

74042-5 **SAMPLE LAYOUT DIAGRAMS**. Layout diagrams are presented for a medium and large size Community Recreation Center. The diagrams are an example of the composition of such a facilities in terms of their functional components, and their respective sizes and adjacencies. The layout diagrams are for illustrative purposes only.

Figure 74042-1. Community Recreation Center – Medium Size Facility

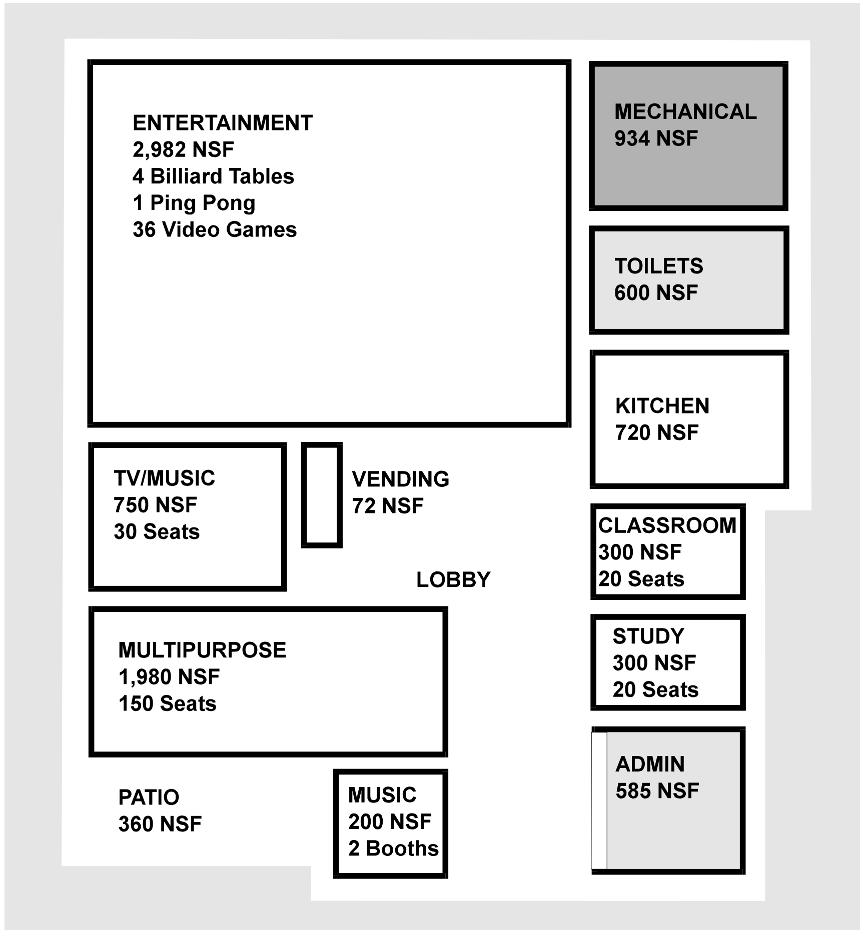
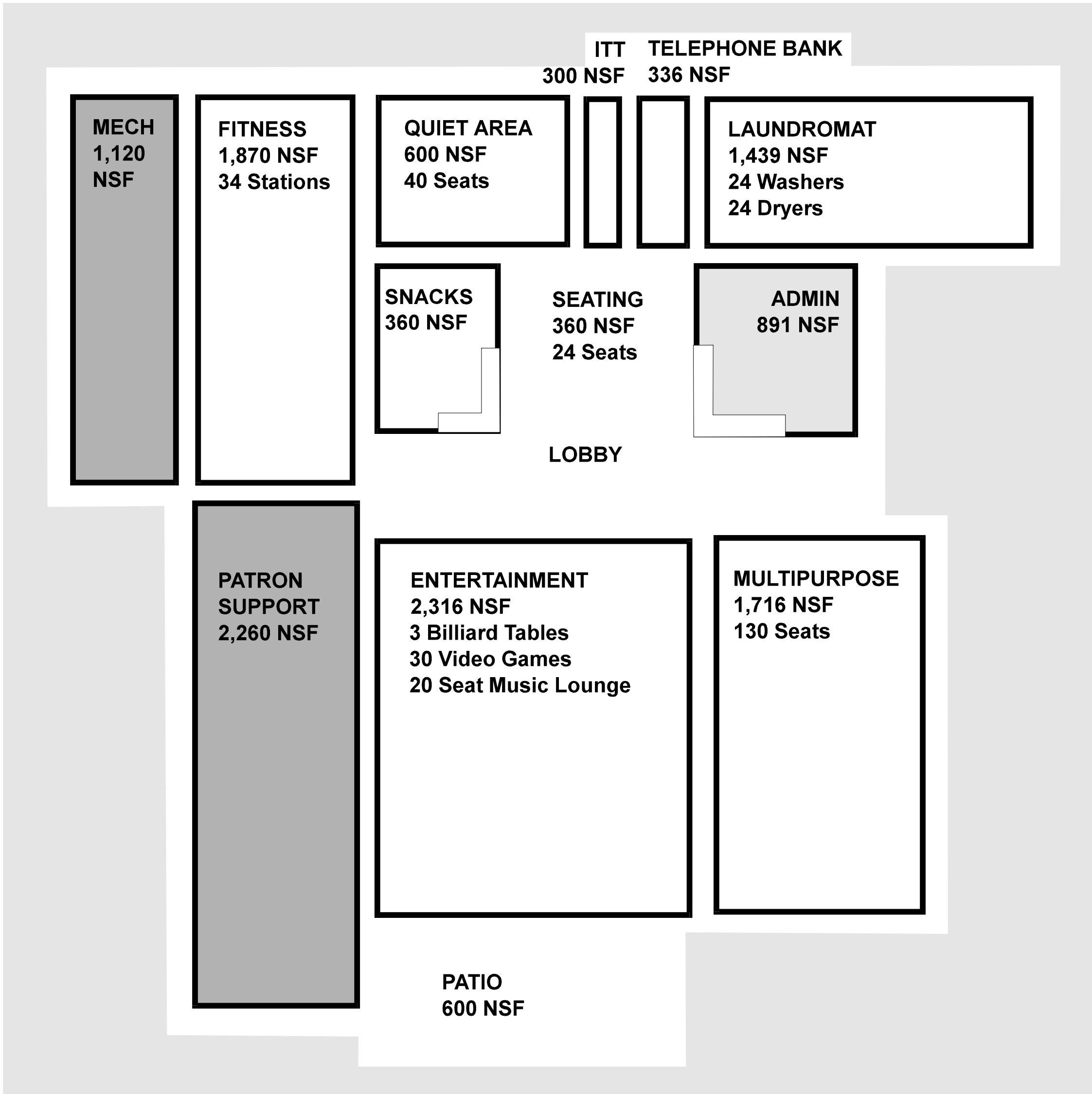


Figure 74042-2. Community Recreation Center – Large Size Facility



740 44 INDOOR PHYSICAL FITNESS CENTER (GYM) (SF)
FAC: 7421
BFR Required: Y

SECNAV-approved Fitness Standards and Metrics are available at http://www.navyfitness.org/fitness/fitness_standards_and_metrics/

- Facility design criteria is available in FC 4-740-02N, “Navy and Marine Corps Fitness Centers” at https://www.wbdg.org/dod/ufc/ufc-4-740-02

74044-1 **GENERAL**. Refer to the introductory material in 740-1, 740-2 and 740-3 found at the beginning of the 740 series category codes for general instructions regarding facility allowance planning procedures. Also, potential loading data sources are discussed in Chapter 1 of this criteria manual.

74044-2 **DEFINITION**. Physical fitness facilities provide facilities and support services to meet the individual physical fitness, coordination, skills development, and recreation and training needs of military personnel. Depending on the geographic location of the Installation, the facilities may also allow usage by family members, retirees and authorized civilians (refer to paragraph 74044-4.1).

Activities which may be accommodated in a facility include: aerobics, athletic gear issue, badminton, basketball, boxing, calisthenics, cardiovascular training, gymnastics, handball, jogging, martial arts, physical fitness training, racquetball, volleyball, Wally ball, weight-training, wrestling, group meetings, etc.

74044-3 **RELATED FACILITIES**. Consideration should be given to co-locating the facility with the following recreational facilities in order to: (1) take advantage of potential savings in space requirements and operating costs, and (2) provide users with the increased convenience of clustered facilities:

- 740 53 Indoor Swimming Pool
- 750 10 Outdoor Playing Courts
- 750 20 Playing Fields
- 750 30 Outdoor Swimming Pool.

74044-4 **SPACE ALLOWANCE**. The primary functional components of an Indoor Fitness Facility—Basketball Court, Aerobics/Exercise Area, Cardiovascular Training Area, Weight Training Area, and Indoor Playing Court—are sized based on installation population. Installation population ranges are as follows:

XSMALL	=	Population 0 - 500
SMALL	=	Population 501 - 3,000
MEDIUM	=	Population 3,001 - 7,000
LARGE	=	Population 7,001 - 14,000
XLARGE	=	Population 14,001 - 30,000
JUMBO	=	Population greater than 30,000

74044-4.1 Installation population is defined as Active Duty enlisted and officers, average on board students, transients, and reservists (see introductory paragraph 740-2.2.4). For overseas locations, include authorized civilians and family members in the installation population total. Population numbers should be consistent with projected base loading data.

74044-4.2 For facility planning purposes at installations with deployable forces, the active duty demand population is comprised of all the non-deployable population, plus two-thirds of the deployable population, to reflect time away on deployment. However, calculation of the deployable population may be adjusted based on the actual deployment experience at individual installations.

74044-4.3 Based on the calculated installation population size, determine the authorized facility space allowance from the interactive Fitness Space Program spreadsheet referred to in paragraph 74044-5.

74044-4.4 Space allowances developed from the spreadsheet are minimum allowances. For areas with large concentrations of military population, actual facility usage data may be used to justify additional space.

74044-4.5 Usage of stateside facilities by family members and retirees has been statistically incorporated in the space allowances used in the spreadsheet. These allowances are reviewed periodically by NAVFAC HQ, BUPERS, and CMC.

74044-4.6 MARINE CORPS INSTALLATIONS ONLY: For installations with a population exceeding 3,000 personnel, determine the fitness area space requirements as follows:

(a) Peak Load = 3.5% of installation population

(b) Fitness Area = 4.21 sq.m. (45.32 SF) per patron at peak load

Example: 6,000 population x 0.035 = 210 patrons at peak load.
210 patrons x 4.21 sq.m. (45.32 SF) = 884 sq.m. (9,517 SF)

For the purposes of this formula, the fitness areas include only the free weight, other resistance weight training equipment, and cardiovascular equipment areas and do not include space for stretching/warm-up/cool-down and the fitness assessment office.

74044-5 **SPACE PLANNING SPREADSHEET**. Minimum space allowances for Indoor Physical Fitness Centers are determined according to the planning criteria incorporated into the Fitness Space Program Spreadsheet, which can be found at https://www.wbdg.org/dod/unified-facilities-space-program-sustainability-spreadsheets.

The total allowance for the planned facility is shown as the sum total of the space allowances for each functional component. The number of units of each component required to meet the demand is obtained from the calculations associated with the installation population.

74044-5.1 Spectator seating (minimum capacity 200 for a small facility, maximum capacity 600 for a large facility) should be provided in the basketball court at 0.4 sq. m. (4.3 NSF) per person. The seating capacity should be justified by the use of the court for activities drawing significant numbers of spectators. Portable or telescopic bleachers may be used.

74044-5.2 Fitness area includes warm up/cool down area, free weights, circuit/weight training machines, and cardiovascular equipment (bicycle, stepper, and rower). Space for one Instructor station should be included in each separate Weight Training Area.

74044-5.3 Staff support spaces consist of:

(a) Control Counter and Administrative Area.
(b) Gear Issue and Laundry Room: Check out of athletic gear and recreation equipment for leisure use.
(c) Gym Equipment Storage Room: Equipment and supplies, such as roll-away baskets goals, volleyball standards, and gym floor coverings, roll-away bleachers, etc.

740 45 FITNESS ROOM (SF)
FAC: 7421
BFR Required: N

74045-1 **DESCRIPTION** Fitness Rooms are stand-alone, unsupervised gym facilities, usually containing cardio equipment and weight machines or free weights, in a single room or small group of rooms within a facility which is classified under a different CCN.

74045-2 **REQUIREMENT** This CCN is primarily for inventory purposes, and the quantity of “fitness rooms” at an installation should be considered when planning new facilities under CCN 740-44.

74045-3 **GUIDANCE** Refer to Commander, Navy Installations Command (CNIC) Instruction 1710.1 dated August 1, 2011 for policy and guidance concerning the operation of unmanned fitness spaces.

740 46 ROLLER/ICE SKATING RINK (SF)
FAC: 7418
BFR Required: N

74046-1 This category code is for inventory only and is no longer approved for new construction.

Table 74046-1
Space criteria for Roller/ice skating rinks

Military Strength (1)	Gross SF
Up to 2,000	10,000 note (2)
2,001 to 20,000	15,000 note (3)
20,001 and up	20,000 note (3)

Gross area is exclusive of mechanical room space.

(1) Military strength is defined as military population plus 50% of the dependent personnel.
(2) Plus additional space for support functions.
(3) Includes space for support functions.

740 47 INFORMATION, TICKETS AND TRAVEL OFFICE (SF)
FAC: 7446
BFR Required: Y

SECNAV Approved Standards and Metrics are available for this CCN at http://mwr.navy.mil/mwrprgms/programstand.htm

74047-1 **GENERAL**. See General Notes to 740 series category codes for General Instructions regarding facility allowance planning procedures.

74047-2 **DEFINITION**. The mission of the Recreation Information, Tickets and Travel (ITT) Office is to serve the military community's leisure needs by providing information on what to see and do locally, offering tours to nearby attractions, selling tickets for musical and theatrical performances, concerts, sporting and other special events, and providing options for Leisure Travel (this may include cruise and airline ticket service).

ITT facilities can vary according to local needs and may range from ticket selling booths and information counters to travel agency type accommodation with display and office desk/seating/waiting area configurations.

74047-3 **RELATED FACILITIES**. ITT operations may benefit from collocation with high traffic uses such as Base Exchanges.

74047-4 **SPACE ALLOWANCE**. The space allowance for ITT Offices is presented below in Table 74047-2.

74047-4.1 The number and appeal of local attractions and recreational opportunities will have a direct impact on the volume of ticket sales and information requests handled by an ITT Office. This volume is the primary determinant of the number of staff required to serve the market at individual bases. Based on analysis of existing operations, the staffing ratio indicated in Table 74047-1 is recommended.

Table 74047-1. Recommended Staffing For ITT Office

Active-Duty Installation Population	Full-Time Staff	Part-Time Staff	Note
250 or less	0	2	(1)
251-1,000	1	1	(1)
1,001-5,000	1	2	(1)
5,001-10,000	3	3	(1)
more than 10,000	3	4	(1)

Note for Staffing Table:

(1) Population numbers should be consistent with projected base loading data. For facility planning purposes at installations with deployable forces, the active-duty demand population is comprised of all of the non-deployable population, plus two-thirds of the deployable population, to reflect time away on deployment. However, calculation of the deployable population may be adjusted based on the actual deployment experience at individual installations.

Table 74047-2. Space Allowance for ITT Office

# Staff	Min. Gross Square Feet (rounded up to the next FTE)	Max. Gross Square Feet
1	200 GSF	450 GSF
2	300 GSF	720 GSF
3	500 GSF	990 GSF
4	840 GSF	1,210 GSF
5	1,100 GSF	1,410 GSF

Note for Space Allowance Table:

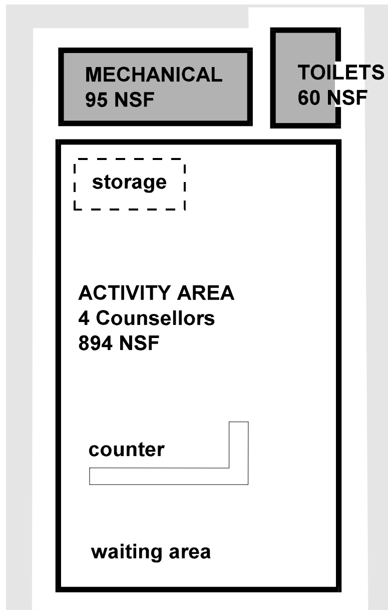
FTE = Full Time Equivalent, in situations where staffing is made up of full- and part-time employees.

74047-4.2 A good location is critical for running a successful ITT operation -- offices should be located in convenient, high visibility locations. Adequate parking should be available near the office per category code 852-10.

74047-4.3 Ticket booths may be located separately from other ITT facilities. On large bases requiring multiple booths, such booths may be clustered in one location or occupy several sites. When siting ticket booths, space for lines to form should be taken into account. Booth locations should allow for long lines to spill over into adjacent parking lots on those occasions when tickets for events drawing large audiences go on sale.

74047-5 **SAMPLE LAYOUT DIAGRAM**. A layout diagram is presented for an extra-large size ITT Office. This diagram is an example of the composition of such a facility in terms of its functional components, their respective sizes and adjacencies. The layout diagram is for illustrative purposes only.

Figure 74047-1. ITT Office – Extra Large Size Facility



740 49 AUSTERE INDOOR PHYSICAL FITNESS CENTER (GYM) (SF)
Facility planning criteria related to Austere Indoor Physical Fitness Centers can be found in FC 2-000-05N - Appendix F "Austere Facilities (Navy)," located at https://www.wbdg.org/FFC/DOD/UFC/fc_2_000_05n_appendixf.pdf.

740 52 GUN, SKEET AND/OR TRAP BUILDING (SF)

This CCN has been deleted. All existing assets should be reassigned to CCN 74090 Recreational Support Building.

740 53 SWIMMING POOL - INDOOR (INCLUDING POOLSIDE DECK) (SF)
FAC: 7422
BFR Required: Y

74053-1 **GENERAL**. See General Notes to 740 series category codes for General Instructions regarding facility allowance planning procedures.

The planning criteria presented below for Category Code 740 53 are also applicable to Category Code 750 30, Outdoor Swimming Pool -- Installation.

74053-2 **DEFINITION**. The primary purpose of Swimming Pools is to support physical readiness programs as well as instructional, informal and intramural activities, and to serve the recreational needs of active-duty military personnel and their spouses and children, retirees and DoD authorized civilians. Note that pools with training and fitness missions are funded as MILCON and purely recreational pools are funded as NAFCON. With the exception of extra-small and small bases, each installation must provide either an all-hands indoor or outdoor pool, or access to aquatic resources in the local community to meet patron recreational demands. All on-base aquatics facilities must be ADAAG/ABA compliant.

74053-2.1 The local Command has discretion over the decision to provide indoor or outdoor Swimming Pools. However, in general, large installations requiring more than one Swimming Pool to meet patron demand, may develop only one indoor pool. The Navy Fitness Program Manager (CNIC N-9) strongly supports an indoor pool collocated with the Fitness Center for all Medium and larger installations to support fitness swimming for Navy Physical Readiness Testing. Additional indoor pools may be developed on the basis of facility planning criteria specified for Combat Training Pool/Tank under Category Code 179 55.

74053-2.2 In addition to the swimming pool, special features such as diving wells, water slides and wading pools (refer to relevant UFC criteria at https://www.wbdg.org/dod/ufc and zero-depth entry areas may be incorporated in the facility if there is sufficient local justification.

74053-2.3 At smaller installations, the potential for shared use of a single pool for both recreational and training needs should be examined.

74053-3 **RELATED FACILITIES**. Consideration should be given to collocating the Swimming Pool with related recreational facilities in order to (i) take advantage of potential savings in space requirements and operating costs, and (ii) provide users with the increased convenience of clustered facilities. These related recreational facilities include:

- 740 44 Indoor Physical Fitness Center (Gym)
- Other MWR recreational and foodservice facilities such as Clubs and Recreation Centers (for purely recreational pools).

74053-4 **DEMAND**. Swimming Pool facilities are sized on the basis of the peak hour demand at each installation, as follows:

74053-4.1 Use projected base loading data to determine the population for each significant population category, as listed in Table 74053-1.

74053-4.2 Calculate peak hour demand by multiplying the population for each category by participation factors found in Tables 74053-1. Add the demand for all population categories to derive Total Demand for each functional component. Adjust the calculated Total Demand as indicated in Table 74053-1 for installations with alternative on-base recreational swimming facilities such as lakes or beaches.

74053-4.3 The determination of the length of the pool is a local Command decision which should be based primarily on patron demand and programmatic considerations. A 25-meter length pool is sufficient to satisfy most fitness and recreational swimming needs. The advantage of a 50-meter length is that the pool may be divided up into 2 or 3 areas and utilized simultaneously for different programs. For example, given sufficient demand, a 50-meter length pool divided into three separate areas may be used simultaneously for recreational swimming, lap swimming for fitness training, and an instructional class in life-saving techniques.

74053-4.4 Calculate the number of lanes required by dividing the Total Demand by the maximum capacity per hour per lane, indicated in Tables 74053-2 or 74053-3, depending on whether the local Command opts for a 25 meter length or 50 meter length Swimming Pool. In general, the development of Swimming Pools with fewer than 6 lanes and more than 10 lanes is not recommended.

Table 74053-1. Swimming Facility Demand Calculation

Note	Population Category	Population (per Base Loading)	x	Participation Factor	=	Peak Hour Demand	
(1), (2)	Enlisted	____	x	.0043	=	____	users
(1), (2)	Officers	____	x	.0045	=	+ ____	users
(1), (2)	Retirees	____	x	.0025	=	+ ____	users
(1), (2)	Authorized Civilians	____	x	.0015	=	+ ____	users
(1), (2), (3)	Dependents	____	x	.0093	=	+ ____	users
Total Demand (rounded to the nearest whole unit)					=	_______	users
Adjustment (**subtraction**) for installations with alternative on-base swimming facilities (such as developed beaches or lakes)						- 30	users
Total Demand (rounded to the nearest whole unit)					=	_______	users

Notes for Demand Calculation -- Table 74053-1:

(1) Population numbers should be consistent with projected base loading data. Officers are O-1 through O-10 and enlisted are E-1 through E-9. Civilians are authorized DoD employees. Retirees are all military retirees within a 30-minute drive of the installation.
For facility planning purposes at installations with deployable forces, the active duty demand population is comprised of all the non-deployable population, plus two-thirds of the deployable population, to reflect time away on deployment. However, calculation of the deployable population may be adjusted based on the actual deployment experience at individual installations.

(2) The participation factors used in the table may be revised periodically by NAVFAC HQ and CNIC (N-9), and the most current figures must be used in all demand calculations.

(3) Dependent population data may be obtained from the base MWR or Housing Offices.

Table 74053-2. Swimming Pool Capacity Calculation—25 Meter Length

Total Demand (rounded to the nearest whole unit)	=	____ users
Divide by maximum capacity per hour per lane (for a 25 meter length Swimming Pool)		÷ 4 users
Total number of lanes for a 25 meter length Swimming Pool	=	____ lanes

Table 74053-3. Swimming Pool Capacity Calculation—50 Meter Length

Total Demand (rounded to the nearest whole unit)	=	____ users
Divide by maximum capacity per hour per lane (for a 50 meter length Swimming Pool)		÷ 6 users
Total number of lanes for a 50 meter length Swimming Pool	=	____ lanes

74053-5 **SPACE ALLOWANCE**. In addition to determining the length of the pool and the number of lanes, a Swimming Pool facility requires a poolside deck area and concession area, as required. Space allowance criteria for these support facilities are presented in Table 74053-4. Furthermore, an adequately sized bathhouse is required and should be sized separately based on the criteria presented under Category Code 74089.

Table 74053-4. Space Allowances for Swimming Pools

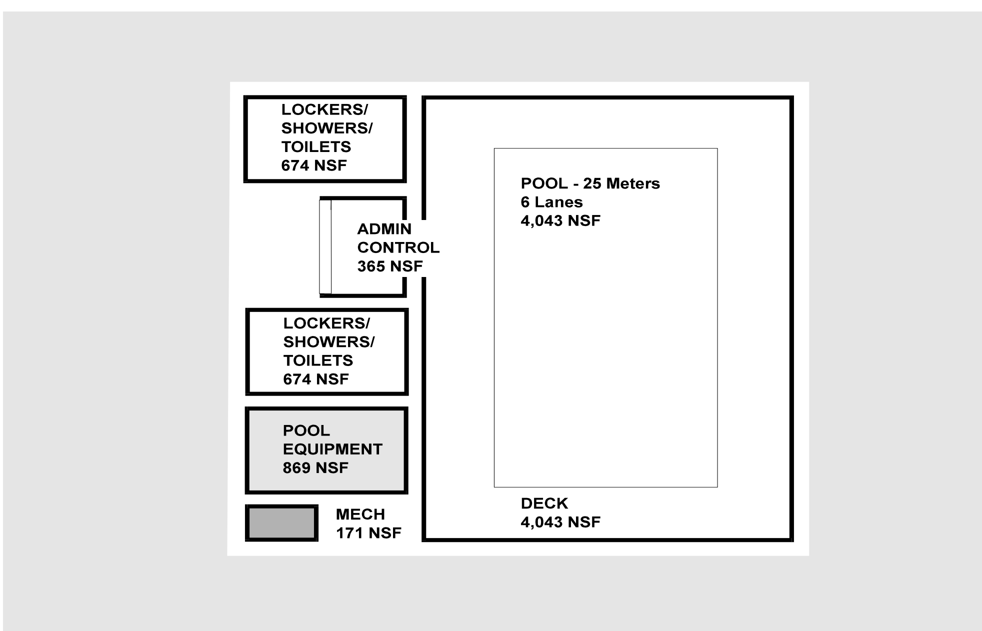
Note	Table	Functional Component	# Units	x	Space Allocation Factor	=	Total NSF	Min. or Max. NSF
		ACTIVITY AREAS						
(1), (2)	74053-2	Swimming Pool—25 meter length	____	X	674 NSF per lane	=	____	
(1), (2)	74053-3	Swimming Pool—50 meter length	____	X	1,348 NSF per lane	=	____	
		Poolside Deck Area						
		for Indoor Pool			100% total NSF lanes	=	____	
		for Outdoor Pool			300% total NSF lanes	=	____	
		BUILDING SUPPORT						
		Entrance/Circulation/Housekeeping			10-15% X subtotal NSF Activity Support Areas	=	____	
		Supplies/Janitor's Closet/ Structure/Partitions						
		Mechanical/Electrical/ Communication Equipment Space			5-10% X subtotal NSF Activity Support Areas	=	____	

Note	Table	Functional Component	# Units	x	Space Allocation Factor	=	Total NSF	Min. or Max. NSF
		Pool Plant Room (pump, filter, etc.)			20% total NSF lanes	=	____	
		Chemical Storage Room(s)			60 NSF per room	=	____	60 min.
		[Separate rooms for different chemicals, as per safety requirements]						
TOTAL FACILITY ALLOWANCE FOR SUPPORT FACILITIES (Gross Square Feet)						=	____	

Notes for Space Allowance -- Table 74053-4:
(1) The determination of the length of the pool is a local Command decision which should be based primarily on patron demand and programmatic considerations.
(2) Minimum lane width of 7' is recommended, with an additional 1'-6" outside lanes on both sides of the swimming pool.
NSF = Net Square Feet
GSF = Gross Square Feet
Minimum or Maximum NSF = Minimum or maximum space allowance to be provided for the particular function or activity.

74053-6 **SAMPLE LAYOUT DIAGRAM**. A layout diagram is presented for a 6-lane, 25-meter length Indoor Swimming Pool facility. This diagram is an example of the composition of such a facility in terms of its functional components, their respective sizes and adjacencies. The layout diagram is for illustrative purposes only.

Figure 74053-1. Indoor Swimming Pool – 25 Meters



740 54 MWR MILITARY RECREATION CENTER (SINGLE SAILOR CENTER / MARINE CENTER) (SF)

This CCN has been deleted. All existing assets should be reassigned to CCN 74042, Community Recreation Center.

740 55 YOUTH (6-18 YRS) & SCHOOL AGE CARE (SAC) (6-12 YRS) CENTER (SF)
FAC: 7417
BFR Required: Y

SECNAV Approved Standards and Metrics are available for this CCN at http://mwr.navy.mil/mwrprgms/programstand.htm

Design Criteria: UFC 4-740-06, webpage: https://www.wbdg.org/dod/ufc/ufc-4-740-06

74055-1 **GENERAL**. See introduction to 740 series category codes for General Instructions regarding facility allowance planning procedures.

74055-2 **DEFINITION**. The Youth Center is a social and recreational center primarily for use by children ages 6 to 18 in support of a Youth Program, as defined by DoD Instruction 6060.3 for School Age Care and DoD Instruction 6060.4 for Youth Programs. The Youth Center supports opportunities for youth to develop their physical, social, emotional, and cognitive abilities and to experience achievement, leadership, enjoyment, friendship, and recognition. Youth Program activities are generally offered free of charge or at a reasonable cost to parents to encourage participation and make them affordable to families. Included in the Youth Center facility, but generally separated from the youth program functions, is a School-Age Care (SAC) program. The SAC program provides accountable childcare (ages 6-12) for a fee. This includes picking children up after school or having them dropped off by school bus and keeping them until parents can pick them up from the center.

74055-3 **RELATED FACILITIES**. The location of Youth Centers should be determined primarily for proximity to the family housing areas served - preferably accessible by the youth within fifteen minutes’ walk or bicycle ride. Collocation of Youth Centers with other MWR facilities is recommended, in particular with youth playing fields, outdoor playing courts, and playgrounds. Consideration should be given to potential savings in Youth Center space requirements for specific Activity Areas, if other MWR facilities provide the same functions conveniently accessible and available for use by the youth.

74055-4 **SIZE DETERMINANTS**. Several factors determine the size of the facility:

Needs Validation Assessment. Conduct a Needs Validation Assessment to determine the need for each of the three core program areas (SAC Program, Youth Program, and Teen Program), the optional spaces, and the size of the populations to be served by each program. The three core program areas may be sized differently within a single facility. In some cases, one or more core program areas may not be needed if the population served is too small or if that population is served by other, existing facilities. When reviewing existing facilities, consider both facilities on the installation and facilities within the community, such as the Boys & Girls Clubs of America, 4-H, and other community centers.

74055-4.1 **SAC Program Size.** Once the need and population size for the SAC program area has been determined, the SAC area is sized based on the number of SAC activity rooms needed. Each room serves two ratio groups or a total of 30 children. The maximum number of SAC rooms permitted per facility is eight. If the needs assessment determines that more than eight rooms are required, provide multiple facilities.

74055-4.2 **Youth Program Size.** Once the need for the Youth Program area has been determined, the size is classified by the number of youth to be accommodated. Each size category provides for appropriate space in the Commons (including the Game Area, Snack and Eating Areas, and circulation space) and support areas and provides the appropriate number of activity rooms.

Table 74055-1. Youth Program Size Classifications

Size Class (No. of Youth)	Navy and Marine Corps Activity Rooms (General or Special)	Navy and Marine Corps Homework / Computer Rooms
Up to 60 Youth	1	1
61 to 90 Youth	2	1
91 to 135 Youth	3	2
136 to 155 Youth	4	2

74055-4.3 Teen Program Size Classifications: Once the need for the Teen Program area has been determined, classify the size as follows: Up to 15 teens, 16 to 30 teens, 21 to 45 teens, and 45 to 60 teens.

74055-4.4 Optional Spaces: Once the Core program areas have been sized (above), determine which optional spaces should be included. Optional spaces include administrative space, multipurpose room, music or multimedia room, laundry room, and outdoor activity area or open area.

74055-5 **SPACE PROGRAM**. The space program for the Youth Centers is developed using interactive Youth Center Space Program spreadsheets. Right click on https://www.wbdg.org/dod/ufc/ufc-4-740-06 to download the spreadsheet.

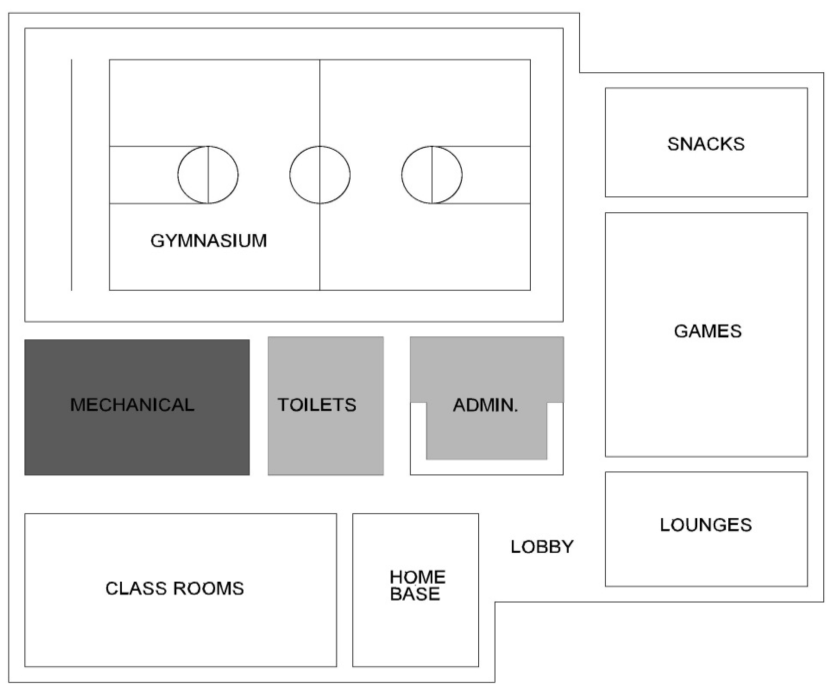
74055-6 **LOCATION DETERMINANTS.** Several factors determine the most appropriate and cost-effective location for a Youth Center.

74055-6.1 **Access.** The Youth Center should be easily accessible by busses (dropping off), privately-owned vehicles (either dropping off/picking up or parking), and by youth patrons via foot or bicycle. Weigh these considerations against the effect on traffic during peak pick-up/drop-off times. For example, a location near or adjacent to a school or child development center may be convenient for patrons, but it may cause traffic congestion at peak times. To accommodate parent/patron access, provide adequate parking as close as possible with a covered walkway to the facility, taking into account AT/FP requirements and parking criteria 852-10.

74055-6.2 **Safety.** Consider the above-noted pedestrian and bicycle traffic by the youth patrons. Minimize the degree to which the pedestrian and bike paths cross vehicular paths in the approach to the Youth Center site. If pedestrian and bike paths cross or run adjacent to busy streets and intersections, provide mitigation measures, such as bollards, to increase safety. Also consider the location of bus access for drop-off and pick-up.

74055-6.3 Other Factors: Consider locating near other facilities such as youth sports fields, open park space, etc.

Figure 74055-1. Youth Center – Medium Capacity



740 56 THEATER (SF)
FAC: 7431
BFR Required: Y

74056-1 **GENERAL:** See introduction to 740 series category codes for General Instructions regarding facility allowance planning procedures.

74056-2 **DESCRIPTION:** A facility for the presentation of motion pictures selected primarily for the entertainment of active duty Navy and Marine Corps personnel and their dependents, as well as other supported Services located at an Installation.

74056-3 **RELATED FACILITIES:** The mini theater that may be provided in the Military Recreation Center (Single Sailor Center) should not be counted against this allowance since it is not accessible to families and is a Category A facility. Theaters are operated as Category C facilities (see General Notes MWR) except for the 8-mm.-film program provided to the ships, Single Sailor Centers, and some Youth Centers. Consequently, to be programmed as a NAF project, any new or replacement theaters would have to be financially justified.

74056-4 **REQUIREMENT:** Space allowances for theaters will be determined by the following method:

74056-4.1 **Step 1:** Determine basic authorized number and seating capacity from Table 74056-1.

Table 74056-1
Authorized Numbers and Seating Capacities for Theaters

Military Population (see note 1)	**Authorized Number of Facilities**	**Seat Capacity**	**Dressing Rooms**
Up to 300	(see note 2)	n/a	n/a
301 to 1,000	1	General Purpose	Without
1,001 to 2,000	1	350	With
2,001 to 3,000	1	500	With
3,001 to 25,000	Program as an auditorium CCN 171-25		

Notes for Table 74056-1:

(1) Military population military strength plus 50% of dependents.

(2) Accommodate in either CCN 740-42 “MWR Community Recreation Center” or CCN 740-54 “MWR Military Recreation Center”.

74056-4.2 **Step 2:** Determine Environmental Adjustment Factor (EAF) from Table 74056-2 and adjust the seat capacity value obtained from Step 1 accordingly. The maximum allowances obtained from Table 74056-1 must be adjusted to reflect available community support and other recreational facilities available on the Installation. Table 74056-2 gives the environmental variables and the individual EAF's for each variable. The product of these individual EAF's is the final EAF to be used. (An example of EAF use follows Table 74056-2.)

Table 74056-2. Environmental Adjustment Factors for Theaters

Condition	**Civilian Community Facilities** (see note 1)	**Other Recreational Facilities** (see note 2)	**Current Installation Theater** (see note 3)
Normal	0.70	0.70	1.00
Poor	1.00	1.00	0.50

Notes for Table 74056-2:

(1) Civilian Community Facilities
Normal: At least one civilian theater or drive-in within 30 minutes driving time of installation and local TV or CATV reception.
Poor: No civilian theater or drive-in within 30 minutes driving time or no local TV or CATV.

Notes for Table 74056-2 (continued):

(2) Other Recreational Facilities (On-installation)
Normal: Three or more of the following five facilities are either available or construction funds have been appropriate:
1) a club or open mess
2) bowling alley
3) hobby shop
4) gymnasium;
5) playing courts and fields.
Poor: Two or less of the five facilities are available and no construction funds have been appropriated for them.

(3) Current Installation Theater (assuming films are shown nightly and changed weekly)
Normal: At least two shows per week have audiences in excess of 67% of capacity.
Poor: At least two shows per week have audiences less than 50% of capacity.

EXAMPLE:	*Assume the military strength is 6,000. There are several theaters close by and the TV reception is good. The installation has only open messes and a gymnasium that currently doubles as a theater. Current attendance is less than one-third full for two shows.*

1. ***Maximum seating allowance*** *from Table 74056-1 is:* *1,000 seats*

2. ***Environmental Adjustment Factors:***
(a) Civilian community – ***normal:*** *select 0.70*
(b) Other recreational facilities - ***poor*** *select 1.00*
(since only two of the five types are available)
(c) Current attendance - ***poor:*** *select 0.50*
Therefore the Environmental Adjustment Factor is (0.70) x (1.00) x (0.5) = 0.35

3. ***Adjusted seating capacity*** *is: 1,000 x 0.35 =* ***350 seats***
(Use Table 74056-3 for GSF Allowance)

74056-4.3 **Step 3:** Determine the gross square footage (GSF) requirements for the facility, based on the adjusted seating capacity from steps 1 and 2, and applied to Table 74056-3. All facilities, except the General Purpose facility, will be provided with a stage.

Table 74056-3. Space Allowances For Theaters

Adjusted Seat Capacity	Gross Square Feet (with dressing rooms)	Gross Square Feet (without dressing rooms)
General Purpose	3,500	3,500
350	6,500	5,800
500	10,900	9,600
1,000	17,200	15,500

740 60 COMMISSIONED OFFICERS' CLUB (SF)
FAC: 7333
BFR Required: N

74060-1 This category code has been deleted. All existing assets should be reassigned to category code 740 67, All Hands Club, and new facilities will be programmed under category code 740 67 and require CNIC N925 and N944 concurrence.

740 64 ENLISTED CLUB (SF)
FAC: 7333
BFR Required: N

74064-1 This category code has been deleted. All existing assets should be reassigned to category code 740 67 All Hands Club, and new facilities will be programmed under category code 740 67 and require CNIC N925 and N944 concurrence.

740 67 ALL HANDS CLUB (SF)
FAC: 7333
BFR Required: Y

Design Criteria: (This category code will become a primary facility in future revisions as: Food / Beverage / Entertainment / Facilities - Clubs) New projects will be reviewed by CNIC N925, N944. Design guidance can be found in FC 4-722-01N Navy and Marine Corps Dining Facilities.

74067-1 **DEFINITION.** This code is used to plan the space requirements for a single facility to accommodate on-base facilities, surrounding competitive environment and size of the supporting population. The facility may include one or more of the following components: Full Table Service Restaurant, Quick Service (over the counter) Restaurant, Banquet/Catering Room(s), Cafeteria, Bingo space, Gaming Room (OCONUS, non-US), Beverage Lounge(s) (may be rank specific) with or without Entertainment. Support spaces such as offices, restrooms, storage, etc. would also be included.

74067-2 **SPACE ALLOWANCE.** For space requirement purposes only, the space allowances in Table 74067-1 may be used. However, the actual size of any programmed club project is based upon market analysis and consequent financial projections that must justify programming of the facility and comply with the financial performance requirements of DODINST 7700.18. Contact CNIC N925, N944 for additional information.

Table 74067-1. Space Allowances for All Hands Clubs

Size Classification	Installation Population	Gross Area (SQ.M./SF)
Small	< 3,000	743.22 sq.m/8,000 SF
Medium	3,001 – 7,000	1,300.64 sq.m/14,000 SF
Large	7,001 – 14,000	1,858.06 sq.m/20,000 SF
Extra Large	> 14,000	2,415.48 sq.m/26,000 SF

740 68 MWR OPERATED CATERINGING AND CONFERENCE CENTER (SF)
FAC: 7333
BFR Required: Y

74068-1 This facility may be stand alone or combined with and Officers' Club, Enlisted Club, All Hands Club, Bowling Center, Marina Clubhouse, or Golf Clubhouse. The Catering facility often includes bingo operations in at least one room. The size of the facility is based upon market analysis and consequent financial projections that must justify programming of the facility. New projects will be reviewed by CNI N9.

740 70 CHIEF PETTY OFFICERS CLUB (SF)
FAC: 7333
BFR Required: Y

74070-1 This category code has been deleted. All existing assets should be reassigned to CCN 74067 All Hands Club and new facilities will be programmed under CCN 74067 and require CNIC N925, N944 concurrence.

740 71 EXCHANGE PACKAGE STORE (SF)
FAC: 7346
BFR Required: Y

74071-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command Planning Branch, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724. See General Notes for NEX facilities at the beginning of the 740 Series.

74070-2 This facility provides for retail sales to authorized customers and the transfer (wholesale) of alcoholic beverages to clubs and open messes. A select few locations have package stores operated by MWR as permitted by Congress.

740 74 CHILD DEVELOPMENT CENTER (SF)
FAC: 7371
BFR Required: Y

Child Development Center Space Program spreadsheet, located at:
https://www.wbdg.org/dod/unified-facilities-space-program-sustainability-spreadsheets

Design Criteria: FC 4-740-14N "Navy and Marine Corps Child Development Centers"
https://www.wbdg.org/dod/ufc/fc-4-740-14n

74074-1 **DESCRIPTION.** A Child Development Center (CDC) is a facility which provides full and part-day developmental child care services for children from ages of 6 weeks old through 5 years of age.

74074-2 REQUIREMENT. Access to developmental child care programs are available to the dependents of active duty military, activated reservists and guardsmen, DoD civilian personnel, and DoD contractors.

74074-2.1 **Demand:** The demand shall be determined by actual count of military dependents through age 5 receiving Installation support who will be using the facility. Actual count must be determined by questionnaire, survey, documented historical data or similar process. Dependents of Civilian Employees through age 5 may be included as per DOD Instruction 6060.2 "Child Development Programs" of March 3, 1989. Justification remains the responsibility of the sponsoring command with requirements based on local needs. Adjust these figures for any projected increase or decrease in military and civilian employee population or mission changes.

74074-2.2 **Demand for New Activities:** Determine the total number of married military families receiving direct Installation support and multiply by 15 percent, plus the number of children of single parent military families receiving direct Installation support. When including dependents of civilian employees, determine the total number of civilian employees and multiply by 2.5 percent.

74074-2.3 **Facility Classification:** The CDC facility sizes are classified as follows, according to the capacity of children it can accommodate:

Table 74074-1 - CDC Size Classifications

Size	Capacity
Small	48 to 100 children
Medium	100 to 200 children
Large	201 to 300 children
Extra Large	More than 300 children

74074-2.4 **Capacity:** The minimum capacity for a CDC is 48 children. When a need is identified to accommodate more than 300 children (an extra-large facility size), consideration should be given to expanding the Family Home Care Program to supplement the requirement for center-based care. Contact the CNIC Child and Youth Programs (CYP) Facilities Specialist (N926) to determine Family Care options before developing requirements for additional CDC’s.

74074-2.5 **Program Requirement:** Planners developing the requirement for a new facility must combine the facility space allowances provided in the space program spreadsheet (refer to paragraph 74074-2) and the outdoor activity areas referred to in paragraph 74074-2.6.

74074-2.5.1 Entrance canopies may be provided for pickup and discharge of passengers in inclement weather regions.

74074-2.6 **Outdoor Activity Areas:** Provide an area for outdoor activity equipment and play, based on 130 SF per child for 50% of the facility capacity. Larger areas can be programmed if authorized by CNIC N926.

74074-2.6.1 Outdoor shade structure(s) are required for locations where extreme sun conditions occur 80% of the time. In these locations, provide for shade structures over 50% of the total outdoor activity area. If there are trees providing natural shade, then the shade structures could be reduced accordingly. Shade structures (not enclosed) are provided without adding to the building gross square footage calculation and may be provided either by extending building overhangs over the activity area or by providing stand-alone structures.

74074-2.6.2 Outdoor storage (for playground materials) may be provided as part of the primary facility or as a separate storage shed. This area is included in the results of the space programming spreadsheet.

74074-2.7 **Impact on Neighborhood.** The planner and program manager must give significant consideration to the impact that a large CDC will have on land use, peak traffic patterns and safety of the children. Providing CDC facilities adjacent to or in close proximity to another CDC, youth center, or school facility may have an impact on traffic, but doing so should not be precluded. Adjacent facilities may be more customer responsive in that a parent may have children in both facilities. Additional site criteria can be found in FC 4-740-14N. In addition, OPNAVINST 1700.9E should be reviewed as a source for site and facility guidance.

74074-2.8 **Location**: Significant consideration must be given by the facility planner, in coordination with CNIC and the Installation Commander, to properly locate the CDC in an appropriate and compatible location with regard to the health and safety of the children. Also take into account the practical future expansion of the CDC, adjacent facilities and associated Force Protection issues.

74074-2.9 **Land area requirements**. Table 74042-2 provides planning guidance for the minimum land area that is required to properly site a new CDC facility. This estimated area will accommodate the CDC facility, the outdoor activity area, parking, service areas, and vehicular and pedestrian circulation.

Table 74074-2 - CDC Site Size Requirements

CDC Size	Min Site Size- (Acres)	Min Site Size (Hectares)
Small	2.07	0.84
Medium	3.78	1.53
Large	5.15	2.08
Extra Large	6.35	2.57

74074-3 **SPACE PLANNING SPREADSHEET**. Minimum space allowances for Child Development Centers are determined according to the planning criteria incorporated into the Child Development Center Space Program spreadsheet, which can be found at https://www.wbdg.org/dod/unified-facilities-space-program-sustainability-spreadsheets

74074-3.1 Space allowances provide for infant, pre-toddler, toddler, and pre-school age activity rooms/spaces, infant crib space, isolation area with toilet, lobby/reception, food service/kitchen, staff training / lounge / curriculum development spaces, offices, laundry, toilets, janitor closet(s), and storage.

740 75 NAVY FLYING CLUB FACILITY (SF)
FAC: 7414
BFR Required: Y

Design Reference: Federal Aviation Regulation (Part 141)

74075-1 The Navy Flying Club is a recreational flying activity located on or near military installations used by authorized personnel and approved by the Department concerned. Flying Clubs are Category C facilities (See General Notes MWR) and must be financially justified for new construction. The space allowances shown in the table below for aero clubs are intended to provide hangar space to be used to maintain aircraft and for aircraft storage during inclement weather to provide ramp space for outdoor aircraft tie-down area, and to provide multipurpose space for administrative, training, classrooms, operations scheduling, safety meetings, and flight planning. Space requirements are based on the number of aircraft operated by the club.

74075-2 Each Navy Flying Club facility must have adequate area for refueling operations, i.e. fuel truck or permanent tanks that meet all local, state, and federal regulations pertaining to that operation.

Table 74075-1. Space Allowances for Aero Clubs

Number of Aircraft	Gross SF Hangar Space	Gross SF Multi-Purpose Space	Gross SF + Ramp Space (Approx. 45' x 20')
1	900	500	Note (1)
2 to 5	2,300	1,000	Note (1)
6 to 10	3,800	1,200	Note (1)
11 to 15	5,300	1,500	Note (1)
16 to 20	6,800	1,700	Note (1)
For each additional 5, add	1,500	375	Note (1)

Note (1): For each aircraft operated multiply by 1350 SF to obtain the required Ramp Space. (Number of aircraft_ X 1350 SF = Ramp SF)

740 76 LIBRARY (SF)
FAC: 7416
BFR Required: Y

SECNAV Approved Standards and Metrics are available for this CCN at http://mwr.navy.mil/mwrprgms/programstand.htm

74076-1 **Main Libraries.** This facility is for recreational reading and study. Space allowances are given in Table 74076-1. The allowances may be increased to 10% where the facility is also designated as a command reference center. If bookmobiles are operated from the main library, an additional 300 SF per bookmobile will be required for book storage, trucks, and work space for bookmobile staffs.

74076-2 **Branch Libraries.** Based on individual justification, branch libraries may be provided in support of an educational services office or for each increment of 3,000 military strength over 10,000. Each branch library shall not exceed 4,000 gross SF area. Where practical, the individual incremental allowances may be combined in one branch library.

For BFR purposes: The total allowance is the main library plus the branch libraries.

Table 74076-1. Space Allowances For Main Libraries

Military Population (1)	Gross SF
Up to 500	2,500 (2)
501 to 1,500	4,500
1,501 to 2,500	6,250

Military Population (1)	Gross SF
2,501 to 4,000	8,000
4,001 to 6,000	10,500
6,001 to 8,000	12,000
8,001 to 12,000	18,000
12,001 to 16,000	20,000
16,001 to 20,000	24,000
20,001 to 26,000	30,000
26,001 to 32,000	36,000
32,001 to 40,000	44,000
40,001 to 50,000	54,000
50,001 to 60,000	64,000
60,001 to 70,000	72,800
70,001 to 80,000	81,000
80,001 to 90,000	90,000
90,001 to 100,000	98,000
For each additional 10,000, add	8,000

(1) Military population is active duty military plus 40% of dependents.
(2) Accommodate in other facilities.

740 77 MWR READY ISSUE/SHOP STORES/MISC. STORAGE (SF)
FAC: 4421
BFR Required: Y

(Not applicable to Marine Corps activities)

74077-1 Storage facilities for miscellaneous equipment and/or goods related to community support will be provided only where they can be individually justified. There are no criteria for this type of facility. General information on normal stacking heights, SF per measurement ton requirements and other parameters are provided in Category Code 440 series.

740 78 RECREATION PAVILION (SF)
FAC: 7531
BFR Required: Y

74078-1 The purpose of this facility is to support recreation areas such as parks, playgrounds, picnic areas, beaches, etc. This facility may include lounge, toilets, bathhouses, storage areas, snack bars, and/or concession stand for limited and related items as required. This CCN also includes concessions stands, restrooms, and announcer's booth facilities associated with ball fields. Space allowances may be utilized in varying numbers and sizes of pavilions. See Table 74078-1 for space allowances.

Table 74078-1
Space Allowances For Recreation Pavilions

Military Population (1)	Gross SF
Up to 1,000	800
1,001 to 3,000	1,350
3,001 to 7,000	2,600
7,001 to 10,000	3,200
10,001 to 15,000	4,000
15,001 to 20,000	4,900
20,001 to 25,000	5,600
25,001 to 30,000	6,300
30,001 to 40,000	7,300
40,001 to 50,000	8,500
50,001 to 60,000	9,600
60,001 to 70,000	10,600
70,001 to 80,000	11,500
80,001 to 90,000	12,400
90,001 to 100,000	13,300
For each additional 10,000 add	900

(1) Military population consists of active duty military plus 60% of dependent population and 25% of retirees supported by the installation.

740 79 RIDING STABLES (SF)
FAC: 7444
BFR Required: Y

74079-1 Provides space for single stalls, box or double stalls, treatment stalls, quarantine areas, quarters for one operator, hay storage area, grain room, tack lockers, sweat pad and blanket drying area, office, and toilets. See Table 74079-1 for space allowances. This CCN also includes boarding stable operations. Both stable types are Category C facilities (See General Notes MWR) and require financial justification for new construction.

Table 74079-1
Space Allowances for Riding Stables

Military Population (1)	Gross SF
Up to 100	None
101 to 1,000	2,100
1,001 to 3,000	2,500
3,001 to 5,000	3,600
5,001 to 7,000	4,700
7,001 to 10,000	5,900
10,001 to 15,000	7,700
15,001 to 20,000	9,600
20,001 to 25,000	11,250
25,001 to 30,000	12,800
30,001 to 40,000	17,800
40,001 to 50,000	18,600
50,001 to 60,000	20,400
60,001 to 70,000	22,800
70,001 to 80,000	24,900
80,001 to 90,000	27,000
90,001 to 100,000	29,000
For each additional 10,000 add	1,600

(1) Military population consists of military strength plus 25% of dependent population.

740 80 GOLF CLUBHOUSE (SF)
FAC: 7413
BFR Required: Y

74080-1 **GENERAL**. See General Notes to 740 series category codes for General Instructions regarding facility allowance planning procedures. Contact CNIC (N9) for additional information.

74080-1.1 In siting golf clubhouses, it is important for sight lines from the pro shop to the first and tenth holes to be maintained. It is also desirable for sight lines from the patio or snack bar areas to the ninth and eighteenth greens to be maintained.

74080-1.2 All golf clubhouse projects must be financially justified as Category C operations. See General Notes MWR at the beginning of the 740 Series.

74080-1.3 Catering Facilities (740-68) may be constructed as part of a golf clubhouse to serve both golf functions and other catering business. When this is done, the restroom support areas should be calculated separately for the golf clubhouse and the catering facility.

74080-2 **DEMAND.** The primary functional components of a Golf Clubhouse - Foodservice and Golf Equipment Areas - are sized based on the number of holes of the golf course and other user demand factors, as follows:

74080-2.1 Use Table 74080-1 to determine the seating demand for each foodservice area. Calculate the number of snack bar and lounge or combined snack bar/lounge seats required to serve golfing patrons, based on the number of golf course holes. Additional capacity may be required to serve non-golfing patrons in snack bar, lounge, and function room spaces, as directed in Notes (1) and (2) to Table 74080-1. Add golfing and non-golfing patron demand to determine number of seats required for each functional component. Food service seating areas should be sufficient to seat a full golf scramble at one time. This would indicate a capacity of 72 seats for 9-hole courses and 144 seats for 18-hole or larger courses. This seating could be in a function room, a snack bar/dining area, a covered patio, or a combination of adjacent areas. Demand for both dining space and pro shop is developed not only by population and number of holes, but also by the number of rounds of golf played on an annual basis.

74080-2.2 Multiply the number of seats required for each functional component by the space allocation factors in Table 74080-2.

74080-2.3 Demand for golf equipment facilities - pro shop, golf bag and cart storage - is directly related to the number of golf course holes. Multiply the number of 9-hole units by the space allocation factors in Table 74080-2. Golf Club Storage for privately owned clubs is not generally a primary functional component because the return on investment for the space required is insufficient to break even financially. Storage of rental clubs is a subset of the Pro Shop along with retail merchandise stock storage.

74080-2.4 Add the net square footage (NSF) for all components and add support area factors as directed in Table 74080-2, to derive the Total Facility Allowance for the Golf Clubhouse.

74080-2.5 Demand for golf course support facilities—golf cart storage—is directly related to the number of golf course holes and golf cars. Criteria for maintenance and storage facilities can be found in Category Code 740 82 "Golf Storage and Maintenance Facility" Cart storage facilities are supported for the number of MWR owned or leased carts. The number of MWR golf carts should be approximately 18 per 9 holes. The number may increase for snack/beverage service carts and course marshal carts. Where the cart storage is located away from the golf maintenance facility a separate maintenance area should be included within the facility. Construction of space for rental to private golf cart owners is not authorized. Multiply the number of units for each functional component by the space allocation factors in Table 74080-3 to determine the space allowances.

Table 74080-1. Golf Clubhouse Foodservice Seating Capacities

Note	Number of Golf Course Holes	Snack Bar	Lounge	Combined Snack Bar/Lounge	Function Room
(1), (2)	9-18	20	10	25	--
(1), (2)	27-36	40	20	50	--
(1), (2)	45-54	60	30	75	--

Notes for Foodservice Seating Capacities:

(1) The figures for seating capacities accommodate only golfing patron demand. Additional snack bar, lounge, and combined snack bar/lounge capacity for non-golfing patrons must be justified by demand analysis and economic operations projections based on local conditions. For example, if the golf course is situated near other installation facilities with significant numbers of workers, there may be a substantial number of non-golfing patrons at lunchtime. In the absence of specific local installation data, assume that non-golfing patron demand requires a 100% increase in snack bar seating and 50% increase in lounge seating from that required to meet the demand of golfing patrons alone.

(2) The capacity of a function room should be based on the size of special events and large group functions for which there is a local requirement, justified by demand analysis and economic operations projections.

74080-3 **SPACE ALLOWANCES**. Space allowances for Golf Clubhouse facilities are determined according to the planning criteria presented in Tables 74080-2 and 74080-3, below. The total allowance for a facility is the sum total of the space allowances for each functional component. Seating capacity requirements for foodservice components are obtained from Table 74080-1.

Table 74080-2. Space Allowances For Golf Clubhouses

Note	Table	Functional Component	# Units	x	Space Allocation Factor	=	Total NSF	Minimum NSF
		ACTIVITY AREAS						
		Foodservice						
	A	Snack Bar (including seating, kitchen, storage)	___	x	27 NSF per seat	=	____	
	A	Lounge (including seating, bar, storage)	___	x	20 NSF per seat	=	+ ____	
(1)	A	Combined Snack Bar/ Lounge (including seating, kitchen, bar, storage)	___	x	25 NSF per seat	=	+ ____	
	A	Function Room (including seating, service kitchen)	___	x	17 NSF per seat	=	+ ____	

Note	Table	Functional Component	# Units	x	Space Allocation Factor	=	Total NSF	Minimum NSF
		Pro Shop (including sales area, stockroom)	___	x	500 NSF per 9 holes	=	+ ____	530
(2)		Golf Cart Storage/Rental	___	x	150 NSF per 9 holes	=	+ ____	200
					Subtotal Activity Areas	=	____	
		ACTIVITY SUPPORT AREAS						
		Patron Support (including lockers, showers, toilets)			20% x Subtotal Activity Areas	=	____	
		Administration/Storage/ Support			5% x Subtotal Activity Areas	=	+ ____	120
					Subtotal Activity Support Areas	=	____	
		BUILDING SUPPORT AREAS						
		Lobby/Circulation/ Structure/ Partitions			25% x (Subtotal Activity Areas + Subtotal Activity Support Areas)	=	+ ____	
		Mechanical/Electrical/ Communication Equip. Space			5-10% x (Subtotal Activity Areas + Subtotal Activity Support Areas)	=	+ ____	
(3)					**TOTAL FACILITY ALLOWANCE**	=	____	GSF

Table 74080-3. Space Allowances for Golf Course Support Facilities

Note	Table	Functional Component	# Units	x	Space Allocation Factor	=	Total NSF	Minimum NSF
(4)		Golf Car Storage	_____	x	65 NSF per car	=	_____	

Notes for Space Allowance Tables 74080-2 and 74080-3:

(1) A combined snack bar/lounge may be provided as an alternative to separate snack bar and lounge areas.

(2) Minimum 200 NSF for golf bag and cart storage allows for 60 club sets (both patron-owned and rental), with bags and carts.

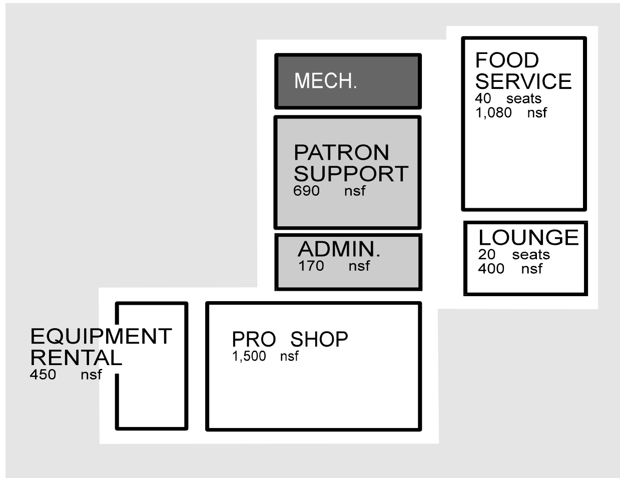
(3) Covered outdoor space (such as an entrance canopy or sheltered patio) is counted at 50% of its area, and must be included within the total gross square footage allowance for the facility.

(4) For safety reasons, the golf car storage facility should be a separate structure, or designed for safety separation if accommodated in the same structure.

NSF = Net Square Feet
GSF = Gross Square Feet
Minimum NSF = Minimum space allowance to be provided for the particular function or activity.

74080-4 **SAMPLE LAYOUT DIAGRAM**. A layout diagram is presented for a medium-size Golf Clubhouse facility. This diagram is an example of the composition of such a facility in terms of its functional components, their respective sizes and adjacencies. The layout diagram is for illustrative purposes only.

Figure 74080-1 Golf Clubhouse – Medium Capacity



740 81 MWR RENTAL ACCOMMODATIONS (SF)
FAC: 7442
BFR Required: Y

74081-1 **GENERAL**. See General Notes to 740 series category codes for General Instructions regarding facility allowance planning procedures. Contact CNIC (N944) for additional information.

74081-2 **DEFINITION.** MWR Rental Accommodations are permanent "stand-alone" or multiplex structures. They may take the form of modern motels, multi-level hotels, primitive camping cabins with no utility connections, or almost anything in between, depending on the geography, the market being served, and demand. Such MWR Rental Accommodation facilities are typically developed to provide recreation overnight and extended stay units in locations which offer outdoor leisure opportunities such as boating, canoeing, fishing, hiking, skiing, golfing, swimming/beach-going, and leisure travel/tourism.

In addition to sleeping rooms/areas, each Rental Accommodation may include a living/dining space, bathroom, kitchen (or kitchenette), and storage area. An open or covered outdoor seating terrace/deck/patio may be provided in appropriate locations.

Where clusters of cottages are planned, a support facility may be included to provide for a janitor closet, laundry, linen storage, and housekeeping supplies/equipment storage.

74081-3 **RELATED FACILITIES.** Locations suitable for the development of MWR Rental Accommodation facilities may also include RV Parks, camping sites, marinas, golf courses, beachfronts, other waterfronts, other outdoor recreation venues, or support facilities to provide patrons with a range of options for accommodation. Support facilities may include recreation/amusement centers, snack bars/restaurants, administrative/check-in offices, supply stores, swimming pools, cabanas, or bathhouses.

74081-4 **SPACE ALLOWANCE.** Space allowances for rental accommodations need to address the following issues:

74081-4.1 **Total Number of Accommodation Units**
The total number of rental accommodation units planned for a site should be based on the following considerations:

- Capacity of the site to accommodate the development of units in a manner which is economical, environmentally appropriate, aesthetically pleasing, and appropriate for the market to be served. Critical site planning considerations include vehicular access and parking, utilities, Antiterrorism/Force Protection (ATFP) considerations, privacy, views, and preservation of flora and fauna. For example, the development of a sufficient number of units in a location with steep, densely wooded slopes would need to weigh the costs of infrastructure provision and the clearing of areas with the impact on the environment.

- Return on Investment (ROI) analysis is based on projected demand/market, revenues, capital investment, and operating and maintenance costs. This type of analysis will determine the financial feasibility of the proposed project, and the number and type of units required to ensure a viable outcome. This analysis must follow the requirements of the template developed by Navy Personnel Command (PERS-652). This template may be obtained by e-mailing your request to either P652D2@persnet.navy.mil or P656D@persnet.navy.mil.

74081-4.2 **Types and Sizes of Individual Rental Cottages/Units**

The type/size of individual units is based on the customer/patron demand determined through a market research/survey process. The research should determine whether individual cottages, efficiencies, primitive camping cabins, or motel/hotel-type lodging is required to meet the documented demand. The space allowance guidance for the different sizes of cottages, efficiencies, cabins, and motel spaces is presented in Table 74081-1 below. The space shown should normally be considered the maximum, with larger units requiring additional justification. Individual units may also include porches, patios, balconies, or deck, etc. that may be covered, open, or screened that are not counted against the respective space allowance guidance.

Table 74081-1 Space Allowances for MWR Rental Accommodations

CAPACITY	SPACE ALLOWANCE GUIDANCE (Gross Area)	
2 Bedroom Cottage	800	74.32
3 Bedroom Cottage	1,000	92.90
Efficiency	500	46.45
Primitive cabin	150	13.94
Single Room	240	22.30
Double Room	350	32.52
Queen Room	400	37.16
King Room	440	40.88
Queen Suite	500	46.45
King Suite	550	51.10
Group Camp (per 8 bunks) (Accommodates 16 people)	1600	148.64

74081-5 **SPACE PROGRAMS.** Space programs for two-bedroom MWR Rental Accommodation (Cottages) are presented to illustrate the possible breakdown of the overall space allowances into functional components, with their respective sizes and capacities. This space program is for illustrative purposes only.

74081-6 **SAMPLE LAYOUT DIAGRAM.** A layout diagram is presented for a two-bedroom MWR Rental Accommodation (Cottage), illustrating the relative sizes and adjacencies of component areas.

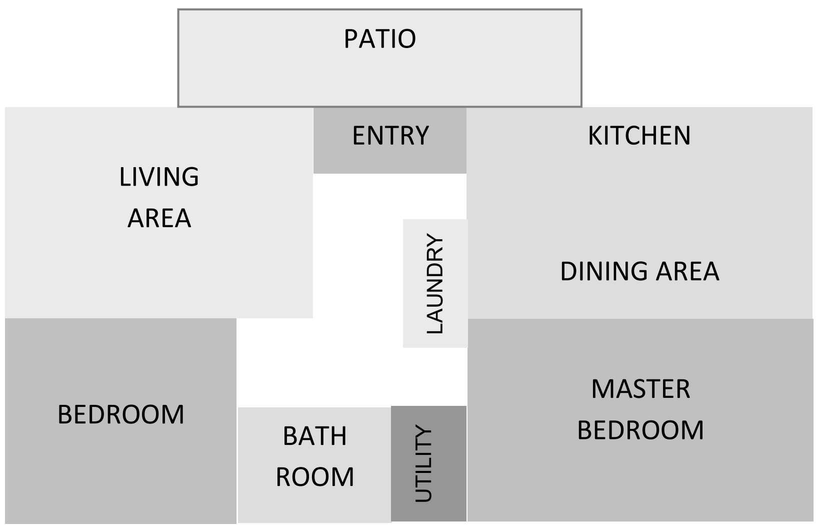
74081-7 **SITE PLANNING.** When site planning for a group of MWR Rental Cottages, keep in mind that privacy between cottages is important and that subdivision or zero-lot-line development is discouraged as it detracts from the quality of the experience for the intended patrons.

Table 74081-2 MWR Rental Accommodation Sample Space Program

ROOM / SPACE	FLOOR AREA (SF)			No. of Occupants Design
	No. Req'd	Net Area Per Room	Total Net Area	
2-Bedroom Unit				
Entry Foyer	1	20	20	3
Living Area	1	200	200	6
Kitchen/Eating Area	1	140	140	4
Master Bedroom	1	155	155	2

ROOM / SPACE	FLOOR AREA (SF)			No. of Occupants Design
	No. Req'd	Net Area Per Room	Total Net Area	
Bedroom 2	1	125	125	2
Bathroom	1	70	70	-
Laundry Closet	1	30	30	-
Utility Room	1	As required		-
Net Area & Occupant Totals			740	6
Allowance for porch, deck, or lanai	23,600		150	6

Figure 74081-1. MWR Rental Accommodation Sample Layout



74080-1 **GENERAL**. See General Notes to 740 series category codes for General Instructions regarding facility allowance planning procedures. Contact CNIC (N9) for additional information.

74080-1.1 In siting golf clubhouses, it is important for sight lines from the pro shop to the first and tenth holes to be maintained. It is also desirable for sight lines from the patio or snack bar areas to the ninth and eighteenth greens to be maintained.

74080-1.2 All golf clubhouse projects must be financially justified as Category C operations. See General Notes MWR at the beginning of the 740 Series.

74080-1.3 Catering Facilities (740-68) may be constructed as part of a golf clubhouse to serve both golf functions and other catering business. When this is done, the restroom support areas should be calculated separately for the golf clubhouse and the catering facility.

740 85 EXCHANGE DISTRIBUTION CENTER (WAREHOUSE) (SF)
FAC: 7388
BFR Required: Y

74085-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724, Head, Planning Branch. See General Notes for NEX facilities at the beginning of the 740 Series.

74085-2 This type warehouse may be provided for bulk back-up storage (exchange stock and operating supplies) to support all exchange operations within a geographical area as determined by NEXCOM or Marine Corps Exchange Services.

74085-3 This central warehouse allowance does not void the need for the installation exchange warehouse, Code 740-86, preferably located contiguous to the exchange main retail store. Space allowances for central warehouses shall be provided by NEXCOM.

740 86 EXCHANGE INSTALLATION WAREHOUSE (SF)
FAC: 7388
BFR Required: Y

74086-1 Navy Exchange facilities requirements are developed by the Navy Exchange Service Command, 3280 Virginia Beach Blvd, Virginia Beach, VA 23452-5724; Head, Planning Branch. See General Notes for NEX facilities at the beginning of the 740 Series.

74086-2 The total storage space that may be provided in installation exchange warehouses to accommodate back-up storage for exchange retail activities on an installation will be provided by NEXCOM. Wherever practicable, the installation exchange warehouses shall be located contiguous to the exchange main retail store in order to reduce the cost of moving stock from the warehouse to the main store sales area.

740 87 MARINA SUPPORT BUILDING (SF), Revised Dec 2011
FAC: 7445
BFR Required: Y

74087-1 This facility provides space for office, equipment check-out, repair, and storage. It does not include docks, marina slips, and walkways which are listed under Code 750 60. This is a special facility which is required only at outdoor recreation areas which have waterfront facilities available for boating activities.

74087-2 This facility may be made up of more than one individual building. Generally, repair facilities would be located in a separate building spaced away from the marina dock, clubhouse and patron parking. The marina clubhouse may include space for dock master/marina manager's office, meeting/training, yacht club office, chandlery/store with convenience items, customer service counter, shower room/restrooms, and equipment storage/checkout. The marina may also support a stackable boat storage facility and a dry land storage operation in either a fenced compound or in small, individual boat storage facilities attached to each other in a T-hangar fashion. All marina facilities must be justified financially. See Category C facilities, General Notes MWR, beginning of 740 Series Section.

See Table 74087-1 for space allowances.

Table 74087-1
Space Allowances for Marina Support Building

Military Population (1)	Gross SF
Up to 100	None
101 to 1,000	3,500
1,001 to 3,000	5,800
3,001 to 5,000	8,450
5,001 to 7,000	10,500
7,001 to 10,000	12,650
10,001 to 15,000	15,600
15,001 to 20,000	18,700
20,001 to 25,000	20,800
25,001 to 30,000	22,000
30,001 to 40,000	23,600
40,001 to 50,000	25,400
50,001 to 60,000	27,000
60,001 to 70,000	28,300
70,001 to 80,000	29,500
80,001 to 90,000	30,600
90,001 to 100,000	31,600
For each additional 10,000 add	1,000

(1) Population consists of retirees and military strength plus 15% of dependent population.

740 88 EDUCATIONAL SERVICES OFFICE (SF)
FAC: 7351
BFR Required: Y

74088-1 The space allowances shown in Table 74088-1 are intended to provide facilities for the advancement of the academic, technical, and vocational education of military personnel of all grades and ranks in order to enhance their potential to the service. These facilities shall make joint use of existing classrooms or other suitable facilities to the maximum extent possible. In cases where joint use is impractical and separate educational facilities are requested, detailed supporting justification is required. When justified by installation requirements, a supporting branch library may be provided in accordance with criteria for Code 740 76.

Table 74088-1. Space Allowances for Educational Services Offices

Military Strength	Basic	OJT (1)	CAC (2)
Up to 250	(3)	None	None
251 to 1,000	4,125	300	500
1,001 to 3,000	8,700	500	500
3,001 to 5,000	13,500	700	500
5,001 to 7,000	16,100	900	500
7,001 to 10,000	19,800	1,200	500
10,001 to 15,000	26,300	1,700	500
15,001 to 20,000	31,800	2,200	500
20,001 to 25,000	36,300	2,700	500
25,001 to 30,000	40,500	3,200	500
30,001 to 40,000	48,000	3,700	500
40,001 to 50,000	55,000	4,200	500
50,001 to 60,000	60,000	4,700	500
For each additional 10,000 add	4,000	500	500

(1) On-The-Job Training program management personnel space. This added space is authorized only in newly constructed facilities.
(2) Career Advisory and Counseling section. This added space is authorized only in newly constructed facilities. If more than one counselor is required, add 80 square feet per counselor.
(2) Accommodate in other facilities.

740 89 BATHHOUSE (SF)
FAC: 7385
BFR Required: Y

74089-1 **GENERAL**. See General Notes to 740 series category codes for General Instructions regarding facility allowance planning procedures.

74089-2 **DEFINITION**. The primary purpose of a bathhouse is to provide a facility for pool and beach users to store their belongings while using the recreational facility, to clean up, and have a place to use the restroom. In addition, the bathhouse contains the offices for the administrative staff and lifeguards.

74089-3 **RELATED FACILITIES**. This category code should be used in conjunction with the following category codes:

- 740 53 Swimming Pool - Indoor
- 750 30 Outdoor Swimming Pool - Installation

74089-4 **SPACE ALLOWANCE**. The space authorized for a bathhouse should be calculated based on the criteria presented in Table 74089-1. This space allowance is valid for bathhouses supporting pools not collocated with Fitness Centers. Where pools are built with Fitness Centers, the lockers, showers and Toilets are intended to be joint use between the Fitness Center and the pool. For that reason, Fitness Center Unified Facilities Criteria (UFC 4-740-02) support family changing rooms where the pool is collocated. The remaining spaces to support a control desk, pool office, lifeguard office and storage are supported for collocated pools.

Table 74089-1. Space Allowances for Bathhouses

Note	Table	Functional Component	# Units	x	Space Allocation Factor	=	Total NSF	Min. or Max. NSF
		ACTIVITY SUPPORT						
		Bathhouse						
(1), (2)	74053-4	Lockers, Showers, Toilets			33.33% total NSF lanes	=	____	
		Control Desk	____	X	45 NSF per station	=	____	45 min.
		Administrative Office	____	X	120 NSF per office	=	____	120 min.
		Lifeguard Office	____	X	40 NSF per station	=	____	80 min.
		Storage (equip., supplies, etc.)	____	X	20 NSF per lane	=	____	100 min.
		Subtotal Activity Support Areas				=	____	
TOTAL FACILITY ALLOWANCE (Gross Square Feet)						=	____	

Notes for Space Allowance -- Table 74089-1:

(1) The total NSF lanes should be determined in Table 74053-4.

(2) For undeveloped beaches use a six-lane, 25-meter pool equivalent and for developed beaches use an eight-lane, 50-meter pool equivalent.

NSF = Net Square Feet
GSF = Gross Square Feet
Minimum or Maximum NSF = Minimum or maximum space allowance to be provided for the particular function or activity.

740 90 MWR EQUIPMENT MAINTENANCE SHOP (SF)
FAC: 7448
BFR Required: Y

74090-1 An MWR Equipment Maintenance Shop is required at installations where MWR equipment such as NAF vehicles and grounds maintenance equipment (non-golf), must be maintained. Size according to amount of equipment and equipment size with typical workspace, circulation, and net to gross factors, using a space analysis and equipment inventory list.

74090-2 For MWR Equipment Maintenance Shops previously captured under CCN 74052 “Gun/Skeet and/or Trap Building”:

74090-2.1 These facilities support respective ranges and contain an operator's office, storage, sales area, gun maintenance shop, toilets and lounge. The Gun, Skeet and/or Trap Building is an MWR Category C facility (see General Notes MWR) and must be financially self- sustaining.

74090-2.2 Refer to Table 74090-1. The space allowances in the table may be used in one facility or divided between multiple facilities. Refer to Category Code 750 52 for land requirements.

Table 74090-1
Space Criteria for Gun, Skeet and/or Trap Building

Military Strength (1)	Gross Area (GSF)
Up to 100	None
101 to 10,000	3,950
10,001 to 15,000	4,300
15,001 to 20,000	4,550
20,001 to 25,000	4,800
25,001 to 30,000	5,100
30,001 to 40,000	5,300
Over 40,000	5,500

(1) Military population consists of military strength assigned to installations.

740 91 MWR OPERATED CAR WASH (SF)
FAC: 7348
BFR Required: Y

This category code has been deleted. All existing assets and future programmed car wash facilities are to be assigned to either category code 740 32 or category code 740 33 depending on the facility type, building or structure.

740 92 MWR RV PARK SUPPORT FACILITIES (SF), Revised Dec 2011
FAC: 7443
BFR Required: Y

74092-1 **GENERAL**. See General Notes to 740 series category codes for General Instructions regarding facility allowance planning procedures. Contact CNIC (N944, N92) for additional information.

74092-2 **DEFINITION**. Recreational RV Parks provide the military community with outdoor recreation opportunities at locations with attractive natural resources. To complement the camping experience, and depending on location, Recreational RV Parks may offer activities such as boating, canoeing, fishing, hiking, hunting, skiing and swimming. Facilities should be designed to take advantage of the natural features of the site, from vegetation to good views to unusual topography. At the same time, development should be environmentally appropriate, and not threaten the preservation of the natural heritage and scenic resources.

The planning criteria in this Category Code addresses the campground support facilities such as camp offices; camp stores; bathhouses; laundry facilities; storage buildings; rental centers, etc. RV park main office facilities may include areas for check-in desks, vending areas, game/activity/community rooms with WIFI service, kitchens, convenience stores, and any necessary ancillary spaces. Bathhouse/laundry facilities should be planned in accordance with Table 74092-1.

Recreational RV Parks are encouraged to make use of the Camp Host concept to assist in the management of the RV Park. Space allowances for MWR Rental Accommodations are addressed under Category Code 740 81. RV Parks may also be associated with Golf Operations and MWR Rental Accommodations. Where an RV Park includes a Rental Accommodation operation, a staff laundry may be included as part of the Support Building.

74092-3 **RELATED FACILITIES**. Where such locations are adjacent to the sea or other body of water, support facilities such as marinas, boat ramps and RV/vehicle/boat storage compounds maybe sited in close proximity to Recreational RV Parks.

74092-4 **SPACE ALLOWANCE**. RV Park Support Buildings will be sized in accordance with a market survey approach. As a Category C facility, the RV Park with a Support Building must be profitable and a financial analysis or pro forma will be provided as well as the CNIC Internal Needs Validation Study (INVS), and finally the Project Validation Assessment. The Planner will accomplish the initial demand investigation and review along with local MWR personnel. If the project is financially sound it will be forwarded via the region to CNIC Fleet & Family Readiness (N944A) for INVS Scoring and possible Project Validation Assessment.

74092-5 **SANITARY FACILITIES**. Once the total number of campsites at a location has been determined under CCN 750-59 Recreation Campground, the required patron sanitary facilities may be selected from the criteria in Table 74092-1. This includes allowances for bath/shower facilities as well as laundry facilities. Sanitary facilities should be consolidated with other support buildings such as main offices or camp stores whenever possible. Note that all bathhouse facilities associated with RV Parks should always be captured under CCN 740-92 and never under CCN 740-89 Bathhouse.

Table 74092-1
Sanitary Facilities Requirements for Recreational Campgrounds

#Tent/Trailer	#Water Closets (M/F)	#Lavatories (M/F)	#Showers (M/F)	#Urinals
1-15	1/1	1/1	1/1	1
16-30	1/2	2/2	1/1	1
31-45	2/2	3/3	1/1	1
46-60	2/3	3/3	2/2	2
61-80	3/4	4/4	2/2	2
81-100	3/4	4/4	3/3	2

Notes for Table 74092-1:

(1) For recreational areas having more than 100 tent/trailer/camper/RV sites, provide one additional water closet and lavatory per each additional 30 sites, and one additional urinal per each additional 60 sites.

(2) For laundry facilities, provide one washer and two dryers for every increment of 12 sites or portion thereof.

(3) Use the following gross square foot (GSF) guidelines for fixture/appliance unit sizing. Allowances include net areas plus associated support areas such as shower drying areas; laundry works areas; janitor’s closets; mechanical/electrical areas; and circulation space. Net-to-gross area calculations are already included in the following:

(a) When only (1) water closet is required it must be handicapped accessible; use 56 GSF per unit.
(b) Where multiple water closets are required, use 56 GSF for the first unit and 22 GSF for all subsequent units.

(c) Lavatories: 22 GSF per unit
(d) Showers: 21 GSF per unit
(e) Urinals: 22 GSF per unit
(f) Washer/dual-dryer module: 43 GSF per module

740 93 SMOKING GAZEBO (SF)
FAC: 7384
BFR Required: N

74093-1 Smoking Gazebo's are provided as designated smoking areas outside of Navy and Marine Corps facilities. Size is standard. This CCN is for inventory purposes.

740 94 TDY OFFICIAL LODGING (SF)
FAC: 7441
BFR Required: Y

Note: Category Code (CCN) 740-94 now includes transient Navy personnel originally captured under CCNs 740-94 and 740-96. All facilities originally captured under CCN 740-96 should be corrected in iNFADs.

74094-1 **GENERAL.** Navy Gateway Inns and Suites (NGIS) Visitor's Quarters provide temporary lodging facilities for visiting personnel at an installation. Initial/preliminary requirements can be generated by local planning staff by following the steps in section 74094-3 "Space Planning." Preliminary site selection will also be performed during the initial planning phase. Once the initial scope is determined, planners will forward the findings to CNIC (N944), Fleet & Family Readiness, Millington, TN (Facilities Support) for review and a subsequent independent assessment will be performed to determine the final project scope. This assessment validates the site selection; determines the final number of room types, support areas, and guest services to be provided; and identifies any companion projects necessary to provide a complete and usable facility.

Table 74094-1 provides a list of potential spaces allowed for a Visitor's Quarters facility and Table 74094-2 provides standardized space allowances for the same. Both tables can be found in UFC 4-720-01 "Lodging Facilities", dated 23 February 2011.

74094-2 **DEFINITION.** These facilities are temporary living accommodations that are rented for a service charge for overnight or short term use to authorized personnel such as official military or civilian visitors to the installation, transient personnel, or families awaiting assignment to quarters. There are two types of lodging facilities:

1. Central. Central facilities accommodate the main check-in function, the majority of the guest services and administration, and the guest rooms and suites. There will always be at least one central facility on an installation that includes visitor lodging.
2. Satellite. Satellite facilities accommodate additional guest rooms, suites and limited services and support functions. They may be located

remotely from the central facility to serve additional installation areas or near the central facility as part of a visitor lodging complex.

Note that the type of facility needs to be defined in order to determine the total allowable space for the project. Table 74094-1 provides a listing of all the LF functional program areas, indicates if each area is included in each type of facility, and describes the function of the area.

Table 74094-1
Functional Program Areas

Functional Program Area	Central	Satellite	Description
Guest Services			
Covered entry	X		Covered vehicle drive for loading/drop-off at main entry
Entrance vestibule	X	X	Entry airlock
Central lobby	X		Central facility lounge seating and circulation space between reception and other central guest services
Satellite lobby		X	Satellite seating/waiting and circulation space adjacent to main entry
Reception	X		Reception desk for check-in/out and guest service
Bell cart station	X	X	Area near the entrance vestibule for storage of bell carts.
Luggage storage	X		Secure room adjacent to reception for storage of guest luggage
ATM	X	X	ATM kiosk
Public toilets	X	X	Public toilets
Fitness room	X	X	Small, guest fitness room
Staff conference room	X		Conference room to accommodate 20 people
Business center	X		Guest-use computers and office equipment
Guest laundry	X	X	Self-service guest laundry
Vending	X	X	Self-service guest vending
Ice	X	X	Self-service ice dispenser on each floor
Guest corridors/ circulation	X	X	Access to guest rooms and remote services
Guest room[1]	X	X	Standard room with a combined living/sleeping area and private bath
Family/business suite (Suite)[1]	X	X	Suite with separate living and sleeping areas, a compact kitchen and private bath
Administration Services			
Lodging communications	X		IT/communications room including guest and staff Internet, television, and administrative file server.
Manager’s office	X		Private office
Asst. manager	X		Optional for larger programs; must be validated via CNIC/N9
Front desk supervisor	X		Private office

Functional Program Area	Central	Satellite	Description
Accounting office	X		A single office or up to 3-4 workstations depending upon operation size
Clerical	X		Workstations for clerical staff in an open office area
Work space	X		Copier, printers, facsimile machines, work space, common files, and administrative storage
Cash room	X		Secure room where front desk agents reconcile shift cash functions and store cashier banks
Floor Support			
Janitor areas	X	X	Janitor closet on each floor or wing.
Housekeeping areas	X	X	Housekeeping support and supplies on each floor or wing
Utility rooms	X	X	Mechanical, electrical, communications, and sprinkler rooms located for efficient utility distribution
Back-of-House Support			
Training office	X		Office and/or training material storage area
Central Janitor areas	X	X	Central janitor closet with additional supply storage
Housekeeping manager	X	X	Private office
Soiled linen storage	X	X	Separate storage from clean linens, adjacent to receiving or laundry
Clean linen storage	X	X	Separate storage from soiled linens
Receiving	X	X	Service entrance/loading dock
Receiving/supply office	X		Private office
Linen laundry	X		Space with industrial-grade equipment, based on local service contract linen costs and availability
Supply/general storage areas	X	X	Storage and warehousing of facility supplies
Cleaning fluid storage	X	X	Separate storage for cleaning chemicals
Utility rooms	X	X	Central facility mechanical, electrical, communications, and sprinkler rooms **(note: counted in net to gross ratio)**
Break area	X	X	Staff break area with kitchenette and lockers
Staff toilets	X	X	Staff facilities
Maintenance workshop	X		Includes limited storage and accommodates repair of small equipment and furnishings
Grounds equipment storage	X		Space with direct exterior access for grounds and exterior building maintenance supplies and equipment
Service circulation	X	X	Separate stairs, corridors and elevators from guest circulation

[1] The final number, mix and variations of room types will be determined by the individual assessment by CNIC/N9. See 74094-1 GENERAL section for more information.

74094-3 **SPACE ALLOWANCE.** Initial project scope for a new or renovated facility will be determined by performing a series of three steps:

1. Obtain occupancy rate information for the facility or facilities in question for the previous two year period.

2. Calculate the necessary quantity of rooms needed to satisfy the TOTAL demand for an 80% occupancy rate (see the below example for details on calculating an 80% occupancy rate). This is the complete total requirement, and not just the difference between what is currently available, and the perceived number of rooms thought to be needed. Note that there are two room types available in a Visitor's Quarters facility and they are both single occupancy: standard rooms (300 NSF) and guest suites (450 NSF.) For planning purposes, apply a 95/05 mix of standard rooms to guest suites once the total room quantity requirement is determined. For example, if 500 rooms are needed, plan for 475 standard rooms and 25 guest suites.
3. Apply the new room quantity requirements (from step 2) and the applicable functional area requirements from Table 74094-1, depending on facility type (Central or Satellite) against the space allowances in Table 74094-2 to obtain a comprehensive facility size. For initial planning purposes, allow for all spaces (required and optional, based on facility type) shown in Table 74094-1.

Below is an example showing the method to calculate projected room quantity requirements based on a two year historical data table. It shows a hypothetical two year occupancy rate for an imaginary facility, as well as a hypothetical list of Certificates of Non-Availability (CNA):

Step1: Obtain loading information from the local MWR lodging staff for the facility or facilities in question. Below is an example of the data that is typically provided:

FY10 Data

Month	**FY10**	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Total/ Overall
# days in month		31	30	31	31	28	31	30	31	30	31	31	30	365
# rooms in the inventory		342	342	342	342	342	342	342	342	342	342	342	342	
Total # room nights per month (RNM)		10602	10260	10602	10602	9576	10602	10260	10602	10260	10602	10602	10260	124830
Total # room nights sold (RNS)		9888	10260	9700	9200	8200	8900	10100	10200	10260	10600	9500	9788	116596
% Occupancy is		93%	100%	91%	87%	86%	84%	98%	96%	100%	100%	90%	95%	93%

FY11 Data

Month **FY11**	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Total/ Overall
# days in month	31	30	31	31	28	31	30	31	30	31	31	30	365
# rooms in the inventory	342	342	342	342	342	342	342	342	342	342	342	342	
Total # room nights per month (RNM)	10602	10260	10602	10602	9576	10602	10260	10602	10260	10602	10602	10260	124830
Month	**FY11**	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Total # room nights sold (RNS)	10211	9899	10500	10602	9576	10200	9866	10154	9200	10098	9956	9233	119495
% Occupancy is	96%	96%	99%	100%	100%	96%	96%	96%	90%	95%	94%	90%	96%

Total/ Overall

Notes:

Step 4) The total # of rooms in the inventory is the total room capacity for a building or series of buildings

Step 5) The total # of room nights per month = number of days in the month (x) the number of rooms in inventory

Step 6) The total # of room nights sold is the sum of rooms sold each night for the month

Step 7) % Occupancy Equation = Total # room nights sold / Total # room nights

Step 8) CNA = Certificate of Non-Availability

Step 2: For this example, assume the total number of CNAs is 62 for FY10 and 34 for FY11. CNAs must be counted as booked rooms even though in reality they were not actually available.

a) Calculate the Room Nights per Month capacity (RNM) by multiplying the number of rooms in the facility by the number of nights in each month and then determine the total number of RNM for the two year period. In this case the total RNM is 249,660 (FY10 124,830 +FY11 124,830.)

b) Calculate the total number of Room Nights Sold (RNS) for the two year period. Add the RNS data for each year PLUS the number of CNAs: RNS =116,596 + 119,495 + 62 + 34 = 236,187.

c) Determine the average occupancy rate for the two year period by dividing the RNS by the RNM. In this example the current occupancy rate is 236,187/249,660 = .94603, or 94.6%

d) Programming for an occupancy rate of 80% is accomplished by applying the aforementioned results to the equation:

Where “X” is the projected number of rooms required to fulfill an 80% occupancy rate, multiply the quantity of existing rooms and the current occupancy rate, then divide the product by .8 to determine “X”.

For this example, the equation is: X = [342 x .946] /.8 = 404.42, or 404 rooms. The intent of the 80% occupancy rate is to allow greater capacity than the projected need to facilitate room turnover, facility maintenance, mission surges, etc. The percentage of standard rooms to guest suites should be 95% and 05% respectively and all rooms/suites are single occupancy. Thus the final requirement is for 384 standard rooms and 20 guest suites. To check for confirmation that the 404 room projection satisfies the 80% average capacity, substitute 404 for the existing facility room count of 342 and re-calculate numbers based on step 2(a) - 2(c) and the FY 10/11 tables. The results will show occupancy rates at 79% and 81% for the next two years, thus fulfilling the 80% average rate requirement.

Step 3: For this example, the plan calls for a central facility and space requirements will be applied for all the functional areas called out in Table 74094-1. These spaces along with the required room quantities will be applied to Table 74094-2 to define overall preliminary requirements for the facility. The example will use a six floor facility with two wings per floor.

Table 74094-2. Space Allowances for NGIS Visitor’s Quarters

Functional Program Area		**Base Area (See Note 1)**		**Space Standard (planning factor)**	**Notes/explanation**	**Sample (See Notes 2 & 4)**		
		ft2	**m2**			**Option/Qty.**	**ft2**	**m2**
Guest Services	Entrance Vestibule	100	9.3	Per Facility	Standard size	Required	100	9.3
	Central Lobby	4	0.4	Per Central Facility guest room (gst rm)	Includes lobby circulation and seating areas	Required	1616	150.1
	Satellite Lobby	260	24.2	100sf + 1sf per Satellite gst rm	Reduced circulation and seating	N/A		0.0
	Reception	150	13.9	150sf <100 Program gst rm + 75sf per ea addl 100 gst rms up to 375sf max	75sf per staff, minimum two staff. Count all program guest rooms	Required	375	34.8
	Bell Cart Station	20	1.9	20sf <100 Facility gst rm + 10sf per ea addl 50 gst rms	10sf per cart	Required	80	7.4
	Luggage Storage	75	7	75sf <100 Program gst rm + .25sf per ea addl gst rm to 150sf max	Count all program guest rooms	Required	150	13.9
	ATM	10	0.9	Per optional Central Facility space	Optional one ATM machine	Yes	10	0.9

Functional Program Area		Base Area (See Note 1) ft2	Base Area (See Note 1) m2	Space Standard (planning factor)	Notes/explanation	Sample (See Notes 2 & 4) Option/Qty.	Sample ft2	Sample m2
	Public Toilets	100	9.3	Minimum for Central Facility toilets is 100 sf ea (male/ female) up to 100 guest rooms + 40sf per ea addl 45 guest rooms. Satellite facilities do not have a public restroom requirement	Based on information in UFCs 3-420-01, and 4-740-03. Applicable codes will dictate final requirement during the independent assessment phase. See General section 74094-1	Required	340	31.6
	Unisex Toilet	50	4.6	Unisex toilet for satellite facility	Satellite facilities only	N/A		0.0
	Fitness Room	300	27.9	300sf <100 Central Facility gst rms +50sf per ea addl 200 gst rm. 600sf max	Calculated at 50sf per cardio machine	Required	350	32.5
	Staff Conference Room	440	40.9	Per optional Central Facility space	Standardized room accommodates 20 people	Yes	440	40.9
	Business Center	75	7	Optional space at 75sf <100 Central Facility gst rms +25sf per ea addl 100 gst rm. 300sf max.	75sf for two workstations and circulation with 25sf for each addl workstation	Yes	175	16.3
	Guest Laundry	110	10.2	Per 40 Facility gst rm	Accommodates two to four washers and two to four dryers per every 40 gst rm	Required	1100	102.2
	Vending	60	5.6	Per optional Facility floor	Accommodates two optional vending machines	Yes	360	33.4
	Ice	30	2.8	Per Facility floor	Accommodates one ice dispenser	Required	180	16.7
	Standard Guest Rooms **(See Note 3)**	300	27.9	Each room **(See Note 3)**	Quantity and distribution of rooms and suites to be determined by an independent assessment.	364	115,200	10,702.4
	Suites **(See Note 3)**	450	41.8	Each suite **(See Note 3)**	Quantity and distribution of rooms and suites to be determined by an independent assessment.	40	9,000	836.1
Administrative Services	Lodging Communications	150	13.9	Per Facility	150 sf min; 1 sf per each addl guest room over 100pn	Required	454	42.2
	Administrative areas							
	Manager	120	11.1	Per office	Typically one per Central Facility	1	120	11.1
	Asst. manager	80	7.4	Per optional office	Only in larger programs with more than 500 guest rooms	0	0	0.0

Functional Program Area		Base Area (See Note 1)		Space Standard (planning factor)	Notes/explanation	Sample (See Notes 2 & 4)		
		ft2	m2			Option/Qty.	ft2	m2
	Front desk super	80	7.4	Per office	Typically one per Central Facility	1	80	7.4
	Accounting	64	5.9	Per Person	1 for every 200 guest rooms, not to exceed 256 sf total	2	128	11.9
	Clerical	64	5.9	Per program	One person; typically combined with reservations and work space	1	64	5.9
	Work space	40	3.7	Per person in admin area: Mg;, Asst Mgr; and Front Desk Super	Typically combined with clerical and reservations	2	80	7.4
	Cash Room	80	7.4	Per Program	For front desk staff to reconcile shift cash	Required	80	7.4
Floor Support	Janitor Areas	25	2.3	Per Facility floor wing		Required	300	27.9
	Housekeeping Areas	200	18.6	Per 30 Facility gst rm	Accommodates two carts and storage	Required	2,600	241.5
	Utility Rooms	16	1.5	Per 25 guest rooms	Comm rooms only; other utility rooms programmed by code and included in the multiplier	Required	256	23.8
	Training Office	80	7.4	Per optional private office/storage closet	Typically one per Central Facility	Yes	80	7.4
	Central Janitor Areas	80	7.4	Per Facility	Serves first floor public and administrative spaces	Required	80	7.4
	Housekeeping Manager	80	7.4	Per Program	Typically one per Facility	1	80	7.4
	Soiled Linen Storage	145	13.5	100sf +15sf per 40 Facility gst rm	Includes carts and sorting space; one cart per 40 gst rm	Required	250	23.2
	Clean Linen Storage	150	13.9	25sf per 16 Facility gst rm	Shelving	Required	400	37.2
	Receiving	150	13.9	150sf <150 Program gst rm + 1sf per ea addl gst rm	Loading dock	Required	404	37.5
	Receiving/supply Office	80	7.4	Per program	Office	Required	80	7.4
	Linen Laundry	450	41.8	Optional central facility space at 450sf <100 Program gst rm + 1sf per ea addl gst rm	Includes space for extractors, dryers and folding activities	Yes	754	70.0
	Addl space for folding machine	60	5.6	Per optional folding machine	Additional laundry room space for optional folding machine	Yes	60	5.6
	Supply Areas/general Storage	600	55.7	600sf <300 Program gst rm + 1sf ea addl gst rm	Includes separate cleaning fluid storage	Required	704	65.4

Functional Program Area	Base Area (See Note 1) ft2	Base Area (See Note 1) m2	Space Standard (planning factor)	Notes/explanation	Sample (See Notes 2 & 4) Option/Qty.	Sample ft2	Sample m2
Central Staff Break (includes staff lockers)	150	13.9	150sf <100 Central Facility gst rm + 1sf per ea addl gst rm	Base area typically includes 4-top tables, other seating, kitchenette, and staff lockers	Required	454	42.2
Addl space if training function	300	27.9	Per optional training module	Additional break room space if this area is to dual function as a training room	Yes	300	27.9
Staff Toilets	100	9.3	100sf <150 Facility gst rm + 100sf ea addl 150 gst rm	Each 100 sf module includes 50sf for each gender	Required	200	18.6
Maintenance Workshop	150	13.9	150sf <100 Program gst rm + .5sf per ea addl gst rm	Work and tool storage space	Required	302	28.1
Grounds Equipment Storage	40	3.7	Per optional Program space	Small shed or exterior closet	Yes	40	3.7
					Sample Subtotal	**137,906**	**12811.6**
					Net-to-Gross Factor @ 30%	41,372	3,843.5
					Sample Total	**179,278**	**16,655.1**

Notes:

1. Base area assumes 100 guest room facility.
2. Sample is for a 404 room, 6 floor Central Facility in a 404 room program, 5% suites.
3. Ratio of Standard Rooms/Suites is 95/05 for planning purposes.
4. The "Option/Quan" column shows whether or not a space is allowed based on the facility type (Central or Satellite) shown in Table 74094-1 "Functional Program Areas." In this example, all of the spaces shown for a "Central" facility are allowed in the "Space Allowance Table" but this may not always be the case when planning for a "Satellite" facility. For this, some spaces will not be planned.

Based on the above example for a 404 room Central lodging facility, the requirement is 179,278 gsf/16,655.1 sm. This provides for an average occupancy rate of 80% based on the room requirements information obtained from section 74094-3 "Space Planning", steps 1 & 2.

Parking. Parking must follow the criteria set forth in category code 852-10. Parking spaces shall be 10 ft. wide (3.1m) minimum. In addition to standard guest parking, provide a minimum of three short-term check-in parking spaces at central facilities. For programs with more than 200 rooms, provide a check-in space at the central facility for 1.5% of all guest rooms. As an option, identify each check-in space with a sign. Additional visitor parking with the exception of accessible parking is not required, but may be an option based on local requirements. Provide one staff parking space for each daytime lodging staff person. Staff parking shall be separated from guest parking.

Based on site size and layout, consider providing an optional sign to indicate staff-only parking with close access to the staff entrance. Parking areas will be sized to local conditions.

740 95 LIMITED SERVICE OFFICIAL LODGING - MISSION (SF),
FAC: 7441
BFR Required: N

74095-1 **GENERAL.** This category code is reserved to capture all existing transient lodging facilities that serve the same function as CCN 740-94 but have been renovated based on previous and outdated criteria. Because of this, the rooms/suites within these facilities vary in size and standardization is not possible. This category code is for inventory purposes only and is not authorized for new construction. All subsequent new construction or renovation projects used to fulfill transient housing requirements shall use CCN 740-94.

740 97 FISHER HOUSE (SF)
FAC: 7441
BFR Required: N

74097-1 **GENERAL.** This category code is for inventory purposes only and should be used to capture Fisher House facility assets once they are turned over to the federal government by the Fisher House Foundation.

DON Fisher Houses provide temporary, convenient, and affordable lodging to Navy Medical Treatment Facility (MTF) patients (“wounded warriors”), members of the families of such patients, and others providing the equivalent of familial support for such patients. Fisher Houses are located at or near military medical treatment facilities and are gifted to the Navy once the facilities are constructed and furnished. The Fisher House Foundation typically coordinates any repairs during the initial 12 month warranty period but all subsequent repairs are the Navy’s responsibility. The Fisher House Foundation holds no interest in the property following transfer to the Navy; however, Fisher Houses will always bear the “Fisher House” name and may never be recapitalized for use as a different type of facility.

For dedicated housing (unaccompanied) for wounded service members please refer to CCN 72147 “Unaccompanied Housing for Wounded Warriors”.

74097-2 **DEFINITION.** Fisher Houses are housing facilities that fit the following conditions:

A. Are located in proximity to a military health care facility;

B. Are available for temporary residential use by patients of that health care facility, family members of such patients, individuals providing the equivalent of family support for such patients and/or individuals who meet Service eligibility requirements; and

C. Are constructed and donated by the Fisher House Foundation or designated by the Secretary of the Navy.

74097-3 **SPACE ALLOWANCE.** Fisher House space allowances are based on a variety of factors and are determined by a collaborative validation of need between the Fisher House Foundation, the receiving medical center, and Commander, Navy Installations Command. (CNIC). There is no standard size requirement, but Fisher Houses typically range in size between 5,000 and 16,000 SF, provide 8 to 21 suites, and accommodate 16 to 42 family members. Fisher Houses typically feature a common kitchen, laundry facilities, large dining room, and spacious living room with library.

740 98 NGIS-OPERATED CONFERENCE CENTER (SF)
FAC: 6100
BFR Required: N

74098-1 **GENERAL**. This criteria is currently being written and will be posted upon completion.

741 40 PRIVATE/ORGANIZATION CLUB BUILDING (Marine Corps only) (SF)
FAC: 7414
BFR Required: Y

74140-1 **GENERAL**. A facility for use by active duty military personnel, authorized civilians, and their family members for private organization/club meetings and activities that are not affiliated with the US government.

744 80 GOLF STORAGE MAINTENANCE FACILITY (SF)
FAC: 7448
BFR Required: Y

74480-1 **GENERAL**. Any proposed new construction must first go through the pre-Internal Needs Validation Study (pre INVS), full Internal Needs Validation Study (INVS), and Project Validation Assessment (PVA). This is a special facility which is required only at installations which have a minimum nine-hole golf course. See also: 740 90 “MWR Maintenance Shop” for non-golf related MWR maintenance facilities.

74480-2 SPACE ALLOWANCE. The Golf Storage/Maintenance Facility consists of space for two separate functions: storage area and maintenance area.

Storage Area (see Figure 74082-1): This area consists of spaces for maintenance equipment (e.g. mowers, aerators, etc.), fertilizer, pesticide and herbicide storage and secure chain link storage cage for small equipment (e.g. weed eaters, hand tools, etc.). This area has a standard size of 4,500 SF.

Maintenance Area (see Figure 74082-2): This consists of space for: administrative offices, men's & women's staff locker rooms with showers, restrooms, break room, maintenance area, an equipment lift, mechanics work area, an enclosed blade grinding room, air compressor and used oil recovery. This area will require 4,000 SF.

Table 74480-1
Storage Area

Note	Table	Functional Component	# Units	X	Space Allocation Factor	=	Total NSF	Minimum NSF
		Storage Area	1	X	4,500 sf	=	4,500	4,500
		Maintenance Area	1	X	4,000 sf	=	4,000	4,000

Table 74480-2
Maintenance Area

ROOM/SPACE:		NET FLOOR AREA				OCCUPANCIES		
		No. Req'd	Net Area/Rm	Total Net Area		Staff		Total
1	Superintendent Office	1	120	120				
2	Mechanical Repair Area (which includes a 170 SF grinding room and 140 SF for Equipment Parts Storage)	1	2,570	2,570				
3	Mechanic's Office	1	120	120				
4	Female Locker Room	1	200	200				
5	Break Room	1	270	270				
6	Open Staff Work Area	1	120	120				
7	Male Locker Room	1	250	250				
8	Janitor's Closet	1	50	50				
9	Elec/Comm/Tele Room	1	150	150				

ROOM/SPACE:		NET FLOOR AREA				OCCUPANCIES		
		No. Req'd	Net Area/Rm	Total Net Area		Staff		Total
10	Mechanical Room	1	150	150				
	Totals		4,000	4,000				

Generally, Golf Support/Maintenance Facilities would be located on the periphery of the golf course but away from the clubhouse and patron parking. Note that golf cart storage is not included here and is supported under CCN 740-80 GOLF CLUBHOUSE.

See next page for concept diagrams for maintenance and storage areas.

Figure 74480-1
Maintenance Area Concept Diagram

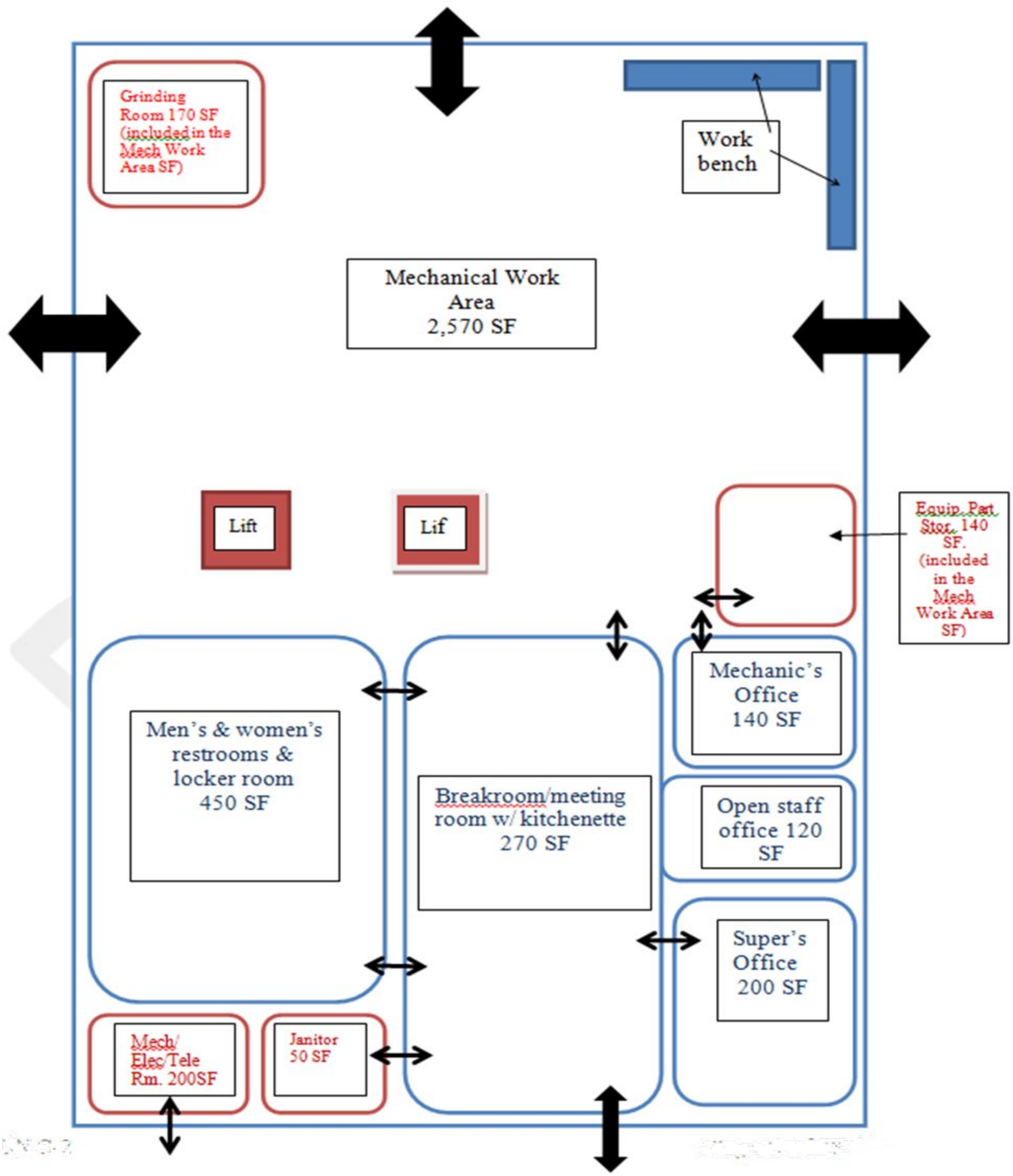
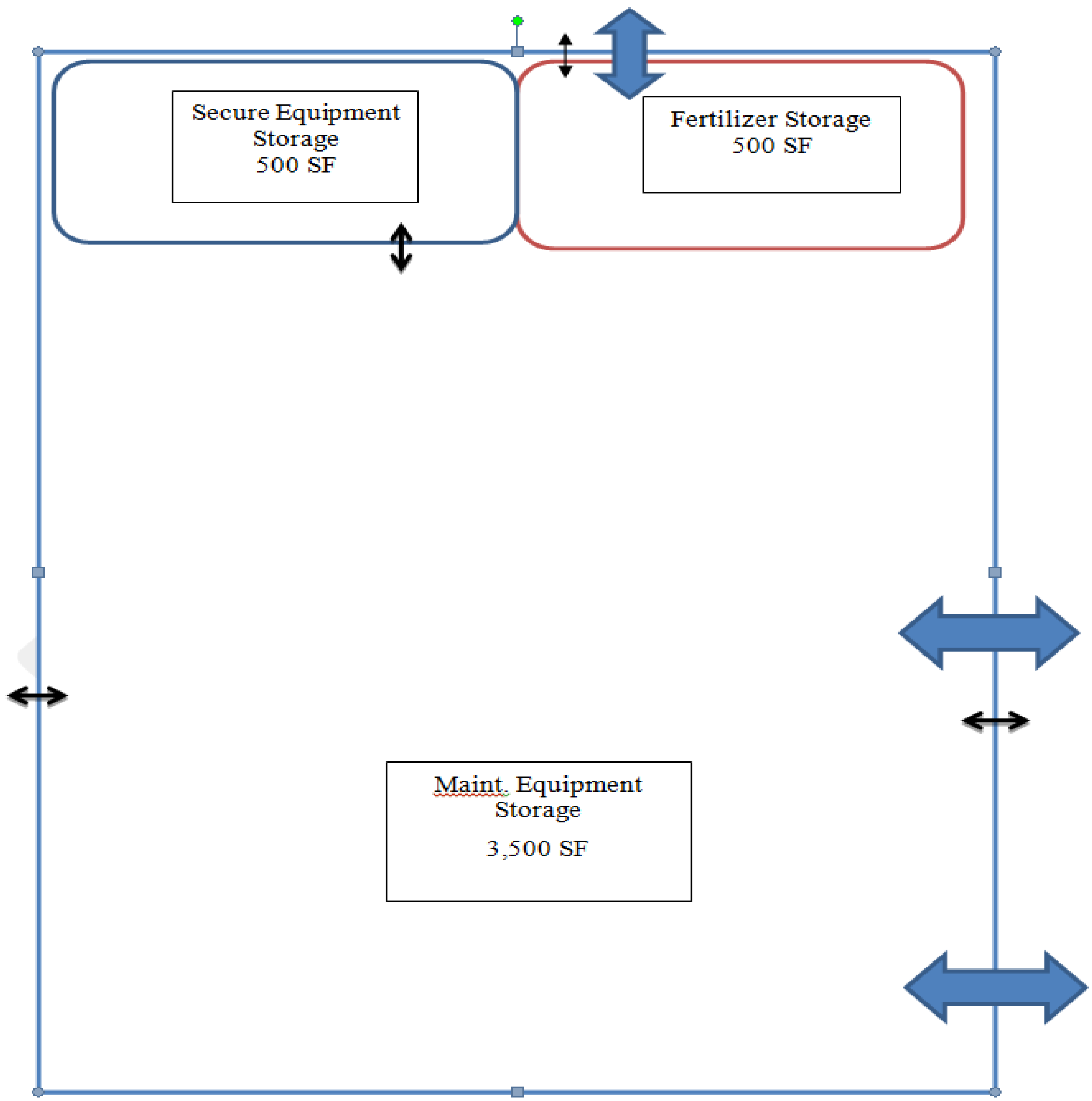


Figure 74480-2
Storage Area Concept Diagram



750 COMMUNITY FACILITIES - MORALE, WELFARE AND RECREATION (OUTDOOR)

750-1 GENERAL

The Navy's Outdoor Recreation Program introduces Sailors and their families to lifetime outdoor recreation activities, and provides them with participation opportunities. The associated values and benefits of participating in outdoor-related activities effectively contribute to Navy quality of life and retention efforts. Outdoor recreation has long lasting, broad scope effects on other areas of a participant's life. Benefits include increased self-esteem, overall happiness and general well-being. The Outdoor Recreation Program promotes physical fitness, teamwork, leadership, skill development and environmental ethics. Examples of human powered outdoor recreation programs include:

Backpacking	Nordic Skiing	White Water Rafting
Canoeing	Rock Climbing	Scuba Diving
Sea Kayaking	Hiking	Orienteering
Snowshoeing	Mountain Biking	Surfing
Fishing	Camping	Alpine Skiing
Snowboarding	Rope Courses	Urban Bicycling
Adventure Races	In-line Skating	Adventure Travel
Skateboarding	BMX Biking	

The Outdoor Recreation Program also includes traditional outdoor recreation activities such as:

Golf	Basketball	Tennis
Volleyball	Baseball	Softball
Football	Soccer	Track and Field
Swimming	Sailing	

The extent and type of Outdoor Recreation Program depends on the Installation location, local geography, and patron interest. The 750 Series of Navy Category Codes provides for the various types of facilities that may be required to support the above programs. Facilities should be attractive, clean, uncluttered, and well maintained. Space should be available to support all core program activities.

750-1.1 **Morale Welfare and Recreation (MWR), Navy Personnel Command (NPC) Role:** The involvement of MWR representatives in the planning process is required, especially for all Category C business-based projects, in order to ensure a match between program needs, and the types and sizes of spaces to be provided. MWR programs are funded by a combination of non-appropriated funds (NAFs) and appropriated funds (APFs). MWR activities are divided into three categories following DoD policy on funding and function:

- **Category A** operations are authorized full APF funding and directly support mission essential requirements. Examples are gymnasiums, fitness centers, and sports programs.

- **Category B** operations are mission enhancing community support programs and are authorized significant APF support. Examples are outdoor recreation, child development, hobby shops, ITT, community pools, school age care, and youth development programs.

- **Category C** operations are business-based activities and are authorized minimal APF (such as SRM, environmental compliance, security, and health and safety support; interior renovation and new construction/additions are NAF funded) except at isolated/remote and OCONUS installations where Category C operations are treated the same as Category B operations. Examples are food and beverage operations, bowling centers, cottages, RV parks, slip rental marinas, and golf courses.

For Category B and C facilities an initial market survey and financial analysis or pro forma is required to determine if the facility will be self-sustaining or profitable, in the case of Category C operations. Once the Installation has completed their analysis, the proposal will be submitted via the regional command to NPC (after 1 October 2004, CNI Field Support Activity) through an Internal Needs Validation Study (INVS). If the project earns sufficient points through the INVS, it will move on to the Project Validation Assessment stage where the demand and scope will be confirmed through independent review.

750-1.4 **Overseas Adjustment:** For overseas activities the net to gross factor (typical net to gross is 1.25 or 25%) will increase as necessary to meet host nation building codes.

750-2 USING THE CRITERIA.

750-2.1 **Size to Accommodate Demand**. The below criteria provide the current approach for determining allowances for Morale, Welfare and Recreational (MWR) facilities. Facility allowances are sized to accommodate the projected demand for the anticipated functions. The projected demand will be estimated using a Market Survey approach. Existing Navy wide surveys (under 2 years old), MWR Pulse Point Surveys, and other local surveys can be used to determine the demand. Existing community facilities will be considered in the Market Analysis approach. The facility capacity requirements will be estimated using industry standards and comparable existing facilities, Navy, DoD, municipal, or commercial.

In addition to the above criteria, attention should be given to relevant planning information in the Base Master Plan, Regional or Functional Plan (RSIP), existing

Unified Facilities Criteria (UFC) as developed, Design Manuals, Military Handbooks or Instructions for the specific facility type.

For Marine Corps Installations results of the MWR Construction Program Patron Survey will be used to provide Marine Corps specific patron desires. Construction Program Patron Survey data is available from the Commandant of the Marine Corps (MW).

750-2.2 **Space Allowance Flexibility**

750-2.2.1 **Aggregate Space Allowances**. For many of these criteria, usage demand, capacity requirements and space allowances are calculated separately for component function-areas of the facility, and then totaled to derive overall facility space allowances. This procedure is designed to respond to local variations in the set of activities and spaces provided, and the relative demand for different activities depending on the needs of the installation population. This approach can also accommodate diverse existing facility situations, when considering additions or complementary new facilities.

750-2.2.2 **Space Programs versus Facility Allowances**. These criteria are used to determine the total space allowance for a facility. Even though area calculations for functional components of the facility are used in deriving the overall allowance, this does not fix the space sizes of the component program areas of the facility. Local installation decisions, in the space programming and design process, should determine the appropriate allocation of areas for each function-space within the total facility allowance. Any such decisions should be fully justified to the regional and CNI MWR program management to ensure compliance with Navy and DoD standards.

750-2.2.3 **Local Variation.** Local demand for program activities may depend on a variety of factors, in addition to the overall installation population, including

- Proportion and relative participation of different user groups among the population.
- Specific program of activities provided.
- Competing on-base and off-base facilities providing similar programs.
- Geographic distribution and accessibility of the user populations.
- Local climate conditions and operating seasons.
- Overseas situations and local customs.
- Installation geography.

750-2.3 Population Basis for Demand Calculations

See Chapter 1 of this instruction for general information on population definitions and base loading data.

750-2.4 Recreational Planning Context

Planning for MWR facilities should involve consideration of the individual facility in relationship to a comprehensive recreational program and facilities plan for the installation and the region. Consider the following factors, in addition to those relationships specifically indicated in the criteria for each facility:

- If other MWR facilities serving the same user population provide the same program activities, reduce the allowed capacity of the proposed facility by the capacity provided elsewhere at the installation or other nearby regional installations.
- Consider collocating the facility with other recreational facilities providing complementary programs, to provide the users with the increased convenience and attractiveness of clustered activities, and to take advantage of potential savings in support space requirements and operating costs.
- Size and locate an individual facility appropriately to the target population and geographical area its particular function is designed to serve. Convenient access for users should be considered in balance with the need for efficient facility operation and avoidance of duplicate facilities. Consider the DoD INST 1015.15 (Enclosure 3, Attachment 1) requirement for the use of appropriated funds (APF) for site development costs, archeological and ammunition clearances, water purification, demolition, excessive utility connections, and road service when selecting sites.
- Consider local community facilities. If the local community has a robust program and facilities for outdoor recreational activities consider partnerships with the local community for services, and/or other Public Private Venture initiatives.

750 10 OUTDOOR PLAYING COURTS (EA)
FAC: 7521
BFR Required: Y

Design Criteria: UFC 4-750-02N - Design: Outdoor Sports and Recreational Facilities

75010-1 **GENERAL**. See introduction to 750 series category codes for General Instructions regarding facility allowance planning procedures.

75010-2 **DEFINITION**. Outdoor Playing Courts provide facilities and support services to meet the individual physical fitness and recreation needs of military personnel. The facilities may also serve dependents, retirees and authorized civilians. Activities that may be accommodated in Outdoor Playing Courts include: basketball, tennis, volleyball, skate/skateboard parks, and outdoor skating/roller hockey rink

75010-3 **RELATED FACILITIES**. Consideration should be given to collocating the Outdoor Playing Courts with the following recreational facilities in order to (i) take advantage of potential savings in space requirements and operating costs, and (ii) provide users with the increased convenience of clustered facilities:

- 740 44 Indoor Physical Fitness Center (Gym)
- 740 45 Fitness Room
- 740 84 Indoor Playing Courts
- 750 20 Playing Fields
- 740 55 Youth Center

75010-4 **DEMAND AND ALLOWANCES**. Demand, market analysis and survey information, as well as the number of existing leagues/teams if applicable determine the number of Outdoor Playing Courts provided at each installation. Provision of lighted courts is recommended where there is a high demand and/or climate warrants later usage by patrons. Youth Outdoor Playing Courts will be provided as needed. They should be sized and located for the youth population, i.e. near the youth center if there is one. The Courts will be sized in accordance with industry standards for the youth age group or adult age group as appropriate.

750 20 PLAYING FIELDS (EA)
FAC: 7522
BFR Required: Y

Design Criteria: UFC 4-750-02N - Design: Outdoor Sports and Recreational Facilities

75020-1 **GENERAL**. See introduction to 750 series category codes for General Instructions regarding facility allowance planning procedures.

75020-2 **DEFINITION**. Playing Fields provide facilities and support services to meet the individual physical fitness, coordination, skills development, training and recreation needs of military personnel. The facilities may also serve dependents, retirees and authorized civilians. Activities which may be accommodated in Playing Fields include: baseball, football, soccer, softball, track and field, etc.

75020-3 **RELATED FACILITIES**. Consideration should be given to collocating the Playing Fields with the following recreational facilities in order to (i) take advantage of potential savings in space requirements and operating costs, and (ii) provide users with the increased convenience of clustered facilities:

- 740 44 Indoor Physical Fitness Center (Gym)
- 740 45 Fitness Room
- 740 53 Indoor Swimming Pool
- 750 10 Outdoor Playing Courts.
- 740 55 Youth Center

75020-4 **DEMAND AND ALLOWANCES**. Demand, market analysis and survey information, as well as the number of existing leagues/teams if applicable determine the number of Outdoor Playing Fields provided at each installation. Provision of lighted fields is recommended for expanded usage. Provision of lighted fields and use of artificial turf or installed sprinkler systems may serve to reduce the total requirement for filds by allowing extended playing hours, extended play without the need for field maintenance/recovery. Youth Outdoor Playing Fields will be provided as needed. They should be sized and located for the youth population, i.e. near the youth center if there is one. The Fields will be sized in accordance with industry standards for the youth age group or adult age group as appropriate.

750 21 BATTING CAGE (EA)
FAC: 7542
BFR Required: N

75021-1 Batting cages may be provided at Installations where there is a demand, where a MWR survey supports the requirement, and there is no convenient local alternative. Size according to industry standards.

750 22 JOGGING TRACK (KM/MI)
FAC: 7542
BFR Required: N

75022-1 Jogging tracks are provided and sized as required.

750 23 GO-CART TRACK (KM/MI)
FAC: 7542
BFR Required: N

75023-1 Go-Cart Tracks may be provided as a Category C facility where they are determined to be profitable enterprises. Market analysis for this facility must be provided by MWR. Size according to demand and industry standards.

750 30 OUTDOOR SWIMMING POOL - INSTALLATION (SQ.M./SF)
FAC: 7512
BFR Required: Y

75030-1 (Use Category Code 740 53 SWIMMING POOL - INDOOR for sizing standards). With appropriate demand analysis, outdoor pools may include water park features and spray parks.

750 33 POOL PUMP/FILTER/TREATMENT FACILITY (SF)
FAC: 7448
BFR Required: N

75033-1 This code is for inventory purposes and only in those cases where such facilities are located in a structure remotely situated from the swimming pool proper.

750 34 WADING POOL/SPLASH POOL (EA)

This CCN has been deleted. All newly programmed and existing assets should be assigned to CCN 75030 Outdoor Swimming Pool-Installation.

750 36 COOPER COAX CCTV AND CATV (LS)
FAC: 1351
BFR Required: N

75036-1 This Category Code is for inventory purposes only. Such facilities are used for the distribution of CCTV, cable TV services and commercial internet services.

750 37 OUTDOOR ADVENTURE AREA (EA)
FAC: 7542
BFR Required: N

75037-1 Includes Ropes Courses, Natural Recreation Features (rock climbing, hiking trails, mountain bike trails, paintball ranges, and motocross/BMX areas). Requirement is based on local availability (geography) and local demand. Size according to industry standards.

750 38 OUTDOOR MWR EQUIPMENT RENTAL STORAGE (SQ.M./SF)
FAC: 4521
BFR Required: Y

75038-1 Outdoor fenced area with lighting for storage of MWR rental equipment (not enclosed). Facility should be co-located with the Outdoor Recreation Center CCN 740-37, if there is one.

750 39 MWR VEHICLE/RV/BOAT STORAGE COMPOUND (SQ.M./SY)
FAC: 8523
BFR Required: Y

75039-1 Vehicle/RV/Boat Storage Compounds may be provided as Category C facilities where they are determined to be profitable enterprises. Market analysis for this facility must be provided by MWR. Size according to demand and industry standards. Covered spaces may be included where justified by demand.

750 40 GOLF COURSE (EA)
FAC: 7513
BFR Required: Y

Design Criteria: UFC 4-750-02N - Design: Outdoor Sports and Recreational Facilities

75040-1 **GENERAL**. See introduction to 750 series category codes for General Instructions regarding facility allowance planning procedures.

75040-2 **DEFINITION**. Golf Courses are recreational facilities which may accommodate: recreational golfing, practice, instruction, tournaments, exhibitions, special events, and winter recreational activities such as cross-country skiing, ice skating, sledding and tobogganing. In addition to the Golf Course, space permitting, the facility may include a driving range, practice hole, chipping green with sand trap, and putting green(s). A Golf Course is a Category C MWR facility.

75040-3 **RELATED FACILITIES**. The Golf Course must be collocated with the following recreational facilities in order to (i) take advantage of potential savings in space requirements and operating costs, and (ii) provide users with the increased convenience of clustered facilities:

- 740 80 Golf Club House (including golf maintenance building/storage compound, chemical/fertilizer/pesticide storage and mixing building, and cart storage facilities).
- 750 56 Golf Driving Range.

75040-4 **DEMAND**. The Golf Course will be sized in accordance with a market survey approach. As a Category C facility, the Golf Course must be profitable and a financial analysis or pro forma will be provided as well as the NPC Internal Needs Validation Study (INVS), and finally the Project Validation Assessment. The Planner will accomplish the initial demand investigation and review along with local MWR personnel. If project is financially sound it will be forwarded via the region to NPC (after 1 October 2004, CNI Field Support Activity) for INVS scoring and possible Project Validation Assessment.

75040-5 **FACILITY ALLOWANCE.** The Golf Course will be sized in accordance with industry standards. One resource for sizing criteria is the National Golf Foundation (NGF). Siting, water availability, and existing land area available will be the key considerations when planning a new Golf Course.

750 50 OUTDOOR THEATER (EA)
FAC: 7532
BFR Required: Y

75050-1 No planning factors are available. If an outdoor theater (either seat- type or drive-in) is provided, the requirements for theaters (Code 740 56) must be reduced accordingly.

750 52 SKEET AND/OR TRAP RANGE (EA)
FAC: 7542
BFR Required: Y

75052-1 Skeet and/or Trap Ranges may be provided as Category C facilities where they are determined to be profitable enterprises. Market analysis for this facility must be provided by MWR. Size according to demand and industry standards. In addition, suitable land must be available, and the activity must have a military population over 100. If a range building is authorized, see Category Code 740 52 for criteria. Table 75052-1 gives the corresponding land requirements. This facility must be self-sustaining.

Table 75052-1. Land Requirements for Skeet and Trap Ranges Land Area

Military Population (1)	Skeet Range	Trap Range
Up to 100	None	None
101 to 10,000	335m x 732m /1100’ x 2400’	335m x 549m / 1100’ x 1800’
10,001 to 15,000	335m x 732m /1100’ x 2400’	335m x 576m / 1100’ x 1890’
15,001 to 20,000	335m x 732m /1100’ x 2400’	335m x 604m / 1100’ x 1980’
20,001 to 25,000	335m x 732m /1100’ x 2400’	335m x 631m / 1100’ x 2070’
25,001 to 30,000	335m x 732m /1100’ x 2400’	335m x 658m / 1100’ x 2160’
30,001 to 40,000	335m x 777m /1100’ x 2550’	335m x 686m / 1100’ x 2250’
Over 40,000	335m x 823m / 1100’ x 2700’	335m x 713m / 1100’ x 2340’

(1) Military population consists of active duty military supported by the installation.

750 54 BAND STAND (EA)
FAC: 7531
BFR Required: N

75054-1 No planning factors are available. Requests for this facility will require individual justification.

750 56 GOLF DRIVING RANGE (EA)
FAC: 7514
BFR Required: Y

75056-1 Installations, where the necessary land is already available, and the facility will be profitable as a Category C facility, are authorized a golf driving range. See category code 750 40.

750 57 MWR OPERATED RECREATION GROUNDS (EA)
FAC: 7516
BFR Required: Y

75057-1 No specific guidance is available. Local conditions usually will govern the development of any parks, playgrounds, or picnic areas. Recreation Pavilions (Code 740 78) are authorized in conjunction with these facilities.

750 58 RECREATIONAL CAMPGROUND-TENT (SQ.M./SF)

This category code has been deleted. All newly programmed and existing assets should be assigned to category code 750 59, Recreational Campground.

750 59 RECREATIONAL CAMPGROUND (AC)
FAC: 7541
BFR Required: Y

75059-1 **GENERAL**. See General Notes to 750 series category codes for General Instructions regarding facility allowance planning procedures.

75059-2 **DEFINITION**. Recreational Campgrounds provide the military community with outdoor recreation opportunities at locations with attractive natural resources. To complement the camping experience, and depending on location, Recreational Campgrounds may offer activities such as boating, canoeing, fishing, hiking, hunting, skiing and swimming. Facilities should be designed to take advantage of the natural features of the site, from vegetation to good views to unusual topography. At the same time, development should be environmentally appropriate and not threaten the preservation of the natural heritage and scenic resources.

The planning criteria in this Category Code addresses only the camping sites and other support elements such as RV dump stations; dumpster stations; playgrounds and courts (associated with the RV Park only); standalone picnic shelters; and any other associated facilities or site features other than buildings. Facilities such as camp offices; camp stores; bathhouses; laundry facilities; storage buildings; campground rental centers, etc. should be categorized under CCN 740-92 MWR RV Park Support Building. Requirements for these facilities can also be found under CCN 740-92. Recreational campgrounds are encouraged to make use of the Camp Host concept to assist in the management of the campground. Space allowances for MWR Rental Accommodations are addressed under CCN 740-81.

Dump stations should generally be provided at campgrounds that accommodate RV's. The sizing and design of dump stations will vary according to local conditions (such as topography, soil conditions, proximity to water sources, etc.). All dump station facilities must comply fully with all applicable environmental regulations.

75059-3 **RELATED FACILITIES**. Where such locations are adjacent to the sea or other body of water, support facilities such as marinas, boat ramps and RV/vehicle/boat storage compounds may be sited in close proximity to Recreational Campgrounds.

75059-4 **SPACE ALLOWANCE**. The total number of camping and/or RV sites provided at a location is primarily determined by two considerations:

- The Recreational Campground will be sized in accordance with a market survey approach. As a Category C facility, the Campground must be profitable and a financial analysis or pro forma will be provided as well as the CNIC Internal Needs Validation Study (INVS), and finally the Project Validation Assessment. The Planner will accomplish the initial demand investigation and review along with local MWR personnel. If the project is financially sound it will be forwarded via the region to CNIC Fleet & Family Readiness (N944A) for INVS Scoring and possible Project Validation Assessment.

- Capacity of the location to accommodate the proposed facilities at a recommended level of use density, and other site planning requirements for access and provision of utilities.

75059-4.1 The number of campsites which may be accommodated per acre will vary depending on the natural features (topography, geology, vegetation, etc.) of the proposed location and the desired degree of privacy between individual sites. Development of as few as 2.4 sites per hectare (6 sites per acre) to a maximum of 5.7 sites per hectare (14 sites per acre) is recommended as a planning guideline. However, this guideline may be modified by the financial analysis, which may, for example, indicate that 2.4 sites per hectare (6 sites per acre) may be too low to justify the investment required to provide the necessary infrastructure (paths, roads, patron support facilities, utilities, etc.). Furthermore, the financial analysis may also indicate a total minimum number of sites required to justify the investment in this recreational resource and the corresponding support building (CCN 740-92). RV Campsites should be planned with a vehicle/picnic pad 20 feet by 40 feet that will accommodate the RV and either towed or towing vehicle, picnic table, fire ring/grill and lantern pole. The adjacent utilities pedestal should offer 20/30/50A electrical service, drinking water hose bibb and sewer connection. WIFI service is also a standard for all RV spaces. Minimum separation between campsites should be 37 feet centerline to centerline of each pad. It is recommended that, where financially feasible, the RV Campground include a mix of back-in and pull-through sites.

75059-4.2 All facilities, which have the potential for causing environmental contamination — for example, dumpsters and dump stations —, must comply fully with all applicable local, state and federal regulations. The planning of Recreational Campgrounds located in areas under the jurisdiction of other agencies such as State Parks and Forests Divisions, the U.S. Forest Service and the National Park Service, must adhere to all applicable development guidelines and review procedures.

750 60 MARINA / BOAT RAMP (EA)
FAC: 7518
BFR Required: Y

75060-1 This facility requires special considerations and must be developed based on local conditions and supported by a detailed analysis. As a Category C facility, the Marina must be profitable and a financial analysis or pro forma will be provided as well as the CNIC Fleet & Family Readiness (N944A) Internal Needs Validation Study (INVS), and finally the Project Validation Assessment (PVA). A marina may also be operated as a Category B operation without resale or private boat berthing. In this case, boats and equipment are MWR-owned and -operated. For a Category B program marina, it is necessary to document the demand and to ensure that APF will be available to support operation of the sailing program. In this case the INVS and PVA goal is to build only to demand capacity and attempt to breakeven financially. The operation of a snack bar, restaurant, or resale outlet is only authorized as a Category C program. The Planner will accomplish the initial demand investigation and review along with local MWR personnel. If the project is financially sound it will be forwarded via the Region to CNIC Fleet & Family Readiness (N944A) with a pre-INVS for evaluation, comment and questions. Once any comments or questions are resolved submission of a full INVS will be invited and scored followed by a possible PVA. CCN 75060 Marina/Boat Ramp includes any combination of boat launch ramps for personal watercraft; boat launch piers that support the ramp; and/or any piers associated with boat slips. Stand-alone recreational piers not affiliated with a marina should be captured under CCN 75061 Recreational Pier. A marina support building or boathouse is authorized in conjunction with a marina and should be programmed as a part of the project nomination and validation process. See category code 74087, Marina Support Building, for marina support building criteria. There are two categories of Marina: Category B is the MWR boating/sailing program and Category C is the rental slip operation.

750 61 RECREATIONAL PIER (EA)
FAC: 7517
BFR Required: Y

75061-1 This CCN is used for stand-alone recreational pier facilities (e.g. fishing piers) where there is no existing Marina.

751 OUTDOOR RECREATION FACILITIES

751 10 PLAYGROUND (EA)
FAC: 7511
BFR Required: N

75110-1 **DEFINITION.** Formerly titled “Community Playground”. Playgrounds are outdoor activity areas provided for children and are an integral part of the functions associated with schools, family housing areas, outdoor athletic and recreational areas, and child development, school age care and youth centers. The playgrounds may utilize traditional playground equipment or may be constructed with zero-depth splash park features.

A playground will have a defined boundary with one or more types of play equipment or features, and fall-protection surfacing appropriate for the equipment provided and anticipated activities. (A playground is differentiated from an open play area which does not have a defined boundary or engineered surfacing, which generally consists of a rubberized, poured surface but may be wood chips, rubber chips, or rubber tiles).

Each playground is specifically planned and designed to meet the age-appropriate activity needs of children playing in these areas. Refer to UFC 3-201-02 “Landscape Architecture” and the US Consumer Product Safety Commission “Public Playground Safety Handbook” for guidance.

Each playground must be Architectural Barriers Act (ABA) compliant for the appropriate age group. For Child Development Centers having multiple outdoor activity areas for each age group, only a single area per age group must be ABA compliant, however all outdoor activity areas must meet the requirements of the Child Development Center UFC 4-740-14. Outdoor activity areas supporting Youth or School Age Care (SAC) Centers must comply with UFC 4-740-06.

Playgrounds do not include purpose-built fields or tracks to support specific sports (refer to the 750 series of Category Codes for sports facilities).

75110-2 **PROPERTY RECORD CARD USAGE.** Each playground location should be shown on a separate property record card, which will include the site and all equipment associated with the playground.

This Category Code is for inventory purposes only.

752 OUTDOOR ATHLETIC FACILITIES

752 40 ATHLETIC STADIUM (EA)

FAC: 7524
BFR Required: N

75240-1 For inventory purposes only.

760 MUSEUMS AND MEMORIALS

760 10 MUSEUM / MEMORIAL BUILDING (SQ.M./SF)

FAC: 7601
BFR Required: Y

Project Approval (Museums): Assistant Secretary SECNAV INSTRUCTION 5755.2A (Museums) (http://neds.nebt.daps.mil/Directives/5755_2a.pdf)

76010-1 No specific planning factors are available for this group. Requirements for each of the above facilities will be established based on individual studies and supporting justification. Museums must be approved by SECNAV.

76010-2 The Office of the Comptroller of the Navy has ruled the use of appropriated funds (including OM&N funds) for the construction and maintenance of memorials is restricted to those memorials specifically approved by Congressional authority. Alternative funding sources should be explored.

760 20 OUTDOOR MONUMENT / MEMORIAL (EA)
FAC: 7602
BFR Required: N

76020-1 The Office of the Comptroller of the Navy has ruled that the use of appropriated funds (including OM&N funds) for the construction and maintenance of memorials is restricted to those memorials specifically approved by Congressional authority. Alternative funding sources should be explored.

760 30 CEMETERY (EA)
FAC: 7603
BFR Required: N

76030-1 No specific planning factors are available for this group. Requirements for each of the above facilities will be established based on individual studies and supporting justification. SECNAV approval will be required.

Version: 800.20253103

FACILITIES CRITERIA (FC)
FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

Series 800: UTILITIES AND GROUND IMPROVEMENTS FACILITIES

Record of Changes:

Date	CCN	CCN Title	Description of Change
13 June 2018	83143	Hazardous Waste Storage Building	Remapped to FAC 4423 per OSD/RPCP FY18.
13 June 2018	892 Series	NA	Added 892 Series “Miscellaneous Utilities-Each”
13 June 2018	89210	Monitoring Wells	CCN added
24 Oct 2018	82112 82122 82130 82140 82310	Heating Plant - Oil / Gas Heating Plant - Coal Heating Plant - Non - Fossil Fuel Steam Plant – Nuclear Gas Generating Plant	Changed Unit of Measure from millions of BTU per hour (MB) to BTU per hour (BH)
28 Jan 2020	81220	Exterior Lighting, Pole Mounted	Title changed from “Street Lighting” to “Exterior Lighting, Pole Mounted”. Primary unit of measure changed from LF to EA.
28 Jan 2020	81240	Perimeter and Security Lighting	CCN 81240 deleted in FY19. Assets consolidated into CCN 81220.
28 Jan 2020	83340	Garbage House/Recycle Center Building	Title changed from “Garbage House” to “Garbage House/Recycle Center Building”.
28 Jan 2020	85215	Bicycle Shelter	Title changed from “Parking Building, Bicycle” to “Bicycle Shelter”. FAC Code changed from 8531 to 7384.
28 Jan 2020	89045	Valve House or Other Enclosure	Title changed from “Valve House or Other Shed/Shelter” to “Valve House or Other Enclosure”.
28 Jan 2020	89210	Monitoring Wells	FAC Code changed from 1499 to 8840.

Date	CCN	CCN Title	Description of Change
28 Jan 2020	87110	Storm Sewer	FAC Code changed from 8321 to 8711
28 Jan 2020	81340	Lightning Protection System, Standalone	Added category code 81340 – Lightning Protection System
20 July 2020	85210	Parking Area	Updated Table 85210-1, Allowances for Non-Organizational Vehicle Parking
20 July 2020	82140	Steam Plant-Nuclear	CCN deleted
20 July 2020	83142	Hazardous Waste Storage Area	FAC code changed from 8926 to 8526
20 July 2020	83231	Sewage Lift Stations	CCN deleted. Redundant. Use 83230.
12 Mar 2021	81220	Exterior Lighting, Pole Mounted	Removed conflicting statement regarding units of measure.
24 Aug 2021	87210	Station Security and Perimeter Fencing and Walls	Added Security Fencing for Magazine Storage and Security Risk (SRC) Categories I and II ordnance.
31 Aug 2021	84441	Stormwater Filtration – Permeable Surface	New Category Code added.
31 Aug 2021	84442	Stormwater Filtration - Swales	New Category Code added.
31 Aug 2021	84451	Stormwater Treatment Structure	New Category Code added.
11 Nov 2021	84420	Water Well	Note that the Real Property Categorization Panel will change the FAC to 8414. Change CCN 84420 title to "Water Well" and change CCN definition information to include the words “either potable or non-potable.”
11 Nov 2021	81340	Lightning Protection System, Standalone	Change definition verbiage.
11 Nov 2021	85235	Other Paved Areas Not Coded In The 100 or 400 Series	CCN definition change only. Removes term "vehicular" from original description.
11 Nov 2021	85240	Miscellaneous Open Storage or Laydown Area – Paved	Change title to add word "Paved"
11 Nov 2021	83320	Garbage Grinder Building	Note that the Real Property Categorization Panel will change the FAC to 8330. Change Unit of Measure (UM) to SF Delete outdated definition and include new

Date	CCN	CCN Title	Description of Change
			information regarding refuse and recycling.
19 August 2022	83312	Refuse/Solid Waste Collection Facility – (Non Hazardous)	Add new category code.
19 August 2022	85239	Miscellaneous Open Storage or Laydown Area - Unpaved	Add new category code.
12 September 2022	85240	Miscellaneous Open Storage or Laydown Area - Paved	In section 85240-1, Reference the use of Table 85240-1 in lieu of Table 852 40.
6 October 2022	81240 81241	Level 1 / Level 2 Electric Vehicle Charging Facility Level 3 Direct Current Fast Charging Facility	Add new category code. Add new category code.
2 Mar 2023	800 Series	UFC 2-000-05N	Change UFC 2-000-05N to FC 2-000-05N document due to the fact that this planning criteria is not unified among the other DoD services.
15 June 2023	81240 81241	Level 1 / Level 2 Electric Vehicle Charging Facility Level 3 Direct Current Fast Charging Facility	Add requirement for electric charging capability to support no less than 15 percent of Government motor vehicles.
15 Jan 2024	87250	Entry Gate	Add new category code.
15 Jan 2024	89018	Utility Vault-Non Communications	Modify category code description.
15 Jan 2024	89046	Utility Tunnel-Non Communications	Modify the category code title and description.
15 Jan 2024	89210	Monitoring Well	Modify the category code description.
15 Jan 2024	89320	Utility Channel-Non Communications	Modify the category code title and description.
27 Feb 2024	81340	Lightning Protection System, Standalone	Change “DEFINITION” and PROPERTY RECORD CARD USAGE” sections to 81340-1 and 81340-2, respectively.
12 Mar 2024	83230	Sewage Waste Pumping Station	Change the word “PUMP” in the title to “PUMPING.” Change the primary unit of measure from EA to KG, which is equivalent to “Thousand Gallons per Day (KG).”

Date	CCN	CCN Title	Description of Change
16 Oct 2024	87230	Mechanical Security Barricade	Include verbiage that drop arms meet the definition of a mechanical security barricade and are included.
16 Oct 2024	83141	Hazardous Waste Storage and Transfer Facility	Renumber individual paragraphs to read 83141-1 through 83141-7.
16 Oct 2024	85120	Vehicular Bridges	Add reference of the Federal Highway Administration regarding the planning of roads, streets, and bridges.
31 Mar 2025	81320	Substation	Under section, "Property Record Card Usage," change 6,000 kVA to 7,500 kVA.
31 Mar 2025	81240 81241	Level 1 / Level 2 Electric Vehicle Charging Facility Level 3 Direct Current Fast Charging Facility	Include Section 81240-3, Parking Space and Access Aisle, siting requirements information for both Category Codes.
31 Mar 2025	83309	Incinerator Building and Incinerator	A definition has been included for defining this type of facility.

800 SERIES
UTILITIES AND GROUND IMPROVEMENTS FACILITIES

Table of Contents

810 ELECTRIC POWER

810-1 DEFINITION

The electric power demand of a Navy or Marine Corps installation will normally be predicated upon an engineering study of personnel and industrial-type consumption load of the installation activities. However, in the absence of an engineering study the following should be utilized for broad planning purposes:

Table 810-1. Electric Demand Planning Factors

Category Group	Description	Unit of Measure	Maximum Demand Per Unit of Measure (Watts)
130	Communication & Navigational Aid	SF	13, 5
	Airfield Lighting	LF	6
140	Land Operations Facilities	SF	7.5
150	Waterfront Operational Facilities	SF FB	5 5×10^3
170	Training Facilities	SF	7.5
210	Maintenance. Shops & Facilities	SF	7.5
220	Production Buildings. & Plants	SF	7.5
310	Research, Development & Test Bldg.	SF	7.5
440	Storage, Covered	SF	2
510/20	Hospital Buildings	SF BD	6 4×10^3
230/40/50	Labs, Clinics, Dispensaries	SF	8
610	Administration Buildings	SF	6
710	Family Housing	SF FA	4.5* 6×10^3*
720	Troop Housing	SF MN	5.5 500
730/40	Community Facilities	SF	7
821	Heating Plants	SF MBH	5 3×10^3
830	Sewage Treatment Plants	MGPD	200×10^3

* Coincident demand for multiple units.

811 ELECTRIC POWER-SOURCE

811-1 DEFINITION. Electric power for base facilities is normally derived from local commercial sources. Where commercial sources are used, transformer substations are required to transform the electrical energy to satisfy the station's load requirement.

Category Code Numbers (CCNs) 81110, 81125, 81145, 81146, and 81150 power generation plants may be used as a primary power source in lieu of commercial power or for reducing dependency on commercial power. CCN 81160 may only be used for standby power generation plants.
Primary power generation plants are real property. Standby generator plants may be real or personal property, depending on what they support. In general, a standby generator shall be considered real property if it supports real property and shall be considered personal property if it supports personal property. See OPNAVINST 11010.20H, Chapter 1, Paragraph 2c for definitions of real property and personal property.

811-2 PROPERTY RECORD CARD. Regardless of whether the real property power plant is within the footprint of another building, in a standalone building, sheltered by a structure or on a pad, or if it is generating primary or auxiliary power, the primary power or standby power generator plant is assigned its own property record card. If the power plant is located within a standalone building, use CCN 81109 for primary power plants or CCN 81159 for standby power plants.

811 09 ELECTRIC POWER PLANT BUILDING (SF)

FAC 8910
BFR Required: N
Revised: August 2015

81109-1 DEFINITION. This category code is used for the buildings or shelters that house the electric power plant and associated equipment included in category codes 81110, 81125, 81145, 81146, 81150 and 81160. If an access road is required, the road is inventoried separately; see 85110 and 85111 for more information.

81109-2 PROPERTY RECORD CARD USAGE. Each electric power plant building, shelter or pad should be captured on a single, individual property record card as a structure. If a separate standalone building is used, then CCN 81109 should be assigned as the utilization on that property record card. If the power generation plant is housed in an existing multi-purpose facility, then the space used for the power generation plant should be assigned a utilization of 81109.

811 10 - 811 50 ELECTRIC POWER PLANTS

81110/81150 – 1 DEFINITION. Consideration as to whether an electric power generating plant is to be planned will depend on the station's geographical location, the availability of a firm uninterrupted adequate power supply from a local electric utility, the economics of using byproduct steam for space heating and industrial process work, and the availability of the required fuel. The electric generating plant (diesel or steam) shall have a total installed capacity equal to the station's total kilowatt demand and in the case of diesel generators there must be one additional standby generating unit with a capacity equal to the largest unit on the line.

In the planning and determination of power plant capacity, due consideration should be given to the estimated demand of all of the station's consumption, both domestic and industrial, plus the anticipated load growth. For initial planning purposes, power plant capacity may be computed by either (1) utilizing the factors indicated under 810 above, or (2) totaling all of the estimated demands in kilowatts of all existing and proposed station buildings and multiplying this total by an appropriate diversity factor. Where a diversity factor is not provided, a factor of eighty percent (80%) may be used. The resultant total is the estimated power plant capacity or the estimated amount of electrical power needed by the station facilities.

811 10 ELECTRIC POWER PLANT - DIESEL (KW)

FAC 8111
BFR Required: N
Revised: August 2015

81110-1 DEFINITION. This category code is used for power plants that use diesel generators as the primary power source for the production of electricity. Additionally, these plants may also be used in auxiliary capacity for peak shaving or other energy reduction. This category includes all necessary equipment for the production of the commodity including fuel tanks, pumps, electrical equipment, plant controls, and all required process equipment for commodity generation. Dual-fuel engines and piston engines utilizing natural gas or other alternate fuels will use this category code.

81110-2 PROPERTY RECORD CARD USAGE. All equipment is inclusive to the power generation plant and shall not be accounted for separately. The power generation plant should be captured on a single, individual property record card. Any switching stations or substations located inside or outside the power plant but associated with the power distribution system of the installation should be shown on a separate property record card. The building that houses the power plant should be reflected on a separate property record card; see 81109 for more information.

811 25 ELECTRIC POWER PLANT - STEAM TURBINE (KW)

FAC 8111
BFR Required: N
Revised: August 2015

81125-1 DEFINITION. A central plant using steam turbine generators for the production of electricity. This category includes all necessary equipment for the production of the commodity. Included are fuel tanks, pumps, electrical equipment, and all required process equipment for commodity generation. The primary unit of measure is kilowatts of generation installed (KW). **NOTE:** All cogeneration plants should be classified using Category Code 81125. A steam turbine typically uses coal, natural gas, or fuel oil, but could also use refuse or a nuclear energy source. Each of these fuel sources has differing components and storage requirements that would be noted during an asset evaluation, but that are considered real property installed equipment (RPIE) of the plant and not called out as separate facilities (e.g., a conveyor system for delivery of coal or storage tanks for fuel).

81125-2 PROPERTY RECORD CARD USAGE. All equipment internal to the power plant shall be included on an individual property record card. Any switching stations or substations located inside or outside the power plant that are associated with the power distribution system of the installation should be shown on a separate property record card. The building that houses the power plant should be on a separate property record card using CCN 81109.

811 45 ELECTRIC POWER PLANT - GAS TURBINE (KW)

FAC 8111
BFR Required: N
Revised: August 2015

81145-1 DEFINITION. A central plant using gas fired turbine generators for the production of electricity. This category includes all necessary equipment for the production of the commodity. Included are fuel tanks, pumps, electrical equipment, and all required process equipment for commodity generation. The primary unit of measure is kilowatts of generation installed (KW). A gas turbine is typically run off of a jet propellant (JP) fuel source. Gas turbines are a source of primary power and are classified as real property.

81145-2 PROPERTY RECORD CARD USAGE. All equipment internal to the power plant should be included on a single, individual property record card. Any switching stations or substations located inside or outside the power plant but associated with the power distribution system of the installation should be shown on a separate property record card.

811 46 ELECTRIC POWER PLANT - WIND TURBINE (KW)

FAC 8114
BFR Required: N
Revised: August 2015

81146-1 DEFINITION. A central plant using wind turbines for the production of electricity. This category includes all necessary equipment for commodity generation. The primary unit of measure is kilowatts of generation installed (KW). These plants generate electricity by capturing the kinetic energy of the wind to drive the turbine. This power generation source is a form of renewable energy and is primarily used for energy reduction. Wind turbines are a passive source of primary power and shall be considered real property.

81146-2 PROPERTY RECORD CARD USAGE. The equipment internal to the power plant should be included on an individual property record. Any switching stations or substations associated with the power distribution system of the installation should be shown on a separate property record card.

811 50 ELECTRIC POWER - PHOTOVOLTAIC SYSTEM (KW)

FAC 8115
BFR Required: N
Revised: August 2015

81150-1 DEFINITION. A power source using photovoltaic (PV) panels for the production of electricity. This category code includes all necessary equipment for the production of the commodity. These plants generate electrical power by converting sunlight into direct current electricity using semiconducting panels. This power generation source is a form of renewable energy and is primarily used for energy reduction. PV systems are a passive source of primary power and are classified as real property.

81150-2 PROPERTY RECORD CARD USAGE. All photovoltaic systems are classified as real property and inventoried in iNFADS. All equipment associated with a photovoltaic system shall be included on a single property record card. The primary unit of measure is the rated output capacity of the inverter in kilowatts (KW) generated by the PV system. Note that roof top mounted units are typically maintained by the tenant command, whereas carport mounted and/or ground mounted units are maintained by the public works utilities department.

811 59 STANDBY GENERATOR BUILDING (SF)

FAC 8910
BFR Required: N
Revised: August 2015

81159-1 DEFINITION. This category code is used for standalone buildings associated with emergency standby generator plants (81160).

81159-2 PROPERTY RECORD CARD USAGE. Each building shall be recorded on an individual property record card. All equipment associated with a standby generator plant shall be included on a separate property record card utilizing CCN 81160.

811 60 STANDBY GENERATOR PLANT (KW)

FAC 8112
BFR Required: N
Revised: August 2015

81160-1 DEFINITION. Standby generator plants include all necessary equipment for the production of power. Such equipment may include day tanks, pumps, power panels, switchgear, controls, battery storage, and automated transfer switches. When dealing with standby generator plants, it is necessary to verify the characteristics of the plant with appropriate facility POC to ensure accuracy of real property status and rated capacity (KW).

There are several categories of standby generator plants:

a. Utilities Standby Power - Utilities standby power generation plants act as auxiliary sources of power and do not require full-time operation. Utilities standby generation plants serve utility production and distribution facilities such as water treatment plants or sewage lift stations, during power outages. Utilities standby power generation plants are classified as real property.

b. Emergency Standby Power - Emergency standby power generation plants provide power upon loss of the primary power source and are classified as Emergency Systems by NFPA 70. They are essential for safety to human life and legally required by municipal, state, federal or other codes or by a governmental agency having jurisdiction. Examples include generators for hospitals or air traffic control towers. Emergency standby power generation plants are classified as real property.

c. Mission Specific Standby Power – Mission specific standby power generation plants support mission specific operations. These essential loads must be supported with emergency standby power generation and provide an adequate uninterrupted power supply in the event (and throughout the period) of power outages and other emergencies. There are two types of mission specific standby power.

1. Where an entire operation must be supported with power, (such as a command operation center, SCIF, or other mission essential operation), these mission specific standby power generators may support a single

building, multiple buildings or a space within the building. Since these generators are supporting a real property, these mission specific standby power generators and associated UPS systems would be classified as real property.

2. Where only critical personal property equipment such as servers, computer room air conditioning (CRAC) units or other telecommunication gear is supported, these generators and associated UPS will be classified as personal property. In these instances, the generators are sized only to support specific critical pieces of personal property equipment. These generators would not be used for building system or task lighting, central or comfort air conditioning system, or power to support personnel operations.

81160-2 PROPERTY RECORD CARD USAGE. A real property standby generator plant should be inventoried on its own property record card. The associated plant equipment (day tanks, UPS, battery bank, transfer switch, etc.) is classified as Real Property Installed Equipment (RPIE) and should not be inventoried separately. Bulk fuel storage tanks must be inventoried separately. Whether real or personal property, in many instances CNIC will not be owner or operator of the standby generator plant and the maintenance fund source codes will vary accordingly. There are many possible owner-operators that could have maintenance responsibility, including CNIC, NAVAIR, NAVFAC, or other non-Navy tenant command such as DLA or BUMED. The primary unit of measure is the rated capacity in kilowatts (KW) generated.

812 ELECTRIC POWER TRANSMISSION AND DISTRIBUTION LINES

812-1 DEFINITION. Distribution and transmission lines are required to supply electricity to buildings, street lighting, floodlighting, and perimeter lighting. Lines may be either overhead or underground and will include poles, duct banks, and controls to distribute electrical energy from the source to each using facility. Planning for distribution and transmission lines will require engineering calculation of critical power demand loads and future load growth. Airfield pavement lighting is planned as described under Category Code 136.

812 09 ELECTRIC DISTRIBUTION BUILDING (SF)

FAC 8910
BFR Required N

81209-1 DEFINITION. This category code should be used for buildings associated with electric distribution system that are not included under Switching

Station/Substation buildings, Category Code 813 10. This Category Code will rarely be used. The unit of measure is square feet.

81209 – 2 PROPERTY RECORD CARD USAGE. Each building should be on a single property record card.

812 12 TRANSFORMERS (KV)

FAC 8133
BFR Required N

81212-1 DEFINITION. Transformers transform electrical power on the primary side to a lower or higher voltage on the secondary side to serve a facility or several facilities. Use the kilovolt ampere (KVA) rating that is found on the nameplate on the transformer or obtained from the manufacturer. It is the lowest rating when multiple ratings are provided (i.e. 12000/16000/20000 – OA/FA/FOA)]. The primary unit of measure is kilovolt ampere (KV) and the alternate unit of measure of EA should be entered into iNFADS. Enter the alternate unit of measure, each (EA), by including the total quantity of transformers listed on the record.

81212-2 PROPERTY RECORD CARD USAGE. A separate property record card shall be created which aggregates all distribution transformers in each special area of an installation, separated by voltage class and also separated by those transformers connected to the overhead distribution system and the underground distribution system. A detailed list of individual transformers totaled on the property record card should be kept in Maximo or by another method (e.g. Excel) and the file attached to the property record card.

Example: Transformers on a 15 KV system will be shown on separate property record cards, one PRC for the overhead distribution system, and one PRC for the underground system for each special area of the installation. If there are 40-500 KVA transformers on a 15 KV overhead electric distribution system, the property record card should reflect a total adequate other measure of 20,000 KVA.

812 20 EXTERIOR LIGHTING, POLE MOUNTED (EA)

FAC 8122
BFR Required N

81220-1 DEFINITION. A utility consisting of secondary power distribution lines (either above or below ground), exterior light fixtures, and poles or standards for mounting the fixtures. This utility includes all forms of exterior lighting (other than that mounted on buildings or other facilities), including that for airfield perimeter lighting; street lighting for traffic circulation; parking lot lighting for traffic circulation, personnel safety, and security; area lighting for personnel safety, security, and night-time use of facilities; and security lighting for arms and ammunition storage areas or facilities, airfield or heliport perimeters, or other mission-essential vulnerable areas. The primary unit of measure is EA (Each) per pole.

NOTE: Pole-mounted floodlighting systems associated with athletic fields are already accounted for under CCN 75020 Playing Fields. For Traffic Control Signals, use CCN 85123.

81220-2 PROPERTY RECORD CARD USAGE. A separate property record card shall be created for each special area of an installation.

812 31 OVERHEAD ELECTRICAL DISTRIBUTION LINES (LF)

FAC 8121
BFR Required N

81231-1 DEFINITION. The overhead lines are for the transmission of electrical power between source, substations and switching stations, and end users. Includes all required wire, poles, pole mounted switches, supports, insulation, metering, etc.(Excluding transformers and sectionalizing switches) necessary for a complete and useable distribution system.
Other Unit of Measure - linear feet of circuit [pole-to-pole distance X number of circuits on pole, NOT number of wires] (LF). Example: A span of electrical overhead distribution 1500 feet in length supporting 2 circuits would be 1500 ft X 2 circuits = 3000 linear feet.

81231-2 PROPERTY RECORD CARD USAGE. A separate property record card shall be created for each special area of an installation for each voltage class.

812 32 UNDERGROUND ELECTRICAL DISTRIBUTION LINES (LF)

FAC 8123
BFR Required N

81232-1 DEFINITION. The underground lines are for the transmission of electrical power between source, substations and switching stations, and end users. It includes all required cable, conduit, duct bank, manholes, switches, insulation, metering, etc. (Excluding transformers and sectionalizing switches) necessary for a complete and useable distribution system.

Other Unit of Measure - linear feet of circuit [manhole-to-manhole distance and pole-to-manhole distance X number of circuits NOT number of cables] (LF). Example: 1000 feet of cable run in duct bank containing 4 circuits would be 1000 ft X 4 circuits = 4000 linear feet.

81232-2 PROPERTY RECORD CARD USAGE. A separate property record card shall be created for each special area of an installation for each voltage class.

812 40 LEVEL 1 / LEVEL 2 ELECTRIC VEHICLE CHARGING FACILITY (KW)

FAC 8124
BFR Required N

81240-1 DEFINITION. An electric vehicle (EV) charging facility delivers either a 120V or 208/240V AC power for charging government-owned vehicles and/or personally owned vehicles at an installation.

81240-2 PARKING REQUIREMENT. Provide adequate electric charging capability concurrently for no less than 15 percent of Government motor vehicles planned for parking at a facility (See UFC 2-100-01 DOD Building Code).

81240-3 PARKING SPACE AND ACCESS AISLE. Provide an EV charging parking space with a minimum width of 132 inches (11 feet) and a minimum length of 240 inches (20 feet) for each vehicle parked. Include an aisle space at least 60 inches (5 feet) wide adjacent to the vehicle parking space. Larger parking spaces may be required to accommodate electric trucks. Designate all vehicle charging parking spaces by markings and include markings for access aisles to prevent non-charging vehicular parking in such areas. One access aisle may be shared between two EV vehicle parking spaces, or a regular parking space adjacent to an EV charging space. However, overlap of the shared aisle should be limited to 60 inches (5 feet).

Note that access aisles should not be encumbered or encroached upon by curbs, wheel stops, bollards, or loose charging cables.

81240-4 PROPERTY RECORD CARD USAGE. EVCFs are permanently constructed to include charging stations (ports**),** electric meters, associated electrical service lines and conduits, dedicated transformers, and concrete pads/footings as required.

The unit of measure (UM) of EVCF systems is kilowatt (KW) and is cumulative for each charging port station associated with the asset.

Example: A row of five charging stations (ports) is considered a single asset with a unit of measure equal to the sum of each port’s KW output.

812 41 LEVEL 3 DIRECT CURRENT FAST CHARGING FACILITY (KW)

FAC 8124
BFR Required N

81241-1 DEFINITION. An electric vehicle (EV) charging facility delivers 50kW-400kW DC power for charging government-owned vehicles and/or personally owned vehicles at an installation.

81241-2 PARKING REQUIREMENT. Provide adequate electric charging capability concurrently for no less than 15 percent of Government motor vehicles planned for parking at a facility (See UFC 2-100-01 DOD Building Code).

81240-3 PARKING SPACE AND ACCESS AISLE. Provide an EV charging parking space with a minimum width of 132 inches (11 feet) and a minimum length of 240 inches (20 feet) for each vehicle parked. Include an aisle space at least 60 inches (5 feet) wide adjacent to the vehicle parking space. Larger parking spaces may be required to accommodate electric trucks. Designate all vehicle charging parking spaces by markings and include markings for access aisles to prevent non-charging vehicular parking in such areas. One access aisle may be shared between two EV vehicle parking spaces, or a regular parking space adjacent to an EV charging space. However, overlap of the shared aisle should be limited to 60 inches (5 feet).

Note that access aisles should not be encumbered or encroached upon by curbs, wheel stops, bollards, or loose charging cables.

81241-4 PROPERTY RECORD CARD USAGE. EVCFs are considered real property when they are constructed as a charging system. EVCFs are permanently constructed to include charging stations (ports), electric meters, associated electrical service lines and conduits, dedicated transformers, and concrete pads/footings as required.

The unit of measure (UM) of EVCF systems is kilowatt (KW) and is cumulative for each charging port station associated with the asset.

Example: A row of five charging stations (ports) is considered a single asset with a unit of measure equal to the sum of each port’s KW output.

813 ELECTRIC POWER SUBSTATIONS AND SWITCHING STATIONS

813 10 SWITCHING STATION / SUBSTATION BUILDING (SF)
FAC 8910
BFR Required N

81310-1 DEFINITION. This Category Code is used for the buildings associated with a substation or switching station (813 20 or 813 30). These are the buildings that contain the switchgear, batteries, charging panels and other equipment located within the substation or switching station.

81310-2 PROPERTY RECORD CARD USAGE. A separate property record card shall be created for each building.

813 20 SUBSTATIONS (KV)
FAC 8131
BFR Required N

81320-1 DEFINITION. Distribution substations, normally consisting of transformers and their associated switchgear, structures, buses, grounding systems, and protective devices; transform electrical power to a lower or higher voltage and put it on the distribution system. This category code shall also be used for unit substations. A unit substation is defined as consisting of one or more transformers, an incoming primary section and a transition section (connected to secondary switchgear). The unit substation may be connected to the electrical distribution system of the activity or to the electrical distribution system of one or more facilities. The rated capacity of the substation or unit substation is the sum of all distribution transformers in the substation. The unit of measure is kilovolt ampere (KV). This rating is found on the nameplate on the transformer or obtained from the manufacturer. It is the lowest rating when multiple ratings are provided (i.e. 12000/16000/20000 kVA – OA/FA/FOA)]

81320-2 PROPERTY RECORD CARD USAGE. Each distribution substation shall be listed on a separate property record card. All unit substations shall be aggregated separately by voltage class (high side of the transformer) and by overhead and underground distribution systems, for each special area. A detailed list of individual unit substations combined on the property record card should be kept in Maximo or by another method (i.e. Excel) and the file attached to the property record card.

Example: Five unit substations of 1,500 KVA each on the underground distribution system at NWS Yorktown – Main Base would be aggregated on a single property record card using CCN 813 20 with a total value of 7,500 kVA.

813 30 SWITCHING STATION FOR SECTIONALIZED DISTRIBUTION CIRCUITS (KV)

FAC 8132
BFR Required N

81330-1 DEFINITION. A switching station is equipment in an electric distribution system where electric power is switched without transformation. Switching stations are located at points where it is necessary to branch off from a main feeder or feeders with smaller components due to physical location of the facilities to be served or to isolate portions of feeders for maintenance or repair. Switching Stations equipment may include circuit breakers, sectionalizing switches, structures, buses, grounding systems, security lighting, and protective devices. The primary unit of measure is kilovolt ampere (KV). It is obtained by multiplying the rated capacity of the switch in kilovolts times the rated capacity of the bus in amperes times the square root of three (1.732). The alternate unit of measure of total number of switches in and out of the switching station (EA) shall be entered on the property record card.

81330-2 PROPERTY RECORD CARD USAGE. All switching stations that are comprised of a group of functionally integrated assets, such as circuit breakers and associated outdoor bus work, which are typically surrounded by a fence and given its own facility number shall be shown on a separate property record card. All other sectionalizing switches shall be totaled separately by voltage class and by overhead and underground distribution systems, for each special area. A detailed list of individual switches totaled on the property record card should be kept in Maximo (SPM) or by another method (e.g. Excel or Access) and the file attached to the property record card.

813 40 LIGHTNING PROTECTION SYSTEM, STANDALONE (EA)

FAC 8134
BFR Required N

81340-1 DEFINITION. Standalone Lightning Protection Systems are those that are not included as part of a specific facility's installed equipment. These are usually constructed to protect a compound, a single building (where the system is constructed of masts and is not a part of the facility) or series of buildings.

81340-2 PROPERTY RECORD CARD USAGE. Capture an entire “system” or “array” on an individual property record card. For example, an array consisting of 12 poles would be captured on an individual property record card, with a count of 12 each (EA). Note that FAC 8134 has an upper limit of four because the most common configuration consists of a wire net held up by four poles. Since systems can differ in number of poles and cables/nets/rods, any system or array consisting of more than four poles requires a size certification code of “C”, indicating that the size of allocation is greater than the FAC upper limit. Otherwise, the Facilities Sustainment Model (FSM) will automatically change the size of the allocation to the “Reset value”.

820 HEAT AND REFRIGERATION (A/C)

820-1 HEAT AND REFRIGERATION

The requirements for heat, hot water, and industrial steam at naval installations will be based on an engineering study of the overall station demand. A central heating facility will include a heating plan, fuel storage, distribution system, and controls. Planning information for heating facilities under the following basic category codes:

- Code 821 Heat, Steam—Source
- Code 822 Heat, Transmission and Distribution Lines
- Code 823 Heat, Gas—Source
- Code 824 Heat, Gas—Transmission
- Code 826 Refrigeration/Air Conditioning

821 HEAT SOURCE

821-1 HEAT SOURCE

The source of heat from steam or high temperature water (HTW) includes a complete central plant and associated fuel storage. The source of heat and steam/HTW are coded to indicate the type of fuel used by the plant. The Navy codes are as follows:

821 09 - 821 50 HEATING PLANTS

82109/82150-1 HEATING PLANTS. A central heating plant will include a structure, piping, equipment, controls, fuel, storage, and all equipment necessary to make a complete usable facility. Central heating plants are justified only when the total owning and operating costs for central plants and distribution systems are less than similar costs for heating systems in individual buildings. Central heating plants are also justified when the overall energy use for providing heat from extraction steam in a steam-electric-power plant would be less than a central plant plus purchased electricity. The type of fuel for the plant, whether an electric power generating plant with by-product heat and steam, or a heating plant, will be selected on the basis of an economic analysis. The heating plant capacity will be based on BTU per hour (BH) rating, and this rating will be determined from an engineering analysis of the need for steam, heat, and hot water at the station.

821 09 HEATING PLANT BUILDING (SF)
FAC 8910
BFR Required N

82109-1 DEFINITION. This Category Code is used for buildings associated with a heating plant including Category Codes 821 12, 821 22, or 821 30.

82109-2 PROPERTY RECORD CARD USAGE. Each heating plant building should be listed on a single, individual property record card. The equipment internal to the power plant should not be listed in this Category code; it should be listed separately on a single separate property record card.

821 12 HEATING PLANT- OIL / GAS (BH)
FAC 8211
BFR Required N

82112-1 DEFINITION. This Category Code is used for a plant that utilizes oil or gas for the production and distribution of heat. This includes steam, hot water, high pressure/low pressure, etc., serving more than one separate facility.
This category code includes all necessary equipment for the production of the commodity including boilers, boiler feedwater, make-up water, controls, compressed air, condensate and blowdown, fuel tanks, pumps, electrical equipment, labs, storage and all required process equipment for commodity generation. The primary unit of measure is plant design capacity in BTU per hour (BH).

82112-2 PROPERTY RECORD CARD USAGE. All equipment for heating plant should be listed on a single, individual property record card. Plants typically contain water treatment facilities as part of the thermal plant and are not reported separately. However, where additional water treatment is required to meet NAVSEA clean steam requirements, the water treatment should be reported separately using Category Code 841 10.

821 22 HEATING PLANT- COAL (BH)
FAC 8211
BFR Required N

82122-1 DEFINITION. This Category Code is used for a plant that utilizes coal for the production and distribution of heat. This includes steam, hot water, high pressure/low pressure, etc., serving more than one separate facility.
This category code includes all necessary equipment for the production of the commodity including boilers, boiler feedwater, make-up water, controls, compressed air, condensate and blowdown, fuel tanks, pumps, electrical equipment, labs, storage and all required process equipment for commodity generation. The primary unit of measure is plant design capacity in BTU per hour (BH).

82122-2 PROPERTY RECORD CARD USAGE. All equipment for heating plant should be listed on a single, individual property record card. Plants typically contain water treatment facilities as part of the thermal plant and are not reported separately. However, where additional water treatment is required to meet NAVSEA clean steam requirements, the water treatment should be reported separately using Category Code 841 10.

821 30 HEATING PLANT- NON - FOSSIL FUEL (BH)

FAC 8211
BFR Required N

This CCN contains assets previously listed in Category Code 821 32 and 821 50.

82130-1 DEFINITION. This Category Code is used for a plant that utilizes a non-fossil fuel for the production and distribution of heat. This includes steam, hot water, high pressure/low pressure, etc., serving more than one separate facility. This category code includes all necessary equipment for production of the commodity including boilers, boiler feedwater, make-up water, controls, compressed air, condensate and blowdown, fuel tanks, pumps, electrical equipment, labs, storage and all required process equipment for commodity generation. The primary unit of measure is plant design capacity in BTU per hour (BH).

NOTE: Geothermal plants should also be listed under this category code.

82130-2 PROPERTY RECORD CARD USAGE. All equipment for heating plant should be listed on a single, individual property record card. Plants typically contain water treatment facilities as part of the thermal plant and are not reported separately. However, where additional water treatment is required to meet NAVSEA clean steam requirements, the water treatment should be reported separately using Category Code 841 10.

821 60 - 821 61 HEATING FUEL OIL STORAGE

82160/82161-1 HEATING FUEL OIL STORAGE. The following criteria pertain to both category codes 821-60 and 821-61. The planning factor is based upon the combined fuel oil consumption at the activity for heating.

82160/82161-1.1 Amount of Storage. The amount of storage varies with the number of personnel attached to the station and the activity. In temperate zones the normal average consumption is 70 gallons per person per month (including civilian employees). This figure would be revised in zones of extreme temperatures. Use this planning factor only if historical data is not available.

Department of Defense policy is that heating plants burning fuel oil must have a minimum of 30 day storage capability based on the coldest 30 day requirement.

Installations that have direct access to and/or are supported directly by major military bulk fuel distribution systems should establish storage requirements based on detailed support agreement with the supply terminal command. Installations that do not have direct access to major fuel distribution systems should investigate logistic support factors (transportation modes; delivery times; precipitation, temperature and weather histories; etc.) to determine if it may be necessary to have storage capability exceeding the 30 day requirements. Activities utilizing fuels for dual purposes (i.e., diesel fuel for heating/transportation) should consider combined consumption when computing storage requirements. Installations should fill all storage tanks by late summer each year in order to reduce cold weather delivery problems, and tanks should be kept as full as possible at all times. This policy has been promulgated by OPNAV Instruction 4100.6 series. Additional justification is necessary for the fuel requirements associated with the generation of steam, operation of power plants, etc. The same 30-day storage requirement is also applicable.

82160/82161-1.1 Types of Oil Stored for Each Category Code. The category codes and corresponding types of oil stored by each facility are as follows:

- Category Code 821-60:

  - Grade No. 1. A light distillate oil intended for use in burners of the vaporizing type in which the oil is converted to a vapor by contact with a heated surface or by radiation. (Includes kerosene and JP-5 aviation turbine fuel).

  - Grade No. 2. A heavier distillate than grade no. 1. It is intended for use in atomizing-type burners which spray the oil into a combustion chamber where the tiny droplets burn while in suspension. The grade of oil is used in most domestic burners and in many medium-capacity commercial industrial burners where its ease of handling and ready availability sometimes justify its higher cost over the residual grade S. (Includes Diesel Marine Fuel (DMF), DF-2 and commercial diesel fuels).

  - Grade No. 3. Usually a light residual but sometimes a heavy distillate. It is intended for use in burners equipped with devices that atomize oils of higher viscosity than domestic burners can handle. Its permissible viscosity range allows it to be pumped and atomized at relatively low storage temperatures. Thus, except in extreme cold weather, it required no preheating for handling.

- Category Code 821-61:

  - Grade No. 4 (light). A residual fuel of intermediate viscosity for burners capable of handling fuel more viscous than grade no. 5 without preheating. Preheating may be necessary in some types of equipment for burning and in colder climates for handling. (Includes Navy Special Fuel Oil (NSFO)).

- Grade No. 5 (heavy). A residual fuel more viscous than grade no. 6 (light). It is intended for similar service. Preheating may be necessary in some types of equipment for burning and in colder climates for handling.

- Grade No. 6. A high-viscosity oil, sometimes referred to as "Bunker C", used mostly in commercial and industrial heating. It requires preheating in the storage tank to permit pumping and additional preheating at the burner to permit atomizing. The extra equipment and maintenance required to handle this fuel usually preclude its use in small installations.

821 60 DISTILLATE HEATING FUEL OIL STORAGE (GA)

FAC 1244
BFR Required N

82160-1 DEFINITION. This Category Code is used for fuel oil tanks used for heating buildings, generation of steam, power plant requirements, and for other heat generating facilities as required. No. 1 fuel oil, No. 2 fuel oil and No. 3 fuel oil are variously referred to as distillate fuel oils. Tanks listed under Category code 821 60 are not day tanks; they are bulk storage for the utility system. The primary unit of measure of gallons (GA).

NOTE: Day tanks are included as part of the plant they serve rather than being reported separately.

82160-2 PROPERTY RECORD CARD USAGE. Each storage tank should be listed on a separate property record card with other unit of measure of total storage capacity of the tank in gallons (GA).

821 61 RESIDUAL HEATING FUEL OIL STORAGE (GA)

FAC 1244
BFR Required N

82161-1 DEFINITION. This Category Code is used for fuel oil tanks used for heating buildings, generation of steam, power plant requirements, and for other heat generating facilities as required. No. 4 fuel oil, No. 5 fuel oil and No. 6 fuel oil are variously referred to as residual fuel oils. Tanks listed under Category code 821 61 are not day tanks; they are bulk storage for the utility system. The primary unit of measure of gallons (GA) and the other unit of measure of storage capacity in gallons (GA) should be entered into iNFADS.

NOTE: Day tanks are included as part of the plant they serve rather than being reported separately.

82160-2 PROPERTY RECORD CARD USAGE. Each storage tank should be listed on a separate property record card with other unit of measure of total storage capacity of the tank in gallons (GA).

822 HEAT TRANSMISSION AND DISTRIBUTION LINES

822-1 HEAT TRANSMISSION AND DISTRIBUTION LINES

This basic category encompasses the transmission and distribution lines for steam and associated hot water lines throughout an installation. In temperate and tropical climates and at locations where the water table is high, steam lines will be aboveground. Routing of steam or hot water lines requiring underground installation under runways and taxiways should be held to a minimum to avoid interference by maintenance and repair operations. Adequate clearances shall be provided above roads, railroads, streets, walks, and tow-ways. Other restrictions such as flight clearances must be maintained. Steam and hot water transmission lines are coded as follows:

822 09 STEAM / HEAT BUILDING / SHELTER (SF)

FAC 8910
BFR Required N

82209-1 DEFINITION. Buildings associated with a heating distribution system (Category Codes 822 12, 822 14, 822 16 or 822 26). The requirement for steam and condensate or hot water pipelines is determined from an engineering study.

82209-2 PROPERTY RECORD CARD USAGE. Each building shall be listed on a single property record card. The equipment contained within the building shall be shown on a separate property record card.

822 10 CONDENSATE RETURN PUMP STATION (EA)

FAC 8924
BFR Required N

82210-1 DEFINITION. A condensate return pump station may serve steam, condensate, hot water, and high temperature water return line pump stations.

82210-2 PROPERTY RECORD CARD USAGE. All pump station equipment and condensate return lines are to be listed on a single property record card. Use the ‘Facility Name’ field to identify the facility as a steam, condensate, hot water or high temperature pump station. If the structure is aboveground, use 'CCN 89009 - Miscellaneous Utility Building' for the pump house building on a separate property record card. If the structure is underground, use 'CCN 89018 – Utility Vault' for the pump house structure (vault) on a separate property record card. Use the ‘Facility Name’ field to identify the building or structure to identify the facility as a steam, condensate, hot water or high temperature pump station building or structure (vault).

822 12 STEAM LINES (LF)
FAC 8221
BFR Required N

This category code contains assets previously listed under CCN 822 22.

82212-1 DEFINITION. This Category Code contains all distribution system pipes that convey steam. The requirement for steam and condensate or hot water pipelines is determined from an engineering study.

82212-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single steam distribution system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation. Each service area of the steam distribution system is considered a linear structure and shall have its own property record card.

822 14 CONDENSATE LINES (LF)
FAC 8221
BFR Required N

This category code contains assets previously listed under CCN 822 24.

82214-1 DEFINITION. This Category Code contains all collection system pipes that convey condensate. The requirement for steam and condensate or hot water pipelines is determined from an engineering study.

82214-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single condensate collection system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation. Each service area of the condensate collection system is considered a linear structure and shall have its own property record card.

822 16 HOT WATER LINES (LF)
FAC 8221
BFR Required N

82216-1 DEFINITION. This Category Code contains all pipes that convey hot water less than 250 degrees. The requirement for steam and condensate or hot water pipelines is determined from an engineering study.

82216-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single hot water system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation. Each service area of the hot water system is considered a linear structure and shall have its own property record card. **Note: Use Category Code 822 14 for condensate lines.**

822 26 HIGH TEMPERATURE HOT WATER LINES (LF)

FAC 8221
BFR Required N

82226-1 DEFINITION. This Category Code contains all pipes that convey hot water heated above 250 degrees. The requirement for steam and condensate or hot water pipelines is determined from an engineering study.

82226-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single high temperature hot water distribution system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation. Each part of the high temperature hot water distribution system is considered a linear structure and shall have its own property record card.

NOTE: Use Category Code 822 14 for condensate lines.

823 HEAT/GAS-SOURCE

823-1 HEAT/ GAS-SOURCE

This basic category includes a central plant for generation of gas and related facilities including connected fuel storage for plant operation and storage of gas for direct heating or as a fuel for central plants. An engineering study is needed to determine the requirements for receipt, storage, distribution and vaporizing capacities of Liquefied Petroleum Gases (LPG). Gas generating and storage facilities are coded as follows:

823 09 GAS GENERATING BUILDING (SF)

FAC 8910
BFR Required N

82309-1 DEFINITION. This Category Code contains buildings associated with a gas generating plant.

82309-2 PROPERTY RECORD CARD USAGE. Each building shall be shown on a separate property record card. The primary unit of measure is square feet.

823 10 GAS GENERATING PLANT (BH)

FAC 8231
BFR Required N

82310-1 DEFINITION. This Category Code contains plant equipment that generates gas for use in the utility system.

82310-2 PROPERTY RECORD CARD USAGE. All equipment in the gas generating plant is included on a single property record card with a facility type code of 4. The buildings that house the gas generating plant equipment is shown on a separate property record card with a Category Code of 82309. The primary unit of measure for a gas generating plant is installed generating capacity in BTUs per hour (BH). The alternate unit of measure is installed generating capacity in cubic feet per minute (CM).

823 15 GAS METER BUILDING (SF)

FAC 8910
BFR Required N

82315-1 DEFINITION. This Category Code contains buildings associated with gas metering.

82315-2 PROPERTY RECORD CARD USAGE. Each building shall be shown on a separate property record card. The primary unit of measure is square feet.

823 20 GAS STORAGE TANKS (CF)

FAC 8232
BFR Required N

82320-1 DEFINITION. This Category Code contains tanks for the storage of liquid natural gas and/or propane connected to a gas distribution system serving multiple facilities.

82309-2 PROPERTY RECORD CARD USAGE. Each tank shall be shown on a separate property record card. The primary unit of measure is each (EA) and the alternate unit of measure is the storage capacity of the tank in cubic feet (CF). Convert gallons to cubic feet by dividing gallons by 7.48.

824 HEAT/GAS TRANSMISSION

824-1 HEAT/ GAS TRANSMISSION.

This basic category applies to exterior lines, mains, and systems for transmission of gas for direct heating or as fuel for central plants.

824 10 GAS MAINS (LF)

FAC 8241
BFR Required N

82410-1 DEFINITION. The planning of gas pipelines includes trenching, piping, valve boxes, controls, and meters. The pipe capacity, strength, and linear footage requirements will be determined by an engineering study.

82410 -2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single gas distribution system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation. Each part of the gas distribution system is considered a linear structure and shall have its own property record card. The unit of measure is length of the pipe in linear feet (LF).

826 REFRIGERATION/AIR CONDITIONING

826-1 REFRIGERATION / AIR CONDITIONING. This category code group is for chilled water and air conditioning plants Exclude cold storage facilities (see Category Code 430 series).

826 10 - 826 40 COOLING SYSTEM PLANTS

82610 THRU 82640-1 COOLING SYSTEM PLANTS. A central refrigeration/air conditioning plant will include buildings with all equipment necessary to make a complete usable facility. If cooling towers are to be used for heat rejection, prevailing winds shall be considered when siting the facilities to avoid problems with moisture drift from the cooling towers, i.e., parking facilities should not be downwind from cooling towers. Vehicle access for equipment maintenance and replacement should be considered. Central plants should be considered when a life cycle cost analysis demonstrate that the owning and operating cost of the plant will be less than that for individual building refrigeration equipment. For planning purposes, central refrigeration/air conditioning plant capacities can be determined by totaling the cooling requirements for all existing and for planned station buildings.

826 10 COOLING SYSTEM PLANT BUILDING (SF)

FAC 8910
BFR Required N

82610-1 DEFINITION. Buildings associated with a cooling system plant (Category Code 826 20).
82610-2 PROPERTY RECORD CARD USAGE. Each building shall be listed on a single property record card. The equipment contained within the building shall be shown on a separate property record card with a category code of 82620.

826 20 COOLING SYSTEM PLANT (TR)

FAC 8261
BFR Required N
This category code contains assets previously listed in CCN 826 25, 826 30, 826 40, and 890 42.

82620-1 DEFINITION. A plant for the production and distribution of a chilled fluid for more than one separate facility.

82620-2 PROPERTY RECORD CARD USAGE. This Category Code includes all the cooling system plant equipment: water systems, electrical systems, chilled water, make-up water, chiller, chiller feedwater, chemical feed, condenser, controls, compressed air, fuel systems, and cooling towers, on a single property record card. The building that houses the cooling system equipment is included on a separate property record card in CCN 826 10. The primary unit of measure is installed cooling system capacity in tons (TR).

827 CHILLED WATER-AIR CONDITIONING TRANSMISSION/DISTRIBUTION

827-1 CHILLED WATER-AIR CONDITIONING TRANSMISSION / DISTRIBUTION.

This basic category encompasses the transmission/distribution of chilled water from a central refrigeration/air conditioning plant to buildings throughout an installation for space air conditioning with water being returned to the plant. Routing of chilled water lines under runways, taxiways, and buildings should be held to a minimum to avoid interference by maintenance and repair operations to the chilled water lines. If lines are located above ground, adequate clearances shall be provided above roads, railroads, walks and tow-ways. Other restrictions such as flight clearance must be considered. See NAVFAC Publication P-80.3. Underground lines have the advantage of reducing undesired heat gains and may not require insulation depending on ground temperatures.

827 10 COOLING SYSTEM VALVE BUILDING (SF)

FAC 8910
BFR Required N

82710-1 DEFINITION. Buildings associated with a cooling distribution system (Category Code 827 20).

82710-2 PROPERTY RECORD CARD USAGE. Each building shall be listed on a single property record card. The equipment contained within the building shall be shown on a separate property record card.

827 20 CHILLED FLUID LINES (LF)

FAC 8271
BFR Required N

This Category Code includes assets previously contained in CCN 827 25.

82720-1 DEFINITION. All distribution system pipes that convey chilled fluid.

82720-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single chilled fluid distribution system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation. Each part of the chilled fluid distribution system that is considered a service area is a linear structure and shall have its own property record card. The unit of measure is length of piping in linear feet (LF).

830 SEWAGE AND WASTE

830-1 DEFINITION

Category group 830 describes the facilities required for the collection, transportation, treatment, and disposal of sewage and industrial waste, and disposal of storm drainage water in storm and sanitary sewer systems. Components of sewage and refuse facilities include sewage treatment plants, outfall sewer lines, septic tanks, septic tank drain fields, sanitary sewers, sewage pumping stations, and incinerators. Certain industrial waste must be kept separately and treated separately from the sanitary sewage. In planning for sewage and waste facilities cognizance shall be taken of the Federal Water Pollution Control Act as amended, applicable to municipalities, industries, and others that may contribute to the pollution of surface and underground waters in the United States.

831 SEWAGE AND INDUSTRIAL WASTE, TREATMENT AND DISPOSAL

831/83109/83110-1 DEFINITION

The preferred method of sewage disposal is by discharge to a municipal or regional sewage system. Where this is not feasible, an on-station sanitary sewage treatment plant will be necessary to provide for the processing of sanitary sewage for ultimate disposal. Disposal of sewage is usually in a stream or other body of water or on land by subsurface irrigation or by direct absorption into the soil. A sewage treatment plant may include aeration tanks or trickling filters, settling basins, sump or storage wells, dry wells, pumps, screens, and accessories. The type and capacity of sewage treatment plant is determined by an engineering study that considers planned population, number of family quarters, and industrial peak loads.

831 09 SEWAGE TREATMENT BUILDING (SF)
FAC 8910
BFR Required N

83109-1 DEFINITION. This Category Code includes the buildings associated with the sewage treatment plant (Category Code 831 10).

83109-2 PROPERTY RECORD CARD USAGE. Each building shall be included on a single property record card. The equipment contained within the building shall be shown a separate property record card.

831 10 SEWAGE TREATMENT PLANT (KG)
FAC 8311
BFR Required N

83110-1 DEFINITION. This category code is used for all type of sewage treatment plants; primary, secondary, or tertiary. Please identify the level of treatment in Facility Use/ Description. All the plant equipment; equalization, preliminary treatment, clarification, holding tanks, biological treatment, chemical treatment, filtration, disinfection, dewatering, digestion, sludge disposal, electrical system, controls, compressed air, storage, and communications, is included as a single wastewater treatment plant. The primary unit of measure is the installed plant processing capacity in thousands of gallons per day (KG). Do not use the permitted capacity for the units of measure.

83110-2 PROPERTY RECORD CARD USAGE. This category code includes all the sewage treatment plant process equipment on a single property record card. The buildings (not tanks) that house the sewage treatment equipment are shown on separate property record cards with Category Code 831 09.

831 11 - 831 16 SPECIALIZED TREATMENT FACILITIES

831 11 BALLAST CONTAMINATION SKIMMER (KG)
FAC 8313
BFR Required N

No criteria are currently available for this Category Code.

831 14 INDUSTRIAL WASTEWATER TREATMENT BUILDING (SF)
FAC 8910
BFR Required N

83114-1 DEFINITION. This category code is used for buildings associated with an industrial wastewater treatment plant (Category Code 831 15).

83114-2 PROPERTY RECORD CARD USAGE. Each building shall be included on a separate property record card. The equipment contained within the building shall be shown on a separate property record card using Category Code 831 15.

831 15 INDUSTRIAL WASTEWATER TREATMENT FACILITY (KG)

FAC 8312
BFR Required N

83115-1 DEFINITION. This Category Code is used for a dedicated industrial wastewater treatment plant. All plant equipment: equalization, preliminary treatment, clarification, holding tanks, biological treatment, chemical treatment, filtration, disinfection, dewatering, digestion, sludge disposal, electrical system, controls, compressed air, storage, and communications, is included as a single wastewater treatment plant. The primary unit of measure is the installed processing capacity of the plant in thousands of gallons per day (KG). Do not use the permitted capacity as the unit of measure.

83115-2 PROPERTY RECORD CARD USAGE. This Category Code includes all the industrial wastewater treatment plant equipment on a single property record card. The buildings (not tanks) that house the industrial wastewater treatment equipment is included on separate property record cards with Category Code 831 14.

831 16 OIL/WATER SEPARATOR (KG)

FAC 8313
BFR Required N

83116-1 DEFINITION. This Category Code is used for oil/water separators that discharge to the sanitary sewer or industrial waste collection system. The primary unit of measure is the installed processing capacity of the equipment in thousands of gallons per day (KG).

83116-2 PROPERTY RECORD CARD USAGE. This category code is used for oil/water separators that discharge to the sanitary sewer or industrial waste collection system. Oil/water separators belong to the facility which it serves. If the oil/water separator discharges to storm sewer, it should be included under Category Code 871 11.

831 20 OUTFALL SEWER LINE (KG)

FAC 8321
BFR Required N

83120-1 DEFINITION. An outfall sanitary sewer line receives the sewage from a collecting system or the effluent from a sanitary sewage plant and carries it to a point of final discharge. Planning for outfall sewer lines will include land acquisition. The primary unit of measure is the capacity of the pipe in thousands of gallons per day (KG).

83116-2 PROPERTY RECORD CARD USAGE. A separate property record card for all the piping for each wastewater treatment plant shall be created.

831 30 SEPTIC TANK AND DRAIN FIELD (GA)
FAC 8314
BFR Required N

83130-1 DEFINITION. A septic tank and drain field facility provides sewage treatment for human waste at isolated facilities where an extension of the central sewer collection system would not be economically feasible. The planning of a septic tank and drain field will include a concrete or protected steel tank and a drain field system including headers, laterals, open joint clay or concrete pipe, gravel, ditching, and land acquisition. The primary unit of measure is tank capacity in gallons per day (GA).

83130-2 PROPERTY RECORD CARD USAGE. If these assets support a single facility, they are considered RPIE of the facility that they serve and a separate property record card should not be created. Where multiple facilities are served with a single tank and drain field a separate property record card shall be created.

831 31 SEPTIC LAGOON AND / OR SETTLEMENT POND (GA)
FAC 8315
BFR Required N

83131-1 DEFINITION. A structure used for collecting and holding sewage to allow for settlement and evaporation. These structures are typically concrete encased. If the lagoon or pond is part of a wastewater treatment or power generation plant, the structure is considered part of the plant and is not listed separately.

83131-2 PROPERTY RECORD CARD USAGE. A separate property record card shall be created for each lagoon or pond.

831 39 RADIOACTIVE WASTE HANDLING BUILDING (SF)
FAC 8910
BFR Required N

831 40 RADIOACTIVE WASTE HANDLING FACILITY (EA)
FAC 8926
BFR Required N

83139/83140-1 DEFINITION. No planning criteria for Category Codes 831 39 and 40 are currently available. Each facility requires individual justification.

831 41 HAZARDOUS WASTE STORAGE AND TRANSFER FACILITY (EA)

FAC 8926
BFR Required N

83141-1 DEFINITION. Use this category code for facilities that are structures (non-buildings). For hazardous waste facilities that are buildings, use category code 83143 “Hazardous Waste Storage Building”. The requirement for this facility is the result of the necessity to ensure that the transfer and storage of hazardous wastes will meet the Federal Criteria mandated by Title 40 of the Code of Federal Regulations (CFR), Parts 260 thru 266 as well as complying with OPNAVINST 6240,3 Series, which implements the requirements of the Resource Conservation and Recovery Act (PL 94-580) (42 USC 6901-6987), the Clean Water Act (PL 92-500), and the Navy Hazardous Materials Environmental Management Program by expanding controls on hazardous materials management in order to protect the environment. It is the intent of Congress and the Policy of the President (Executive Order 12088) that naval activities comply with these requirements to the same extent as any other entity or person.
Hazardous waste is any substance that cannot legally be disposed of in a normal sanitary landfill or into a refuse incinerator designated to handle municipal type refuse or cannot be discharged into a sanitary sewerage system. This facility is not intended to handle certain hazardous materials such as radioactive or ordnance wastes, for which other category codes have been designated. Any hazardous material can become a waste after having served its intended purpose, after exceeding its shelf life, by becoming contaminated, or by having been spilled. However, hazardous materials that have served a primary purpose and/or are excess to their primary user may have a secondary use. Such recyclable materials, though "excess" or "waste" to one organization, are not considered waste if their disposition is to a secondary user. By elimination, a hazardous waste is a non-reusable material that must be treated and/or disposed of in a specially designated facility that meets the regulatory requirements of the Resource Conservation and Recovery Act (RCRA) of 1976 (PL 94-580). It might be noted that sludge generated from treatment facilities may also be hazardous wastes.

83141-2 FACILITY TYPES. There are basically two types of facilities to handle hazardous waste 1) a short-term storage facility where materials are stored for periods of less than 90 days and 2) a long term storage facility where materials are stored for more than 90 days. The short-term facility does not require a permit to operate but is required to meet all packaging and labeling requirements and to date the receipt of hazardous wastes. The requirements for short-term facilities are given in 40 CFR 262.34. The long-term facility is subject to the requirements of 40 CFR, parts 264 and 265 and the permit requirements of 40 CFR, part 122.

83141-3 DESIGN REQUIREMENTS. The design requirements are found in UFC 3-201-01. It has been assumed that covered storage will be required to minimize the run-off from the facility and that the run-off will be packaged. In climate where runoff will not create a problem, open storage is acceptable and category code 831-41, Hazardous Waste Storage Area, may be used. The modification of existing facilities is an acceptable alternative to the construction of new facilities.

83141-4 SQUARE FOOTAGE REQUIREMENTS. The square footage requirements for this facility are directly related to the Hazardous Waste Management Plan that must be filed by every identified activity handling this type of material in accordance with OPNAVINST 6240. This plan must indicate the type of hazardous waste collected, the rate of accumulation, and the frequency of movement from the activity in accordance with prescribed procedures. The selection of a short-term facility vs. a long-term facility is dependent upon the permits requested by the activity for the disposal of said waste.

83141-5 PLANNING PREPARATION. Prior to planning and establishing hazardous waste storage and transfer facilities, any actions must be cleared with the cognizant NAVFAC FEC which has the responsibility for area-wide coordination of the Navy Hazardous Materials Environmental Management program.

83141-6 SITING. A buffer zone of 150 meters (500 feet) shall be provided between the facility and the nearest inhabited area, stream, body of water, or critical mission areas such as ammunition, POL, or flammable stores.

83141-7 SPACE ALLOCATIONS FOR OTHER FUNCTIONS. Provide space for the following types of functions: laboratory, operation room office/lunchroom, enclosed loading dock and storage for the following kinds of waste: reactive, unknown, acid, general, organic, oxidizer and caustic.

831 42 HAZARDOUS WASTE STORAGE AREA (SY)

FAC 8526
BFR Required N

83142-1 DEFINITION. The requirements for this facility are similar to those for category code 831 41 Hazardous Waste Storage and Transfer Facility. This type of storage facility is acceptable in climates where run-off will not create a problem. A buffer zone of 150 meters (500 feet) shall be provided between this facility and the nearest inhabited area, stream, body of water, or critical mission area such as ammunition, POL and inflammable stores.

However, this facility may be located in the proximity of the Hazardous Waste Storage and Transfer Facility when it is used to augment it.

83142-2 SEGREGATION OF MATERIAL. The danger involved in the storage of hazardous material are not measured solely by the quantity of material stored, but also by its sensitivity to reaction with one type of material with another.

83142-3 PLANNING PROCEDURES:

1. Determine the number and types of hazardous waste to be stored and their compatibility.
2. Determine rate of accumulation by past records.
3. Determine length of storage required (i.e. less than 90 days, etc.).
4. Items 1, 2 and 3 determine maximum number of drums to be stored at any given time. Note: Not all drums will be filled and sometimes more than one drum will be required for any given type of waste.
5. Criteria: Use 2.1 gross square yards per drum stored when each 55 gallon drum is stored in clusters of 4 per pallet or area.

Example: Given: 24 drums in six clusters, four per cluster.
Solution: A typical layout for this type of facility would be a concrete pad 23.0 ft. long and 19.5 ft. wide. An 8.0 ft. access aisle in the middle of the 19.5 ft. wide pad would provide room for the forklift truck to deposit and retrieve pallets, which are orientated at a 45 degree angle to the aisle. Each four foot square pallet would support four drums, and the apex of each pallet would be three feet from the adjacent pallet. The centerline of the aisle would also serve as the high point of the slab so that any accidental spillage of the waste would not react with any of the surrounding material.

831 43 HAZARDOUS WASTE STORAGE BUILDING (SF)

FAC 4423
BFR Required Y

83143-1 DEFINITION. Use this category code for facilities that are buildings used for hazardous waste storage (non-structures). For hazardous waste facilities that are structures, use category code 83141 “Hazardous Waste Storage and Transfer Facility”. Use the information found under CCN 83141, sections 83141-1 through 83141-8 to develop space requirements.

832 SEWAGE AND INDUSTRIAL WASTE - COLLECTION

832-1 DEFINITION

This basic category includes collection systems and lines including pumping stations for sewage and industrial waste and collection of storm drainage. Planning for the sanitary sewer system will include piping, fittings, pumps, lift stations, and accessories. A sanitary sewer collection system will be required at all Naval installations, and it will be based primarily on the population. The requirements will be determined by an engineering survey.

832 10 SANITARY SEWER LINE (LF)

FAC 8321
BFR Required N

83210-1 DEFINITION. All distribution system pipes that collect and transport sanitary sewage. Types include gravity or forced main systems. The primary unit of measure is linear feet of pipe (LF).

83210-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single sanitary sewer collection system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation process. Each part of the sanitary sewer collection system is considered a linear structure and shall have its own property record card.

832 20 COMBINED SEWER LINE (LF)

FAC 8321
BFR Required N

83220-1 DEFINITION. All distribution pipes that collect and transport both sanitary sewage and storm water. The primary unit of measure is linear feet of pipe (LF).
83220-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single combined sewer collection system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation process. Each part of the combined sewer collection system is considered a linear structure and shall have its own property record card.

832 29 SEWAGE PUMP STATION BUILDING (SF)

FAC 8910
BFR Required N

83229-1 DEFINITION. Buildings associated with a sewage pump station. The primary unit of measure is square feet (SF).

83229-2 PROPERTY RECORD CARD USAGE. Each pump station building shall be shown on a separate property record card. The equipment inside the pump station shall be shown on a separate property record card with a Category Code of 83230.

832 30 SEWAGE WASTE PUMPING STATION (KG)

FAC 8316
BFR Required N

83230-1 DEFINITION. A sewage pumping station is a facility used to move sewage through mains to a treatment plant, to serve where a gravity system is not feasible, and/or to lift sewage from one level to another in a gravity system. A sewage pumping station will include at least a sump or storage well and other pumping equipment, automatic controls, and hose equipment for cleaning the tanks. The primary unit of measure is pump station capacity "Thousand Gallons per Day" (KG). Use Category Code 832 30 for all sewage pump stations.

83230-2 PROPERTY RECORD CARD USAGE.
Any lift station associated with a single building, either inside the basement of the building or just outside the foundation of the building, should be considered RPIE to the building. Any lift station serving multiple facilities is considered part of an installation utility sewage or storm drainage system and shall be shown on a separate property record card. Include the building that houses the equipment for sewage pump stations on a separate property record card under Category Code 832 29.

832 40 INDUSTRIAL WASTEWATER LINE (LF)

FAC 8321
BFR Required N

83240-1 DEFINITION. This Category Code includes all distribution system pipes that collect and transport industrial wastewater. Types include gravity or forced main. The primary unit of measure is linear feet of piping (LF).

83240-1 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single industrial wastewater collection system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation process. Each part of the industrial wastewater collection system that is considered a service area is considered a linear structure and shall have its own property record card.

832 41 INDUSTRIAL WASTEWATER PUMP STATION (EA)

FAC 8316
BFR Required N

83241-1 DEFINITION. Industrial wastewater pump stations are required to transport waste streams to holding tanks or industrial waste treatment plants, to serve where a gravity system is not feasible, and/or to lift waste streams from one level to another in a gravity system. The waste streams result from shore-based activities such as plating operations, painting and stripping operations, degreasing operations, firefighting schools and similar industrial processes.
Industrial process waste streams may contain both standard wastes and toxic pollutants. Typical pollutants found in industrial wastewater are oils, greases, heavy metals, acids, alkalis, non-metallic materials (such as arsenic or selenium), phenols and halogenated phenols, paint stripping agents, solvents, surfactants, and degreasers.
An industrial wastewater pumping station will include at least a sump or storage well and a structure to house pumping equipment, automatic controls, and hose facilities for cleaning the tanks. Where space is available, the lift station should include a ships ladder. The capacities and other requirements for industrial wastewater pump stations

will be determined by an engineering survey.

NOTE: Pump Stations supporting Oily Water/Waste Oil (OWWO) discharges and Ship's Overboard Discharge (SOD) operations from naval vessels should also be listed under CCN 83241.

83241-2 PROPERTY RECORD CARD USAGE. All pump station equipment is listed on a single property record card. If the pump station supports OWWO operations, use the 'Facility Name' field to identify the facility as an OWWO Pump Station. For the building component which houses the pump station equipment, use 'CCN 89009 - Miscellaneous Utility Building' and modify the "Facility Name" field to identify the facility as an Industrial Wastewater or OWWO Pump Station Building.

833 SOLID WASTE MANAGEMENT

833-1 DEFINITION OF SOLID WASTE

The term "solid waste" used here is defined as non-hazardous solid waste. For the incinerator and landfill functions and possibly others listed below, the historical tonnage generation data is a necessity to determine accurate facility requirements. If the historical tonnage data cannot be determined, estimates can be developed from:

a) Population: estimates the tonnage generated based upon the population served.
b) Land use factors: estimates tonnage based upon the type and quantity of facilities served.

These factors can be found in solid waste textbooks or from the EPA or other regulators.

833 09 INCINERATOR BUILDING AND INCINERATOR (TN)

FAC 8332
BFR Required N

83309-1 DEFINITION. An incinerator building is associated with an incinerator. An incinerator is a facility for burning combustible refuse to reduce it to stable gases and inert solids. An incinerator structure not associated with a building must be permanently attached in place to be considered real property. See Category Code 833 10 for information about an exterior incinerator.

833 10 INCINERATOR - EXTERIOR (TN)

FAC 8332
BFR Required N

83309/83310-1 DEFINITION. An incinerator is a facility for burning combustible refuse to reduce it to stable gases and inert solids. An incinerator may be justified when the refuse of the Naval installation cannot be disposed of in a sanitary fill; when such method of disposal would create an unhealthy condition or nuisance and the land is not available for such purposes; when local municipal facilities or other Government facilities for disposal are not suitable or available at reasonable prices; or when contract prices for collection and disposal of refuse are economically excessive as opposed to collection and disposal by station personnel. Incinerator capacity will not exceed the capacities listed for applicable populations.

Table 83309/83310-1. Incinerator Capacities

Population (military-civilian residing on station)	Incinerator capacity (tons per 8 hr day)
up to 2,000	5
2,001 to 4,000	10
4,001 to 6,000	15
6,001 to 8,000	20
8,001 to 10,000	25

The capacities, as shown, include 25 percent excess over average hourly needs to allow for irregularity in delivery of refuse to the incinerator. The planner should consider the merits of the dump and charge method where the refuse may be stored for periodic regular burning with resultant economy of operation.

833 12 REFUSE/SOLID WASTE COLLECTION FACILITY – NON HAZARDOUS (SF)

FAC 8331
BFR Required N

83312-1 DEFINITION. This facility serves as the collection center for non-hazardous solid waste awaiting disposal.

833 15 SANITARY/CUT-FILL DISPOSAL AREA (EA)

FAC 8333
BFR Required N

83315-1 DEFINITION. Landfilling solid waste is the technology of last resort. Consult EPA and State regulations and the latest solid waste textbooks for engineering principles and practices in siting and scoping a landfill. Because of the large land requirements associated with a landfill, consider the size of the landfill first.

833 20 GARBAGE GRINDER BUILDING (SF)

FAC 8330
BFR Required N

83320-1 DEFINITION. A building used for the collection of refuse or recyclable materials before they are processed for disposal or recycling.

833 21 GARBAGE GRINDER (TN)

FAC 8331
BFR Required N

833 30 GARBAGE STAND (EA)

FAC 8526
BFR Required N

833 40 GARBAGE HOUSE/RECYCLE CENTER BUILDING (SF)

FAC 8910
BFR Required N

83320/83321/83330/83340-1 DEFINITIONS. No planning criteria for Category Codes 833 20 through 833 40 are currently available. Each facility requires individual justification.

840 WATER FACILITIES

840-1 DEFINITION.

Water facilities at naval installations provide potable water for domestic and industrial use; purification of raw water from deep wells, lakes, and rivers; storage of water in bulk storage tanks or reservoirs; and distribution of water to demand areas. The location of the supply sources may be determined by topographic maps, soil maps, climate data, and geologic surveys. The selection of water sources must be consistent with economic considerations, such as gravity delivery if possible. Separate nonportable water fire protective systems may be provided where applicable.

Planning information is provided for the following facility groups:

- Code 841 Potable Water - Supply, Treatment, and Storage
- Code 842 Water Distribution System - Potable
- Code 843 Water - Fire Protection

- Code 844 Water Supply/Storage – Nonpotable
- Code 845 Water Distribution System – Nonpotable

841 POTABLE WATER - SUPPLY, TREATMENT, AND STORAGE

841-1 DEFINITION

Planning for the treatment of water will include, as applicable, screening, settling, coagulation and sedimentation, filtration, disinfection, softening, and aeration. The water treatment systems are normally planned in millions of gallons (MG) per day capacity and distribution is in linear feet (LF). The systems must be adequate to meet the domestic and industrial requirements and to provide fire protection if a separate fire protection system is not provided. If separate nonpotable water protective systems are not provided, the capacity of the water supply system will be determined by the fire flow demand (see Code 843). Planning requirements for water treatment facilities will be based on the results of an engineering survey and an economic analysis to determined sources of water versus commercial or municipal supply. For water treatment methods see MIL HDBK-1005/7.

841 09 WATER TREATMENT FACILITY BUILDING (SF)

FAC 8910
BFR Required N

84109-1 DEFINITION. This Category Code includes buildings associated with a Water Treatment Plant (841 10), Desalinization Plant (841 25), or Wells - Potable Water (841 50).

84109-2 PROPERTY RECORD CARD USAGE. Each building shall be included on a single property record card. The equipment contained within the building shall be shown a separate property record card.

841 10 WATER TREATMENT PLANT - POTABLE (KG)

FAC 8412
BFR Required N

84110-1 DEFINITION. This Category Code includes the structures, equipment, and processes required to treat potable water.

84110-2 PROPERTY RECORD CARD USAGE. All the water treatment plant equipment; clear wells, preliminary treatment, coagulation flocculation, sedimentation, adsorption, filtration, chemical treatment and storage, disinfection, electrical, water and compressed air systems, controls, and communication, is included on a single property record card. The Unit of Measure is installed capacity in thousands of gallons per day (KG). Use CCN 841-09 in conjunction with CCN 841-10 to capture the both the treatment plant and the associated building on separate property record cards.

841 15 NUCLEAR REACTOR WATER TREATMENT FACILITY (KG)

FAC 8412
BFR Required N

84115-1 DEFINITION. No criteria for this facility are currently available.

841 20 WATER SUPPLY LINE (LF)

FAC 8421
BFR Required N

84120-1 DEFINITION. The pipe that conveys water from source to point of treatment or to the point of consumption. A pressure main will be needed if the water is pumped. However, if topography permits, a gravity system is planned. A twin conduit may be used to insure uninterrupted water supply. The unit of measure is linear feet of each pipe.

84120-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single water supply system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation process. Each part of the water supply system that is considered a linear structure shall have its own property record card.

841 25 DESALINIZATION PLANT (KG)

FAC 8415
BFR Required N

84125-1 DEFINITION. A water treatment plant that utilizes a process, such as distillation, reverse osmosis, or electro dialysis, that removes dissolved mineral salts and other dissolved solids from water. The primary unit of measure is installed capacity of the plant in thousands of gallons per day (KG).

84125-2 PROPERTY RECORD CARD USAGE. All the equipment involved in the desalination process; clear wells, preliminary treatment, coagulation flocculation, sedimentation, adsorption, filtration, chemical treatment and storage, disinfection, electrical, water and compressed air systems, controls and communication, is included on a single property record card.

841 30 STORAGE TANKS - ELEVATED, POTABLE (GA)

FAC 8413
BFR Required N

841 40 STORAGE TANKS - GROUND LEVEL, POTABLE (GA)
FAC 8413
BFR Required N

83130/84140-1 DEFINITION. Water storage tanks for potable water are elevated or ground-level structures used to store bulk quantities of potable water. Elevated tanks for potable water provide both storage and static pressure for the distribution system. Ground-level tanks accommodate peak demand requirements without affecting the capability of the source. The planning for potable water storage tanks will be based on the requirements determined by an engineering survey. These surveys will determine the capacities and pressures required for the water system. Elevated tanks will not be planned in the immediate vicinity of an airfield. Water uses which must be considered in estimating potable water requirements for shore installations are (a) domestic, (b) industrial, and (c) fire protection.

84130/84140 – 2 PROPERTY RECORD CARD USAGE. Water storage tanks located at the water treatment facility that are part of the plant process are included with the water treatment facility (841 10) and are not classified as separate real property. Water storage tanks that are considered part of the distribution system shall be listed on individual property record cards. The unit of measure is rated storage capacity of the tank in gallons (GA).

841 50 WATER WELLS - POTABLE (KG)
FAC 8414
BFR Required N

84150-1 DEFINITION. Equipment that pumps water from underground sources to treatments plants or directly to distribution with minor treatment possibly injected. The building that houses the well equipment shall be listed on a separate property record card utilizing category code 841 09. The primary unit of measure is well capacity in thousands of gallons per day (KG) and the alternate unit of measure - installed capacity in gallons per minute (GM) shall both be included on the property record card.

84150-2 PROPERTY RECORD CARD USAGE - All equipment associated with a single well shall be shown on an individual property record card. Each well shall be shown on a separate property record card.

841 51 RESERVOIR - POTABLE WATER (MG)
FAC 8443
BFR Required N

84151-1 DEFINITION. An open body of water for the collection and storage of water used by a water treatment facility or water distribution system. The Unit of Measure is reservoir capacity in millions of gallons (MG)

84151-2 PROPERTY RECORD CARD USAGE – Each reservoir shall be shown on a separate property record card.

841 52 WATER CATCHMENT STRUCTURE (GA)
FAC 8442
BFR Required N

84152-1 DEFINITION. A man-made structure designed to capture or collect rainwater and used to produce potable water. The primary unit of measure is linear feet around the structure (LF).

84151-2 PROPERTY RECORD CARD USAGE – Each structure shall be shown on a separate property record card.

842 WATER DISTRIBUTION SYSTEM, POTABLE

84209/84210-1 DEFINITION. Potable water will be transmitted from a storage tank or a treatment plant to all station demand points through a pipeline. An engineering study of the pressures and quantities of water required at the demand points will serve as the basis for planning the sizes and lengths of pipe required for the water distribution pipelines. Planning for a potable water distribution pipeline will include requirements for piping, valves, pumps, connections, excavation, and backfilling. The pipeline shall be listed in linear feet (LF). Requirements will be determined by an engineering study.

842 09 WATER DISTRIBUTION BUILDING, POTABLE (SF)
FAC 8910
BFR Required N

84209-1 DEFINITION. This Category Code includes buildings associated with the distribution of potable water, typically housing distribution pumps and equipment.

84209-2 PROPERTY RECORD CARD USAGE – Each building shall be included on a single property record card. The equipment contained within the building shall be shown on a separate property record card using category code 842 15.

842 10 WATER DISTRIBUTION LINE, POTABLE (LF)
FAC 8421
BFR Required N

84210-2 DEFINITION. All pipes that convey potable water from the treatment plant to the end user. The primary unit of measure is linear feet of pipe (LF).

84210-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single water distribution system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation process.

Each part of the water distribution system that is considered a linear structure shall have its own property record card.

842 15 PUMP STATION - POTABLE WATER (KG)

FAC 8422
BFR Required N

84215-1 DEFINITION. This category code will include the pump(s) and appurtenant piping, valves, and other mechanical and electrical equipment for pumping water in the potable water system. The primary unit of measure is installed pumping capacity of the station in thousands of gallons per day (KG) and the alternate unit of measure is the installed pumping capacity of the station in gallons per minute (GM) .

84215-2 PROPERTY RECORD CARD USAGE. All equipment in a single pump station is contained on one property record card.

843 WATER, FIRE PROTECTION

843-1 DEFINITION. Fire protection requirements often dominate the plans of a water supply system. When the supply of fresh water is not adequate, salt water may be used. Since fire flow demands are usually greater than either the domestic or industrial demands, the capacity of the system will generally be determined by the fire flow demands. Fire flows are expressed in gallons per minute and are separate from the other water requirements.

Normal fire flow demands are as follows:

843-1.1 Dwellings. The fire flow requirements for residential areas shall be as follows:

Individual and duplex units--1 story--500 gallons per minute
Individual and duplex units--2 stories--750 gallons per minute
Multifamily (3 or more) units--1 story--750 gallons per minute
Multifamily (3 or more) units--2 stories --1,000 gallons per minute

843-1.2 Light and Ordinary Hazards. In both light and ordinary hazard areas, the fire flow requirements for both hose streams and automatic sprinkler systems shall be as indicated in the table below.

Table 843-1
Fire Flow Requirements (Gallons Per Minute)

Height and Area (Sq Ft)	Unsprinkered		Sprinklered				
	Hose Streams		Hose Streams		Sprinkler Demand	Total	
	Fire Resistive, N.C. (Masonry) Ordinary, and Heavy Timber	Frame, N.C. (All Metal)	Fire Resistive, N.C. (Masonry) Ordinary, and Heavy Timber	Frame, N.C. (All Metal)		Fire Resistive, N.C. (Masonry) Ordinary, and Heavy Timber	Frame, N.C. (All Metal)
1 Story							
0-10,000	750	1,250	250	250	500	750	750
10,000-20,000	1,000	1,750	250	250	750	1,000	1,000
20,000-80,000	1,250	2,500	250	500	1,000	1,250	1,500
Multistory							
0-10,000	1,000	2,000	250	500	500	750	1,000
10,000-20,000	1,250	2,500	250	500	750	750	1,250
20,000-80,000	1,750	3,000	300	750	1,000	1,500	1,750

Notes:
1. All one-story buildings above 20 feet in height shall be classified as multistory.
2. Flows for hose streams shall be provided at 20 psi residual pressure.
3. Sprinkler demand requirements shall be based on a residual pressure at grade to provide a minimum pressure of 15 psi at the highest sprinkler.
4. In unsprinklered one-story buildings, less than 1,000 square feet ground floor area, hose streams requirement of 500 gallons per minute (gpm) generally will be satisfactory.

843-1.3 Special Areas. If the source demands are for a combination system, then it must be of sufficient capacity to provide for the domestic, industrial, and fire flow requirements simultaneously. If the source of supply is unreliable, a storage system may be justified. Normally the most practical facility is the ground-level reservoir. Water storage requirements for fire protection are as listed in the following table

Table 843-2
Water Storage Requirements For Fire Protection

Fire Flow Demands (gallons per minute)	Storage Requirements (hours)	Storage Requirements (gallons)
up to 750	1-1 ½	66,500
up to 1,250	2	150,000
up to 1,750	2	210,000
up to 2,250	2-2 ½	338,000
up to 3,000	3	540,000
over 3,000	4	960,000

843 10 FIRE PROTECTION LINES (LF)
FAC 8432
BFR Required N

84310-1 DEFINITION. Fire protection pipelines are used exclusively in the transmission of water for fire protection, not domestic use. Planning for protection pipelines includes hydrants, valves, connections, pumps, piping, excavating, and backfill. The primary unit of measure is linear feet of pipe (LF).

84310-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single water distribution system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation process. Each part of the water distribution system that is considered a linear structure shall have its own property record card.

843 20 FIRE PROTECTION PUMP STATION (KG)
FAC 8434
BFR Required N

84320-1 DEFINITION. A fire protection pumping station is a collection of pumps and supporting equipment used to increase the pressure in the fire protection system.

84310-2 PROPERTY RECORD CARD USAGE. All equipment in a single pump station is contained on one property record card. The building that houses the equipment shall be listed on a separate property record card using Category Code 843 50.

843 30 WATER STORAGE TANK - FIRE PROTECTION WATER (MG)
FAC 8435
BFR Required N

84330-1 DEFINITION. Tanks that provide fire protection water storage to accommodate peak demand requirements. The primary unit of measure is tank capacity in millions of gallons (MG) and the alternate unit of measure is tank capacity in gallons (GA).

84330-2 PROPERTY RECORD CARD USAGE – Each tank shall be shown on a separate property record card.

843 35 RESERVOIRS - FIRE PROTECTION WATER (MG)
FAC 8433
BFR Required N

84335-1 DEFINITION. This Category Code is for a reservoir that has a capacity greater than or equal to one million gallons and typically provides water reserves to insure an uninterrupted flow for fire protection. The primary unit of measure denoting reservoir capacity is millions of gallons (MG).

84335-2 PROPERTY RECORD CARD USAGE – Each reservoir shall be shown on a separate property record card.

843 40 WELLS - FIRE PROTECTION WATER (GM)

FAC 8431
BFR Required N

84340-1 DEFINITION. This Category Code is for equipment that pumps water from underground sources to the fire protection system. The primary unit of measure is well capacity in gallons per minute (GM). The building that houses the well equipment shall be shown on a separate property record card utilizing Category Code 843 50.

84340-2 PROPERTY RECORD CARD USAGE – Each well shall be shown on a separate property record card.

843 50 FIRE PROTECTION BUILDING (SF)

FAC 8910
BFR Required N

84350-1 DEFINITION. This Category Code includes buildings associated with the distribution of fire protection water, typically housing distribution pumps and equipment.

84350-2 PROPERTY RECORD CARD USAGE. Each building shall be included on a single property record card. The equipment contained within the building shall be shown a separate property record card using Category Code 843 20.

844 WATER SUPPLY/STORAGE, NONPOTABLE WATER

844-1 DEFINITION

The water from these facilities will be used primarily for industrial purposes or as an emergency supply should there be a failure of the principal source. When a requirement for nonpotable water source exists, firefighting water requirements usually will be combined with this group. Requirements for this facility group are similar to that for Category Group 841 and 843. The Category Group 844 contains the following individual codes:

844 10 WATER DISTRIBUTION BUILDING, NONPOTABLE WATER (SF)

FAC 8910
BFR Required N

Note: This Category Code contains assets that were previously listed in CCN 845 10.

84410-1 DEFINITION. This Category Code includes all buildings associated with the supply or distribution of non-potable water, typically housing distribution pumps and equipment. All former property record cards with category code 845 10 should be listed using this category code number.

84410-2 PROPERTY RECORD CARD USAGE. Each building shall be included on a single property record card. The equipment contained within the building shall be shown a separate property record card using category code 844 30 or 844 20.

844 20 WATER WELL (KG)

FAC 8414
BFR Required N

84420-1 DEFINITION. This Category Code includes equipment that pumps water from underground sources to a dedicated water distribution system, either potable or non-potable. The primary unit of measure is well capacity in thousands of gallons per day (KG).

84420-2 PROPERTY RECORD CARD USAGE. Each well and associated equipment shall be included on a single property record card with a facility type code of 4. The building that houses that houses the equipment shall be shown on a separate property record card using category code 844 10.

844 30 PUMP STATION - NONPOTABLE WATER (KG)

FAC 8452
BFR Required N
This Category code contains assets that were previously shown in 845 30.

84430-1 DEFINITION. This Category Code includes the collection of pumps and supporting equipment used to supply water to the non-potable water system. The primary unit of measure is the installed pumping capacity of the station in thousands of gallons per day (KG).

84430-2 PROPERTY RECORD CARD USAGE. The equipment in a single pump station is contained on a single property record card. The building that houses the equipment shall be listed on a separate property record card using Category Code 844 10.

844 40 STORAGE TANKS - NONPOTABLE WATER (GA)
FAC 8442
BFR Required N

84440-1 DEFINITION. This Category Code includes tanks that provide non-potable water storage to accommodate peak demand requirements.

84440-2 PROPERTY RECORD CARD USAGE. Each tank shall be shown on a separate property record card.

844 41 STORMWATER FILTRATION – PERMEABLE SURFACE (SY)
FAC 8716
BFR Required N

84441-1 DEFINITION. A stormwater management structure where runoff passes through the pavement surface and subbase layers, infiltrating into the soils below, e.g., Permeable Pavers, Pervious Concrete, Porous Asphalt, Reinforced Turf, Reinforced Gravel.

844 42 STORMWATER FILTRATION – SWALES (SY)
FAC 8716
BFR Required N

84442-1 DEFINITION. A Stormwater management structure that provides routing and damming of stormwater to achieve needed water filtration and reduce stormwater discharge rates, e.g., Dry Swale, Wet Swale.

844 50 RESERVOIRS - NONPOTABLE WATER (MG)
FAC 8443
BFR Required N

84450-1 DEFINITION. This Category Code includes a reservoir that has a capacity greater than or equal to one million gallons and typically provides water reserves to insure an uninterrupted flow for non-potable water requirements. The primary unit of measure is reservoir capacity in millions of gallons (MG).

84440-2 PROPERTY RECORD CARD USAGE. Each reservoir shall be shown on a separate property record card.

844 51 STORMWATER TREATMENT STRUCTURE (GM)
FAC 8717
BFR Required N

84451-1 DEFINITION. A stormwater control structure that uses chambers, gradations, or other built-in feature(s) in combination with filter media to remove sediment and other pollutants from stormwater before entering the storm sewer system. This includes manufactured filter structures.

845 WATER DISTRIBUTION SYSTEM - NONPOTABLE

845-1 DEFINITION. Facilities in this group support non-potable water supply systems and are similar to those described under Category Group 842. This group contains the following individual codes:

845 20 WATER DISTRIBUTION LINE, NONPOTABLE (LF)
FAC 8451
BFR Required N

84520-1 DEFINITION. This Category Code includes all pipes that transmit water in a dedicated nonportable water distribution system. The primary unit of measure is linear feet of pipe (LF).

84520-2 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single non-potable water distribution system after the utilities Maximo team has divided the installation into service areas as part of the linear segmentation process has been completed. Each part of the non-potable water distribution system that is considered a linear structure shall have its own property record card.

850 ROADS AND STREETS

851 10 ROADS (SY)
FAC 8511
BFR Required N

851 11 ROADS, UNSURFACED (SY)
FAC 8512
BFR Required N

851 15 LOAD/UNLOAD RAMP (SY)
FAC 8928
BFR Required N

851 20 VEHICULAR BRIDGES (SY)
FAC 8513
BFR Required N

85110/85111/85115/85120-1 DEFINITION. Roads, streets, and bridges are generally planned to conform to the standards and practices of the American Association of State Highway Officials (AASHO), Federal Highway Administration (FHWA), and State and local governments.

851 21 VEHICULAR PARKING, UNSURFACED (SY)
FAC 8522
BFR Required Y

85121-1 DEFINITION. An unpaved surface for parking and/or staging private and/or government owned vehicles and equipment. The surface is usually graveled. Use the criteria under CCN 85210 Parking Area to develop parking requirements.

851 22 VEHICLE STAGING AREA (SY)
FAC 8523
BFR Required Y

85122-1 DEFINITION. This category code represents surfaced areas for the temporary holding of vehicles and equipment awaiting deployment. It is not intended to be used for vehicle parking identified under CCN 85210 or un-surfaced parking and storage designated under CCN 85235 or CCN 85240.

851 23 TRAFFIC CONTROL SIGNALS (EA)
FAC 8541
BFR Required N

85123-1 DEFINITION. Traffic control signals are devices used for directing pedestrian, vehicular or rail traffic by means of power-operated controls. Costs include signal devices, necessary supports, and electric power cables.

85123-2 PROPERTY RECORD CARD USAGE. Each (EA) is defined as one "intersection" as the unit of measure regardless of how many individual traffic signals or supports are in place at an intersection, with the understanding that in some cases the individual signal count may be low and in other cases it may be high - it averages out. List all traffic control signals on one PRC per site.

851 25 VEHICULAR TUNNELS (LF)
FAC 8514
BFR Required N

85125-1 DEFINITION. Vehicular tunnels are used for slope stabilization and automobile access in areas where steep slopes limit development and require innovative access solutions. These tunnels serve vehicular and pedestrian traffic as well as housing utility runs. They are also often used to combat soil erosion and protect facilities and personnel.

852 SIDEWALKS AND OTHER PAVEMENTS

852 10 PARKING AREA (SY)
FAC 8521
BFR Required Y

85210-1 ORGANIZATIONAL VEHICLE PARKING. The paved and/or stabilized area within an organizational motor pool and parking lot, including space required for entrance and exit roads and aisles within the lot, will not exceed the following:

85210-1.1 Navy and Marine Corps installations (except Marine Corps installations with FMF Ground Units assigned). Forty square yards per unit for 75% of the equipment supported. The 40 square yards per unit takes into account the varied sizes and types of automotive, construction, and materials handling equipment to be parked.

85210-1.2 Marine Corps installations with FMF Ground Units assigned. Seventy-five square yards for each vehicle to be accommodated. The 75 SY will be reduced to 50 SY per vehicle if more than 50% of the vehicles to be accommodated have an overall length of 18 feet or less and a width of 6 1/2 feet or less (such as administrative-type vehicles).

85210-2 NON-ORGANIZATIONAL VEHICLE PARKING. Authorized parking spaces for non-organizational vehicles are listed in Table 852-10. The space allowance for each parking space is 35 square yards. This provides room for the parked vehicle and for normal interior lanes, entrances, and exits.

Parking spaces for a facility not listed in the table shall be based on a special study of traffic analysis considering eligible vehicles, multiple utilization, time and space intervals, available public transportation, group-car riding and government-furnished transportation. For example, no planning factor has been established for parking space required for shipboard personnel while in homeport. Therefore, a special study would be required to determine parking space needed to support this requirement. Such a study would take into consideration the number of ships which would be in the homeport at any one time and a derivation there from of the number of shipboard personnel requiring parking space. Where there is no direct experience, valid projections of available data may be made. Parking space for a listed facility, whether existing or planned, may be increased when justified by a special study or traffic analysis.

Table 85210-1
Allowances for Non-Organizational Vehicle Parking

Facility	Number of Parking Spaces
Administration, Headquarters, and Office Buildings	60% of assigned personnel
Bakeries	75% of employees
Bank and Credit Union, when not included in a Community Shopping	2% of customers served
Cafeteria, Civilian, when not included in a Community Shopping Center	15% of seating capacity
Central Food Preparation Facilities	38% of employees
Chapels	30% of seating capacity
Child Development Centers (Patron Parking)	10% of children served
Child Development Centers (Staff Parking)	80% of staff
Commissary Stores, Food Sales, when not included in a Community Shopping Center	Contact DeCA for parking requirements.
Community Shopping Center, including such elements as Main Exchange, Miscellaneous Shops, Restaurant, Commissary Stores, Food Sales, Bank, Theater, Post Office	4% of customers served
Dental Clinic Parking	3 spaces per treatment room
Dormitories (BEQ, Enlisted Unaccompanied Personnel Housing)	70% of design capacity
Enlisted Personnel Dining Facilities (Staff Parking)	38% of employees

Facility	Number of Parking Spaces
Enlisted Personnel Dining Facilities (Patron Parking)	8% of enlisted personnel served
Exchanges, Main, when not included in a Community Shopping Center	25% of customers served
Family Housing	2.5 spaces per living unit
Field House, combined with Football and Baseball Facilities	1% of military strength
Fire Stations	100% of largest shift
Guard Houses, Brigs, Military Police Stations	30% of guard and staff strength
Fitness Center	1 percent of military strength served
Laundries and Dry Cleaning Plants	38% of employees
Libraries (Central)	1 space for each 46 m2 (500 ft2) of gross floor area
Libraries (Branch)	8 spaces
Maintenance Shops	40% of employees
Medical Facilities (Staff Parking)	Use UFC 4-510-01
Medical Facilities (Outpatient / Visitor Parking)	Use UFC 4-510-01
Naval Criminal Investigation Service Field Offices, Resident Agencies and Resident Units	60% of assigned personnel
Officers' Quarters (BOQ, Officer Unaccompanied Personnel Housing)	100% of living suites
Reserve Training Center Parking	80% of reservists, largest drill period
Schools, Dependent, with Auditorium	2 spaces per classroom plus 15 percent of auditorium seats
Schools, Dependent, without Auditorium	2 spaces per classroom
Security Offices: Population served 100 to 2,000	5 spaces
Security Offices: Population served 2,001 to 4,000 population	10 spaces

Facility	Number of Parking Spaces
Security Offices: Population served 4,001 to 6,000 population	15 spaces
Security Offices: Population served 6,001 to 10,000 population	20 spaces
Security Offices: Population served 10,001 and over	To be based on a special study.
Service Clubs (Open Mess and Club Facility)	2% of military strength served
Swimming Pools	20 percent of the pool capacity
Temporary Lodging Facilities	90% of bedrooms
Theaters, when not included in a Community Shopping Center	25% of seating capacity
Training Buildings (Staff Parking)	70% of staff
Training Buildings (Student Parking)	60% of students
Warehouses	40% of employees

85210-3 REFUELING VEHICLE PARKING. A paved area to provide parking for partially or fully loaded refueling units is required where such units are employed to provide fuel for aircraft. This area is to be differentiated from line vehicle parking (Category Code 116 45) which may provide operational parking for some refueling units requiring immediate access to aircraft apron. To determine the area required, a planning factor of 400 square yards per vehicle (refueling semi-trailer with tractor) may be used as a guide. The following criteria shall be adhered to:

85210-3.1 Separation Distances. One hundred feet is the optimum separation between fueling vehicle parking areas and surrounding buildings. This separation should be applied in the planning of new areas. For existing areas this separation should be used wherever possible without requiring extensive relocation or ground improvement. In such cases the 100-foot distance may be modified on the basis of local conditions, taking into consideration the size, nature, and importance of nearby exposed buildings. However, this separation distance should not be reduced below 50 feet.

A separation of 25 feet of centers will be maintained between parked fueling vehicles in designated areas. Distance between rows will vary depending upon the type and the length of the individual vehicles and their turning characteristics. However, the distance between rows will not exceed 50 feet.

85210-3.2 Vehicle Alignment. Vehicles should be aligned in single rows and should be capable of being driven out of storage areas in a single turn.

NOTE: The above-mentioned requirements do not apply to spacing and/or placing fueling vehicles in structures designed for servicing equipment of this nature.

852 15 BICYCLE SHELTER (SF)

FAC 7384
BFR Required Y

A facility to protect bicycles from the elements.

852 20 SIDEWALK (SY)

FAC 8524
BFR Required N

852 30 PEDESTRIAN BRIDGES (SY)

FAC 8525
BFR Required N

85220/85230-1 DEFINITION. Planning of sidewalks and pedestrian bridges is derived from the general development map of the activity. See TM 5-822-2 / AFM 88-7 CHAP 5 for design criteria.

852 35 OTHER PAVED AREAS NOT CODED IN THE 100 OR 400 SERIES (SY)

FAC 8526
BFR Required N

85235-1 OTHER PAVED AREAS NOT CODED IN THE 100 OR 400 SERIES. This code is for miscellaneous pavements not captured in other 100 or 400 series category codes.

852 39 MISCELLANEOUS OPEN STORAGE OR LAYDOWN AREA – UNPAVED (SY)

FAC 8522
BFR Required N

85239-1 DEFINITION. This area is an unpaved laydown area for staging private and/or government-owned vehicles and equipment but is not used as parking lots. The unpaved surface is typically gravel. See CCN 85121 for unpaved parking lots.

852 40 MISCELLANEOUS OPEN STORAGE OR LAYDOWN AREA - PAVED (SY)

FAC 8526
BFR Required N

85240-1 MISCELLANEOUS OPEN STORAGE OR LAYDOWN AREA - PAVED. This code is for open storage areas other than those used for general supply operations (Category Code 451 10). It includes Public Works Open Storage facilities. See Table 85240-1 for allowances.

Table 85240-1
Allowances for Public Works Open Storage

PW Shop Type	Square Yards
A, B, C	225
D	380
E	780
F	1,180

NOTE: For Public Works Open Storage supporting PW shops larger than type F, add 2 SY of open storage for each maintenance craftsman over 500.

852 41 BUILDING/TRAILER PAD WITH UTILITY CONNECTIONS (SY)

FAC 8526
BFR Required N

85241-1 BUILDING/TRAILER PAD WITH UTILITY CONNECTIONS. Paved surface constructed to support a temporary facility or trailer. Utility connections are part of the trailer pad requirements and allow temporary facilities (often Class 3 property) to be easily installed.

853 PARKING BUILDINGS, MISCELLANEOUS

853 10 PARKING BUILDING (SF)

FAC 8531
BFR Required Y

85310-1 DEFINITION. A structure or building designed for parking private and/or government owned vehicles and equipment in individual parking spots/locations. The facility may be above ground or underground. The parking building should be justified by land restrictions and economic considerations. Allow 33 m2/ 40 SY for each passenger vehicle. See table 85210-1 for authorized spaces.

860 RAILROAD TRACKS

860-1 RAILROAD TRACKS DESCRIPTION

This category group covers all two-rail tracks including spurs, sidings, yards, turnouts, with accessories and appurtenances such as barricades. It includes trackage on ship repair facilities, marine railways and portal crane structures.

860 10 RAILROAD TRACKAGE (MI)

FAC 8601
BFR Required N

86010-1 RAILROAD TRACKAGE. The planning of railroad trackage will be based on an economic analysis of the cost of truck haulage versus the cost of the proposed use of railroad facilities. Trackage is planned to connect the base with the common carrier and for holding and unloading freight cars as required. The amount of railroad trackage to be constructed by the government is determined by the proximity of the common carrier lines and the traffic volume.

860 20 EXPLOSIVE BARRICADE FOR SUSPECT TRUCKS AND RAILROAD CARS (EA)

FAC 1495
BFR Required N

86020-1 EXPLOSIVE BARRICADE FOR SUSPECT TRUCKS AND RAILROAD CARS. A suspect cargo site is for placing trucks and railcars containing ammunition or explosives that are suspected of being in a hazardous condition. These sites may be used jointly for railcars, motor vehicles and cargo containers. This facility should have effective barricades on three sides and sited in accordance with OP-5 Vol.1. Barricaded rail or truck spurs used for temporary holding of railcars and/or motor vehicles (non-suspect) may be captured under this function. This Category Code is for inventory purposes only, a BFR is not required.

860 30 RAILROAD BRIDGE AND TRESTLE (MI)

FAC 8611
BFR Required N

860 40 CRANE TRACKAGE (MI)
FAC 8601
BFR Required N

86030/86040-1 RAILROAD BRIDGE AND TRESTLE AND CRANE TRACKAGE. When planning track layouts, railroad trackage should be separated from portal crane trackage, because, apart from the similarity of the rails, portal crane trackage requirements are completely different from railroad trackage. Where separation is impossible, both cranes and rolling stock will utilize a common rail, and the other railroad trackage rail shall be placed inside the crane gauge.

860 41 RAILROAD SCALEHOUSE (SF)
FAC 8612
BFR Required N

86041-1 RAILROAD SCALEHOUSE. A railroad scale house is a facility designed to weigh rail cargo. Typically, tracks are laid to allow railcars to be pulled through the scale house.

870 GROUND IMPROVEMENT STRUCTURES

870-1 DEFINITION. This category group includes drainage and storm sewer systems, boundary fencing, gates, guard towers and shelters and other related facilities.
871 GROUNDS, DRAINAGE

871 10 STORM SEWER (LF)
FAC 8711
BFR Required N

871/87110-1 DEFINITION. Storm sewers are components of a storm drainage system that collects the surface runoff water and conveys it to outlet points. Storm sewers are required at installations or areas where open drainage ditches would create a hazard to the operation of vehicles and aircraft or would prove hazardous to pedestrians. Storm sewers shall not be combined with sanitary sewers.

871 11 OIL/WATER SEPARATOR - RUNOFF WATER (KG)
FAC 8313
BFR Required N

87111-1 DEFINITION. A facility for the separation of grease, oil, or grit from wastewater.

871 15 STORM WATER PUMPING STATION (EA)

FAC 8452
BFR Required N

87111/87115-1 DEFINITION. Requirements for Category Codes 871 11 and 15 must be individually justified. No criteria are available.

871 16 STORMWATER RETENTION PONDS (MG)

FAC 8715
BFR Required N

87116-1 DEFINITION. An impoundment for the temporary storage of water resulting from runoff and drainage.

871 20 DRAINAGE DITCH (LF)

FAC 8711
BFR Required N

87120-1 DEFINITION. Drainage ditches serve the same purpose as storm sewers. They are preferable to covered structures to minimize construction, to conserve materials, and to facilitate maintenance. Ditches should be planned to provide adequate depth to contain all runoff water anticipated from snow, ice, thaws, frozen ground, and severe rainfalls. In the planning of the drainage system, consideration should be given to the location of ditches to minimize the creation of hazards to vehicles or personnel. See MIL HDBK-1005/3 for technical information.

871 25 DAM (LF)

FAC 8714
BFR Required N

87125-1 DEFINITION. A dam is an artificial or natural barrier usually constructed across a stream channel to impound water. Timber, rock, concrete, earth, steel or a combination of these materials may be used to build the dam. Dams must have spillway systems to safely convey normal stream and flood flows over, around, or through the dam. Spillways are commonly constructed of non-erosive materials such as concrete. Dams should also have a drain or other water-withdrawal facility to control the water level and to lower water levels for normal maintenance and emergency purposes.

87125-2 Dimensions and Capacity: A dam is at least six feet in height, measured vertically from top of barrier to elevation of lower downstream toe, and has an impounding capacity greater than 50 acre-feet; or is at least 25 feet in height, and has an impounding capacity greater than 15 acre-feet.
Toe of Dam: The junction of the downstream face of a dam with the natural ground surface. This is also referred to as the downstream toe.

87125-3 Requirements for a new dam must be individually justified by an engineering study. When planning for this category code, consult with NAVFAC Engineering Service Center, Code CIOFP4.

871 26 LEVEE AND/OR DIKE (LF)

FAC 8714
BFR Required N

87126-1 DEFINITION. A levee is a type of dam that runs along the banks of a river or canal. Levees reinforce the banks and help prevent flooding. By confining the flow, levees can also increase the speed of the water. Levees can be natural or man-made. A natural levee is formed when sediment settles on the riverbank, raising the level of the land around the river. To construct a man-made levee, workers pile dirt or concrete along the riverbanks, creating an embankment. This embankment is flat at the top, and slopes at an angle down to the water. For added strength, sandbags are sometimes placed over dirt embankments.

871 30 IRRIGATION FACILITY (LF)

FAC 8451
BFR Required N

871 35 RETAINING WALL (LF)

FAC 8712
BFR Required N

871 45 DREDGED SPOIL HANDLING FACILITY (GM)

FAC 8714
BFR Required N

87130/87135/87145-1 DEFINITION. Requirements for Category Codes 871 30 through 45 must be individually justified. No criteria are available.

872 GROUNDS FENCING, GATES AND GUARD TOWERS

872-1 DEFINITION

This basic category provides boundary security in the form of fencing, walls, gates, watch towers, guard walks, and guard shelters. The type and amount of security planned is a function of the security classification required, and the economical utilization of security guards.

872 10 STATION SECURITY AND PERIMETER FENCING AND WALLS (LF)

FAC 8721
BFR Required N

87210-1 DEFINITION. Security fencing and walls define the limits of security areas and facilitate the effective and economical use of security personnel. Fencing is planned on the basis of a study of the security classification requirements of the installation. The permanency of the installation, availability of materials, presence of natural aids to security, guard personnel, security hazards, and problems and degree of security required, must be considered in all fence construction. Security fencing is generally of the type known as chain link or cyclone, or under certain conditions it may be barbed wire. Fences should be 50 to 150 feet from buildings or critical supplies to be protected. There should be at least 20 feet between perimeter fences and structures, parking areas, or natural features outside the fenced area which could offer concealment or assistance to unauthorized access to area protected. When this is not possible, perimeter fencing should be increased in height or otherwise designed to compensate for the proximity of aids to concealment or access. See Table 87210-1 for appropriate applications and characteristics of fences.

87210-1.1 Standard Security Fencing. The average standard security fence of the so-called man proof type is the 7-foot cyclone, chain link fence with 1-1/2 foot outriggers mounting 3 barbed wire strands at 45 degrees, increasing the overall height of the fence to 8 feet. See UFC 4-022-03, Security Fences and Gates, for additional design details.

87210-1.2 **Security Fencing for Storage of Security Risk Categories I and II**. The fence fabric, height, installation, clear zones, and number of gates for SRC I and II Ammunition and Explosive (A&E) storage facilities must meet DoDM 5100.76, latest revision requirements. Additional design details are promulgated in UFC 4-022-03, Security Fences and Gates.

87210-1.3 Barbed Wire. There are instances such as in isolated air stations, where three strand barbed wire cattle fence will suffice around the entire perimeter of the station, augmented by standard security fencing of critical areas, if such exist and can be adequately patrolled.

87210-1.4 Walls. Where walls, floors, and roofs serve as barriers, they should be constructed and arranged to provide uniform protection equivalent to that provided by chain link fencing as specified.

Table 87210-1
Applications and General Characteristics Of Fences

Application	Location or Special Requirement	Suitable Type	Height	
			Feet	Inches
Restricted Area Security	Restricted Areas — as defined in OPNAVINST 5530.14E	Chain link security fence with three strands of barbed wire mounted on outriggers (facing out except for brigs).	Refer to OPNAVINST 5530.14E	
Magazines storing SRC I & II A&E	Restricted Areas — as defined in DoDM 5100.76	Fence fabric shall be chain link, i.e., galvanized, aluminized, or plastic-coated woven steel, 2-inch square mesh made from 9-gauge diameter wire, excluding coating that meets Federal Specification RR-F-191K.	Refer to DoDM 5100.76	
Non-metallic Security Fence Requirement	Where restrictions of visibility into activity is desired.	Wooden Security fence	Refer to OPNAVINST 5530.14E	
	At radio direction-finder structures.	Wooden Security fence		
	Where chain link materials are not available.	Wooden Security fence		
Protection of sports facilities, users and spectators	Athletic courts.	Chain link.	10-12	--
	Swimming pools.	Chain link or decorative wood.	6	--
	Playgrounds.	Chain link or decorative wood.	5	--
Snow fencing	Where drifting snow is a problem.	Picket interwoven with wire-studded metal posts	4	--
Right-of-way fencing	Railways, highways	Woven wire fencing or wooden or metal posts with or without barbed wire.	4.5	--
Animal Fencing	*Woven wire fencing with wooden or metal posts—barbed wire as indicated:*			
	Horses, mules, cattle, general.	1 strand top	--	47
	Hogs.	1 strand at bottom	--	32-39
	Sheep and goats.	1 strand at top	--	39-47
	Poultry.	None	--	48-72
Perimeter marking	Property lines, firing ranges, outside security barrier of high security area	Two strand barbed wire.	--	42
		Three strand barbed wire (wood or metal posts).	--	48
Decorative wood fencing	To discourage passage or access.	Picket fence.	3-5	--
		Post and rail or horizontal board.	4	--
	To provide privacy and screening.	Stockade fence.	6-8	--
		Louver fence.	6-7	--

Application	Location or Special Requirement	Suitable Type	Height	
			Feet	Inches
		Basket weave fence.	6-8	--

Refer to OPNAVINST 5530.14E “Navy Physical Security and Law Enforcement Program” for definitions of critical areas.

872 11 HARDENED SECURITY FENCE (SF)

FAC 8722
BFR Required N

87211-1 DEFINITION. Security is a key issue for all military installations; hardened security fencing is used very effectively but will not stop a determined intruder. To be effective, such barriers must be augmented by security force personnel and other means of protection, detection, delay, and assessment. Security fences are used primarily to:

a) Define the perimeter of a restricted area.
b) Provide a physical and psychological deterrent to entry while serving notice that entry is not freely permitted.
c) Prevent accidental entry.
d) Optimize security force operations.
e) Enhance detection and apprehension of intruders.
f) Channel and control the flow of personnel and vehicles through designated portals.

87211-2 Prior to making decisions to employ security fencing, perform a thorough risk and threat analysis to determine the degree of physical security required. As indicated in Chapter 2 of Chief of Naval Operations Instruction (OPNAVINST) 5530.14E “Navy Physical Security and Law Enforcement Program”, extensive and costly security measures may be justified in certain cases to protect certain assets of security interest; however, ultimately the commanding officer of an activity is responsible for complying with established security requirements while at the same time working to achieve economy. To achieve this objective, higher echelon security requirements must be clearly understood. Additionally, evaluate the relative criticality and vulnerability of the security interest in relation to a ranking of potential threats, and calculate the specific level of security to ensure the best possible protection for that threat level in a cost-effective manner. Only after the above preliminary factors are addressed can a proper design be initiated. See MIL-HDBK-1013/1A, “Design Guidelines for Physical Security of Facilities”, for guidance and more detailed procedures which may be helpful in the decision process.

872 15 INTERIOR FENCING (NOT CODED IN 872 10) (LF)

FAC 8721
BFR Required N

This Category Code is for inventory purposes only, a BFR is not required.

872 20 GUARD AND WATCH TOWERS (EA)
FAC 1499
BFR Required N

87220-1 DEFINITION. Where authorized, guard or watchtowers should be constructed at locations that will provide the best observation of security areas. The general building of guard towers at other than correctional facilities and certain special weapons projects is not presently considered appropriate. Each local security situation should be solved on its own merits.

872 30 MECHANICAL SECURITY BARRICADE (EA)
FAC 1458
BFR Required N

87230-1 DEFINITION. Mechanically operated barricade consisting of pop-up bollards, rising road plates, or wedges designed to control vehicle or other traffic. Drop arm barriers found at gates or railroad crossings and floating barrier systems around ships meet the definition of a mechanical security barricade and are included. Costs include barrier installation, remote controls, safety loops, traffic arm, and traffic lights. CCTV, cameras, and alarms are considered equipment and are not included.

87230-2 PROPERTY RECORD CARD USAGE. EA is defined as a single barricade blocking a lane of traffic. A lane may have two barricades, one inside the gate entrance and one outside the gate entrance, therefore the count for that lane would be 2 (EA).

872 50 ENTRY GATE (LF)
FAC 8721
BFR Required N

87250-1 ENTRY GATE. An entry gate is the frame, gate, or other apparatus that allows or restricts vehicle and animal entrance on access roads and pedestrian access through the perimeter fences or walls of an installation.

880 FIRE AND OTHER ALARM SYSTEMS

880-1 FIRE AND OTHER ALARM SYSTEMS

This basic category includes separate integral signal systems such as fire alarm, watch reporting, and security. Telephone reporting systems are planned with telephone systems (see Code 130).

880 10 FIRE ALARM SYSTEM (MI)

FAC 1351
BFR Required N

88010-1 FIRE ALARM SYSTEM. Fire alarm systems are of two general types: exterior systems and interior systems. Exterior systems normally have alarm initiating devices outside buildings but may have components within buildings. Interior systems service a single building or group of buildings and may be connected to an exterior system.

88010-1.1 Exterior Fire Reporting Facilities. Exterior fire reporting systems of either telegraphic radio or supervised telephonic types are authorized for installation in built-up areas at military installations. The type of system selected for use shall be established on the basis of dependability, initial cost, and ability to maintain the system in operating condition. Extension of fire reporting systems will require consideration of compatibility with existing equipment. Fire reporting facilities will not normally be provided at isolated small areas, ammunition and ordnance storage, and similar restricted areas where personnel are not generally present to detect fires.

88010-1.2 Interior Fire Reporting Facilities

88010-1.2.1 Automatic Fire Alarm Systems. Automatic fire detection and alarm systems are authorized for installation in:

1. Buildings, for protection of life, or in isolated and/or important facilities where automatic sprinkler protection would normally be provided but is not economically or technically feasible.
2. Combustible buildings used for the confinement of military prisoners where automatic sprinklers, normally provided, cannot be made available.
3. Combustible buildings of hospital groups and specific areas of noncombustible buildings of hospital groups, where automatic sprinklers are not provided.
4. One and two-story combustible dormitory-type living quarters, including bachelor officers' quarters, guesthouses, nurses' quarters, civilian dormitories, and similar buildings used for sleeping purposes.

88010-1.2.2 Manual Fire Alarm Systems. Manual fire and evacuation alarms are authorized for installation in:

1. Barracks, dormitories, bachelor officers' quarters and similar sleeping quarters involving 20 or more persons not otherwise provided with automatic fire detection alarms.
2. Combustible buildings used for confinement of military prisoners, not otherwise provided with automatic sprinkler or automatic fire detection systems.
3. Buildings involving personnel occupancy such as administration, clubs, schools, classrooms, hospitals, laboratories, industrial and similar structures.

Normally, such buildings having occupancy of 20 or more persons will be provided with this type of alarm system.

880 20 WATCH REPORTING SYSTEM (MI)
FAC 1351
BFR Required N

88020-1 WATCH REPORTING SYSTEM. A watch reporting system provides a method for the automatic and non-automatic detection of fire and for security protection (Intrusion Detection System) throughout designated areas, buildings, and structures. The watch reporting system provides local alarms and central station alarms to building occupants and to station security and firefighting personnel. Watch reporting systems are planned on the basis of engineering surveys to determine the degree of fire protection and security required.

880 30 BASE ALERT SYSTEMS (MI)
FAC 1351
BFR Required N

88030-1 BASE ALERT SYSTEMS. Base alert systems shall be planned for all Navy installations. The system may alert base personnel to air raids, chemical/biological attacks or any other type of terrorist attack. Horns of high-power type may be used as signal devices. Their locations shall be coordinated with structures and buildings to spread audible signals evenly and with enough intensity to be heard over a whole area or activity.

880 40 AIR CRASH/ALERT (MI)
FAC 1351
BFR Required N

88040-1 AIR CRASH/ALERT. No planning criteria are currently available.

890 MISCELLANEOUS UTILITIES

890 09 MISCELLANEOUS UTILITY BUILDING (SF)
FAC 8910
BFR Required N

89009-1 DEFINITION. This Category Code is used for structures associated with public works utilities shops and other miscellaneous utility buildings. If a utility building cannot be classified under one of the other utility type buildings, this Category Code should be used. Specific the general use of the building in the facility name field.

890 10 ACETYLENE PLANT (EA)
FAC 8921
BFR Required N

890 11 ACETYLENE DISTRIBUTION SYSTEM (LF)
FAC 8930
BFR Required N

89010/89011-1 DEFINITION. Generally, the generation of acetylene is a function of private industry. Where commercial sources are nonexistent or of poor quality, a generating plant may be built. The quantity of acetylene required and the siting of an acetylene plant within safety criteria are determined by an engineering study. A typical acetylene generator building has an approximate gross area of 2,200 square feet.

890 15 NITROGEN PLANT (EA)
FAC 8921
BFR Required N

89015-1 DEFINITION. A nitrogen plant is required for the provision of large quantities of nitrogen for special applications. Nitrogen is used where an inert gas is required. It prevents oxidation in welding and soldering. It prevents spoilage of perishable supplies by displacing air in special storage facilities. Nitrogen is also used in the quick freezing of food. Nitrogen is provided by commercial sources where available. A requirement for a nitrogen plant shall be determined by a special study. Nitrogen and oxygen are by-products of each other so preliminary guidance may be taken from oxygen plant criteria (Category Code 141 87 Liquid Oxygen Facility and 890 30 Industrial Oxygen Plant).

890 18 UTILITY VAULT-NON COMMUNICATIONS (EA)
FAC 8927
BFR Required N

89018-1 DEFINITION. A utility vault is an enclosed structure generally made of concrete that contains utility equipment, connections and/or lines (non-communications). A utility vault is typically an underground structure. For communications maintenance vaults, use category code 131 12. This category code is for inventory purposes only.

890 20 COMPRESSED AIR PLANT (EA)
FAC 8921
BFR Required N

890 21 COMPRESSED AIR DISTRIBUTION SYSTEM (LF)

FAC 8930
BFR Required N

89020/89021-1 DEFINITION. Compressed air is used by the Navy in numerous applications, such as for pneumatic tools, laundry equipment, instrumentation and control equipment, and in hospitals and laboratories. If the requirement is sufficiently large at an installation, a central compressed air plant and distribution system should be installed. A careful analysis of all compressed air operating requirements is necessary to determine the capacity and pressure of the distribution system. Usually, compressed air is distributed at 100 to 125 psig from a central system for general purpose needs. Special, high-pressure systems are required for ordnance plants, ammunition depots, catapults, and submarine facilities.

89020/89021-1 PROPERTY RECORD CARD USAGE. There may be multiple property record cards for a single compressed air distribution system after the linear segmentation process has been completed. Each part of the compressed air distribution system that is considered a linear structure shall have its own property record card. There will be multiple linear segments within a linear structure, and they will be recorded in GIS. They do not need to be shown on the property record card. All property record cards for a single network are related by a RPNUID.

890 25 CARBON DIOXIDE PLANT (EA)

FAC 8921
BFR Required N

89025-1 DEFINITION. A carbon dioxide plant at a naval activity provides space for the storage and transfer of carbon dioxide. The space contains a storage tank and a distribution system used for refilling carbon dioxide fire extinguishers. The space required will approximate 1,200 to 2,000 square feet.

890 27 ICE-MAKING PLANT (TN)

FAC 7322
BFR Required N

89027-1 DEFINITION. No planning criteria are currently available.

890 30 INDUSTRIAL OXYGEN PLANT (EA)

FAC 8921
BFR Required N

890 31 OXYGEN DISTRIBUTION SYSTEM (LF)

FAC 8930
BFR Required N

89030/89031-1 DEFINITION. Industrial oxygen is obtained from private industry where feasible. Where oxygen must be produced, it is obtained by breakdown of air into oxygen and nitrogen. Nitrogen is a by-product. Breathing oxygen is handled separately from industrial oxygen because of more stringent purity requirements. See Category Code 141 87 Liquid Oxygen Facilities for breathing oxygen.

890 45 VALVE HOUSE OR OTHER ENCLOSURE (SF)

FAC 8910
BFR Required N

89045-1 DEFINITION. This Category Code is used for any structure used for housing valves or other utility equipment that is not contained in any other CCN.

890 46 UTILITY TUNNEL–NON COMMUNICATIONS (LF)

FAC 8931
BFR Required N

89046-1 DEFINITION. This category code is for an underground tunnel in which utility systems (non-communications) are routed. There may be multiple utility systems in a single tunnel network. Utility tunnels are of a large enough cross section to allow walk-through access. For communications maintenance tunnels, use category code 131 13.

890 50 ICS COMMUNICATION LINES (MI)

FAC 1351
BFR Required N
Revised August 2015

89050-1 DEFINITION. This category code is used for Industrial Control System (ICS) communication lines. By definition, wireless ICS communications are not addressed or inventoried in iNFADS.

89050-2 PROPERTY RECORD CARD USAGE. Industrial Control System communication lines shall be listed on a single property record card. Large installations with multiple geographic service areas will require a property record card for each geographic service area containing ICS communication lines.

890 51 ICS MONITORING STATION (SF)

FAC 8910
BFR Required: Y
Created August 2015

89051-1 BACKGROUND. The Navy and Marine Corps Smart Grid Program aggregates building energy information, utility information, and operational technologies (i.e. Industrial Control System (ICS)) in order to reduce facility maintenance costs, reduce energy consumption, and support mission assurance. Centralization of an ICS requires the establishment of regional and installation level ICS Monitoring Stations where various building and utility systems can be monitored and controlled.

89051-2 DEFINITION. The ICS Monitoring Station is the utility support facility that houses the operational components of the ICS as well as the personnel that operate the system. The ICS Monitoring Station is a component of the ICS and makes the ICS complete and usable. An ICS Monitoring Station should not be confused with a National Operations Center (NOC), Regional Operations Center (ROC) or Emergency Operations Center (EOC).

89051-2.1 Types of ICS Monitoring Stations.

Although a variety of ICS Monitoring Station types exist, they all encompass processes that enable the intelligent monitoring, forecasting, response to and control of Navy and Marine Corps building and utility systems. ICS Monitoring Stations are organized around a central master control space, ranging from a large room with multiple workstations to a single computer workstation. For this UFC, it is assumed that an ICS Monitoring Station will be one of two basic types:

- Consolidated: Integrates all required systems and components into one facility
- Distributed: Locates required spaces and components throughout two or more facilities or locations

Many variations are possible within these two basic types. Consult FC 4-141-05N for design criteria.

Table 89051-1 below is provided for reference purposes and itemizes the various components of an Industrial Control System, of which the ICS Monitoring Station is just one component

Table 89051-1: Components of an Industrial Control System

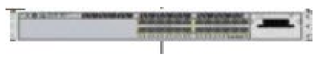
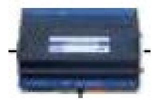
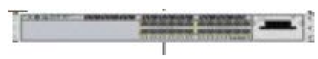
ICS Components Located OUTSIDE of a Controlled Building or Utility		
Component	**Picture**	**Property Classification**
ICS Monitoring Station (Building – Square Feet)		Real Property (CCN 89051)
Wired Communications (Cable – Linear Feet)		Real Property (CCN 89050)
Network Devices		Personal Property
Computers		Personal Property
Software		Personal Property
Wireless Communications		Personal Property

Table 89051-2: Components of an Industrial Control System

ICS Components Located <u>INSIDE</u> of a Controlled Building or Utility		
Component	**Picture**	**Property Classification**
Supervisory Controllers		Real Property Installed Equipment
Network Devices		Personal Property
Supervisory Control and Data Acquisition (SCADA)		Real Property Installed Equipment
Direct Digital Control (DDC)		Real Property Installed Equipment
Advanced Metering Infrastructure (AMI) Meters		Real Property Installed Equipment
Sensors		Real Property Installed Equipment
Actuators		Real Property Installed Equipment
Cameras		Personal Property
Protection		Personal Property

89051-3 SPACE TYPES AND PLANNING FACTORS

89051-3.1. Office and General Purpose Spaces.

89051-3.1.1. Private Offices. Allocate 120 NSF/PN per Private Office required.

89051-3.1.2. Open Offices. Allocate 64 NSF/PN per Open Office required.

89051-3.1.3. Administrative Support Space. This space supports the administrative functions and includes all such functions not included in personal office space. It includes space for working office storage, copiers, working files, printers, scanners, shredders, safes, and facsimile machines. Allocate 8 NSF/PN for all personnel in office spaces.

89051-3.1.4. Conference Room. For a Regional ICS Monitoring Station with up to 24 total personnel, provide one conference room at 400 NSF. For an Installation Level ICS Monitoring Station conference room (if required), allocate 200 NSF.

89051-3.1.5. Reception Area. A Reception Area is used for receiving visitors and controlling access to ICS Monitoring Station spaces and are justified only for large, consolidated ICS Monitoring Stations. Allocate 64 NSF for a reception desk and include space for up to 5 visitors @ 20 NSF/visitor.

89051-3.1.6. Circulation. This is space used to provide for circulation in and around the administrative space types above. Apply an Office and Assembly Space Circulation multiplier of 10% to the NSF allocation.

89051-3.2. Special Purpose Spaces

89051-3.2.1. ICS Integration and Application Space. ICS Integration and Application Space is used for training and work bench space, but it is not continuously manned. Allocate 200 NSF for ICS Integration and Application Space.

89051-3.2.2. IT Storage Space. IT Storage Space is used for storage of IT equipment and supplies. Allocate 150 NSF for IT Storage Space.

89051-3.2.3. Master Control Room. A Master Control Room (MCR) is the central monitoring and action function within the ICS Monitoring Station. Sizing of the MCR is based on the number of operators and associated workstations. It includes a minimum of two operator workstations and may include a large, centralized, flat panel display area with a minimum of 24" deep enclosed computer space on video walls. The MCR is rectangular in shape; depth is based on operator visual range, and width is based on the number of operators and necessary display information. Allocate 90 NSF/operator station.

89051-3.2.4. Server Room. A Server Room contains computer equipment mounted in racks. The average rack size is assumed to 24"W x 40"D x 81"H. An evaluation shall be done to determine the total number of racks required. Once the required number of racks has been determined, use "Table 131-6, Equipment Room Requirement by Total Racks" (in the 100 series document) to determine NSF requirement:

89051-3.2.5. Technical Equipment Area. A Technical Equipment Area is required for charging, check-out network update, and maintenance of laptop, ELMRS radios, etc. Allocate 100 NSF for a Technical Equipment Area.

89051-3.2.6. Bunk Room. A Bunk Room may be justified due to base emergency event protocols for self-sufficiency as determined by the base commanding officer. For a Consolidated ICS Monitoring Station, allocate 130 NSF for Bunk Room.

89051-3.2.7. Break Room. A Break Room is justified for all ICS monitoring stations unless a kitchen is justified in its place. Allocate 20 NSF/PN based on the number of people in MCR during the largest shift.

89051-3.2.8. Kitchen. A Kitchen may be justified due to base emergency event protocols for self-sufficiency as determined by the base commanding officer. Allocate 30 NSF/PN based on the number of people in MCR during the largest shift.

89051-3.2.9. Locker Room. A Locker Room area may be justified based on permanent staff within the MCR. Allocate 10 NSF/Locker/PN based on the number of people in MCR during the largest shift.

89051-3.2.10. Shower Room. A Shower Room may be justified due to base emergency event protocols for self-sufficiency as determined by the base commanding officer. Allocate 20 NSF/Shower when required, up to a maximum of two showers.

89051-3.2.11. Special Purpose Space Circulation. This space used for circulation within the Special Purpose Spaces. Apply a Special Purpose Space Circulation factor of 10% to the NSF allocated.

89051-3.2.12. Electrical, Mechanical and Rest Rooms and other common areas are included within the Net to Gross factor.

For an ICS Monitoring Station, apply an overall Net to Gross Factor of 1.35.

Table 89051-4: Planning Factors for ICS Monitoring Station

Space Type	NSF Factor/Multiplier
Office and Assembly Space:	
Private Offices	120 NSF/person
Open Offices	64 NSF/person
Administrative Support Space	8 NSF/PN for office space personnel.
Conference Room at Installation Level ICSMS	200 NSF
Conference Room at Regional Level ICSMS	400 NSF
Reception Area at Regional Level ICSMS	164 NSF
Office and Assembly Space Circulation Multiplier	10%
Special Purpose Space:	
ICS Integration and Application Space	200 NSF
IT Storage Space	150 NSF
Master Control Room	90 NSF/Operator Work Station
Reception Area	164 NSF
Server Room	See Table 89051-4
Technical Equipment Area	100 NSF
Bunk Room (for emergency events)	130 NSF
Break Room (apply in lieu of Kitchen)	20 NSF/PN
Kitchen (for emergency events)	30 NSF/PN justified
Locker Room	10 NSF/Locker/PN justified
Shower Room (for emergency events)	20 NSF/Shower
Circulation Multiplier	10%
ICS Monitoring Station NTG Factor:	1.35

Table 89051-5: Example BFR for an ICS Monitoring Station

Space Type: Office and General Purpose Space	Qty	NSF Factor or Multiplier	Subtotal NSF	Total Area NSF
Private Office Space (PN)	4	120		480
Open Office Space (PN)	8	64		512
Administrative Support Space Factor (PN)	12	8		96
Conference Room (EA) Installation	0	200		0
Conference Room (EA) Regional	1	400		400
Reception Area (EA) Regional	1	164		164
Office and Assembly Space Subtotal (NSF)			1,652	
Office and Assembly Space Circulation (NSF)		10%	165	
Total Office and Assembly Space (NSF):				1,817
Space Type: Special Purpose Space				
ICS Integration and Application Space (EA)	1	200		200
IT Storage Space (EA)	1	150		150
Master Control Room (WS)	6	90		540
Server Room (Racks)	4	60		240
Technical Equipment Area (EA)	1	100		100
Break Room (based MCR personnel during largest shift)	8	160		160
Bunk Room for Emergency Events (EA)	0	130		0
Kitchen (based MCR personnel during largest shift)	0	20		0
Locker Room (based MCR personnel during largest shift)	0	10		0
Shower Room (Up to two showers)	0	20		0
Special Purpose Space Subtotal (NSF)			1390	
Circulation Multiplier: (NSF)		10%	139	
Total Special Purpose Space (NSF)				1,529
Total Net Area Subtotal			3346	
Net-to-Gross Factor (NTG)		35%	1,171	
Total Gross Area (GSF)				4,517

89051-4 PROPERTY RECORD CARD USAGE. Each ICS Monitoring Station should be listed on an individual property record card. At smaller installations where an ICS Monitoring Station may consist of a single room for an ICS workstation within a public works facility, use CCN 89051 as the utilization for that area of the building.

890 56 WEIGHTING FACILITY (EA)

FAC 8923
BFR Required N

No criteria are currently available for this Category Code.

890 77 STORAGE FOR UTILITY SYSTEMS (READY ISSUE/SHOP STORES/MISC.) (SF)

FAC 8910
BFR Required Y

89077-1 DEFINITION. This facility provides covered storage for large items and materials required for the maintenance of base utility systems to include, but not limited to: spare pole mounted transformers, power cable spools, and large diameter piping. It is independent of the facilities required for the storage of items and materials required for the maintenance of station buildings and grounds (use Category Code 219 77). Because of the size and variation of specific items or materials requiring covered storage included in this category code, warehouse stacking methodology may not apply. When this is the case, a space analysis must be used to develop the BFR.

892 MISCELLANEOUS UTILITIES-EACH

892 10 MONITORING WELLS (EA)

FAC 8840
BFR Required N

89210-1 DEFINITION. Monitoring wells are for inventory purposes only. Monitoring wells are installed around a site in order to detect the discharge of any leachate. Samples from the wells are to be analyzed prior to the disposal of any waste in order to establish baseline data. Report all wells associated with a single contamination site or single fuel monitoring requirement as one asset and record the quantity of wells per site in the associated property record.

893 MISCELLANEOUS UTILITIES-LINEAR FEET

893 20 UTILITY CHANNEL NON-COMMUNICATIONS (LF)

FAC 8932
BFR Required N

89320-1 DEFINITION. A utility channel is an underground channel for utility distribution systems (non-communications) that both protects systems and provides relatively easy access for maintenance. A utility channel has a much smaller cross-section than a utility tunnel and does not provide walk-through access. These are generally concrete channels with a series of ground level concrete access panels that constitute the top of the channel structure. For communications maintenance channels, use category code 131 17.

FACILITIES CRITERIA (FC)
FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

Series 900: REAL ESTATE FACILITIES

Record of Changes:

Date	CCN #	CCN Title	Description of Change
10 October 2021	91215	State Owned Land - Hawaii	Change FAC to 9110 Change Title to State Owned Land - Hawaii
10 October 2021	91210	Federal Withdrawn Public Land - Permanent	Change FAC to 9110 Change Title to Federal Withdrawn Public Land - Permanent
10 October 2021	91220	Federal Withdrawn Public Land - Temporary	Change FAC to 9110 Change Title to Federal Withdrawn Public Land - Temporary
10 October 2021	91310	Licensed and Permitted Land	Change FAC to 9110 Change Title to Licensed and Permitted Land
10 October 2021	91310	Licensed and Permitted Land – Temporary Permit	Change FAC to 9110 Change Title to Licensed and Permitted Land – Temporary Permit
10 October 2021	91410	Public Land of Territories or Possessions – Temporary or Long-Term (AC)	Change FAC to 9110 Change Title to Public Land of Territories or Possessions – Temporary or Long-Term (AC)
10 October 2021	91420	Public Land of Territories or Possessions (AC)	Change FAC to 9110 Change title to Public Land of Territories or Possessions (AC)
10 October 2021	92130	Land Easement – By Purchase (AC)	Change FAC to 9110 Change title to Land Easement – By Purchase (AC)
10 October 2021	92140	Land Easement – By Condemnation (AC)	Change FAC to 9110 Change title to Land Easement – By Condemnation (AC)
10 October 2021	92150	Land Easement – By Exchange	Change FAC to 9110 Change title to Land Easement – By Exchange
10 October 2021	92110	Land Easement – Aviation – By Purchase (AC)	Change FAC to 9900 Change title to Land Easement – Aviation – By Purchase (AC)
10 October 2021	92120	Land Easement – Aviation – By Condemnation (AC)	Change FAC to 9900 Change title to Land Easement – Aviation – By Condemnation (AC)

Date	CCN #	CCN Title	Description of Change
10 October 2021	92210	In-Leased Land – Private Enterprise (AC)	Change FAC to 9110
10 October 2021	92220	Land – In Lease – State and Local Governments	Change FAC to 9110
10 October 2021	92230	Land – In Lease – Long-Term (AC)	Change FAC to 9110
10 October 2021	92310	Land – Foreign, 99-Year Lease	Change FAC to 9110
10 October 2021	92320	Land – Foreign, Base Rights	Change FAC to 9110
10 October 2021	92330	Land – Foreign Reciprocal Aid	Change FAC to 9110
10 October 2021	92340	Land – Foreign, Occupied Area	Change FAC to 9110
10 October 2021	92350	Land – Foreign, In-Lease	Change FAC to 9110
10 October 2021	92360	Land – Foreign, Miscellaneous	Change FAC to 9110
25 August 2022	91210, 91220, 92115, 92150	Land	Add descriptive information.
12 September 2022	913-20	Land – Public Domain – Temporary Permit	Change title to “Land – Public Domain – Temporary Permit.”
2 March 2023	900 Series	UFC 2-000-05N	Change UFC 2-000-05N to FC 2-000-05N document due to the fact that this planning criteria is not unified among the other DoD services.
6 February 2024	99002	Water Easement Clearance, Perpetual	Add new category code under Basic Category 990 Land Rights.

900 SERIES
REAL ESTATE FACILITIES

Table of Contents

900 REAL ESTATE

900-1 DEFINITION

This Facility Class applies to real estate in which the Navy has, or intends to obtain, a vested interest. The interest may be acquired by purchase, condemnation, donation, or exchange, and may be held in fee simple, leasehold, or easement. Real estate planned for the Navy is defined under the category codes for classifying real property as found in NACFAC P-72 / Classification is done according to the methods of acquisition and the type of real estate acquired as follows:

- Category Group 910 Land – Government Owned
- Category Group 920 Other Rights
- Category Group 930 Site Improvements

900-2 POLICY

As a general policy, all permanent Naval installations within the United States and its possessions shall be established on land owned in fee by the Federal Government under the custody and accountability of the Department of the Navy. This policy is based on the need for the unconditional use of the land for the unrestricted execution of the assigned military mission.

Additional real estate will not be acquired for the Department of the Navy by any method unless a determination has been made that consistent with the requirements of the military mission, such needs cannot be fulfilled by maximum utilization of the real estate under the control of the three military departments. Current requirements will, in the absence of unusual circumstances, be given preference over anticipated future needs and mobilization requirements. Care must be taken however, to prevent modifications that would interfere with mobilization plans for the property. The following are broad policies of the Department of the Navy in connection with the real estate transactions:

1. To acquire only the real property necessary to meet present and immediately foreseeable requirements;
2. To acquire title or other interest to real property by negotiation and direct purchase wherever possible;
3. To base estimate of value upon appraisals made by private local appraisers or by staff appraisers;
4. To take prompt action to dispose of real property excess to current and foreseeable needs of the Navy;
5. To authorize for private use, after advertising, real property which is temporarily excess to the needs of the Navy and is not required for use by other Federal agencies;
6. To require the payment of fair value for easements granted and for property which is made available for private use under out-leases, licenses or otherwise; and

7. To construct buildings or improvements of permanent type only on lands in which the rights of the Government are fee title or permanent easements.

900-3 DETERMINATION OF REQUIREMENTS

Prior to acquisition of additional land, it shall be determined that the requirements cannot be met by:

1. Exercise of recapture-of-use rights;
2. Use of property excess to the needs of other military departments or another government agency;
3. Exercise of joint use with other agencies;
4. Acquisition of land from public domain; or
5. Transfer from state or municipal governments.

900-4 ACQUISITION CODE VERSUS RETENTION CODE

Real estate is acquired under the 900 Code but is transferred, usually at the end of the fiscal year, to the code under which it is used. Coding in the 900 series denotes the type of interest acquired in the property and the means of acquisition.

900-5 REASONS FOR ACQUISITION

Land is acquired to supply operational and building areas and to provide security and safety clearances. Requirements for real estate are generated by the assignment of missions for which facilities are not available. When a mission has been assigned to a specific activity, the Commanding Officer reviews available facilities and such deficiencies as exist from the basis of a requirement for the expansion of the installation or the development of a new one. These requirements are submitted for CNO approval through the Military Construction Review Board procedures. See NAVFAC P-73, Real Estate Administration, for the detailed procedures.

900-6 AUTHORITY TO ACQUIRE REAL PROPERTY

The authority to acquire real property and execute real estate functions is vested in the Naval Facilities Engineering Command. Authority to acquire real property must be supported by legislative authorization with an appropriation of funds available for that purpose.

900-7 DELEGATION OF AUTHORITY

Authority is delegated to the field offices from time to time for certain functions in relation to real property. This delegation is made to the Commanders/CC's, Naval Facilities Engineering Command Field Divisions.

900-8 LEGISLATIVE AUTHORIZATION (MCON ACTS)

Navy Department land acquisitions usually are provided for in Acts of Congress authorizing construction projects at naval installations. These Acts are commonly known as Military Construction Acts (MCON Acts). They are sometimes referred to as Public Works Authorization Acts.

900-9 ACQUISITION COST

Acquisition exceeding $50,000 is included with the MCON Acts as a line item for action of the Congress. Acquisition not exceeding $25,000 is vested in the Secretary of the Navy. This authority is for land or real property interest determined necessary for national defense. The authority for expenditure of up to $25,000 may not be used to acquire two or more contiguous parcels that together cost more than $50,000. The detailed method of acquisition is found in NAVFAC P-73, Real Estate Procedural Manual.

910 LAND - GOVERNMENT OWNED

910-1 **GOVERNMENT OWNED LANDS.** All land interests are included in Category Group 910 with the exception of easement rights, in-lease rights, and foreign rights which are in Category Group 920.

911 LAND - PERMANENT USE LAND

911-1 **PERMANENT USE LAND.** This basic category includes lands acquired in fee purchase, condemnation, donation, exchange or transfer, which is owned in fee by the Federal Government, and under custody and accountability of the Department of the Navy.

911 10 LAND – PURCHASE (AC)
FAC 9110
BFR Required N

91110-1 **PURCHASE.** Land acquired in fee by purchase is a negotiated sale of the property from private owners to the Federal Government by conveyance of deed.

911 20 LAND – DONATION (AC)
FAC 9110
BFR Required N

91120-1 **DONATION.** Land acquired in fee by donation usually consists of a conveyance of fee title by the donor without monetary consideration.

911 30 LAND – TRANSFER (AC)
FAC 9110
BFR Required N

911 40 LAND – CONDEMNATION (AC)
FAC 9110
BFR Required N

91140-1 **CONDEMNATION.** Land is acquired by condemnation where land is essential for a project which affects national defense or security, and the consideration for purchase cannot be mutually agreed upon between the owner and the Navy.

911 50 LAND – EXCHANGE (AC)
FAC 9110
BFR Required N

91150-1 **EXCHANGE.** Land acquired by exchange is similar in principle to acquisitions by purchase except that the consideration is by land value rather than cash. Land exchange may be negotiated at the Field Engineering Division level between the Navy and private owners after approval by the interested bureau or office and the Naval Facilities Engineering Command. For value exceeding $50,000, approval by the Congressional Armed Services Committees is required.

912 LAND - PUBLIC DOMAIN WITHDRAWAL

912-1 **GENERAL.** The Navy Department may acquire land by withdrawal from public domain under jurisdiction of the Department of the Interior. Withdrawals of less than 5,000 acres are made by Public Land Order. Withdrawal of more than 5,000 acres for any one project must be approved by Act of Congress. In addition to securing authorization from the Armed Services Committees of Congress, a bill must be introduced in the Committees on Public Land and Insular Affairs for acquisition of public domain lands in excess of 5,000 acres. Land withdrawn from public domain is coded as follows:

912 10 FEDERAL WITHDRAWN PUBLIC LAND-PERMANENT (AC)
FAC 9110
BFR Required N

91210-1 **GENERAL.** This category code involves Federal Government land permanently excluded from some or all forms of entry, use, sale, or other disposal under the public lands laws as specified in the public land order, executive order, or act of Congress and those lands that are reserved for a specified department or agency for a specific public purpose.

912 15 STATE OWNED LAND-HAWAII (AC)
FAC 9110
BFR Required N

91215-1 **GENERAL.** This category code includes Federal Government land reserved through land trust in the State of Hawaii.

912 20 FEDERAL WITHDRAWN PUBLIC LAND-TEMPORARY (AC)
FAC 9110
BFR Required N

91220-1 **GENERAL.** This category code involves Federal Government land permanently excluded from some or all forms of entry, use, sale, or other disposal under the public lands laws as specified in the public land order, executive order, or act of Congress and those lands that are reserved for a specified department or agency for a specific public purpose for a specified period of time.

913 LAND - LICENSE OR PERMIT (AC)

913-1 **GENERAL.** This category code does not include land acquired by a withdrawal from public domain.

913 10 LICENSED AND PERMITTED LAND (AC)
FAC 9110
BFR Required N

91310-1 **GENERAL.** This land is acquired for temporary use under license or permit. The license or permit is a privilege, revocable at will, to use the property of the licenser, for a specified purpose and period of time.

913 20 LAND – PUBLIC DOMAIN – TEMPORARY PERMIT (AC)
FAC 9110
BFR Required N

91320-1 **GENERAL.** Land from Public Domain used under temporary permit is obtained under agreement between the Navy Department, and the Department of the Interior. The temporary permit implies no use detrimental to the land such as contamination.

914 PUBLIC LAND - TERRITORIES AND POSSESSIONS

914-1 **GENERAL.** Land from U.S. possessions is acquired for temporary or long-term use by Executive Order or permit agreement for a limited specific use.

914 10 PUBLIC LAND OF TERRITORIES OR POSSESSIONS- TEMPORARY OR LONG-TERM (AC)
FAC 9110
BFR Required N

91410-1 **GENERAL.** This code is used for public land of U.S. possessions acquired and used under long-term agreements or temporary agreements.

914 20 PUBLIC LAND OF TERRITORIES OR POSSESSIONS (AC)
FAC 9110
BFR Required N

91420-1 **GENERAL.** This code is used to designate public land of U.S. possessions assigned to the Navy on temporary permit.

920 LAND OTHER RIGHTS

920-1 **GENERAL.** This category group includes easements, leases, and foreign rights.

921 LAND – EASEMENT

921-1 **GENERAL.** An easement is a conveyance of interest in real property for particular purposes and needs of the Navy. An easement is acquired by deed for a term of years or in perpetuity. The grantor of an easement may continue to use the land within the stipulations of the easement.

921 10 LAND EASEMENT – AVIATION - BY PURCHASE (AC)
FAC 9900
BFR Required N

92110-1 **GENERAL.** An aviation easement is purchased to convey certain property rights from the private owner to the Federal Government. This is done by conveyance of deed. Easements are acquired to insure free and unobstructed aircraft passage through the airspace. The easement provides the right to limit structure height and natural growth.

921 20 LAND EASEMENT- AVIATION - BY CONDEMNATION (AC)
FAC 9900
BFR Required N

92120-1 **GENERAL.** This code varies from 921 10 only in the method of acquisition. Possession is obtained by condemnation only when the purchase price cannot be mutually agreed upon between the owner and the Navy.

921 30 LAND EASEMENT - BY PURCHASE (AC)
FAC 9110
BFR Required N

92130-1 **GENERAL.** Easements other than for navigation are acquired by negotiated sale. These easements provide rights-of-way for typical utility lines and access roads as well as many other purposes, including restrictions on use.

921 40 LAND EASEMENT - BY CONDEMNATION (AC)
FAC 9110
BFR Required N

92140-1 **GENERAL.** This is similar to 921 30 but differs in that agreement on a negotiated easement cannot be reached, and the easement is obtained by condemnation for reason of national defense or security.

921 50 LAND - EASEMENT BY EXCHANGE (AC)
FAC 9110
BFR Required N

92150-1 **GENERAL.** This category code is similar to 92130, but differs in that consideration is land value in lieu of cash.

922 LAND - IN-LEASED

922-1 **GENERAL.** An in-lease is a conveyance of a possessory interest in real property for a term of years for rent or other consideration. Leased property is categorized under three groups as follows.

922 10 LAND - IN-LEASE - PRIVATE ENTERPRISE (AC)
FAC 9110
BFR Required N

92210-1 **GENERAL.** This land is leased from private owners for periods under 25 years.

922 20 LAND - IN-LEASE - STATE AND LOCAL GOVERNMENTS (AC)
FAC 9110
BFR Required N

92220-1 **GENERAL.** This land is leased from State and local governments for periods under 25 years.

922 30 LAND - IN-LEASE - LONG-TERM (AC)
FAC 9110
BFR Required N

92230-1 **GENERAL.** Land in-lease for 25 years or more is categorized as "long-term". The land may be leased from private enterprise, or State or local governments.

923 LAND - FOREIGN RIGHTS

923-1 **GENERAL.** This is land under custody and accountability of the Navy Department comprising a Navy installation in a foreign country except land under easement, Code 921. The method of acquisition or use of real property in a foreign country depends upon, and is accomplished by, diplomatic agreement and subsidiary military agreements or, where applicable, by lease or other agreement. Fee simple title to real property in a foreign country is not acquired. The extent of interest which may be acquired in such property depends upon the agreement. Acquisition or use of real property in an occupied country is accomplished by requisition or other local arrangements. The Navy codes for foreign rights are as follows:

923 10 LAND - FOREIGN, 99-YEAR LEASE
FAC 9110
BFR Required N

923 20 LAND - FOREIGN, BASE RIGHTS
FAC 9110
BFR Required N

923 30 LAND - FOREIGN RECIPROCAL AID
FAC 9110
BFR Required N

923 40 LAND - FOREIGN, OCCUPIED AREA
FAC 9110
BFR Required N

923 50 LAND - FOREIGN, IN-LEASE
FAC 9110
BFR Required N

923 60 LAND - FOREIGN, MISCELLANEOUS
FAC 9110
BFR Required N

931 BUILDINGS

932 STRUCTURE/UTILITY SITE IMPROVEMENTS

932-1 **GENERAL.** This code group is for site improvements which are not associated with a specific building or structure within its own category code such as clearing, grading, landscaping, erosion control, and similar. This group contains the following individual codes:

933 DEMOLITION

933-1 **GENERAL.** This group is for demolition of buildings, structures, or utilities and removal of debris performed primarily to make usable or disposable an otherwise unusable site. Demolition directly related to a construction project is assigned the same code as for the project.

990 LAND RIGHTS

990 02 WATER EASEMENT CLEARANCE, PERPETUAL (AC)
FAC 9900
BFR Required N

99002-1 **GENERAL.** This category code applies to non-possessory interest in waterways used for mitigating encroachment that can limit or restrict military training, testing, and operations.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
100					OPER & TRNG FAC		
110					AIRFIELD PAVEMENTS		
111					RUNWAYS		

Series 111 Category Codes include criteria for runways for fixed wing aircraft and runways or landing pads for rotary wing aircraft. Runways are prepared surfaces for the landing and takeoff of both fixed wing and rotary wing aircraft. Landing pads are prepared surfaces for the Vertical Takeoff and Landing (VTOL) of rotary wing aircraft (including V-22).

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
11110	1111	LS	[SY]	LF	RUNWAY / FW	Y	PREPARED SURFACES FOR THE LANDING AND TAKEOFF OF AIRCRAFT.
11112	1114	LS	[SY]	LF	RUNWAY/FIXED-WING-UNSURFAC	Y	RUNWAYS FOR ROTARY WING AIRCRAFT THAT DO NOT CONSIST OF A PAVEMENT OR HARDSTAND SURFACE.
11115	1112	LS	[SY]	LF	RUNWAY / ROTARY WING	Y	PREPARED SURFACES FOR THE LANDING AND TAKEOFF OF HELICOPTERS.
11120	1112	LS	[SY]		HELICOPTER LANDING PAD	Y	PREPARED AREA FOR THE HOVERING, VERTICAL TAKEOFF AND LANDING (VTOL) OF HELICOPTERS AND OTHER VTOL AIRCRAFT.
11125	1111	LS	[SY]		FW A/C (VTOL) LANDING PAD	Y	A LANDING/TAKEOFF PAD FOR VTOL AIRCRAFT SUCH AS THE HARRIER AND JOINT STRIKE FIGHTER.
11130	1113	LS	[SY]		RUNWAY OVERRUN - PAVED	Y	AREAS EXTENDING AT EACH END OF A RUNWAY. THE RUNWAY OVERRUN AREAS ARE REQUIRED TO REDUCE SERIOUS DAMAGE TO AN AIRCRAFT IN THE EVENT THAT THE AIRCRAFT RUNS OFF OF THE RUNWAY END DURING TAKEOFF OR LANDING.
112					TAXIWAYS		
11210	1121	LS	[SY]	LF	TAXIWAY	Y	TAXIWAYS ARE PAVED SURFACES ON WHICH AIRCRAFT, BOTH FIXED AND ROTARY WING, MOVE UNDER THEIR OWN POWER TO AND FROM LANDING, SERVICE AND PARKING AREAS.
113					APRONS		

All outdoor pavements used for parking aircraft, and for the loading, unloading and servicing of aircraft in addition to providing parking space.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
11320	1131	LS	[SY]		AIRCRAFT PARKING APRON	Y	PARKING APRONS ARE REQUIRED FOR LOADING, UNLOADING AND SERVICING OF AIRCRAFT AND PROVIDING PARKING SPACE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
11340	1131	LS	[SY]			AIRCRAFT ACCESS APRON	Y	AIRCRAFT ACCESS APRONS PROVIDE ACCESS TO AIRCRAFT MAINTENANCE HANGARS FROM THE AIRCRAFT PARKING APRON.
116						AIRFIELD PAVEMENTS - OTHER		

Miscelaneous airfield pavements, other than runways, taxiways, and aprons, such as washracks, rinse facilities, compass calibration pads, arming/de-arming pads, Ground Controlled Approach (GCA) pads, blast protective pavement, line vehicle parking, towways, ordnance handling pads, fire and rescue vehicle alert pads, and tactical support van pads.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
11610	1163	LS	[SY]			AIRCRAFT WASHRACK PAVEMENT	Y	AIRCRAFT WASHRACKS ARE PROVIDED AT ALL AIR INSTALLATIONS FOR CLEANING OF AIRCRAFT.
11612	1165	LS	[SY]			AIRCRAFT PAVEMENT SHOULDER	Y	THE AREA EXTENDING LATERALLY FROM THE EDGE OF THE RUNWAY PAVEMENT.
11615	1167	LS	[SY]			AIRCRAFT RINSE FACILITY	Y	AN AIRCRAFT RINSE FACILITY PROVIDES AN UNATTENDED TAXI-THROUGH, TREADLE OPERATED, FRESHWATER DELUGE SYSTEM TO RINSE AIRCRAFT.
11620	1161	LS	[SY]			ACFT COMPASS CALIBRATE PAD	Y	A PAVED AREA IN A MAGNETICALLY QUIET ZONE WHERE THE COMPASS IN THE AIRCRAFT IS CALIBRATED.
11635	1131	LS	[SY]			ARMING & DE-ARMING PAD	Y	A PAVED AREA FOR ACTIVATING OR DEACTIVATING WEAPONS SYSTEMS ON-BOARD AIRCRAFT.
11640	1164	LS	[SY]			PREC APPR RADAR PAD	N	PRECISION APPROACH RADAR (PAR) PAD IS A PAVED HARDSTAND PROVIDED TO SUPPORT THE PAR EQUIPMENT IN OPERATING POSITION.
11642	1164	LS	[SY]			BLAST PROTECTIVE PAVEMENT	N	BLAST PROTECTIVE PAVEMENT IS PROVIDED ADJACENT TO THE RUNWAY THRESHOLD AND END TURNOFF FOR JET RUNWAYS TO PROTECT PAVEMENT FROM DAMAGE DUE TO JET BLAST.
11645	1164	LS	[SY]			LINE VEHICLE PARKING	N	LINE VEHICLE PARKING SPACES CONTIGUOUS TO TAXIWAY AND PARKING APRONS ARE ALLOCATED FOR GROUND SUPPORT EQUIPMENT ASSIGNED FOR FLIGHT LINE USE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
11650	1131	LS	[SY]			TOWWAY	N	A TOWWAY IS A PAVED ROADWAY USED FOR TOWING FIXED OR ROTARY WING AIRCRAFT.
11655	1131	LS	[SY]			ORDNANCE HANDLING PAD	Y	AN ORDNANCE HANDLING PAD IS PROVIDED FOR AIR INSTALLATIONS WHERE THERE IS A REQUIREMENT FOR LOADING OR OFF-LOADING EXPLOSIVES FROM CARGO AIRCRAFT.
11656	1131	LS	[SY]			CMBT A/C LOADING AREA	Y	A COMBAT AIRCRAFT LOADING AREA (CALA) IS PRIMARILY AN APRON WHERE EXPLOSIVES ARE LOADED/OFF-LOADED FROM COMBAT AIRCRAFT DEPARTING AND/OR RETURNING FROM WEAPONS TRAINING FLIGHTS.
11660	1164	LS	[SY]			FIRE / RESCUE VEHICLE PAD	N	THIS FACILITY PROVIDES A PARKING AREA FOR IMMEDIATE RESPONSE ALERT VEHICLE.
11665	1164	LS	SY	[EA]		TACTICAL SUPPORT LAYDOWN	Y	A CONCRETE PAD FOR THE PARKING OF TACTICAL VEHICLES OR EQUIPMENT.
120						LIQUID FUELNG & DISPNG FAC		
121						AIRCRAFT FUELNG/DISPNG FAC		

Refueler trucks are the preferred method to fuel aircraft. However, direct fueling stations may be considered for: (1) carrier aircraft, including helicopters, when the mission dictates a continuing need for rapid turnaround without shutting engines down, (2) cargo/transport aircraft with prescribed short ground times or (3) patrol aircraft which require an average refueling of 2500 gallons or more.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
12110	1211	S		OL	[GM]	ACFT DIRECT FUELING STA	Y	AIRCRAFT DIRECT FUELING STATIONS PROVIDE OUTLETS WHERE AIRCRAFT CAN BE FUELED FROM A CLOSED CIRCUIT FUEL SYSTEM AS OPPOSED TO REFUELER TRUCKS.
12120	1261	S		OL	[GM]	ACFT TRUCK FUELING FAC	Y	AN AIRCRAFT TRUCK FUELING FACILITY IS USED TO TRANSFER FUEL TO AIRCRAFT REFUELING TRUCKS.
12130	1212	S		OL	[GM]	AIRCRAFT DEFUELNG FACILITY	N	THIS CATEGORY CODE IS FOR DEFUELING AIRCRAFT OF EXCESS OR RESIDUAL FUEL. AIRCRAFT SHALL BE DEFUELED INTO TANK TRUCKS DESIGNATED FOR THAT PURPOSE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
12150	1241	S		[GA]		ACFT READY FUELS STORAGE	Y	AIRCRAFT READY FUEL STORAGE PROVIDES AN OPERATION AND RESERVE SUPPLY OF AVIATION GASOLINE AND JET FUEL.

122 MARINE FUEL DISPENSING

This basic Category Code includes the following: Marine fueling facilities designed for small vessels and capital ships that should be able to refuel the largest ship that can dock at the station¿s waterfront. Small craft fueling stations used to refuel such small craft as crash boats and administrative boats. Marine ready fuel storage tanks for the ready issue operation storage of a particular grade of fuel for small boats and yard craft.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
12210	1221	S		OL	[GM]	MARINE FUELING FACILITY	Y	A MARINE FUELING FACILITY IS DESIGNED FOR SMALL VESSELS AND CAPITAL SHIPS AND SHOULD BE ABLE TO REFUEL THE LARGEST SHIP THAT CAN DOCK AT THE STATION¿S WATERFRONT.
12220	1221	S		OL	[GM]	SMALL CRAFT FUELING STA	Y	A SMALL CRAFT FUELING STATION IS USED TO REFUEL SUCH SMALL CRAFT AS CRASH BOATS AND ADMINISTRATIVE BOATS. IT SHALL INCLUDE DISPENSING PEDESTAL-TYPE COMMERCIAL PUMPS, PIPING, TANKS, HOSES, FLOODLIGHTS AND GROUNDING DEVICES, ELECTRICAL POWER, AND FIRE PROTECTION.
12230	1242	S		[GA]		SM CRAFT READY FUEL STRG	Y	A MARINE READY FUEL STORAGE TANK IS THE READY ISSUE OPERATIONAL STORAGE OF A PARTICULAR GRADE OF FUEL FOR SMALL BOATS. (E.G. SMALL TUGS, SECURITY BOATS, REPAIR BARGES AND YARD CRAFT)

123 LAND VEH FUELNG/DISPNG FAC

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

This Category Code group is for facilities serving official government land vehicles and equipment only. If NEX operates the facility, see Category Code 740-30/31, Exchange Service and Auto Repair/Supplemental Gasoline Station. For Aviation Fueling and Dispensing, see Category Code Series 121. For Marine and Small Craft Fueling and Dispensing, see Category Code series 122. For bulk fuel storage such as tank farm installation, see Category Code series 411.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
12310	1231	S		[OL]	GM	FILLING STATION	Y	A FILLING STATION IS A FUELING FACILITY FOR OFFICIAL VEHICLES AND EQUIPMENT ON NAVY AND MARINE CORPS INSTALLATIONS. THIS CATEGORY CODE APPLIES TO PUMP OUTLETS INCLUDING THE COVERED ISLANDS THAT SUPPORT THE PUMP OUTLETS, THE CONCRETE PARKING AREA, LIGHTING AND THE ACCESS PAVING TO THE PUMPS/ISLANDS.
12315	8910	B	[SF]			FILLING STATION BUILDING	Y	THIS CODE IS USED FOR REPORTING THE ADMINISTRATIVE SHELTER ASSOCIATED WITH A FILLING STATION. IF THE FILLING STATION IS OPERATED BY A PRIVATE ENTITY, THEN USE THE 740-30/31 CATEGORY CODES. WHERE CREDIT CARD SYSTEMS ARE USED AND OPERATORS ARE NOT NEEDED, A SHELTER IS NOT REQUIRED.
12316	1459	S	[SF]		EA	OVERHEAD COVER, AIRFIELD	N	THIS CATEGORY CODE CAN BE USED FOR OVERHEAD COVERS LOCATED ON THE AIRFIELD (THAT ARE NOT CLASSIFIED AS EQUIPMENT).
12317	1459	S	[SF]		EA	OVERHEAD COVER, MISC	N	THIS CATEGORY CODE CAN BE USED FOR OVERHEAD COVERS LOCATED AT THE MAIN GATES OF INSTALLATIONS, OVERHEAD COVERS ATOP GAS PUMPS, AND ANY OTHER TIME THAT AN OVERHEAD COVER IS USED.
12330	1243	S		[GA]		VEH & EQUIP RDY FUEL STOR	Y	THIS CODE IS USED FOR REPORTING THE TANK STORAGE REQUIREMENT ASSOCIATED WITH CATEGORY CODE 123 10 AND 740 30, INCLUDING THOSE TANKS IN REMOTE LOCATIONS THAT ARE CONSIDERED REAL PROPERTY.
12340	1243	S			[GA]	ETHANOL RDY FUEL STOR	Y	THIS CATEGORY IS FOR ALTERNATIVE FUEL FACILITIES IN SUPPORT OF ETHANOL OPERATION OF VEHICLES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
12350	1243	S			[GA]	BIODIESEL READY FUEL STOR	Y	THIS CATEGORY IS FOR ALTERNATIVE FUEL FACILITIES IN SUPPORT OF BIODIESEL OPERATION OF VEHICLES.
124						OPERATING FUEL STORAGE		
125						POL PIPELINE		

This category is for pipelines and accessory equipment between tank farms and operating fuel storage facilities and intermediate points.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
12510	1251	LS		[LF]		POL PIPELINE MULTI SITES	N	TRANSFER PIPELINES USED FOR THE TRANSFER AND TRANSPORT OF PETROLEUM, OILS, LUBRICANTS AND FUELS BETWEEN SITES.
12516	1262	S		[GM]	EA	POL PIPELINE PUMP STA	N	PUMPING STATIONS AND ANCILLARY EQUIPMENT USED TO MOVE THE FUEL THROUGH THE PIPES. THIS FACILITY MAY ALSO INCLUDE CONTROLS, GAUGES, METER, LIGHTING, FIRE PROTECTION, AND VENTILATION.
12520	1459	S	[SF]		EA	SHLTR FOR PUMP STA	N	THIS IS USED FOR STRUCTURES HOUSING PUMPING STATIONS AND ANCILLARY EQUIPMENT.
12521	1252	LS		[LF]		POL PIPING-SINGLE SITE	N	POL PIPELINES USED FOR THE TRANSFER AND TRANSPORT OF PETROLEUM, OILS, LUBRICANTS AND FUELS WITHIN A SITE (EXCEPT THOSE WITHIN A MARINE OR AIRCRAFT FUELING FACILITY).
12530	1244	S		[GA]		SURGE STORAGE	N	A SURGE TANK IS USED WHERE THERE IS A RISK OF HYDRAULIC SHOCK. HYDRAULIC SHOCK CAN OCCUR WHEN THE PUMP USED TO DELIVER FUEL IS GREATER THAN THE PIPELINE CAPACITY; UNLOADING RATE OF THE DELIVERY TANKER/BARGE EXCEEDS THE RATE OF THE SHORE PUMPING SYSTEM; OR WATER, AIR OR OTHER BLOCKAGE OCCURS IN THE PIPELINE.
126						OTHER LIQUID FUELNG/DISPNG		

Category Code Report (All Series)

Use this Category Code for liquid fuel or petroleum products facilities not specifically related to aviation, marine craft, or ground vehicle fuel requirements (see Category Codes series 121, 122, and 123, respectively). Use Category Code 821 60 or 821 61 for heating plant fuel storage. This Category Code includes fuel loading and unloading; drum storage, loading and maintenance; and miscellaneous fuel storage (i.e., heating fuel, kerosene, propane, fuel oil, etc.). See Category Code series 411 for depot level storage.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
12610	1261	S		[OL]	EA	DRUM AND CAN LDING FACY	Y	A DRUM AND CAN LOADING FACILITY IS A FUEL FACILITY EQUIPPED TO FILL DRUMS WITH FUEL OIL, DIESEL, KEROSENE, JET ENGINE FUEL, MOTOR GASOLINE, AVIATION GASOLINE, AND LUBRICATING OILS. THE FACILITY MAY ALSO BE PROVIDED WITH A DRUM RECONDITIONING PLANT.
12615	1244	S		[GA]		PETROLEUM RDY FUEL STOR FA	Y	THIS CATEGORY SHALL BE USED FOR THE STORAGE OF PETROLEUM PRODUCTS USED TO FILL DRUMS AS PROVIDED IN CATEGORY CODE 126 10, HEATING OIL TANKS (SEE CATEGORY CODE 821-60 OR 61 FOR HEATING PLANT FUEL STORAGE), LUBE OIL TANKS, GREASE, PROPANE TANKS, OR FUEL STORAGE TANKS FOR GENERATORS AND OTHER EQUIPMENT.
12630	1261	S		[OL]		TANK TRUCK/CAR LOAD FAC	Y	A TANK TRUCK LOADING FACILITY (EITHER A TRUCK FILL STAND OR STANDS) DISPENSE FUELS OTHER THAN AIRCRAFT FUELS TO DELIVERY TRUCKS. EACH STAND HAS ONE DUAL OUTLET, A METER, STATIC LINE, PLATFORM, ROADWAY, STRAINER AND NECESSARY VALVES, PIPING, PUMP, AND ELECTRICAL CONTROLS
12640	1261	S		[OL]		TANK TRUCK/CAR UNLOAD FAC	Y	A TANK CAR UNLOADING FACILITY UNLOADS LIQUID PRODUCTS FROM TANK CARS. EACH FACILITY HAS STATIC LINES, STRAINER, ACCESS ROAD, SECURITY FENCING, LIGHTING, NECESSARY VALVES, PIPING, PUMP, ELECTRICAL CONTROLS, AND A SHELTER STRUCTURE FOR USE OF ACCOUNTING AND/OR CONTROL HOUSE.

130 COMMS/NAV AIDS & AFLD LTNG

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
131						COMMUNICATIONS - BUILDINGS		

This group of Shore Facilities supports the reception, processing, distribution, and/or transmission of classified and unclassified voice, data, and video communications in support of the Department of Navy operational missions.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13110	1311	B	[SF]			CABLE HOUSE	Y	A CABLE HOUSE IS AN UNMANNED FACILITY THAT FUNCTIONS EITHER AS AN EXTERNAL JUNCTION POINT FOR COAXIAL CABLES, OR AS MECHANICAL SPACE FOR SUPPORT EQUIPMENT ASSOCIATED WITH EXTREMELY LOW FREQUENCY (ELF) AND VERY LOW FREQUENCY (VLF) ANTENNAS.
13115	1311	B	[SF]			COMM, INFO, OR INTEL FAC	Y	COMMUNICATIONS, INFORMATION, OR INTELLIGENCE FACILITIES ARE RESPONSIBLE FOR INFORMATION PROCESSING, DELIVERY OF INFORMATION SERVICES, AND INFORMATION/DATA STORAGE. THESE ULTIMATELY SUPPORT THE JOINT INFORMATION ENVIRONMENT (JIE). THE JIE IDENTIFIES SEVERAL DIFFERENT TYPES OF FUNCTIONAL NODES: COMPUTING NODES (E.G. DATA CENTERS), COMMUNICATION NODES (E.G. NETWORK GATEWAYS), AND OPERATIONS NODES (E.G. ENTERPRISE OPERATION CENTERS). THESE NODES SHOULD BE VIEWED AS FUNCTIONAL ENCLAVES, NOT SEPARATE FACILITIES; IN FACT, MULTIPLE NODES AND NODE TYPES MAY BE PRESENT IN A SINGLE PHYSICAL FACILITY.
13120	1311	B	[SF]			COMMS RELAY BLDG	Y	A COMMUNICATIONS RELAY FACILITY IS AN UNMANNED FACILITY OR ENCLOSURE ASSOCIATED WITH THE OPERATION OF MICROWAVE (MW) COMMUNICATIONS SYSTEMS. IT CONTAINS RACK MOUNTED COMMUNICATIONS RECEIVING, AMPLIFICATION, AND TRANSMITTING EQUIPMENT, ALONG WITH AN UNINTERRUPTIBLE POWER SOURCE (UPS) AND AN EMERGENCY GENERATOR.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13122	1311	B	[SF]			VHF/UHF COMMS FAC	Y	A VHF/UHF COMMUNICATIONS FACILITY CAN EITHER BE CONTAINED WITHIN A PERMANENT FACILITY OR WITHIN CLASS III PROPERTY. IT CONTAINS A LIMITED AMOUNT OF RACK MOUNTED COMMUNICATIONS RECEIVING, AMPLIFICATION, AND TRANSMITTING EQUIPMENT ASSOCIATED WITH AIRFIELD OPERATIONS, SECURITY AND FIRE OPERATIONS, OR AN TACTICAL COMMUNICATIONS SYSTEM INTEGRAL TO UNIQUE SPECIAL OPERATIONS.
13124	1312	B	[SF]			SAT COMMS FAC	Y	A SATELLITE COMS FACILITY IS OFTEN REFERRED TO AS A `GATEWAY FACILITY¿ SUPPORTING WORLDWIDE, REGIONAL, AND AREA OF RESPONSIBILITY (AOR) COMS. IT CONTAINS DIVISION LEVEL OFFICE AND SUPPORT REQUIREMENTS, EQUIPMENT AND OPERATIONAL AREAS, MAINTENANCE AND TRAINING AREAS, AND LIMITED STORAGE AREAS FOR READY-TO-ISSUE COMS SYSTEMS AND SUBSYSTEMS REQUIRED FOR INCOMING AND OUTGOING COMS TRAFFIC.
13125	1311	B	[SF]			TELEMETRY BUILDING	Y	A TELEMETRY BUILDING IS AN EXTREMELY SPECIALIZED AND UNIQUE FACILITY SPECIFICALLY DESIGNED FOR THE TRACKING OF MISSILES AND SATELLITES.
13130	1311	B	[SF]			HELIX HOUSE	Y	A HELIX HOUSE CONTAINS A HELICAL COIL AND ASSOCIATED ANTENNA TUNING DEVICES DIRECTLY ASSOCIATED WITH, AND INTEGRAL TO, THE TRANSMISSION OF LOW FREQUENCY (LF), VERY LOW FREQUENCY (VLF), AND EXTREMELY LOW FREQUENCY (ELF) COMMUNICATIONS.
13135	1311	B	[SF]			RECEIVER BUILDING	Y	A RECEIVER BUILDING SUPPORTS A 24 HOUR A DAY, 7 DAY A WEEK OPERATIONAL REQUIREMENT FOR SHORE TO SHORE AND SHIP TO SHORE ADMINISTRATIVE, TACTICAL, AND STRATEGIC HIGH FREQUENCY (HF) COMMUNICATIONS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13140	1311	B	[SF]			TELEPHONE EXCHANGE BLDG	Y	A TELEPHONE EXCHANGE BUILDING CAN SUPPORT WORLDWIDE, REGIONAL AND AREA COMMUNICATIONS FOR A NAVAL SHORE ACTIVITY. THE TELEPHONE EXCHANGE BUILDING CAN CONTAIN THE TELEPHONE SWITCH, MAIN DISTRIBUTION FRAME, INTERMEDIATE DISTRIBUTION FRAME, STAFF SUPPORT SPACES, OPERATORS WORK POSITIONS, MAINTENANCE AND STORAGE SPACES, AND IS SUPPORTED BY UPS AND EMERGENCY GENERATORS.
13142	1311	B	[SF]			AUTO COMMS SWITCH CNTR	Y	AN AUTOMATIC-COMMUNICATIONS SWITCHING-CENTER IDENTIFIES A FACILITY THAT CONTAINS THE TELEPHONE SWITCH AND ITS IMMEDIATE SUPPORT INFRASTRUCTURE. ALTHOUGH IT IS POSSIBLE THAT SOME ISOLATED EXAMPLES OF THIS CONFIGURATION MAY STILL EXIST, THE CURRENT COMMUNICATIONS ARCHITECTURE FOR THIS EQUIPMENT PLACES IT WITHIN A TELEPHONE EXCHANGE BUILDING
13145	1311	B	[SF]			TERMINAL EQUIPMENT BLDG	Y	THIS FACILITY ORIGINALLY, AND CURRENTLY TO A MINOR EXTENT, PERFORMS AS A SINGLE-FUNCTION BUILDING THAT IS IN DIRECT SUPPORT OF HIGH FREQUENCY (HF) OR LOW FREQUENCY (LF) COMMUNICATIONS. IT PROVIDES AN INTERMEDIATE CONNECTION POINT THAT IS REQUIRED TECHNICALLY TO SUPPORT COMMUNICATIONS CONFIGURATION, OR IS REQUIRED AS THE RESULT OF WAVEGUIDE OR CABLE LOSS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13150	1311	B	[SF]			TRANSMITTER BUILDING	Y	A TRANSMITTER BUILDING SUPPORTS A 24 HOUR A DAY, 7 DAY A WEEK OPERATIONAL REQUIREMENT FOR SHORE TO SHORE AND SHORE TO SHIP ADMIN, TACTICAL, AND STRATEGIC HIGH FREQUENCY (HF), LOW FREQUENCY (LF), VERY LOW FREQUENCY (VLF) AND EXTREMELY LOW FREQUENCY (ELF) COMS. A SMALL PERSONNEL SUPPORT SPACE CONTAINING A TOILET FACILITY AND BREAK AREA IS CONSIDERED PART OF THE FACILITY.
13155	1311	B	[SF]			CIRC DISP ANT ARRAY BLDG	N	A CIRCULARLY DISPOSED ANTENNA ARRAY (CDAA) BUILDING IS A HIGH FREQUENCY DIRECTION FINDING (HFDF) FACILITY THAT CONTAINS THE TUNING AND RECEIVING EQUIPMENT ASSOCIATED WITH THE AN/FRD-10 ANTENNA.
13156	1311	B	[SF]			DIRECTION FINDER BUILDING	N	A DIRECTION FINDER BUILDING IS A HIGH FREQUENCY DIRECTION FINDING (HFDF) FACILITY THAT CONTAINS THE TUNING AND RECEIVING EQUIPMENT ASSOCIATED WITH THE AN/FRD-13 ANTENNAS. IT IS ASSOCIATED WITH FUNCTIONS PERFORMED BY VARIOUS DON COMMUNICATIONS, INTELLIGENCE, AND OPERATIONAL MISSIONS.
13160	1311	B	[SF]			MIL AFFIL RADIO STA (MARS)	N	THE MILITARY AFFILIATE RADIO SYSTEM IS PART OF NAVY TELECOMMUNICATIONS COMPLEX. SIZE OF THE STATION VARIES WITH THE TYPE OF OPERATIONS AND EQUIPMENT USED. AS A GENERAL RULE, THE SPACE FOR A MARS STATION IS PROVIDED WITHIN EXISTING NAVY FACILITIES AND NO SPECIFIC PROJECTS SHOULD BE PLANNED. THIS CODE IS MAINLY INTENDED FOR INVENTORY PURPOSES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

This facility group encompasses radio antennas, switching stations and public address systems. The antennas required are a function of the number and type of radio circuits to be incorporated in the communications system.

13210	1321	S		[EA]		ANTENNA - COMMUNICATIONS	N	THIS FACILITY GROUP ENCOMPASSES RADIO ANTENNAS, SWITCHING STATIONS AND PUBLIC ADDRESS SYSTEMS. THE ANTENNAS REQUIRED ARE A FUNCTION OF THE NUMBER AND TYPE OF RADIO CIRCUITS TO BE INCORPORATED IN THE COMMUNICATIONS SYSTEM.
13250	1321	S		[EA]		P/A SYSTEM OUTDOOR	N	OUTDOOR PUBLIC ADDRESS SYSTEMS (GIANT VOICE) WILL BE PLANNED AND INSTALLED TO MEET INDIVIDUAL NEEDS OF A FACILITY
13255	1321	S		[EA]		CIRC DISP ANT ARRAY	N	THIS ANTENNA ARRAY IS GENERALLY PLANNED IN CONJUNCTION WITH A CIRCULARLY DISPOSED ANTENNA ARRAY BUILDING. SEE CATEGORY CODE 131 55 FOR ADDITIONAL GUIDANCE.

133						NAV & TRAFFIC AIDS - BLDGS		

Basic Category Code group 133 applies to those Air Traffic Control Facilities (ATCFs) that contain the equipment, devices, and personnel responsible for air traffic control and navigational aids. This group discusses complete air traffic control classes and systems, which are defined below. Other elements of air traffic control and navigation aids that are remotely located around the airfield can be found in the 133, 134 and 135 series of Category Codes.

13315	1331	B	[SF]			RAWIN BUILDING	Y	A RAWIN BUILDING (RADAR WIND SOUNDING) IS A SPECIALIZED WEATHER REPORTING FACILITY. IT HOUSES TRACKING EQUIPMENT USED IN CONJUNCTION WITH BALLOONBORNE RADIOSONDE TRANSMITTERS.
13320	1331	B	[SF]			VHF OMNI-DIR RNG (VOR) FAC	Y	THE VERY HIGH FREQUENCY (VHF) OMNI-DIRECTIONAL RANGE (VOR) BUILDING HOUSES A VHF, FIXED GROUND-BASED STATION WHICH CONTINUOUSLY TRANSMITS BEARING, IDENTIFICATION, AND WITH PROPER EQUIPMENT, DISTANCE INFORMATION TO PROPERLY EQUIPPED AIRCRAFT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13325	1331	B	[SF]			TACAN BUILDING	Y	THE TACTICAL AIR NAVIGATION (TACAN) BUILDING HOUSES UHF GROUND-BASED STATION WHICH TRANSMITS BEARING, IDENTIFICATION, AND DISTANCE INFORMATION TO PROPERLY EQUIPPED AIRCRAFT. THE TACAN IS PRIMARILY A MILITARY SHORT-RANGE 322 KM (200 MILE) NAVIGATIONAL AID THAT IS GENERALLY PLANNED FOR EACH NAVY AND MARINE CORPS AIR STATION.
13330	1331	B	[SF]			VHF RNG TACAN FACILITY	Y	THE VERY HIGH FREQUENCY (VHF) OMNI-DIRECTIONAL RANGE/TACTICAL AIR NAVIGATION (VORTAC) BUILDING HOUSES VHF/UHF FIXED GROUND-BASED STATION THAT CONTINUOUSLY TRANSMITS BEARING, IDENTIFICATION, AND DISTANCE INFORMATION TO PROPERLY EQUIPPED AIRCRAFT WHEN DISTANCE MEASURING EQUIPMENT (DME) IS INSTALLED.
13335	1331	B	[SF]			NDB FACILITY	Y	THIS NON-DIRECTIONAL BEACON (NDB) FACILITY IS AN UNATTENDED FACILITY WHICH HOUSES ELECTRIC EQUIPMENT (RADIO BEACON) USED TO TRANSMIT A NON-DIRECTIONAL RADIO SIGNAL PATTERN TO AIRCRAFT EQUIPPED WITH AUTOMATIC RADIO DIRECTION AND FINDING (ADF) EQUIPMENT.
13365	1331	B	[SF]			AIR NAVIGATION BUILDING	Y	AN AIR NAVIGATION BUILDING IS A SPECIALIZED FACILITY FOR PROVIDING A READILY AVAILABLE SOURCE OF OPERATIONAL AND AERONAUTICAL INTELLIGENCE INFORMATION; STORAGE AND ISSUE OF AERONAUTICAL MAPS AND CHARTS; AND SECURE STORAGE OF CLASSIFIED MATERIAL UP TO TOP SECRET DOCUMENTS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13371	1331	B	[SF]			RATCF FACILITY	Y	THE RADAR AIR TRAFFIC CONTROL FACILITY (RATCF) PROVIDES HOUSING FOR EQUIPMENT AND PERSONNEL TO SUPPORT INSTRUMENT FLIGHT RULES (IFR) CONTROL OF AIRCRAFT ON APPROACH TO OR DEPARTURE FROM THE TERMINAL RADAR FACILITY OR AIRPORT. OTHER FUNCTIONS INCLUDE PRECISION APPROACH RADAR (PAR) FOR LANDING AIRCRAFT DURING INCLEMENT WEATHER AND LIMITED VISIBILITY.
13372	1331	B	[SF]			MTRACON	Y	A MILITARY TERMINAL RADAR APPROACH CONTROL (MTRACON) FACILITY IS USED TO CONTROL AIR TRAFFIC TO PROVIDE SAFE, EXPEDITIOUS, AND ORDERLY MOVEMENT OF AIRCRAFT UNDER ALL WEATHER CONDITIONS. JUSTIFICATION FOR A MTRACON IS ESTABLISHED BY THE CHIEF OF NAVAL OPERATIONS.
13373	1331	B	[SF]			FACSFAC	Y	THE FLEET AREA CONTROL SURVEILLANCE FACILITY (FACSFAC) BUILDING HOUSES THE FACSFAC TRACKING SYSTEM (FACTS) AND NAVY TACTICAL DATA SYSTEM/ADVANCED COMBAT DIRECTION SYSTEM (NTDS/ACDS) EQUIPMENT AND PERSONNEL TO PROVIDE A VARIETY OF SERVICES TO AIR, SURFACE AND SUBSURFACE UNITS.
13374	1331	B	[SF]			JCF FACILITY	Y	THE JOINT CONTROL FACILITY (JCF) IS AN AIR TRAFFIC CONTROL FACILITY, A RADAR AIR TRAFFIC CONTROL FACILITY (RATCF), AND A RANGE OPERATIONS CENTER (ROC) UNDER ONE ROOF.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13375	1331	B	[SF]			AIR SURVEILLANCE RADAR FAC	Y	THE AIR SURVEILLANCE RADAR (ASR) FACILITY IS AN UNATTENDED FACILITY WHICH SERVES AS A MAJOR COMPONENT OF THE RADAR AIR TRAFFIC CONTROL FACILITY (RATCF); THE MILITARY TERMINAL APPROACH CONTROL FACILITY (MTRACON); AND THE JOINT CONTROL FACILITY (JCF). IT PROVIDES DETECTION AND IDENTIFICATION FOR CONTROL OF AIRCRAFT OPERATING IN A LINE-OF-SIGHT RANGE AND ALTITUDES DETERMINED BY SYSTEM DESIGN.
13376	1331	B	[SF]			ARSR FACILITY	Y	THE AIR ROUTE SURVEILLANCE RADAR (ARSR) FACILITY HOUSES THE ELECTRONIC LONG RANGE RADAR SYSTEM USED TO OBTAIN THE RANGE AND AZIMUTH OF AN AIRCRAFT.
13380	1331	B	[SF]			WHEELS WATCH SHELTER	Y	A PORTABLE WHEELS WATCH BOOTH IS PROVIDED WITH THE RUNWAY WHEELS-UP/WAVE-OFF LIGHTING SYSTEM, CATEGORY CODE 136 45. THE SHELTER IS LOCATED APPROXIMATELY 302 METERS (990 FEET) SHORT OF THE RUNWAY THRESHOLD NEAR THE WHEELS-UP/WAVE-OFF LIGHTING SYSTEM. THE FACILITY MAY BE EITHER A TRAILER OR TRUCK.
134						NAV & TRAFFIC AIDS - OTHER		

Basic Category Code group 134 applies to structures which function as aircraft navigation/ traffic aids.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13410	1341	S		[EA]		ANTENNA - NAVIGATION	N	AN ANTENNA SYSTEM FOR NAVIGATION AID WILL VARY WITH THE TYPE AND PURPOSE OF THE NAVIGATIONAL AID. THIS CATEGORY CODE SHALL BE USED TO INDICATE ENTIRE ANTENNA SYSTEMS.
13420	1341	S		[EA]		AP/HP BEACON	N	AN AIRPORT AND/OR HELIPORT BEACON IS AN INTERNATIONALLY RECOGNIZED ROTATING OR FLASHING ILLUMINATED BEACON OPERATED AS A VISUAL AID TO AIR NAVIGATION TO ASSIST AIRCREWS IN LOCATING AND IDENTIFYING AIRPORTS AND/OR HELIPORTS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13440	1341	S		[EA]		GROUND CONTROL APPR SYST	Y	A GROUND CONTROL APPROACH (GCA) SYSTEM IS A RADAR APPROACH SYSTEM OPERATED FROM THE GROUND BY AIR TRAFFIC CONTROL PERSONNEL TRANSMITTING INSTRUCTIONS TO THE PILOT BY RADIO.
13441	1341	S			[EA]	PREC APPR RADAR	Y	THE PRECISION APPROACH RADAR (PAR) IS AN UNATTENDED SELF-CONTAINED RADAR SYSTEM. THE PAR DETECTS AZIMUTH, ELEVATION, AND RANGE INFORMATION OF AIRCRAFT ON FINAL LANDING APPROACH TO PAR INSTRUMENTED RUNWAYS. THE INFORMATION IS DISPLAYED IN THE MILITARY TERMINAL RADAR APPROACH CONTROL (MTRACON) FACILITY.
13442	1341	S			[EA]	PREC APPR LAND SYS	Y	THE PRECISION APPROACH LANDING SYSTEM (PALS) IS AN UNATTENDED, SELF-CONTAINED RADAR SYSTEM. THE PALS DETECTS AZIMUTH, ELEVATION, AND RANGE INFORMATION OF AIRCRAFT ON FINAL APPROACH TO PALS INSTRUMENTED RUNWAYS.
13443	1341	S			[EA]	INSTR LAND SYS	Y	THE INSTRUMENT LANDING SYSTEM (ILS) PROVIDES AZIMUTH, DISTANCE, ELEVATION, AND GLIDE PATH POSITION TO AIRCRAFT ON A PRECISION APPROACH TO THE ILS INSTRUMENTED RUNWAY. THE ILS OPERATES IN THE VHF AND UHF RADIO BANDS.
13444	1341	S			[EA]	MICROW LAND SYS	Y	THE MICROWAVE LANDING SYSTEM (MLS) PROVIDES AZIMUTH, DISTANCE, ELEVATION, AND GLIDE PATH POSITION TO AIRCRAFT ON A PRECISION APPROACH TO THE MLS INSTRUMENTED RUNWAY. THE MLS OPERATES IN A NARROW BAND MICROWAVE FREQUENCY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13445	1341	S			[EA]	SHORE AUTOM CARR LAND SYS	Y	THE SHORE-BASED AUTOMATIC CARRIER LANDING SYSTEM (ACLS) IS AN UNATTENDED, SELF-CONTAINED RADAR SYSTEM. THE ACLS CONSISTS OF PRECISION TRACKING RADAR COUPLED TO A COMPUTER DATA LINK TO PROVIDE CONTINUOUS INFORMATION TO THE AIRCRAFT, MONITORING CAPABILITY TO THE PILOT, AND A BACKUP APPROACH SYSTEM.
13450	1341	S		[EA]		OBSTRUCTION LTG / MARKINGS	N	OBSTRUCTION LIGHTING PROVIDES VISUAL IDENTIFICATION OF OBJECTS AT NIGHT, OR IN SOME CASES IN DAY TIMES, THAT ARE POTENTIALLY HAZARDOUS TO AIR NAVIGATION.
13455	1341	S		[EA]		VISUAL APPR SLOPE INDICTR	N	THE VISUAL APPROACH SLOPE INDICATOR (VASI) SYSTEM IS AN UNATTENDED SYSTEM THAT PROVIDES VISUAL GLIDE SLOPE GUIDANCE TO PILOTS OF AIRCRAFT DURING THE FINAL LANDING APPROACH. THE VASI IS HELPFUL DURING DAY AND NIGHT OPERATIONS AND FOR VISUAL FLIGHT RULES (VFR) AND INSTRUMENT FLIGHT RULES (IFR) OPERATIONS.
13456	1341	S			[EA]	PREC APPR PATH IND SYS	Y	THE PRECISION APPROACH PATH INDICATOR (PAPI) SYSTEM IS AN UNATTENDED SYSTEM WHICH PROVIDES VISUAL GLIDE SLOPE GUIDANCE TO PILOTS OF AIRCRAFT DURING THE FINAL LANDING APPROACH. THE PAPI SYSTEM PROVIDES THIS INFORMATION DURING THE DAY AND NIGHT FOR VISUAL FLIGHT RULES (VFR) AND INSTRUMENT FLIGHT RULES (IFR) OPERATIONS AS LOW AS CATEGORY I CONDITIONS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13460	1341	S		[EA]		OPT LANDING AIDS	N	OPTICAL LANDING AIDS PROVIDE THE PILOT APPROACHING FOR A LANDING WITH A VISUAL SIGNAL TO ASSIST IN INTERCEPTING AND MAINTAINING THE CORRECT APPROACH GLIDE SLOPE. THE OLA IS A REQUIRED VISUAL AID FOR LANDINGS ON AIRCRAFT CARRIERS, BUT ON SHORE-BASED AIRFIELDS THE OLA IS PRIMARILY AN AID FOR TRAINING OR PRACTICE. THE OLA MAY BE USED DURING DAY OR NIGHT OPERATIONS AND IN ALL WEATHER CONDITIONS.
13462	1341	S		[EA]		WIND DIRECTION INDICATOR	N	A WIND DIRECTION INDICATOR PROVIDES VISUAL INFORMATION OF THE SURFACE WIND DIRECTION AND GENERAL INDICATION OF THE WIND SPEED TO THE AIRCREW. THIS WIND INFORMATION IS MOST USEFUL DURING TAKEOFF, FOR ORIENTATION TO MAKE AN APPROACH, AND IN THE FINAL PHASE OF APPROACH PRIOR TO TOUCHDOWN.
13464	1341	S		[EA]		RUNWAY DISTANCE MARKERS	N	THE PURPOSE OF RUNWAY DISTANCE MARKERS IS TO INDICATE TO AIRCREWS THE DISTANCE REMAINING TO THE END OF THE RUNWAY DURING TAKEOFF AND LANDING. THE RDM PROVIDE THIS INFORMATION FOR DAY AND NIGHT OPERATIONS IN ALL WEATHER CONDITIONS. THE RDM SHOULD BE PROVIDED FOR ALL RUNWAYS WHERE FIXED WING JET AIRCRAFT OPS ARE CONDUCTED AND ARE RECOMMENDED FOR RUNWAYS INTENDED FOR OPS OF PROPELLER TYPE AIRCRAFT.
13466	1341	S		[EA]		VOR/TACAN CHK SIGN	N	A VOR/TACAN CHECK SIGN PROVIDES INFORMATION FOR THE PILOT WHEN VERIFYING THE OPERATION OF THE NAVIGATIONAL AID IN THE AIRCRAFT BEFORE TAKING OFF. THIS CHECK SIGN IS A VISUAL IDENTIFICATION MARKER ERECTED IN THE AREA ADJACENT TO THE AIRCRAFT HOLDING POINT AT THE TAXIWAY ACCESS TO RUNWAY ENDS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13470	1341	S		[EA]		RADAR TOWER	N	RADAR TOWERS ARE TOWERS HOSTING VARIOUS RADAR SYSTEMS AND MUST BE PLANNED ON AN INDIVIDUAL BASIS.
13471	1341	S		[EA]		AVIATION METEORLOGICAL FAC	N	WEATHER FORECASTING FACILITY THAT SUPPORTS AIR OPERATIONS.

135 COMM & CONTROL LINES

Communication lines provide circuits between the various activities on or off the station.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13510	1351	LS		[MI]		COMM LINES EXCL TELEPHONE	N	COMMUNICATION LINES PROVIDE CIRCUITS BETWEEN THE VARIOUS ACTIVITIES ON OR OFF THE STATION. THE COMMUNICATIONS NET MAY INCLUDE TRUNK LINE SERVICE CABLE, FEEDER LINES, AND DIRECT CIRCUITS DEPENDING ON THE COMPLEXITY OF THE SYSTEM.
13520	1351	LS		[MI]		TELEPHONE LINES	N	COMMUNICATION LINES, TO INCLUDE OVERHEAD, UNDERGROUND, AND MARINE CABLES AND LINES.

136 AIRFIELD PAVEMENT LIGHTING

Airfield pavement lighting includes facilities for lighting all airfield pavements and approaches including airfield Visual Landing Aids for approaches, landings, takeoffs, taxiing, and surface maneuvering of aircraft on Navy and Marine Corps airfields. The visual landing aids include lighting and markings.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13610	1361	S		[LF]		APPROACH LIGHTING	N	APPROACH LIGHTING ENHANCES THE AIRCREW¿S ABILITY TO ACQUIRE THE RUNWAY ENVIRONMENT VISUALLY WHEN MAKING AN APPROACH FOR LANDING DURING PERIODS OF REDUCED VISIBILITY. VISUAL CUES FOR DIRECTIONAL AND ROLL GUIDANCE ARE PROVIDED TO THE AIRCREW FOR OPERATIONS AT NIGHT AND IN MARGINAL WEATHER CONDITIONS BY DAY. THE SYSTEM INCLUDES BOTH APPROACH LIGHTS AND SEQUENCED FLASHERS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13620	1361	S		[LF]		APRON & PKG APRN LIGHTING	N	APRON AND PARKING AREA LIGHTING ENABLES THE AIRCREW TO GUIDE THEIR AIRCRAFT INTO POSITION FOR LOADING, SERVICING, OR PARKING AND PROVIDES ILLUMINATION TO PERFORM SUCH FUNCTIONS AS FUELING, MAINTENANCE, LOADING, UNLOADING, AND SECURITY.
13630	1361	S		[LF]		RUNWAY EDGE LIGHTING	N	THIS CATEGORY CODE INCLUDES TWO GROUPS OF LIGHTS, RUNWAY EDGE LIGHTS, WHICH DEFINE THE LATERAL LIMITS OF THE PAVEMENT, AND CIRCLING GUIDANCE LIGHTS (CGLS), WHICH ENABLE AN AIRBORNE AIRCREW TO LOCATE THE RUNWAY WHILE OFF TO THE SIDE OF THE RUNWAY, AND ESTABLISH THE PROPER TRAFFIC PATTERN.
13635	1361	S		[LF]		RUNWAY CENTERLINE LIGHTING	N	RUNWAY CENTERLINE LIGHTING PROVIDES VISUAL AID TO ASSIST THE AIRCREW IN KEEPING THE AIRCRAFT CENTERED ON THE RUNWAY DURING TAKE-OFF AND AFTER LANDING AT NIGHT OR IN CONDITION OF REDUCED VISIBILITY. IT IS A SUPPLEMENT TO RUNWAY EDGE LIGHTING AND MARKINGS AND CIRCLING GUIDANCE LIGHTING, CATEGORY CODE 136 30.
13636	1362	S		[EA]		SIMULATE CARRIER DECK LTG	Y	A SIMULATED CARRIER DECK IS USED TO TRAIN PILOTS ASHORE FOR LANDING AIRCRAFT UNDER SIMULATED CONDITIONS OF A CARRIER AT SEA. SIMULATED CARRIER DECK LIGHTING AND MARKINGS PERMITS TRAINING DURING THE DAY, NIGHT, AND ADVERSE VISIBILITY CONDITIONS.
13645	1362	S		[EA]		WHEELS UP / WAVE OFF LTG	N	WHEELS-UP AND WAVE-OFF LIGHTS ARE PROVIDED TO ALLOW EITHER THE WHEEL WATCH, THE LANDING SIGNAL OFFICER (LSO), OR CONTROL TOWER PERSONNEL TO DETERMINE IF A LANDING AIRCRAFT HAS ITS LANDING GEAR FULLY EXTENDED AND/OR TO SIGNAL TO AN AIRCREW TO ABORT OR ¿WAVE-OFF¿ A LANDING ATTEMPT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13650	1361	S		[LF]		TAXIWAY LIGHTING	N	TAXIWAY LIGHTING AND MARKINGS DEFINE THE LATERAL LIMITS AND DIRECTION OF A TAXIWAY, CATEGORY CODE 112-10, TO GUIDE AIRCRAFT MOVEMENT BETWEEN THE RUNWAY OPERATIONAL AREA AND THE AIRCRAFT PARKING AREA DURING NIGHT OPERATIONS OR CONDITIONS OF POOR VISIBILITY.
13655	1362	S		[EA]		TOUCHDOWN ZONE LIGHTING	N	TOUCHDOWN ZONE LIGHTING DELINEATES THE TOUCHDOWN ZONE AND PROVIDES DIRECTIONAL AND ROLL GUIDANCE FOR AIRCRAFT APPROACHING THE THRESHOLD. IT PROVIDES VISUAL CUES FOR MORE ACCURATELY CENTERING THE AIRCRAFT ON THE RUNWAY, ADJUSTING ATTITUDE FOR TOUCHDOWN, AND DETERMINING THE TOUCHDOWN POSITION. THE LIGHTING CONSISTS OF BARS OF WHITE LIGHTS IN THE PAVEMENT ON EACH SIDE OF THE RUNWAY CENTERLINE.
13660	1362	S		[EA]		THRESHOLD LIGHTING	N	THRESHOLD LIGHTING IS A SYSTEM OF LIGHTS DEFINING THE ENDS OF THE USABLE RUNWAY SURFACE. THEY INCLUDE THRESHOLD LIGHTS, DISPLACED THRESHOLD LIGHTS, RUNWAY END IDENTIFICATION LIGHTS (REIL) AND RUNWAY END LIGHTS. THE THRESHOLD LIGHTS ARE DISPLACED FROM THE EXTREMITY OF THE RUNWAY WHEN A PORTION IS UNAVAILABLE FOR NORMAL OPERATIONS
13665	1361	S		[LF]		HELIPORT LIGHTING	N	HELIPORT LIGHTING IS A SYSTEM OF LIGHTS ARRANGED TO CLEARLY DEFINE THE HELICOPTER LANDING PAD FOR OPERATIONS AT NIGHT AND DURING PERIODS OF POOR VISIBILITY. HELIPORT LIGHTING INCLUDES ALL VISUAL REFERENCE ASPECTS OF THE APPROACH AND LANDING OF ROTARY WING AIRCRAFT. THIS INCLUDES VISUAL AIDS, MARKINGS, PERIMETER AND APPROACH LIGHTS, AND RUNWAY AND TAXIWAY LIGHTS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
137						SHIP NAV&TRAFFIC AIDS-BLDG		

This code group applies to buildings for housing sea traffic control, navigation aids and navigation services.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13720	1371	B	[SF]	CP		LIGHTHOUSE	Y	A LIGHTHOUSE IS A BUILDING THAT HOUSES A NAVIGATION BEACON THAT MAY EMIT LIGHT, SOUND, RADIO, RADAR, OR A COMBINATION THEREOF. IT MAY BE ONSHORE OR OFFSHORE. CONSTRUCTION IS DONE OVERSEAS WHEN APPROPRIATE BY THE NAVAL FACILITIES ENGINEERING COMMAND.
138						SHIP NAV&TRAFFIC AIDS-OTHR		

This code group applies to structures which function as sea traffic navigation/traffic aids.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
13810	1381	S		[EA]		BEACON-SHIP	N	THE U.S. COAST GUARD HAS SPECIFIC JURISDICTION OVER ALL AIDS TO NAVIGATION (DAY BEACONS, BUOYS, FOGHORNS, ETC.,) IN THE CONTINENTAL UNITED STATES AND IN ALL OUTLYING TERRITORIES AND POSSESSIONS. DAY BEACONS ARE UNLIGHTED STRUCTURES USED TO MARK ISOLATED DANGERS OR CHANNELS, EDGES, OR ALIGNMENT.
13820	1381	S		[EA]		NAVIGATION AID TARGET	N	THIS CATEGORY CODE IS TO BE USED FOR NAVIGATIONAL AID TARGETS WHICH ARE A PART OF MARITIME NAVIGATIONAL AIDS.
13825	1381	S		[EA]		ANTENNA-NAVIGATION	N	THIS CATEGORY CODE IS TO BE USED FOR ANTENNAS OR ANTENNA SYSTEMS WHICH ARE A PART OF MARITIME NAVIGATIONAL AIDS.
140						LAND OPERATIONAL FACILITYS		
141						OPERATIONAL - BUILDINGS		

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

All buildings, which are non-ship related, used for housing operational types of activities and equipment

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14111	1412	B	[SF]			AIR PASSENGER TERMINAL	Y	THE AIR PASSENGER TERMINAL PROVIDES FACILITIES FOR PROCESSING AUTHORIZED PASSENGERS AND THEIR BAGGAGE AND FOR PROCESSING INCIDENTAL FREIGHT. SPACE IS PROVIDED IN THE TERMINAL FOR THE FOLLOWING FUNCTIONAL AREAS: ADMINISTRATIVE SPACE, BAGGAGE CLAIM ROOM, CHECK-IN COUNTER, MINOR FREIGHT STORAGE, INFORMATION COUNTER, AND WAITING LOUNGE WITH FOOD CONCESSIONS.
14112	1412	B	[SF]			AIR CARGO TERMINAL	Y	AN AIR CARGO TERMINAL IS PLANNED FOR AIR STATIONS WHERE CARGO AND FREIGHT HANDLING EXCEEDS 10,000 POUNDS PER DAY. THE AIR CARGO TERMINAL IS SEPARATE FROM THE AIR PASSENGER TERMINAL WHERE ONLY INCIDENTAL FREIGHT IS HANDLED. AIR CARGO TERMINAL FUNCTIONS INCLUDE RECEIPT OF PACKAGES, CONTROL DOCUMENTATION, PALLETIZATION, HOLDING FOR SHIPMENT, AIRCRAFT LOADING AND UNLOADING.
14113	1412	B	[SF]			COURIER STATION	Y	THIS FACILITY IS USED TO STORE AND DISSEMINATE CLASSIFIED MATERIAL FOR MISSION PLANNING, PILOT TRAINING AND BRIEFINGS IN SUPPORT OF ATTACK AIRCRAFT OPERATIONS.
14120	1411	B	[SF]			ACFT FIRE AND RESCUE STA	Y	THE AIRCRAFT FIRE AND RESCUE STATION PROVIDES FIRE AND EMERGENCY RESCUE PROTECTION FOR PILOTS AND AIRCRAFT. WHEN FEASIBLE, THE AIRCRAFT FIRE AND RESCUE STATION IS COMBINED WITH THE STRUCTURAL FIRE STATION (CATEGORY CODE 730 10) TO FORM ONE COMPLETE EMERGENCY FACILITY, CATEGORY CODE 141 25, COMBINED STRUCTURAL/ AIRCRAFT FIRE/RESCUE STATION.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14125	1411	B	[SF]			COMBINED FIRE/RESCUE STA	Y	A COMBINED STRUCTURAL/AIRCRAFT FIRE/RESCUE STATION IS PLANNED UNDER CERTAIN CONDITIONS TO SERVE THE FUNCTION OF A STRUCTURAL FIRE STATION (CATEGORY CODE 730 10) AND AN AIRCRAFT FIRE AND RESCUE STATIONS. FIRE AND RESCUE STATION. THE COMBINED FACILITY IS PLANNED FOR A LOCATION THAT SATISFIES THE RESPONSE TIME AND DISTANCE REQUIREMENTS FOR BOTH THE STRUCTURAL FIRE AND THE AIRCRAFT FIRE.
14130	1412	B	[SF]			ACFT LINE OPERATIONS BLDG	Y	THE AIRCRAFT LINE OPERATIONS BUILDING IS USED TO CENTRALIZE GROUND OPERATIONS OF THE FLIGHT LINE. THE BUILDING IS UTILIZED IN KEEPING OF SQUADRON DAILY FLIGHT BOOKS, AIRCRAFT STATUS BOARDS, AND BULLETIN BOARDS AND AS SUPPORT FOR LINE OPERATIONS PERSONNEL BY PROVIDING SHELTER, A WATER COOLER, AND A CHEMICAL TOILET.
14140	1412	B	[SF]			ACFT OPS BLDG *EXC 141-70*	Y	AN AIRCRAFT OPERATIONS BUILDING IS PLANNED FOR ALL NAVY AIR STATIONS, AUXILIARY AIR STATIONS, AND AIR FACILITIES. THE BUILDING HOUSES THE ADMINISTRATION OF FLIGHT OPERATIONAL ACTIVITIES WITH ALL SUPPORTING FUNCTIONS INCLUDING FLIGHT CONTROL, COMMUNICATIONS, AND WEATHER SERVICES.
14141	1412	B	[SF]			MATCU OPERATIONS BUILDING	Y	THE MATCU PERFORMS A COMBINED FUNCTION SIMILAR TO THAT ACCOMPLISHED WITH GROUND CONTROL APPROACH (GCA) SYSTEM; TACAN BUILDING; AND, AIR SURVEILLANCE RADAR (ASR) BUILDING. DEPENDING ON THE LEVEL OF AIRCRAFT OPERATIONS, THE MATCU OPERATIONS BUILDING MAY PROVIDE THE SOLE GCA SUPPORT AT AN AIR INSTALLATION OR MAY SUPPLEMENT AND BE IN ADDITION TO PERMANENT ASR, TACAN, AND GCA FACILITIES

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14142	1444	B	[SF]			AIR INTELLIGENCE SUPPT CTR	Y	THIS FACILITY IS USED TO STORE AND DISSEMINATE CLASSIFIED MATERIAL FOR MISSION PLANNING, PILOT TRAINING AND BRIEFINGS IN SUPPORT OF ATTACK AIRCRAFT OPERATIONS.
14160	1441	B	[SF]			VISUAL INFORMATION FAC	Y	A PHOTOGRAPHIC BUILDING IS PLANNED TO SUPPORT THE PHOTOGRAPHIC MISSION OF AN ACTIVITY. IT PROVIDES THE LABORATORY COMPLETE WITH EQUIPMENT AND STORAGE THAT APPLIES TO THE SPECIFIC MISSION.
14165	1441	B	[SF]			FLEET RECON PHOTO LAB	Y	A FLEET RECONNAISSANCE PHOTOGRAPHIC LABORATORY IS PLANNED ONLY WHERE THE STATION SUPPORTS THE MISSION OF PHOTOGRAPHIC RECONNAISSANCE SQUADRONS AND THERE IS NO PHOTOGRAPHIC BUILDING (CATEGORY CODE 141 60) TO PROVIDE THE SUPPORT.
14170	1413	B	[SF]			CONTROL TWR ATTD/FREE STD	Y	A CONTROL TOWER PROVIDES SPACE FOR EQUIPMENT AND PERSONNEL TO CONTROL AIRCRAFT TRAFFIC. IT IS AN ELEVATED BUILDING HAVING AN UNOBSTRUCTED LINE-OF SIGHT TO THE AIRFIELD APPROACH AREAS, RUNWAYS, TAXIWAYS, AIRCRAFT PARKING AREAS, AND ALL OTHER AREAS OVER WHICH AIRCRAFT MOVEMENTS MUST BE CONTROLLED.
14181	1412	B	[SF]			GCA CREW FACILITY	Y	THE GROUND CONTROL APPROACH (GCA) CREW FACILITY PROVIDES A READY ROOM FOR ON DUTY PERSONNEL ASSIGNED TO THE GCA VAN. THE FACILITY CONSISTS OF TWO (2) STANDARD DESIGN SKID-MOUNTED SHELTERS (EACH 12 FEET BY 20 FEET). THE CREW FACILITY IS AUTHORIZED WHENEVER THE MOBILE GCA UNIT IS FURNISHED.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14182	1412	B	[SF]			FULL PRESSURE SUIT FAC	Y	PRESSURE SUIT MAINTENANCE PERFORMED UNDER THIS CATCODE, NORMALLY IN THE PARACHUTE AND SURVIVAL EQUIPMENT SHOP (CATEGORY CODE 211 34). SPECIAL JUSTIFICATION IS REQUIRED TO PROVIDE A SEPARATE FACILITY FOR THIS PURPOSE.
14187	4122	B	[SF]	GA		LIQUID OXY/NIT FAC(NONIND)	Y	A LIQUID OXYGEN/NITROGEN FACILITY IS REQUIRED AT EACH NAVY AND MARINE CORPS AIR STATION WHERE 50 OR MORE ATTACK AND FIGHTER-TYPE AIRCRAFT ATE ASSIGNED. THE FACILITY PROVIDES FOR STORAGE, VAPORIZATION, AND TRANSFER OF NON-INDUSTRIAL OXYGEN AND NITROGEN AND FOR TEST AND REPAIR OF CRYOGENIC EQUIPMENT ASSOCIATED WITH AVIATOR AND AIRCRAFT SUPPORT.
14188	1465	S	[SF]			HARDENED AIRCRAFT SHELTER	Y	A REINFORCED HANGAR OR SHELTER USED TO PROTECT AIRCRAFT FROM ATTACK AND OFTEN USED IN FORWARD DEPLOYED LOCATIONS.

142 OPERTNL HELIUM PLANTS&STRG

Facilities for receipt, storage, processing and reprocessing helium gas. Includes tanks, pipes, valves, valve chambers, and similar equipment and facilities.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14210	1421	B	[SF]			HELIUM PROCESSING PLANT	Y	A BUILDING FOR THE RECEIPT, BULK STORAGE, PROCESSING, AND DISPENSING OF HELIUM GAS. INCLUDED ARE TANKS, VALVES, VALVE CHAMBERS, AND SIMILAR EQUIPMENT.
14219	1421	B	[SF]			HELIUM STORAGE BUILDING	Y	A BUILDING FOR THE STORAGE OF BULK HELIUM GAS.
14220	1422	S		[EA]		HELIUM STORAGE FACILITY	Y	A FACILITY, OTHER THAN A BUILDING, FOR THE BULK STORAGE OF HELIUM GAS.

143 SHIP & OTHER OPERTNL-BLDGS

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

All buildings, which are ship related, used for housing operational types of activities and equipment

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14309	1444	B	[SF]			EXP OPS SUP FAC	Y	AN EXPEDITIONARY OPERATIONS SUPPORT MODULE (EOSM) PROVIDES SPACES FOR THE FOLLOWING: ADMIN, MEDICAL, MISSION PLANNING CELL (MAY OR MAY NOT BE PART OF SCIF), TRAINING CLASSROOMS, ARMORY, STORAGE, AND LOCKER AND SHOWER SPACES.
14310	5307	B	[SF]			EMERGENCY VEHICLE GARAGE	Y	THIS IS A SHELTER FOR OFFICIAL EMERGENCY AND ALERT VEHICLES, SUCH AS AN AMBULANCE. IT IS JUSTIFIED IN INSTANCES WHEN IMMEDIATE RESPONSE REQUIRED BY SPECIAL WATERFRONT OPERATIONAL VEHICLE.
14311	1444	B	[SF]			OPERATIONAL VEHICLE GARAGE	Y	AN OPERATIONAL VEHICLE GARAGE IS USED FOR THE STORAGE OF VEHICLES WHICH ARE NOT UTILIZED ON A DAILY BASIS AND WHICH ARE EXPOSED TO ADVERSE WEATHER CONDITIONS THAT WOULD HAVE A DETRIMENTAL EFFECT UPON THEM IF STORED OUT IN THE OPEN. ACCORDINGLY, THE TYPE OF VEHICLE STORED, FREQUENCY OF USE AND CLIMATIC CONDITIONS, WILL DETERMINE WHETHER THIS TYPE OF FACILITY IS WARRANTED.
14312	8523	LS	[SY]			OPRTNL VEHICLE LAYDWN AREA	Y	AN OPERATIONAL VEHICLE PARKING AND/OR LAYDOWN AREA CONSISTS OF AN ASPHALT OR CONCRETE PAVED AREA LARGE ENOUGH TO STORE AND PROVIDE CIRCULATION FOR THE VEHICLES AND EQUIPMENT FOR WHICH THE COMMAND IS RESPONSIBLE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14315	1731	B	[SF]			RANGE OPERATIONS CENTER	Y	A RANGE OPERATIONS CENTER IS THE CONTROL POINT FOR TESTING TORPEDOES, CALIBRATING SHIPS¿ FIRING SYSTEMS, AND TRAINING PILOTS AND TESTING AIRCRAFT ON GUNNERY AND BOMBING RANGES. THE CENTER WILL VARY WITH THE EQUIPMENT AND CONTROL AREAS REQUIRED. STANDARD PLANNING FACTORS FOR A CENTER ARE NOT AVAILABLE. ITS SIZE MUST BE PLANNED TO SUPPORT THE EQUIPMENT AND CONTROL AREAS TO BE HOUSED.
14317	1444	B	[SF]			SPACE SURVEILANCE FACILITY	Y	FACILITIES TYPICALLY SUPPORT GLOBAL SPACE SURVEILLANCE NETWORK WHICH DETECTS, TRACKS, IDENTIFIES, AND CATALOGS MAN-MADE OBJECTS IN SPACE AND PROVIDES POSITION INFORMATION ON THESE OBJECTS. REQUIREMENTS ARE DETERMINED BY NAVAL NETWORK AND SPACE OPERATIONS COMMAND.
14320	1444	B	[SF]			ORDNANCE OPERATIONS BLDG	Y	AN ORDNANCE OPERATIONS BUILDING IS AUTHORIZED WHERE THERE IS A NEED TO CONTROL AN ORDNANCE OPERATION. ORDNANCE OPERATIONS ARE THOSE INVOLVING AMMUNITION STORAGE, HANDLING OR DISPOSAL AND ORGANIZATIONAL LEVEL MAINTENANCE. THE FACILITIES WHOSE PRIMARY FUNCTION IS ORDNANCE MAINTENANCE, INTERMEDIATE LEVEL AND ABOVE, ARE ADDRESSED IN THE 200 SERIES CATEGORY CODES.
14321	1443	B	[SF]			AMMUNITION SEGREGATION FAC	Y	A SEGREGATION FACILITY IS A BUILDING OR SERIES OF BUILDINGS WHERE FLEET RETURN EXPLOSIVE AND INERT MATERIAL ARE SCREENED AND GROUPED BY TYPE AND PHYSICAL CONDITION.
14322	1444	B	[SF]			NAVY EOD SHORE DET	Y	THIS FACILITY PROVIDES SUPPORT FOR EOD SHORE DETACHMENTS PERMANENTLY ASSIGNED TO NAVY INSTALLATIONS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14323	1444	B	[SF]			NAVY EODMU	Y	A FACILITY THAT SUPPORTS EXPLOSIVE ORDNANCE DISPOSAL MOBILE UNITS. EODMUS ARE RESPONSIBLE FOR MANNING, EQUIPPING AND TRAINING OF ANY NUMBER OF DEPLOYABLE EOD DETACHMENTS: MOBILE DETACHMENTS, AREA SEARCH DETACHMENTS, ORDNANCE CLEARANCE DETACHMENTS, MOBILE COMMUNICATIONS DETACHMENTS, COMBAT SERVICE SUPPORT DETACHMENTS, FLY AWAY RECOMPRESSION CHAMBER DETACHMENTS, MINE COUNTER MEASURES DETACHMENTS
14324	1444	B	[SF]			MARINE CORPS EOD FAC	Y	THESE FACILITIES PROVIDE SUPPORT FOR MARINE CORPS EOD SHORE TEAMS AND PLATOONS PERMANENTLY ASSIGNED TO MARINE CORPS INSTALLATIONS. THE MANNING STRUCTURE FOR EOD TEAMS AND PLATOONS HAS INCREASED AND IS REFLECTED BELOW IN CATEGORY CODES 143 24 AND 143 26.
14325	1444	B	[SF]			SEAL TEAM BUILDING	Y	THIS FACILITY IS FOR THE SUPPORT OF SEAL TEAMS. THE REQUIREMENTS FOR THESE FACILITIES ARE DEVELOPED BY AN INDUSTRIAL ANALYSIS FOR THE SPECIFIC FACILITY. SEE CATEGORY CODE 610 10 FOR ADMINISTRATIVE SPACE GUIDELINES AND CATEGORY CODE 159 64 FOR WATERFRONT OPERATIONS BUILDING GUIDELINES.
14326	1444	B	[SF]			MARINE CORPS EOD PLATOON	Y	THIS FACILITY IS RESPONSIBLE FOR MANNING, EQUIPPING, AND TRAINING FOR EOD OPERATIONS IN SUPPORT OF FLEET MARINE FORCES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14335	1444	B	[SF]			REGISTERED PUB ISSUE OFF	Y	A REGISTERED PUBLICATIONS ISSUING OFFICE (RPIO) HAS A PRIMARY MISSION OF SUPPORTING COMMUNICATIONS OPERATIONS OF THE FLEET, NAVAL AVIATION, U.S. MARINE CORPS, AND THE U.S. COAST GUARD. RPIO¿S RECEIVE, STORE, ISSUE, ACCOUNT FOR, AND-OFFICIATE DURING THE DESTRUCTION OF HIGHLY CLASSIFIED CRYPTOLOGICAL PUBLICATIONS, EQUIPMENT, AND DEVICES CIRCULATING IN THE REGISTERED PUBLICATIONS SYSTEM (RPS).
14341	1431	B	[SF]			AMPHIBIOUS OPERATIONS BLDG	Y	ORGANIZATIONAL FACILITY FOR EXPEDITIONARY AMPHIBIOUS OPERATIONS.
14345	4427	B	[SF]			ARMORY	Y	A NAVY INSTALLATION ARMORY PROVIDES SPACE FOR STORAGE AND ROUTINE MAINTENANCE OF SMALL ARMS AND EMERGENCY GEAR. THE MATERIALS STORED WILL PROVIDE FOR EMERGENCIES AND FOR TRAINING OF SELECTED PERSONNEL IN THE HANDLING OF STATION EMERGENCIES, CIVIL DISORDERS, AND AREA DISASTERS.
14346	1446	B	[SF]			MARINE BRKS-GEN PURP BLDG	Y	THE CRITERIA CONTAINED HEREIN ARE APPLICABLE TO CNO COMMANDED MARINE BARRACKS. THE PURPOSE OF THE MARINE BARRACKS IS TO PROVIDE SUCH SECURITY AS APPROVED BY THE CHIEF OF NAVAL OPERATIONS, IN COORDINATION WITH THE COMMANDANT OF THE MARINE CORPS, AND TO PERFORM SUCH ADDITIONAL FUNCTIONS AS DIRECTED BY CMC.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14347	1446	B	[SF]			ALERT FORCE BUILDING	Y	AN ALERT FORCE BUILDING IS PROGRAMMED IN CONJUNCTION WITH AN AIR/UNDERWATER WEAPONS SHOP, WHEN REQUIRED TO MEET THE ALERT FORCE RESPONSE TIMES ESTABLISHED FOR THE SHOP. THE ALERT FORCE BUILDING BARRACKS FACILITIES, INCLUDING LIMITED FACILITIES NECESSARY TO SUPPORT THE GUARD OF THE DAY FOR AN AUW SHOP. IT ALSO CONTAINS A DUTY OFFICE, PROVISION FOR WEAPONS STORAGE AND AN ALARM REPEATER PANEL.
14355	1444	B	[SF]			TRANSIT SHED	Y	A TRANSIT SHED IS PLANNED TO SUPPORT THE RAPID AND ORDERLY TRANSFER OF TRUCK AND RAIL FREIGHT IN SHIPMENT FROM ONE CARRIER TO ANOTHER WITH MINIMUM STORAGE. FOR A WATERFRONT TRANSIT SHED, SEE CATEGORY CODE 156 10. THE TRANSIT SHED IS OF THE MINIMUM DESIGN THAT WILL PROTECT THE FREIGHT FROM THE WEATHER AND PROVIDE ANY SECURITY NECESSARY.
14360	1431	B	[SF]			EXPLOSIVES SHIP/TRAN DEP	Y	AN EXPLOSIVES TRANSFER DEPOT IS A FACILITY USED TO TRANSFER BREAK-BULK AMMUNITION AND EXPLOSIVES BETWEEN AUTOMOTIVE VEHICLES AND RAILCARS FOR FURTHER SHIPMENT, OR FOR DELIVERY TO A STORAGE MAGAZINE, LOADING BUILDING, WATERFRONT OR AIRFIELD.
14365	1431	B	[SF]			REG/INST EMER OPS CTR	Y	A REGION/INSTALLATION EMERGENCY OPERATIONS FACILITY IS A SHORE MISSION SPECIFIC COMMAND, CONTROL, AND COORDINATION (C3) AREA IN DIRECT SUPPORT OF THE OPERATIONAL MISSION OF A REGION/INSTALLATION NAVY OR MARINE CORPS ACTIVITY. THIS FACILITY CAN ALSO BE DESIGNATED AS A REGIONAL OPERATIONS CENTER (ROC), EMERGENCY CONTROL CENTER (ECC), OR EMERGENCY ACTION CENTER (EAC).

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14370	1442	B	[SF]			RADIATN INST CALIBRTN FAC	Y	A HEALTH PHYSICS CALIBRATION BUILDING CONTAINS FACILITIES REQUIRED FOR CALIBRATION OF HEALTH PHYSICS SURVEY INSTRUMENTS AND AREA MONITORING DEVICES. THESE DEVICES ARE USED TO PROTECT PERSONNEL AGAINST IONIZING RADIATION FROM X-RAYS AND ATOMIC PARTICLES.
14375	1442	B	[SF]			POL OPN/SAMPLING/TEST BLDG	Y	THE POL OPERATION BUILDING PROVIDES SPACE REQUIRED FOR QUALITY CONTROL AND ADMINISTRATION OF FUEL ACTIVITY. SPACE IS PROVIDED IN THE BUILDING FOR AN ADMINISTRATIVE OFFICE, CONTROL/GAUGE MONITORING CENTER, AND FUELS TESTING LABORATORY. PHYSICAL OPERATION AND CONTROL OF THE FUEL SYSTEM WILL BE ACCOMPLISHED ELSEWHERE (SUCH AS THE PUMP HOUSE).
14377	1443	B	[SF]			OPERATIONAL STORAGE	Y	OPERATIONAL STORAGE SUPPORTS MULTIPLE DEPARTMENTS/DIVISIONS WITHIN A COMMAND. IT IS UNDER THE CONTROL OF THE LOGISTICS AND SUPPLY DEPARTMENT. THIS CATEGORY CODE IS USED TO IDENTIFY AREAS USED FOR BULK STORAGE AREAS OF MAJOR END ITEMS, AND OPERATIONAL MATERIAL.
14378	1443	B	[SF]			OP HAZARD/FLAMMABLE STRGE	Y	THIS CATEGORY WILL BE USED TO PROVIDE A FACILITY FOR THE STORAGE OF MATERIALS USED IN DAILY OPERATIONS THAT REQUIRE SPECIAL ENVIRONMENTAL SEPARATION. THESE MATERIALS SUCH AS PAINT, ACETONE, OIL, ETC. ARE CONSIDERED TO BE HAZARDOUS AND/OR FLAMMABLE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14380	1404	B	[SF]			MISSION OPS COMM/CONTR FAC	Y	A MISSION OPERATION COMMAND AND CONTROL FACILITY IS A SPECIALIZED FACILITY THAT IS ONLY REQUIRED IN SELECT LOCATIONS TO SUPPORT THE OPERATIONS OF FORCE COMMANDERS AND FLEET COMMANDERS (E.G. US FLEET FORCES COMMANDER, PACIFIC FLEET) AND SELECTED OTHERS AS ESTABLISHED BY DOD. A MISSION OPERATION COMMAND AND CONTROL FACILITY MAY ALSO CONTAIN FACILITY REQUIREMENTS FOR TYPE COMMANDS (E.G. AIRLANT, SUBPAC), OPERATIONAL SUPPORT COMMANDS (E.G. CTF AND CTG) AND A MARITIME OPERATIONS CENTER (MOC).
14385	1311	B	[SF]			JOINT RESERVE INTEL CENTER	Y	JOINT RESERVE INTELLIGENCE CENTER (JRIC). A JRIC IS A JOINT INTELLIGENCE PRODUCTION AND TRAINING ACTIVITY THAT USES INFORMATION NETWORKS TO LINK RESERVIST INTELLIGENCE PERSONNEL, ACTIVE DUTY UNITS AND CONTRACTORS WITH THE COMBATANT COMMANDS, SERVICES, AND/OR COMBAT SUPPORT AGENCIES.

144

145

146

148 SHIP OPRTNL FAC-OTHER

This category group contains facilities and structures which support tactical or organizational ship and other land operations in which do not fall readily into another category. For facilities supporting aircraft operations, use category group 149.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14810	1481	S		[EA]		NUCLEAR PROPULSN SUPP FAC	Y	A FACILITY, OTHER THAN A BUILDING, DIRECTLY RELATED TO NUCLEAR PROPULSION OPERATIONS. PLANNING AND PROGRAMMING FOR THIS FACILITY REQUIRES CONCURRENCE AND PLANNING GUIDANCE BY NAVSEA CODE 08 (NUCLEAR POWER DIRECTORATE).

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14815	1491	S		[EA]		NUCLEAR WPNS HANDLING FAC	Y	A FACILITY, OTHER THAN A BUILDING, DIRECTLY RELATED TO NUCLEAR WEAPONS HANDLING OPERATIONS. PLANNING AND PROGRAMMING FOR THIS FACILITY PLEASE CONTACT DIRECTOR, STRATEGIC SYSTEMS PROGRAM (SSP) OFFICE.
14817	1456	S		[EA]		SPACE SURVEILLANCE ANTENNA	N	REQUIREMENTS ARE DETERMINED BY NAVAL NETWORK AND SPACE OPERATIONS COMMAND. FACILITIES TYPICALLY SUPPORT GLOBAL SPACE SURVEILLANCE NETWORK WHICH DETECTS, TRACKS, IDENTIFIES, AND CATALOGS MAN-MADE OBJECTS IN SPACE AND PROVIDES POSITION INFORMATION ON THESE OBJECTS.
14820	1497	S		[EA]		ORDNANCE DEMOLITION AREA	Y	AN ORDNANCE DEMOLITION (TREATMENT) AREA IS A LOCATION SPECIFICALLY DESIGNATED AND RESERVED FOR DESTROYING EXPLOSIVES AND EXPLOSIVES-LOADED DEVICES. THE FUNCTION TYPICALLY MEANS BURNING OR DETONATING EXPLOSIVES IN A BERMED OPEN BURN/OPEN DETONATION (OB/OD) AREA.
14825	1492	S	SY	[EA]		EXPLOSIVE TRUCK HOLDG YD	Y	THIS YARD IS WHERE TRUCKS CONTAINING AMMUNITION AND/OR EXPLOSIVES ARE HELD FOR INTERIM PERIODS OF TIME PRIOR TO STORAGE OR SHIPMENT. SAFE HAVENS AND WHARF YARDS NEAR PIERS AND WHARVES SHOULD BE CATEGORIZED UNDER THIS FUNCTION. EACH FACILITY REQUIRES INDIVIDUAL JUSTIFICATION. DEPENDING ON LAND CONSTRAINTS AND EXPLOSIVE SAFETY CRITERIA THESE FACILITIES MAY OR MAY NOT BE BARRICADED.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14830	1493	S		[EA]	LF	EXPLOSIVES RR CAR HOLDG YD	Y	THIS IS A TEMPORARY HOLDING AREA FOR RAILCARS CONTAINING ORDNANCE PRIOR TO STORAGE OR SHIPMENT. EACH FACILITY REQUIRES INDIVIDUAL JUSTIFICATION. DEPENDING ON LAND CONSTRAINTS AND EXPLOSIVE SAFETY CRITERIA THESE FACILITIES MAY OR MAY NOT BE BARRICADED. FOR CONTAINERIZED ORDNANCE USE CATEGORY CODE 148 35, CONTAINER HOLDING YARD.
14835	1492	S	SY	[EA]		CONTAINER HOLDING YARD	Y	THIS IS AN OPEN AREA THAT PROVIDES A TEMPORARY HOLDING OR STAGING AREA FOR CONTAINERS LOADED WITH EXPLOSIVE ORDNANCE. WHARF YARDS NEAR PIERS AND WHARVES ARE ALSO DESCRIBED BY THIS FUNCTION.
14840	1492	S	SY	[EA]		CONTNR TRANSFER FAC (ORD)	Y	A CONTAINER TRANSFER FACILITY IS USED TO TRANSFER CONTAINERS BETWEEN RAIL FLATCARS AND TRUCK FLATBEDS OR CHASSIS, ON A PAVED HARDSTAND AREA, BY MEANS OF A BRIDGE CRANE OR CONTAINER HANDLING EQUIPMENT. SCALE EQUIPMENT SHOULD BE EXPECTED TO A PART OF THIS FUNCTION. THE AREA MAY BE BARRICADED OR UNBARRICADED.
14845	1492	S	SY	[EA]		RAIL/TRUCK RECEIVING STA	Y	A RAIL/TRUCK RECEIVING STATION WEIGHS AND INSPECTS ALL INCOMING SHIPMENTS OF BREAK-BULK AND CONTAINERIZED ORDNANCE ARRIVING BY RAIL OR TRUCK AND ALSO A PERCENTAGE OF THE OUTGOING SHIPMENTS. THIS STATION CAN BE USED AS A SHORT TERM STORAGE FACILITY LIMITED TO OVERNIGHT AND WEEKEND PERIODS AND AS AN INTERCHANGE STORAGE FACILITY LIMITED TO OVERNIGHT AND WEEKEND PERIODS AND AS AN INTERCHANGE YARD.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

This category group contains facilities such as towers and structures which support tactical or organizational aircraft related operations and which do not fall readily into another category. It includes protective construction.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14910	1495	S		[EA]		PROT BARR/REVETMENT	Y	PROTECTIVE BARRICADES (ALSO KNOWN AS REVETMENTS) ARE CONSTRUCTED AT LOCATIONS WHERE EXPLOSIVES SAFETY DICTATES THE NEED, SUCH AS IN MAGAZINE AREAS, COMBAT AIRCRAFT LOADING AREAS, EXPLOSIVE HOLDING YARDS, ETC.
14915	1467	S		[EA]	SP	FIXED PT UTIL SYS	Y	FIXED POINT UTILITIES SYSTEMS SUPPLY UTILITIES TO AIRCRAFT PARKING APRON SERVICE POINTS AND AIRCRAFT MAINTENANCE HANGAR SERVICE POINT. THE FPUS CAN PROVIDE COMPRESSED AIR, PRECONDITIONED AIR FOR HANGARED AIRCRAFT, AND/OR ELECTRICAL POWER. IT CAN CONSIST OF AN ENCLOSED PUMP HOUSE AND STORAGE TANKS, AN IN-GROUND DIST. SYSTEM AND SERVICE POINTS IN AIRCRAFT PARKING APRONS OR AIRCRAFT HANGARS.
14920	1462	S		[EA]		AIRCRAFT CATAPULT	N	THIS IS A FACILITY FOR AIR INSTALLATIONS WHERE SPECIALIZED TRAINING, TEST AND EVALUATION, OR RESEARCH AND DEVELOPMENT ARE PERFORMED ON CATAPULT TAKEOFFS.
14930	1461	S		[EA]		AIRCRAFT ARRESTING GEAR	N	AIRCRAFT ARRESTING GEAR IS DESIGNED TO BRING AN AIRCRAFT TO A STOP IN CASE OF AN ABORTED TAKEOFF OR AN EMERGENCY LANDING.
14945	3901	S		[EA]		MISSILE LAUNCH FACILITY	N	THIS CATEGORY CODE IS FOR LOCATIONS LAUNCHING MISSILES OR DRONES, IT ALSO IS PROVIDED FOR INVENTORY PURPOSES OF MISSILE AND DRONE LAUNCH PADS. SEE NAVSEA OP-5 FOR EXPLOSIVE SAFETY SITING CRITERIA OF ENERGETIC LIQUIDS ASSOCIATED WITH LAUNCH PADS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
14950	1464	S		[EA]	LF	BLAST DEFLECTOR FENCE	N	BLAST DEFLECTOR FENCES ARE STRUCTURES THAT DIRECT THE EXHAUST FROM JET ENGINES UPWARD. THEY ARE USED IN CONGESTED AREAS AND PARKING AND MAINTENANCE AREAS TO PROTECT PERSONNEL AND FACILITIES FROM THE BLAST EFFECT OF JET ENGINE EXHAUST. BLAST FENCES ARE ALSO USED TO PREVENT EROSION OF PAVED AND UNPAVED AREAS AND TO PROVIDE PROTECTION FROM FLYING DEBRIS.
14985	1467	S	SY	[EA]		EXPEDITIONARY AIR CONTROL	Y	THESE ARE MARINE CORPS FACILITIES REQUIRED TO ACCOMMODATE, IN-GARRISON, THE EQUIPMENT USED FOR EXPEDITIONARY AIRCRAFT COMMAND AND CONTROL. THESE FACILITIES ARE ASSIGNED TO SPECIALIZED MARINE CORPS SQUADRONS, AND THE EXPEDITIONARY EQUIPMENT USED IN CONJUNCTION WITH THESE FACILITIES IS NORMALLY SQUADRON PROPERTY.
14986	4422	S	SF	[EA]		OPERATIONS SUPPORT SHED	Y	STORAGE SHED OR OTHER COVERED AREA USED FOR OPERATIONAL SUPPORT. NOT FOR WEAPONS CLEANING AREAS.

150 WATERFRONT OPRTNL FAC

151 PIERS

Includes all piers regardless of function served, protective dolphins at pier heads, fendering systems, mooring fixtures, original dredging performed specifically for the purpose of providing the pier facility, all trackage on the pier, and all supporting utilities and services.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15110	1511	S	SY	[FB]	DW	AMMUNITION PIER	Y	AMMUNITION PIERS ARE DESIGNED FOR USE IN THE RECEIPT OF AMMUNITION FOR STORAGE AND FOR THE OUTLOADING OF AMMUNITION ONTO BARGES AND SHIPS. IN SOME CASES OUTGOING AMMUNITION IS FIRST LOADED FROM THE AMMUNITION PIER ONTO BARGES FOR TRANSFER TO SHIPS MOORED OFFSHORE OR IN A ROADSTEAD.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15120	1511	S	SY	[FB]	DW	GENL PURP/BERTHING PIER	Y	GENERAL PURPOSE BERTHING PIERS ARE USED PRIMARILY FOR MOORING HOME PORTED AND TRANSIENT SHIPS THAT DO NOT REQUIRE PIERS EQUIPPED WITH SHIPYARD FACILITIES. BERTHING PIERS ARE CLASSIFIED AS ACTIVE OR INACTIVE. THE ACTIVE BERTHING PIERS ARE USED WHEN SHIPS ARE BERTHED FOR A RELATIVELY SHORT TIME; THE INACTIVE CLASSES ARE USED WHEN SHIPS ARE TO BE TIED UP FOR LONG PERIODS IN A DECOMMISSIONED STATUS.
15140	1511	S	SY	[FB]	DW	FUELING PIER	Y	FACILITIES FOR BERTHING SHIPS WHILE DISCHARGING FUEL TO STORAGE OR RECEIVING FUEL FROM STORAGE ARE PROVIDED AT FUELING PIERS. SUCH PIERS WILL PROVIDE SALT WATER FOR FIREFIGHTING, TELEPHONE AND FIRE ALARM FACILITIES AND MAY PROVIDE FRESHWATER, STEAM IN COLD CLIMATES, ELECTRIC POWER.
15150	1511	S	SY	[FB]	DW	REPAIR PIER	Y	REPAIR PIERS ARE CONSTRUCTED AND EQUIPPED TO PERMIT OVERHAUL OF THOSE PORTIONS OF A VESSEL ABOVE THE WATERLINE. THESE STRUCTURES WILL NORMALLY BE EQUIPPED WITH A GANTRY CRANE AND STANDARD-GAGE RAILROAD TRACKS AND HAVE FACILITIES TO PROVIDE SALT AND FRESHWATER, STEAM, COMPRESSED AIR, TELEPHONE AND FIRE ALARM SERVICE, AND ELECTRIC POWER FOR SHIP SERVICE, LIGHTING AND WELDING.
15160	1511	S	SY	[FB]	DW	SUPPLY PIER	Y	SUPPLY PIERS ACCOMMODATE BERTHING FOR THE TRANSFER OF MATERIALS BETWEEN SHIP AND SHORE. A LARGE BUILDING OR TRANSIT SHED NORMALLY OCCUPIES THE CENTRAL PORTION OF A SUPPLY PIER.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15170	1511	S	SY	[FB]	DW	ORDNANCE CONT HANDL PIER	Y	AN ORDNANCE CONTAINER HANDLING PIER IS USED PRIMARILY FOR THE OUTLOADING AND RECEIVING OF EXPLOSIVE ORDNANCE IN CONTAINERS FROM NON-SELF-SUSTAINING CONTAINER SHIPS.
15171	1511	S	SY	[FB]	DW	DEGAUSSING PIER	Y	THESE PIERS ARE USED TO ERASE THE MAGNETIC SIGNATURE OF A SHIP OR SUBMARINE. SIZING FOR THIS CATEGORY CODE IS BASED ON THE TYPE OF VESSELS TO BE SERVICED AND IS DRIVEN BY THE NAVSEA SPECIFIED EQUIPMENT. SPECIAL STUDIES ARE REQUIRED ON A CASE BY CASE BASIS.
15180	1511	S	SY	[FB]	DW	DEPERMING PIER	Y	THESE PIERS ARE USED TO ERASE THE MAGNETIC SIGNATURE OF A SHIP OR SUBMARINE. SIZING FOR THIS CATEGORY CODE IS BASED ON THE TYPE OF VESSELS TO BE SERVICED AND IS DRIVEN BY THE NAVSEA SPECIFIED EQUIPMENT. SPECIAL STUDIES ARE REQUIRED ON A CASE BY CASE BASIS.
15190	1513	S	[SY]		SF	ACCESS TRESTLE PIERS WHRVS	Y	A VEHICULAR AND/OR RAILROAD TRESTLE CONNECTING SHORE FACILITIES TO A PIER OR WHARF.

152 WHARFS

A wharf is an open type marginal structure for the berthing of vessels; it is usually connected to the shore at more than one point. In general, the planning criteria that apply to piers are also applicable to wharves. Either may serve the same practicable purpose, however, since their physical design and layout will be much different, their capacities for berthing and cargo handling will vary. Piers are generally preferable structures; however, certain locations will dictate the use of a wharf rather than a pier because of the marginal fairway and topography involved.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15210	1512	S	SY	[FB]	DW	AMMUNITION WHARF	Y	AMMUNITION WHARVES ARE DESIGNED FOR USE IN THE RECEIPT OF AMMUNITION FOR STORAGE AND FOR THE OUTLOADING OF AMMUNITION ONTO BARGES AND SHIPS. IN SOME CASES OUTGOING AMMUNITION IS FIRST LOADED FROM THE AMMUNITION PIER ONTO BARGES FOR TRANSFER TO SHIPS MOORED OFFSHORE OR IN A ROADSTEAD.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15220	1512	S	SY	[FB]	DW	GENL PURP/BERTHING WHARF	Y	GENERAL PURPOSE BERTHING WHARVES ARE USED PRIMARILY FOR MOORING HOME PORTED AND TRANSIENT SHIPS THAT DO NOT REQUIRE PIERS EQUIPPED WITH SHIPYARD FACILITIES. BERTHING PIERS ARE CLASSIFIED AS ACTIVE OR INACTIVE. THE ACTIVE BERTHING PIERS ARE USED WHEN SHIPS ARE BERTHED FOR A RELATIVELY SHORT TIME; THE INACTIVE CLASSES ARE USED WHEN SHIPS ARE TO BE TIED UP FOR LONG PERIODS IN A DECOMMISSIONED STATUS.
15230	1512	S	SY	[FB]	DW	FITTING OUT WHARF	Y	WHARVES FOR FITTING OUT ARE VERY SIMILAR TO THOSE USED FOR REPAIR PURPOSES, PROVIDING APPROXIMATELY THE SAME FACILITIES. HOWEVER, FITTING OUT PIERS WILL HAVE, IN ADDITION TO LIGHT AND HEAVY GANTRY CRANES, A LARGE FIXED TOWER CRANE FOR HANDLING GUNS, TURRETS, ENGINES, AND HEAVY ARMOR.
15240	1512	S	SY	[FB]	DW	FUELING WHARF	Y	FACILITIES FOR BERTHING SHIPS WHILE DISCHARGING FUEL TO STORAGE OR RECEIVING FUEL FROM STORAGE ARE PROVIDED AT FUELING WHARVES. SUCH WHARVES WILL PROVIDE SALT WATER FOR FIREFIGHTING, TELEPHONE AND FIRE ALARM FACILITIES AND MAY PROVIDE FRESHWATER, STEAM IN COLD CLIMATES, ELECTRIC POWER.
15250	1512	S	SY	[FB]	DW	REPAIR WHARF	Y	REPAIR WHARVES ARE CONSTRUCTED AND EQUIPPED TO PERMIT OVERHAUL OF THOSE PORTIONS OF A VESSEL ABOVE THE WATERLINE. THESE STRUCTURES WILL NORMALLY BE EQUIPPED WITH A GANTRY CRANE AND STANDARD-GAGE RAILROAD TRACKS AND HAVE FACILITIES TO PROVIDE SALT AND FRESHWATER, STEAM, COMPRESSED AIR, TELEPHONE AND FIRE ALARM SERVICE, AND ELECTRIC POWER FOR SHIP SERVICE, LIGHTING AND WELDING.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15260	1512	S	SY	[FB]	DW	SUPPLY WHARF	Y	SUPPLY WHARVES ACCOMMODATE BERTHING FOR THE TRANSFER OF MATERIALS BETWEEN SHIP AND SHORE. A LARGE BUILDING OR TRANSIT SHED NORMALLY OCCUPIES THE CENTRAL PORTION OF A SUPPLY WHARF.
15270	1512	S	SY	[FB]	DW	ORDNANCE CONT HANDL WHARF	Y	AN ORDNANCE CONTAINER HANDLING WHARF IS USED PRIMARILY FOR THE OUTLOADING AND RECEIVING OF EXPLOSIVE ORDNANCE IN CONTAINERS FROM NON-SELF-SUSTAINING CONTAINER SHIPS.
15271	1512	S	SY	[FB]	DW	DEGAUSSING WHARF	Y	THESE WHARVES ARE USED TO ERASE THE MAGNETIC SIGNATURE OF A SHIP OR SUBMARINE. SIZING FOR THIS CATEGORY CODE IS BASED ON THE TYPE OF VESSELS TO BE SERVICED AND IS DRIVEN BY THE NAVSEA SPECIFIED EQUIPMENT. SPECIAL STUDIES ARE REQUIRED ON A CASE BY CASE BASIS.
15280	1512	S	SY	[FB]	DW	DEPERMING WHARF	Y	THESE WHARVES ARE USED TO ERASE THE MAGNETIC SIGNATURE OF A SHIP OR SUBMARINE. SIZING FOR THIS CATEGORY CODE IS BASED ON THE TYPE OF VESSELS TO BE SERVICED AND IS DRIVEN BY THE NAVSEA SPECIFIED EQUIPMENT. SPECIAL STUDIES ARE REQUIRED ON A CASE BY CASE BASIS.

153 CARGO HANDLING FACILITIES

A cargo staging area is an open hardstand for temporary storage of cargo awaiting further transshipment.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15310	1531	S		[SY]		CARGO STAGING AREA	Y	A CARGO STAGING AREA IS AN OPEN HARDSTAND FOR TEMPORARY STORAGE OF CARGO AWAITING FURTHER TRANSSHIPMENT.

154 SEAWLS/BULKHDS/QUAYWLS

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Shore protective structures not intended primarily for berthing vessels. Bulkheads and quaywalls have the principal advantage of affording accessibility for their entire length along the foreshore.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15410	1541	S		[LF]		BLKHD QW NO RELIEVG PLATFM	N	THIS TYPE OF BULKHEAD OR QUAYWALL IS A STRUCTURE TO RETAIN EARTH ALONG A SHORELINE IN SHALLOW WATER. THE DEPTH OF WATER IS TYPICALLY LIMITED TO A 25 FEET AND THE STRUCTURE HAS NO RELIEVING PLATFORM. THIS STRUCTURE DOES NOT PROVIDE SHIP BERTHING (151 PIERS AND 152 WHARVES SHOULD BE USED FOR ANY SHIP BERTHING REQUIREMENT).
15420	1512	S	SY	[LF]		BLKHD QW WITH R PLATFM	Y	THIS TYPE OF BULKHEAD OR QUAYWALL IS A STRUCTURE TO RETAIN EARTH ALONG A SHORELINE IN DEEP WATER. TYPICALLY WITH A WATER DEPTH EXCEEDING 25 FEET AND INCLUDES A RELIEVING PLATFORM TO SUPPORT HEAVY LOGISTICS OPERATIONS. THIS STRUCTURE DOES NOT PROVIDE SHIP BERTHING (151 PIERS AND 152 WHARVES SHOULD BE USED FOR ANY SHIP BERTHING REQUIREMENT).
15430	1541	S		[LF]		SEAWALLS AND RIP RAP	N	THESE ARE STRUCTURES BUILT ALONG AND PARALLEL TO A SHORELINE (RIVER OR COAST LINE) PROTECTING AND STABILIZING THE SHORE AGAINST EROSION RESULTING FROM WAVE AND CURRENT ACTION. THIS IS A FUNCTIONAL DEFINITION AND VARIOUS TYPES OF CONSTRUCTION CAN BE USED TO SUPPORT THIS FUNCTION.

155						SMALL CRAFT BERTHING		

All facilities supporting small craft operations. Included in this category are, but not limited to, yard craft, tug boats, security and service craft.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15510	1551	S		[FB]		FLEET LANDING	Y	A FLEET LANDING IS A FIXED OR FLOATING PIER DESIGNED FOR THE LOADING AND/OR UNLOADING OF A SHIP'S PERSONNEL ONTO OR FROM A PERSONNEL BOAT OR FERRY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15511	1552	B	[SF]			FLEET LANDING BUILDING	Y	A FLEET LANDING BUILDING IS USED TO ACCOMMODATE SHIP'S PERSONNEL BEING LOADED OR UNLOADED FROM A PERSONNEL BOAT OR FERRY.
15520	1551	S		[FB]		SMALL CRAFT BERTHING	Y	THIS CATCODE SHOULD INCLUDE FACILITIES FOR HARBOR AND PILOT LAUNCHES, SURVEY BOATS, WORK BOATS, SPECIAL SERVICE CRAFT, RESCUE BOATS, AND OTHER SMALL CRAFT.
15521	1552	B	[SF]			SMALL CRAFT BOATHOUSE	Y	A BOATHOUSE IS NECESSARY WHERE AN ALERT CREW IS REQUIRED, WHERE A BOAT FACILITY IS REMOTE FROM THE SUPPORTING ACTIVITY, OR WHERE BOAT REPAIR FACILITIES ARE ESSENTIAL.
15522	1593	S	SY	[EA]		SM CRAFT BOAT RAMP FAC	Y	SMALL BOAT LAUNCH RAMPS FOR OPERATIONAL OR SECURITY FORCES THE PURPOSES OF CONDUCTING IN-SHORE TRAINING MANEUVERS OR SECURITY PATROLS.
156						CARGO HANDLING FAC/BLDGS		
15610	1443	B	[SF]			WATERFRONT TRANSIT SHED	Y	A WATERFRONT TRANSIT SHED IS A BUILDING OR SHED FOR STORAGE OF CARGO AWAITING FURTHER TRANSSHIPMENT AND REQUIRING PROTECTION.
15620	1443	B	[SF]			CONTAINER OPERATIONS BLDG	Y	A CONTAINER OPERATIONS BUILDING IS ESSENTIAL FOR SAFE DIRECTION AND CONTROL OF CONTAINER OPERATIONS TO PROMOTE EFFICIENT AND CONTINUOUS FLOW TO, WITHIN, AND FROM THE HANDLING AREA.
159						OTHER WATERFRONT OPERATION		

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

This basic category group provides for facilities which cannot be coded in basic groups 151 through 156.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15910	1593	S	SY	[EA]		AIRCRAFT DOCKING FACILITY	N	WATERFRONT FACILITIES THAT WERE ORIGINALLY CREATED TO SUPPORT SEAPLANES SUCH AS PBY CATALINAS AND SIMILAR FROM THE WWII ERA AND LATER. IT IS NOT ASSOCIATED WITH ANY AIRFIELD CRITERIA AND NEW FACILITIES WILL NOT BE PLANNED UNDER THIS CCN.
15920	1431	B	SF	[EA]		DEGAUSSING BUILDING	Y	DEGAUSSING IS THE SCIENCE DEALING WITH THE METHODS AND TECHNIQUES OF REDUCING A SHIP'S MAGNETIC FIELD SO THAT THE POSSIBILITY OF DETECTION BY MAGNETIC MINES AND OTHER MAGNETIC INFLUENCE DETECTION DEVICES IS MINIMIZED. IT CONSISTS OF TWO FUNCTIONALLY INTERDEPENDENT INSTALLATIONS: AN UNDERWATER DEGAUSSING RANGE INSTALLATION AND THIS FACILITY, WHICH SERVES AS AN INSTRUMENT STATION.
15921	1591	S		[EA]		DEGAUSSING RANGE	N	A DEGAUSSING RANGE IS AN AREA SET ASIDE IN A CHANNEL OR HARBOR THAT CONTAINS SUBMERGED INSTRUMENTS, CONNECTED TO THE COMPUTER IN THE DEGAUSSING BUILDING (CATEGORY CODE 159 20), WHICH REGISTERS A SHIP'S MAGNETIC SIGNATURE AS IT PASSES THROUGH THE RANGE.
15930	1431	B	SF	[EA]		DEPERMING BUILDING	Y	A DEPERMING BUILDING IS A FACILITY THAT CONTAINS ELECTRICAL INSTRUMENTS USED TO REGULATE AND MONITOR THE DEPERMING OPERATION. DEPERMING, THE SECOND PHASE OF DEGAUSSING, IS THE PROCESS BY WHICH A SHIP'S PERMANENT LONGITUDINAL AND ATHWARTSHIP MAGNETISM IS REMOVED AND ITS PERMANENT VERTICAL MAGNETISM STABILIZED AT A LOW LEVEL.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
15950	1551	S		[FB]		FERRY SLIP	N	A FERRY SLIP PROVIDES THE ANCHORAGE FOR FERRIES WHILE LOADING OR UNLOADING. IT CONSISTS OF WATER AREAS DIRECTLY IN FRONT OF TRANSFER BRIDGES AND IS USUALLY BORDERED BY FENDER RACKS.
15964	1431	B	[SF]	EA		WATERFRONT OPERATIONS BLDG	Y	A WATERFRONT OPERATIONS BUILDING, PROVIDES FOR ALL SHIP BERTHING, SMALL CRAFT MAINTENANCE INCLUDING RELATED ELECTRONICS SYSTEMS, AND PROVIDING SUCH FACILITIES AS A DUTY CREW BUNK ROOM, CREW'S LOUNGE, BOATSWAIN¿S LOCKER, BERTHING FOR SMALL BOATS IF AN INTEGRAL PART OF THE BUILDING, SPACE FOR STORAGE OF BOAT GEAR AND PAINT, OIL SPILL EQUIPMENT AND A BATTERY CHARGING ROOM.
15966	1593	S	SY	[EA]		LANDING CRAFT RAMP	Y	A WATERFRONT LAUNCH RAMP FOR PURPOSES OF LAUNCH AND RETRIEVAL OF LANDING CRAFT.
160						HARBOR AND COASTAL FAC		
161						HARBOR PROTECTION FAC		

This basic category provides facilities for protecting the harbor against military action.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
16120	1611	S		[EA]		FIXED NET ANCHORAGE	N	THIS CATEGORY CODE INCLUDES SUCH FUNCTIONS AS PILE CLUSTERS AND PLATFORMS USED TO SUPPORT ANTI-TERRORISM/FORCE PROTECTION (AT/FP) FLOATING BARRIERS. IF A TRADITIONAL SUBMERGED HARBOR NET IS USED, THIS TYPE OF FEATURE WOULD ALSO BE REQUIRED.
16130	1611	S	SF	[EA]		WINCH HOUSE	N	A WINCH HOUSE IS A STRUCTURE USED IN CONTROL OF HARBOR NETS, FLOATING BARRIERS AND OIL BOOMS.
162						COASTAL PROTECTION FAC		

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

This basic category provides facilities for protecting the coast against military action.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
16210	1499	S		[EA]		GUN EMPLACEMENTS	N	SPACE IN STRATEGIC SITES IS PROVIDED ON BASE FOR THE INSTALLATION OF GUN EMPLACEMENTS, INCLUDING ANTI-AIRCRAFT GUNS, FOR USE IN HARBOR DEFENSE.

163 MOORINGS

Fixed structures for mooring vessels.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
16310	1631	S		[EA]		MOORING DOLPHIN	N	MOORING DOLPHINS ARE INDEPENDENT STRUCTURES THAT ARE OFTEN PLACED AT THE OUTBOARD ENDS OF PIERS OR WHARVES TO PROVIDE A MOORING POINT THAT PERMITS TYING MOORING LINES AT FAVORABLE ANGLES WITHOUT HAVING TO EXTEND THE ENTIRE PIER OR WHARF STRUCTURE.
16320	1631	S		[EA]		MOORING PLATFORM	N	A MOORING PLATFORM IS AN ISOLATED STRUCTURE CONSISTING OF A TIMBER, STEEL OR CONCRETE DECK SUPPORTED ON PILING OR CAN BE A STEEL PILE, SHEET PILE OR CONCRETE TYPE CAISSON. TWO OR MORE PLATFORMS ARE PROVIDED IN LINE FOR BERTHING OF ONE OR MORE VESSELS ALONGSIDE.
16330	1631	S		[EA]		STAKE PILE MOORING	N	A STAKE PILE MOORING CONSISTS OF A STAKE PILE DRIVEN BELOW THE SURFACE OF THE FIRM BOTTOM OF THE OCEAN FLOOR. A CHAIN ATTACHED TO THE STAKE IS USED TO MOOR THE VESSEL.

164 MARINE IMPROVEMENTS

Structures for protecting the harbor, land area, or coastline from current or wave action and from flood conditions.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
16410	1641	S		[LF]	EA	BREAKWATER	N	A BREAKWATER IS A FREESTANDING BARRIER DESIGNED TO BREAK UP AND DISPERSE HEAVY SEAS AND TO SHIELD THE WATERS OF A HARBOR FROM WAVE ACTION.
16420	1641	S		[LF]	EA	GROINS AND JETTIES	N	GROINS AND JETTIES ARE STRUCTURES BUILT TO INTERCEPT AND DEFLECT CURRENTS TO CONTROL LITTORAL DRIFT AND DEPOSIT OF SAND AND SILT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
16430	8714	S		[LF]	EA	LEVEES	N	LEVEES ARE EARTHEN EMBANKMENTS DESIGNED TO PROTECT PROPERTY FROM WATER DAMAGE DURING THE FLOOD STAGE OF RIVERS AND/OR OTHER HIGH WATER.

165 DREDGING

Original dredging such as channel and turning basin dredging not directly related to the specific construction of a facility is planned under Basic Category 165. Dredging performed primarily to provide fill shall be coded under Basic Category 932, Site Improvement. Dredging directly related to the specific construction of an item shall bear the same code as the item. Do not use this category code for inventory purposes.

169 OTHER HARBOR & COASTAL

Harbor and entrance control points and signal towers.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
16910	1611	S		[EA]		HARBOR ENTRANCE CONTR FAC	N	A LARGE PAVED SITE FOR LAYOUT AND ASSEMBLY OF HARBOR NETS AND ALLIED EQUIPMENT. THE LAYOUT AREA SHOULD BE NEAR THE WATERFRONT AND ACCESSIBLE TO MOBILE CRANES FOR NET AND EQUIPMENT HANDLING. THE AREA IS KNOWN AS THE NET DEPOT AND IS USED FOR NET MAINTENANCE AND FOR TRAINING IN NET HANDLING.

170 TRAINING FACILITIES

Facilities designated for the service career and reserve training of Navy and Marine Corps personnel. There are two basic categories under this code: 171 TRAINING BUILDINGS, and 179 TRAINING FACILITIES OTHER THAN BUILDINGS

171 TRAINING BUILDINGS

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Class room/special buldings designed to provide space for training and general instruction. Facilities in this basic category are identified according to the nature of instruction provided. The major building types are: 171-1.1 Academic Instruction Building, 171-1.2 Reserve Training Building, 171-1.3 Applied Instruction Building, and 171-1.4 Operational Trainer Space.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17110	1711	B	[SF]		PN	ACADEMIC INSTRUCTION BLDG	Y	THERE ARE GENERALLY TWO TYPES OF CLASSROOM: GENERAL ACADEMIC CLASSROOM - IS ONE WHICH SUPPORTS APPROVED TRAINING PROGRAMS AND PROVIDES ACCOMMODATIONS FOR CLASSROOM LECTURE INSTRUCTION, AND MODIFIED ACADEMIC CLASSROOM - IS ONE WHICH IS EQUIPPED WITH DESKS OR OTHER WORKING SURFACES
17115	1714	B	[SF]		PN	NAVY & MC RSRV TRNG BLDG	Y	THIS CATEGORY CODE REFERS TO THE RESERVE TRAINING CENTER ONLY. CRITERIA FOR OTHER FACILITIES NOT INCLUDED IN THIS SECTION (E.G., UNACCOMPANIED HOUSING, DINING, AIRCRAFT MAINTENANCE HANGARS, ETC.) FOLLOW THE SAME CRITERIA AS ACTIVE DUTY, AND CAN BE FOUND IN THE SUBSEQUENT CATEGORY CODES. REFER TO NAVFAC P-72 FOR A FUNCTION / CATEGORY CODE CROSS-REFERENCE.
17117	1441	B	[SF]			TV CTR/INSTRUCTION MATTER	Y	THIS FACILITY MAY BE PROVIDED ONLY WHEN SPECIFICALLY AUTHORIZED BY CNET. REQUIREMENTS WILL BE DETERMINED FOR EACH INDIVIDUAL CASE, WITH CNET GUIDANCE.
17120	1712	B	[SF]		PN	APPLIED INSTRUCTION BLDG	Y	THIS FACILITY PROVIDES FOR TRAINING PERSONNEL THROUGH THE APPLIED USE OF TECHNICAL EQUIPMENT AND TOOLS.
17125	7431	B	[SF]		SE	GEN PRPSE AUDITORIUM	Y	AN AUDITORIUM MAY BE AUTHORIZED WHEN REQUIRED AS AN ADJUNCT TO TRAINING OR OTHER FUNCTIONS (EXCEPT ADMINISTRATION). THE PRIMARY PURPOSE OF THE AUDITORIUM IS AN ASSEMBLY AREA FOR INSTRUCTION AND TRAINING.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17130	1715	B	[SF]			PE FACILITY	Y	A SERVICCE ACADEMY LEVEL PHYSICAL FITNESS TRAINING FACILITY FOR USE BY THE US NAVAL ACADEMY.
17135	1721	B	[SF]			OPERATIONAL TRAINER FAC	Y	THIS FACILITY HOUSES LARGE OPERATIONAL TRAINERS, USUALLY DUPLICATING PART OR ALL OF SURFACE OR AIR WEAPONS SYSTEM.
17136	1724	B	[SF]			RADAR SIMULATOR FACILITY	Y	THIS FACILITY HOUSES VARIOUS RADAR TRAINING FACILITIES AND MAY BE PROVIDED ONLY WHEN SPECIFICALLY AUTHORIZED BY CNET. REQUIREMENTS WILL BE DETERMINED FOR EACH INDIVIDUAL CASE, WITH CNET GUIDANCE.
17140	1714	B	[SF]			DRILL HALL	Y	A COMPONENT OF A RESERVE TRAINING FACILITY USED PRIMARILY TO PRACTICE DRILLING AND MARCHING.
17145	1732	B	[SF]			MOCK-UP TRNG AID PREP CTR	Y	FACILITY FOR THE CONSTRUCTION, MAINTENANCE, AND REPAIR OF TRAINING MOCK UPS FOR TRAINING FACILITIES.
17150	1718	B	[SF]		FP	SMALL ARMS RANGE - INDOORS	Y	AN INDOOR SMALL ARMS RANGE PROVIDES TRAINING SPACE FOR THE USE OF PISTOLS AND SMALL CALIBER (22) RIFLES. RANGES WILL BE USED BY ALL SERVICES ON A JOINT BASIS WHEN FEASIBLE, AND THEY MUST BE OF SUFFICIENT SIZE AND CAPACITY TO PROVIDE CONTINUAL TRAINING AND RETRAINING FOR ALL MILITARY PERSONNEL THAT REQUIRE WEAPONS TRAINING/QUALIFICATION.
17160	6100	B	[SF]		PN	RECRUIT PROCESSING BLDG	Y	A RECRUIT PROCESSING BUILDING IS A FACILITY FOR RECEIVING, EXAMINING, AND OUTFITTING RECRUITS. THE PROCESSING BUILDING MUST PROVIDE SPACE FOR THE COMPLETE ORIENTATION, EXAMINATION, AND PROCESSING (MEDICAL, DENTAL, SUPPLY, ADMINISTRATIVE) OF ALL NEWLY INDUCTED AND RECRUITED PERSONNEL.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17177	1732	B	[SF]			TRNG MATRL STRG	Y	STORAGE FACILITIES FOR MISCELLANEOUS GOODS OR EQUIPMENT RELATED TO TRAINING FACILITY SUPPORT WILL BE PROVIDED ONLY WHERE IT CAN BE INDIVIDUALLY JUSTIFIED. THERE ARE NO CRITERIA FOR THIS TYPE OF FACILITY.
172						SIMULATION FACILITIES		
17230	1723	B	[SF]			GAS CHAMBER	Y	A GAS CHAMBER IS A BUILDING USED FOR TRAINING PERSONNEL IN THE USE OF PROTECTIVE MASKS AND THE EFFECTS OF CHEMICAL WARFARE.
173						TRAINING SUPPORT FACILITIES		
17310	1731	B	[SF]			RANGE OPERATIONS BLDG	Y	RANGE OPERATIONS BUILDINGS ARE DESIGNED FOR DIRECT SUPPORT TO RANGE OPERATIONS. SUCH BUILDINGS CAN SUPPORT A VARIETY OF OPERATIONS FOR A FIRING RANGE, SUCH AS : RANGE OPERATIONS, ADMINISTRATIVE SUPPORT, TARGET STORAGE AND ISSUE, EQUIPMENT STORAGE AND MAINTENANCE, AND AMMUNITION BREAKDOWN AND DISTRIBUTION (NOT STORAGE).
17311	1731	B	[SF]			RANGE SUPPORT BLDG	Y	A RANGE SUPPORT BUILDING WOULD BE A BUILDING WHICH HOUSES SUPPORT FUNCTIONS CONDUCTED AT THE RANGE COMPLEX, BUT NOT COVERED ELSEWHERE. THIS INCLUDES RANGE BILLETS, CLASSROOM SPACE AT A RANGE, BUILDINGS TO CONDUCT AFTER ACTION REVIEWS, AND ALL OTHER RANGE SUPPORT ACTIVITIES WITH THE EXCEPTION OF ACTIVITIES DESCRIBED IN RANGE OPERATIONS BUILDING, WEAPONS RANGE OBSERVATION TOWER, AND PUBLIC TOILET.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17320	1732	B	[SF]	TRAINING AIDS CENTER	Y	A TRAINING AIDS CENTER IS A BUILDING THAT IS USED TO FABRICATE, MAINTAIN, STORE, AND ISSUE TRAINING DEVICES AND MATERIALS INCLUDING MULTIPLE INTEGRATED LASER EQUIPMENT SYSTEM (MILES) AND VISUAL INFORMATION (VI) AIDS; IT ALSO PROVIDES THE ADMINISTRATIVE SPACE FOR THE TRAINING SUPPORT DIVISION (TSD) MANAGEMENT STAFF.
17330	1733	S	[SF]	COVERED TRAINING AREA	Y	COVERED TRAINING AREAS ARE STRUCTURES WHICH PROVIDE A COVERED AREA TO SUPPORT AND CONDUCT TRAINING OR FOR FEEDING OF PERSONNEL ON A TRAINING FACILITY WHILE PROVIDING PROTECTION FOR EQUIPMENT AND PERSONNEL FROM THE ELEMENTS.

174 IMPACT, MANVR, TRNG AREAS

All space for ground and air combat forces to practice movements and tactics. This includes all area having designated boundaries within which all ordnance will detonate or impact.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17410	1741	S	[AC]	MNVR/TRNG AREA, LT FORCES	N	THIS CATEGORY INCLUDES ALL SPACE FOR GROUND AND AIR COMBAT FORCES TO PRACTICE MOVEMENTS AND TACTICS. DIFFERENT TYPES OF UNITS MAY SUPPORT ONE ANOTHER (COMBINED ARMS), OR A UNIT MAY OPERATE INDEPENDENTLY. THE ¿LIGHT¿ DESIGNATION REFERS TO AREAS WHERE MANEUVER IS RESTRICTED TO ONLY SMALL UNITS OR UNITS HAVING ONLY WHEELED VEHICLES.
17411	1741	S	[AC]	MNVR/TRNG AREA, AMPHIB	N	THIS CATEGORY INCLUDES ALL SPACE FOR GROUND AND AIR COMBAT FORCES TO PRACTICE MOVEMENTS AND TACTICS DURING AMPHIBIOUS (SHIP-TO-SHORE) OPERATIONS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17412	1741	S	[AC]	EA		LAND NAVIGATION COURSE	N	A LAND NAVIGATION COURSE IS AN AREA LOCATED WITHIN THE TRAINING COMPLEX WHICH IS PRINCIPALLY SCHEDULED AND USED FOR MAP READING, TERRAIN ASSOCIATION, OR NAVIGATIONAL TRAINING.
17413	1741	S	[AC]	EA		FIELD TRAINING AREA	N	A FIELD TRAINING AREA IS A SPECIFIC AREA THAT IS INTENDED FOR THE TRAINING OF PERSONNEL OR ANIMALS IN A FIELD ENVIRONMENT THAT CANNOT BE CATEGORIZED BY THE OTHER CATEGORY CODES IN THE 174 BASIC SERIES. TRAINING CONDUCTED IN SUCH AN AREA MAY INCLUDE MEDICAL, K-9, OR COMMUNICATIONS EQUIPMENT.
17420	1742	S	[AC]			MNVR/TRNG AREA, HEAVY	N	THIS CATEGORY INCLUDES ALL SPACE FOR GROUND AND AIR COMBAT FORCES TO PRACTICE MOVEMENTS AND TACTICS. DIFFERENT TYPES OF UNITS MAY SUPPORT ONE ANOTHER (COMBINED ARMS), OR MAY OPERATE INDEPENDENTLY. THE ¿HEAVY¿ DESIGNATION REFERS TO AREAS WHERE MANEUVER IS UNRESTRICTED AND CAN CONSIST OF ALL TYPES OF VEHICLES AND EQUIPMENT, INCLUDING TRACKED VEHICLES.
17430	1743	S	[AC]			IMPACT AREA DUDDED	N	AN AREA HAVING DESIGNATED BOUNDARIES WITHIN WHICH ALL ORDNANCE WILL DETONATE OR IMPACT SHALL BE CATEGORIZED AS IMPACT AREA DUDDED. THIS AREA INCLUDES ALL IMPACT AREAS THAT DO NOT CONTAIN AUTOMATED TARGETS OR TARGETS CLASSIFIED AS REAL PROPERTY.
17431	1743	S	[AC]			IMPACT AREA NON-DUDDED	N	AN AREA HAVING DESIGNATED BOUNDARIES WITHIN WHICH ORDNANCE THAT DOES NOT PRODUCE DUDS WILL IMPACT IS AN IMPACT AREA NON-DUDDED. THIS AREA IS COMPOSED MOSTLY OF THE SAFETY FANS FOR SMALL ARMS RANGES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17440	1744	S	[AC]	EA		PERS/EQUIP DROP ZONE	N	A LARGE, FLAT, CLEARED AREA FOR PERSONNEL AND EQUIPMENT TO LAND FOLLOWING A PARACHUTE JUMP SHALL BE CATEGORIZED AS A PERSONNEL/EQUIPMENT DROP ZONE.
175						SMALL ARMS RANGES		
17501	1750	S	AC		[FP]	AUTOMATIC RIFLE RANGE	Y	THE AUTOMATIC RIFLE RANGE IS DESIGNED FOR TRAINING TARGET ENGAGEMENT TECHNIQUES WITH RIFLES AND SQUAD AUTOMATIC WEAPON (SAW). THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO EMPLOY AUTOMATIC AND SEMI-AUTOMATIC FIRING TECHNIQUES.
17502	1750	S	AC		[FP]	NON-STD SMALL ARMS RANGE	Y	THE NON-STANDARD SMALL ARMS RANGE IS DESIGNED FOR TRAINING REQUIREMENTS THAT ARE NOT ASSOCIATED WITH CURRENT PUBLISHED DOCTRINE, BUT FALL WITHIN A COMMANDER¿S TRAINING REQUIREMENTS. THIS RANGE INCLUDES ALL SMALL ARMS RANGES THAT DO NOT FIT INTO OTHER CATEGORIES.
17510	1751	S	AC		[FP]	BASIC ZERO FIRING RANGE	Y	A BASIC ZERO FIRING RANGE IS DESIGNED FOR TRAINING SHOT-GROUPING AND ZEROING EXERCISES WITH RIFLES AND MACHINE GUNS. THIS RANGE IS USED TO TRAIN INDIVIDUAL PERSONNEL ON THE SKILLS NECESSARY TO ALIGN THE SIGHTS AND PRACTICE BASIC MARKSMANSHIP TECHNIQUES AGAINST STATIONARY TARGETS.
17520	1752	S	AC		[FP]	AUTO FLD FIRE (AFF) RANGE	Y	AN AUTOMATE FIELD FIRE RANGE IS DESIGNED FOR TRAINING TARGET ENGAGEMENT TECHNIQUES WITH RIFLES. THIS RANGE IS USED TO TRAIN AND FAMILIARIZE PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY INFANTRY TARGETS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17530	1753	S	AC		[FP]	RECORD FIRE RANGE	Y	A RECORD FIRE RANGE IS DESIGNED FOR TRAINING AND DAY/NIGHT QUALIFICATION REQUIREMENTS WITH RIFLES. THIS RANGE IS USED TO TRAIN AND TEST PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY INFANTRY TARGETS.
17531	1753	S	AC		[FP]	AUTO RECORD FIRE RANGE	Y	AN AUTOMATED RECORD FIRE RANGE IS DESIGNED FOR TRAINING AND DAY/NIGHT QUALIFICATION REQUIREMENTS WITH RIFLES. THIS RANGE IS USED TO TRAIN AND TEST PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY INFANTRY TARGETS. ALL TARGETS ARE FULLY AUTOMATED AND THE EVENT SPECIFIC TARGET SCENARIO IS COMPUTER DRIVEN AND SCORED FROM THE RANGE OPERATIONS CENTER.
17532	1753	S	AC		[FP]	MOD RECORD FIRE RANGE	Y	A MODIFIED RECORD FIRE RANGE IS DESIGNED FOR TRAINING AND DAY/NIGHT QUALIFICATION WITH RIFLES.
17550	1755	S	AC		[FP]	RIFLE (KD) RANGE	Y	A RIFLE KNOWN DISTANCE RANGE IS DESIGNED FOR TRAINING RIFLE MARKSMANSHIP AND TARGET ENGAGEMENT TECHNIQUES. THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY TARGETS IN A STATIC ARRAY FROM A KNOWN DISTANCE.
17560	1756	S	AC		[FP]	SNIPER FIELD FIRE RANGE	Y	A SNIPER FIELD FIRE RANGE IS DESIGNED TO MEET TRAINING AND QUALIFICATION REQUIREMENTS WITH THE SNIPER RIFLE. THIS RANGE IS USED TO TRAIN AND TEST SNIPERS ON THE SKILLS NECESSARY TO DETECT, IDENTIFY, ENGAGE, AND HIT STATIONARY AND MOVING INFANTRY TARGETS IN A TACTICAL ARRAY IN ACCORDANCE WITH APPLICABLE FIELD MANUALS. IN THIS RANGE TARGETS ARE NOT FULLY AUTOMATED.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17561	1756	S	AC		[FP]	AUTO SNIPER FLD FIRE RNG	Y	AN AUTOMATED SNIPER FIELD FIRE RANGE IS DESIGNED TO MEET THE TRAINING AND QUALIFICATION REQUIREMENTS WITH THE SNIPER RIFLE. THIS RANGE IS USED TO TRAIN AND TEST SNIPERS ON THE SKILLS NECESSARY TO DETECT, IDENTIFY, ENGAGE, AND HIT STATIONARY AND MOVING INFANTRY TARGETS IN A TACTICAL ARRAY IN ACCORDANCE WITH APPLICABLE FIELD MANUALS.
17570	1757	S	AC		[FP]	PISTOL (KD) RANGE	Y	A PISTOL KNOWN DISTANCE (KD) RANGE IS DESIGNED FOR TRAINING PISTOL AND REVOLVER MARKSMANSHIP AND TARGET ENGAGEMENT TECHNIQUES. THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY TARGETS IN A STATIC ARRAY FROM A KNOWN DISTANCE.
17571	1757	S	AC		[FP]	COMBAT PISTOL QUAL CRSE	Y	A COMBAT PISTOL/MP FIREARMS QUALIFICATION COURSE IS A RANGE DESIGNED TO MEET TRAINING AND QUALIFICATION REQUIREMENTS WITH COMBAT PISTOLS AND REVOLVERS. THIS RANGE IS USED TO TRAIN AND TEST PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY INFANTRY TARGETS.
17572	1757	S	AC		[FP]	AUTO COMBAT PSTL QUAL	Y	AN AUTOMATED COMBAT PISTOL/MP FIREARMS QUALIFICATION COURSE IS A RANGE DESIGNED TO MEET TRAINING AND QUALIFICATION REQUIREMENTS WITH COMBAT PISTOLS AND REVOLVERS. THIS RANGE IS USED TO TRAIN AND TEST PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY INFANTRY TARGETS.
17573	1758	S	AC		[FP]	SUBMACHINE GUN RANGE	Y	A SUBMACHINE GUN RANGE IS DESIGNED FOR TRAINING TARGET ENGAGEMENT TECHNIQUES WITH THE SUBMACHINE GUN. THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY INFANTRY TARGETS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17580	1758	S	AC		[FP]	MACHINE GUN TRANS RANGE	Y	A MACHINE GUN TRANSITION RANGE IS DESIGNED TO MEET THE TRAINING REQUIREMENTS WITH MACHINE GUNS. THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY INFANTRY TARGETS AT KNOWN DISTANCES.
17581	1758	S	AC		[FP]	MACHINE GUN FF RANGE	Y	A MACHINE GUN FIELD FIRE RANGE IS DESIGNED TO TRAIN TARGET ENGAGEMENT TECHNIQUES WITH SQUAD ASSAULT WEAPONS AND MACHINE GUNS. THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY INFANTRY, VEHICLE, AND BUNKER TYPE TARGETS.
17582	1758	S	AC		[FP]	AUTOMATED MPMG RANGE	Y	AN AUTOMATED MULTIPURPOSE MACHINE GUN (MPMG) RANGE IS DESIGNED FOR ZEROING, TRAINING, AND QUALIFICATION REQUIREMENTS WITH SQUAD ASSAULT WEAPONS (SAW) AND MACHINE GUNS. THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO IDENTIFY, ENGAGE, AND HIT STATIONARY INFANTRY TARGETS.
176						WEAPONS RANGES		
17610	1761	S	AC		[FP]	GRENADE LAUNCHER RANGE	Y	A GRENADE LAUNCHER RANGE IS DESIGNED TO MEET TRAINING AND QUALIFICATION REQUIREMENTS OF THE 40MM M203 GRENADE LAUNCHER. THIS RANGE IS USED TO TRAIN AND TEST PERSONNEL ON THE SKILLS NECESSARY TO ENGAGE AND DEFEAT STATIONARY TARGET EMPLACEMENTS WITH THE 40MM GRENADE LAUNCHER.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17620	1762	S	AC	LN	[FP]	40MM QUALFICATION RANGE	Y	A 40MM MACHINE GUN QUALIFICATION RANGE IS DESIGNED TO CONDUCT TRAINING QUALIFICATION FIRING WITH THE GRENADE MACHINE GUN (E.G., MK-19). THIS RANGE IS USED TO TRAIN PERSONNEL WITH THE WEAPON EITHER GROUND OR VEHICLE MOUNTED. TARGETS IN THIS RANGE MAY BE EITHER NON-AUTOMATED OR FULLY AUTOMATED AND THE EVENT SPECIFIC TARGET SCENARIO IS COMPUTER DRIVEN AND SCORED FROM THE RANGE OPERATIONS CENTER.
17630	1763	S	AC		[FP]	LAW RANGE SUBCALIBER	Y	A LIGHT ANTI-ARMOR WEAPONS RANGE IS DESIGNED FOR TRAINING TARGET ENGAGEMENT TECHNIQUES WITH LIGHT ANTI-ARMOR WEAPONS (E.G., LAW/AT-4). THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO EMPLOY THE WEAPON AND HIT STATIONARY AND MOVING TARGETS USING A SUB-CALIBER TRAINING DEVICE.
17631	1763	S	AC		[FP]	LAW RANGE LIVE	Y	A LIGHT ANTI-ARMOR WEAPONS RANGE LIVE IS DESIGNED FOR TRAINING TARGET ENGAGEMENT TECHNIQUES WITH LIGHT ANTI-ARMOR WEAPONS (E.G., LAW/ AT-4). THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO EMPLOY THE WEAPON AND HIT STATIONARY AND MOVING TARGETS USING LIVE ROCKETS OR A SUB-CALIBER TRAINING DEVICE.
17640	1764	S	AC	LN	[FP]	ANTIARMOR TRK/ FIRE RANGE	Y	AN ANTI-ARMOR TRACKING AND LIVE-FIRE RANGE IS A COMPLEX DESIGNED TO MEET TRAINING AND QUALIFICATION REQUIREMENTS WITH MEDIUM AND HEAVY ANTI-ARMOR WEAPONS SYSTEMS. THIS COMPLEX IS USED TO TRAIN AND TEST SOLDIERS ON THE SKILLS NECESSARY TO EMPLOY THE WEAPON, IDENTIFY, TRACK, ENGAGE, AND DEFEAT STATIONARY AND MOVING ARMOR TARGETS PRESENTED INDIVIDUALLY OR AS PART OF A TACTICAL ARRAY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17641	1764	S	AC	LN	[FP]	AUTO AA TRK/FIRE RANGE	Y	AN AUTOMATED ANTI-ARMOR TRACKING AND LIVE-FIRE RANGE IS A COMPLEX DESIGNED TO MEET TRAINING AND QUALIFICATION REQUIREMENTS WITH MEDIUM AND HEAVY ANTI-ARMOR WEAPONS SYSTEMS. THIS COMPLEX IS USED TO TRAIN AND TEST PERSONNEL ON THE SKILLS NECESSARY TO EMPLOY THE WEAPON, IDENTIFY, TRACK, ENGAGE, AND DEFEAT STATIONARY AND MOVING ARMOR TARGETS PRESENTED INDIVIDUALLY OR AS PART OF A TACTICAL ARRAY.
17650	1765	S	AC	[EA]	FP	F/A DIRECT FIRE RANGE	Y	A FIELD ARTILLERY DIRECT FIRE RANGE IS DESIGNED TO MEET TRAINING REQUIREMENTS OF FIELD ARTILLERY CREWS. THIS RANGE IS USED TO TRAIN FIELD ARTILLERY CREWS ON THE SKILLS NEC4ESSARY TO EMPLOY DIRECT FIRE GUNNERY TECHNIQUES WITH INDIRECT FIRE EQUIPMENT AGAINST STATIONARY TARGETS IN A TACTICAL ARRAY USING LIVE DIRECT FIRE ARTILLERY.
17660	1766	S	AC	[EA]	FP	TANK/FTNG VEHICLE RANGE	Y	A TANK/FIGHTING VEHICLE STATIONARY GUNNERY RANGE IS DESIGNED FOR CONDUCTING WEAPONS SYSTEM BORE SIGHTING, SCREENING, ZEROING AND/OR HARMONIZATION. ARMOR, INFANTRY AND/OR AVIATION CREW USE THIS RANGE.
17670	1767	S	AC	[EA]	FP	MORTAR RANGE	N	A MORTAR RANGE IS DESIGNED TO MEET THE TRAINING REQUIREMENTS OF MORTAR CREWMEN. THIS RANGE IS USED TO TRAIN MORTAR CREWS ON THE SKILLS NECESSARY TO APPLY FIRE MISSION DATA, ENGAGE, AND HIT STATIONARY TARGETS IN A TACTICAL ARRAY USING LIVE FIRE MORTARS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17671	1767	S	AC	[EA]	FP	F/A INDIRECT FIRE RANGE	N	A FIELD ARTILLERY INDIRECT FIRE RANGE IS DESIGNED TO MEET THE TRAINING AND QUALIFICATION REQUIREMENTS OF FIELD ARTILLERY UNITS. THIS RANGE IS USED TO TRAIN FIELD ARTILLERY CREWS ON THE SKILLS NECESSARY TO APPLY FIRE MISSION DATA, ENGAGE, AND HIT STATIONARY TARGETS IN A TACTICAL ARRAY WITH INDIRECT FIRE.
17680	1768	S	AC	[EA]	FP	MORTAR SCALED RANGE	Y	A MORTAR SCALED RANGE IS DESIGNED TO MEET THE TRAINING REQUIREMENTS OF MORTAR CREWMEN. THIS RANGE IS USED TO TRAIN MORTAR CREWS ON THE SKILLS NECESSARY TO APPLY FIRE MISSION DATA, ENGAGE, AND HIT STATIONARY TARGETS IN A TACTICAL ARRAY USING SUB-CALIBER TRAINING DEVICES.
17681	1768	S	AC	[EA]	FP	F/A SCALED RANGE	Y	A FIELD ARTILLERY SCALED RANGE IS DESIGNED TO MEET TRAINING REQUIREMENTS OF FIELD ARTILLERY CREWS. THIS RANGE IS USED TO TRAIN FIELD ARTILLERY CREWS ON THE SKILLS NECESSARY TO APPLY FIRE MISSION DATA, ENGAGE, AND HIT STATIONARY TARGETS IN A TACTICAL ARRAY USING SUB-CALIBER TRAINING DEVICES.
17690	1769	S	AC	[EA]	FP	SCALED RANGE (1:30/60)	Y	A SCALED GUNNERY RANGE (1:30 AND 1:60) IS DESIGNED TO MEET TRAINING REQUIREMENTS OF ARMOR CREWS. THIS RANGE IS USED TO TRAIN ARMOR CREWS ON THE SKILLS NECESSARY TO DETECT, IDENTIFY, ENGAGE, AND HIT STATIONARY AND MOVING SCALED TARGETS IN A TACTICAL ARRAY USING SUB-CALIBER TRAINING DEVICES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17691	1769	S	AC	[EA]	FP	SCALED RANGE (1:5/10)	Y	A SCALED GUNNERY RANGE (1:50 AND 1:10) IS DESIGNED TO MEET TRAINING REQUIREMENTS OF ARMOR AND INFANTRY CREWS. THIS RANGE IS USED TO TRAIN ARMOR AND INFANTRY CREWS ON THE SKILLS NECESSARY TO DETECT, IDENTIFY, ENGAGE, AND HIT STATIONARY AND MOVING SCALED TARGETS IN A TACTICAL ARRAY USING SUB-CALIBER TRAINING DEVICES AND/OR SIMULATIONS.
177						TEAM AND UNIT RANGES		
17710	1771	S	AC	LN	[FP]	MULTIPURPOSE TRNG RANGE	Y	A MULTIPURPOSE TRAINING RANGE IS DESIGNED TO MEET THE TRAINING AND QUALIFICATION REQUIREMENTS FOR THE CREWS, TEAMS AND SECTIONS OF COMBAT UNITS. THIS RANGE IS USED TO TRAIN AND TEST ARMOR, INFANTRY, AND AVIATION CREWS AND SECTIONS ON THE SKILLS NECESSARY TO DETECT, IDENTIFY, ENGAGE, AND DEFEAT STATIONARY AND MOVING ARMOR AND INFANTRY TARGETS IN A TACTICAL ARRAY.
17711	1771	S	AC	LN	[FP]	AUTO MP TRAINING RANGE	Y	AN AUTOMATED MULTIPURPOSE TRAINING RANGE IS SPECIFICALLY DESIGNED TO SATISFY THE TRAINING AND QUALIFICATION REQUIREMENTS FOR THE CREWS, TEAMS AND SECTIONS OF COMBAT UNITS. THIS RANGE SUPPORTS DISMOUNTED INFANTRY SQUAD TACTICAL LIVE-FIRE OPERATIONS EITHER INDEPENDENTLY OF, OR SIMULTANEOUSLY WITH SUPPORTING VEHICLES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17720	1772	S	AC	[EA]	FP	T/FV PLATOON BATTLE RUN	Y	A TANK/FIGHTING VEHICLE PLATOON BATTLE RUN IS DESIGNED TO MEET THE TRAINING AND QUALIFICATION REQUIREMENTS FOR PLATOONS OF ARMOR AND INFANTRY UNITS. THIS RANGE IS USED TO TRAIN AND TEST ARMOR AND INFANTRY PLATOONS AND SECTIONS ON THE SKILLS NECESSARY TO DETECT, IDENTIFY, ENGAGE, AND DEFEAT STATIONARY AND MOVING ARMOR AND INFANTRY TARGETS IN A TACTICAL ARRAY.
17721	1772	S	AC	[EA]	FP	T/FV MP RANGE COMPLEX, LT	Y	A TANK/FIGHTING VEHICLE MULTIPURPOSE RANGE COMPLEX, LIGHT, AUTOMATED, IS DESIGNED TO MEET THE TRAINING AND QUALIFICATION REQUIREMENTS FOR LIGHT AND MECHANIZED INFANTRY, ARMOR, AND AVIATION UNITS. IT IS USED TO TRAIN AND TEST INFANTRY, ARMOR, AND AVIATION TEAMS AND CREWS ON THE SKILLS NECESSARY TO DETECT, IDENTIFY, ENGAGE, AND DEFEAT STATIONARY AND MOVING ARMOR AND INFANTRY TARGETS.
17722	1772	S	AC	[EA]	FP	T/FV MP RANGE COMPLEX, HV	Y	A TANK/FIGHTING VEHICLE MULTIPURPOSE RANGE COMPLEX, HEAVY, AUTOMATED, IS DESIGNED FOR TRAINING AND QUALIFICATION REQUIREMENTS FOR THE CREWS OF ARMOR, INFANTRY AND AVIATION UNITS. IT SUPPORTS INFANTRY SQUAD TACTICAL LIVE-FIRE OPERATIONS. IT IS USED TO TRAIN AND TEST ARMOR, INFANTRY, AND AVIATION TEAMS ON THE SKILLS TO DETECT, IDENTIFY, AND DEFEAT STATIONARY AND MOVING ARMOR AND INFANTRY TARGETS.
17730	1773	S	AC	LN	[FP]	FIRE AND MOVEMENT RANGE	Y	A FIRE AND MOVEMENT RANGE IS DESIGNED FOR TRAINING INDIVIDUAL AND BUDDY/TEAM FIRE AND MOVEMENT TECHNIQUES. THE TEAM NEGOTIATES MANEUVER UTILIZING COVER AND CONCEALMENT TECHNIQUES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17740	1774	S	AC	[EA]	FP	SQUAD DEFENSE RANGE	Y	A SQUAD DEFENSE RANGE IS DESIGNED FOR TRAINING INDIVIDUALS AND SQUADS ON DEFENSIVE ENGAGEMENT TECHNIQUES AND MUTUALLY SUPPORTING FIRES. THIS RANGE IS USED TO TRAIN PERSONNEL ON THE SKILLS NECESSARY TO DESIGNATE SECTORS OF FIRE, IDENTIFY, AND PROVIDE SUPPRESSIVE FIRE ON STATIONARY INFANTRY TARGETS.
17750	1775	S	AC	[EA]	FP	INF SQUAD BATTLE COURSE	Y	AN INFANTRY SQUAD BATTLE COURSE IS FOR THE TRAINING AND QUALIFICATION REQUIREMENTS OF TEAMS AND SQUADS ON INDIVIDUAL AND COLLECTIVE TACTICS, TECHNIQUES, AND PROCEDURES AND EMPLOYMENT IN TACTICAL SITUATIONS. IT IS USED TO TRAIN AND TEST TEAMS AND SQUADS ON THE SKILLS NECESSARY TO CONDUCT TACTICAL MOVEMENT TECHNIQUES, DETECT, IDENTIFY, AND DEFEAT STATIONARY AND MOVING ARMOR AND INFANTRY TARGETS.
17751	1775	S	AC	[EA]	FP	AUTO INF SQD BAT COURSE	Y	AN AUTOMATED INFANTRY SQUAD BATTLE COURSE IS DESIGNED FOR TRAINING AND QUALIFICATION REQUIREMENTS OF TEAMS AND SQUADS ON INDIVIDUAL AND COLLECTIVE TACTICS, TECHNIQUES AND PROCEDURES AND EMPLOYMENT IN TACTICAL SITUATIONS. IT IS USED TO TRAIN AND TEST TEAMS AND SQUADS ON THE SKILLS TO CONDUCT TACTICAL MOVEMENT TECHNIQUES, DETECT, IDENTIFY, AND DEFEAT STATIONARY AND MOVING ARMOR AND INFANTRY TARGETS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17752	1775	S	AC	[EA]	FP	INF PLATOON BAT COURSE	Y	AN INFANTRY PLATOON BATTLE COURSE IS DESIGNED FOR THE TRAINING AND QUALIFICATION REQUIREMENTS OF INFANTRY PLATOONS, EITHER MOUNTED OR DISMOUNTED, ON MOVEMENT TECHNIQUES AND OPERATIONS. THIS COMPLEX IS USED TO TRAIN AND TEST PLATOONS ON THE SKILLS NECESSARY TO CONDUCT TACTICAL MOVEMENT TECHNIQUES, DETECT, IDENTIFY, ENGAGE, AND DEFEAT STATIONARY AND MOVING ARMOR AND INFANTRY TARGETS.
17753	1775	S	AC	[EA]	FP	AUTO INF PLTN BAT COURSE	Y	AN AUTOMATED INFANTRY PLATOON BATTLE COURSE IS DESIGNED FOR THE TRAINING AND QUALIFICATION REQUIREMENTS OF INFANTRY PLATOONS, EITHER MOUNTED OR DISMOUNTED, ON MOVEMENT TECHNIQUES AND OPERATIONS. THIS COMPLEX IS USED TO TRAIN AND TEST PLATOONS ON THE SKILLS TO CONDUCT TACTICAL MOVEMENT TECHNIQUES, DETECT, IDENTIFY, ENGAGE, AND DEFEAT STATIONARY AND MOVING ARMOR AND INFANTRY TARGETS.
17760	1776	S	AC	[EA]	FP	MOUT ASSAULT COURSE	Y	A MOUT ASSAULT COURSE IS A FACILITY FOR LOW-LEVEL COLLECTIVE TRAINING USING LIVE FIRE OR MILES. THIS FACILITY IS USED FOR TRAINING SPECIFIC TASKS BEFORE TRAINING ON UNIT PROFICIENCY MOUT SITES OR COMBAT IN CITIES FACILITY, CARRIED UNDER CATEGORY CODE 179 61.
178						EXPLOSIVE AND FLAME RANGES		
17810	1781	S	AC		[FP]	LIVE HAND GRENADE RANGE	Y	A LIVE HAND GRENADE RANGE IS DESIGNED TO SATISFY THE TRAINING REQUIREMENT OF THROWING LIVE FRAGMENTATION GRENADES. THIS RANGE FAMILIARIZES SOLDIERS WITH THE EFFECTS OF LIVE FRAGMENTATION GRENADES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17820	1782	S	AC		[FP]	ENGR QUALF RANGE, N/STD	Y	AN ENGINEER QUALIFICATION RANGE, NON-STANDARDIZED, IS DESIGNED TO MEET THE TRAINING AND QUALIFICATION REQUIREMENTS FOR ENGINEER AND COMBAT ENGINEER CREWS. THIS RANGE IS USED TO TRAIN AND TEST ENGINEER CREWS ON THE SKILLS NECESSARY TO ZERO AND/OR BORESIGHT WEAPONS SYSTEMS, IDENTIFY, CLASSIFY, AND REDUCE OBSTACLES.
17821	1782	S	AC		[FP]	ENGR QUAL RANGE, AUTO	Y	AN ENGINEER QUALIFICATION RANGE, AUTOMATED/STANDARDIZED, IS DESIGNED FOR THE TRAINING AND QUALIFICATION REQUIREMENTS OF ENGINEER AND COMBAT ENGINEER CREWS. THIS RANGE IS USED TO TRAIN AND TEST ENGINEER CREWS ON THE SKILLS NECESSARY TO ZERO AND / OR BORESIGHT WEAPONS SYSTEMS, IDENTIFY, CLASSIFY, AND REDUCE OBSTACLES.
17830	1783	S	AC		[FP]	LIGHT DEMOLITION RANGE	Y	A LIGHT DEMOLITION RANGE IS DESIGNED FOR THE TRAINING AND QUALIFICATION OF EMPLOYING EXPLOSIVES AND DEMOLITION CHARGES. THIS RANGE IS USED TO TRAIN PERSONNEL ON THE PROPER TECHNIQUES OF WIRE, MINEFIELD AND CONCRETE OBSTACLE BREACHING, TIMBER AND STEEL CUTTING, ROAD CRATERING, AND EXPLOSIVE DEMOLITION.

179 TRAING FAC-OTHER THAN BLDG

This basic category includes requirements for weapons ranges, training courses and mockups, training pools/tanks, and parade and drill fields, but it does not include expendable targets.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17901	1799	S	AC	[EA]	FP	BAYONET ASSAULT COURSE	Y	A BAYONET ASSAULT COURSE IS DESIGNED FOR TRAINING ASSAULT TECHNIQUES WITH A RIFLE AND BAYONET. THESE TECHNIQUES ARE APPLIED THROUGH A SERIES OF OBSTACLES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17902	1790	S		[EA]		(TD) RANGE, NON-FIRING	Y	A TARGET DETECTION RANGE, NON-FIRING, IS A NON-FIRING RANGE TO TEACH SOLDIERS HOW TO DETECT PERSONNEL ON THE BATTLEFIELD UNDER VARYING DEGREES OF CONCEALMENT AND VISIBILITY.
17903	1799	S		[EA]		HAND TO HAND COMBAT PIT	Y	A HAND TO HAND COMBAT PIT IS A STRUCTURE CONTAINING A CIRCLE OF SAND OR SAWDUST FOR TRAINING IN HAND-TO-HAND FIGHTING.
17904	1790	S		[EA]		POW TRAINING AREA	Y	A PRISONER OF WAR TRAINING AREA IS TYPICALLY AND AREA FENCED IN WITH BARBED WIRE AND WITH GUARD TOWERS USED FOR THE TRAINING OF PERSONNEL IN THE HANDLING OF PRISONERS-OF-WAR. THE FACILITY MAY ALSO BE USED FOR THE TRAINING OF PERSONNEL IN A SIMULATED POW ENVIRONMENT.
17905	1776	S	AC	[EA]		MINE WARFARE AREA	Y	A MINE WARFARE AREA IS A CLEARED AREA FOR TRAINING IN THE PLACEMENT, ARMING, DISARMING, AND DETECTION OF VEHICLE AND ANTI-PERSONNEL MINES USING NON-EXPLOSIVE TRAINING MATERIAL.
17906	1741	S	AC	[EA]		WHEEL VEH DRIVER COURSE	Y	A WHEELED VEHICLE DRIVERS COURSE IS FOR TEACHING BASIC DRIVING SKILLS, AND FOR PRACTICE IN FOUR-WHEEL DRIVE SITUATIONS, PARKING, AND BACKING UP.
17907	1742	S	AC	[EA]		TRACK VEH DRIVER COURSE	Y	A TRACKED VEHICLE DRIVERS COURSE IS AN AREA TO TEACH THE BASIC DRIVING SKILLS OF STEERING AND GEAR SHIFTING ON A LEVEL COURSE. THE FACILITY MAY ALSO CONTAIN A HILLY COURSE FOR DEVELOPING ADVANCED TRACKED VEHICLE DRIVING SKILLS SUCH AS TURNING ON SLOPES AND NEGOTIATING STEEP GRADES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17908	1742	S	AC	[EA]		AMPH VEH TRAINING AREA	Y	AN AMPHIBIOUS VEHICLE TRAINING AREA CONTAINS SAND OR IS CLOSE TO A BEACH FOR TRAINING MILITARY PERSONNEL ON UNIQUE DRIVING, TECHNICAL AND TACTICAL TASKS ASSOCIATED WITH AMPHIBIOUS OPERATIONS.
17909	1790	S		[EA]		SHIP LOAD/UNLOAD MOCKUP	Y	A MOCKUP OF A SHIP USED FOR TRAINING PERSONNEL IN SHIP LOADING AND OFF-LOADING. TRAINING AREA CAN ALSO INCLUDE NEGOTIATING CARGO NETS USED DURING AMPHIBIOUS OPERATIONS AND OPERATIONS AT DOCKSIDE.
17910	1793	S		[EA]		ACFT GUN BOMB ROCKET RNGES	N	AIRCRAFT GUNNERY, BOMBING AND ROCKET RANGES (AIRCRAFT WEAPONS RANGES) PROVIDE AIR CREWS WITH OPERATING AREAS FOR THE DEVELOPMENT OF PROFICIENCY IN GUNNERY, BOMBING, ROCKETRY, MISSILE DELIVERY, STRAFING, AND MINE LAYING.
17911	1790	S		[EA]		AIR TRANSPORT MOCKUP	Y	AN AIR TRANSPORT MOCKUP IS A RAMP AND A PLATFORM STRUCTURE USED TO SIMULATE VARYING TYPES OF FIXED- AND ROTARY-WING AIRCRAFT. STRUCTURE ALLOWS LOADING, SECURING, AND UNLOADING OF VEHICLES, EQUIPMENT, AND/OR PERSONNEL.
17912	1734	S		[EA]		TRNG TOWER/PLATFORM	Y	A STRUCTURE THAT SUPPORTS VARIOUS TRAINING SCENARIOS, INCLUDING USES SUCH AS PARACHUTE LANDING PLATFORMS, SUSPENDED HARNESS MOCKUPS, AND MOCK JUMP TOWERS.
17916	1790	S	AC	[EA]		COMBAT TRAIL	Y	A COMBAT TRAIL IS A TRAINING SITE USED FOR VARIOUS TYPES OF PROFICIENCY AND SUSTAINMENT TRAINING BY ROTATION THROUGH DIFFERENT STATIONS IN A ROUND-ROBIN SCENARIO.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17917	1790	S		[EA]	RAPPELLING TRAINING AREA	Y	A RAPPELLING TRAINING AREA IS AN AREA THAT INCLUDES AT LEAST ONE STRUCTURE USED TO PRACTICE RAPPELLING (ROPE DESCENT). THE TRAINING AREA MAY ALSO INCLUDE MODIFIED TOWERS FOR TRAINING IN HELICOPTER RAPPELS.
17918	1111	LS	AC	[EA]	AIRFIELD DEMO RANGE	Y	AN EXPEDITIONARY TRAINING AREA COMPRISED OF CONSTRUCTED RUNWAY SURFACES THAT ARE INTENTIONALLY DAMAGED, THEN REPAIRED BY EXPEDITIONARY FORCES IN AN EFFORT TO INCREASE EXPEDIENCY OF REPAIRS DAMAGED IN THEATER BY INSURGENTS USING IEDS AND OTHER MEANS.
17919	1790	S		[EA]	TIMBER BRIDGE AREA	Y	A TIMBER BRIDGE AREA IS A CLEARED AREA BESIDE A DITCH OR RAVINE FOR ENGINEER UNITS TO PRACTICE BUILDING TIMBER BRIDGES.
17920	1790	S		[EA]	PANEL BRIDGE AREA	Y	A PANEL BRIDGE AREA IS A CLEARED AREA BESIDE A CREEK OR RAVINE FOR ENGINEER UNITS TO PRACTICE BUILDING PANEL BRIDGES.
17921	1790	S		[EA]	ARMORED VEH LAUNCH AREA	Y	AN ARMORED VEHICLE LAUNCH BRIDGE, RAFT, AND FORD AREA IS A CLEARED PIECE OF LAND BESIDE A CREEK OR RAVINE USED FOR ERECTION AND RETRIEVAL OF ARMORED VEHICLE LAUNCH BRIDGES (AVLB) AND SCISSOR BRIDGES.
17922	1790	S		[EA]	FLOATING BRIDGE SITE	Y	A FLOATING BRIDGE SITE IS A CLEARED RIVERBANK AREA FOR ENGINEER UNITS TO PRACTICE FORDING WATER OBSTACLES AND ERECTION AND RETRIEVAL OF FLOATING BRIDGING EQUIPMENT.
17924	1742	S	AC	[EA]	WATER SUPPLY TRNG AREA	Y	A WATER SUPPLY TRAINING AREA IS PARTIALLY IMPROVED LAND FOR PERFORMING WATER PURIFICATION AND STORAGE OPERATIONS. IT SHOULD BE LOCATED ON A FLOWING STREAM WITH FIRM BANKS AND ALL-WEATHER ACCESS ROADS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17925	1742	S	AC	[EA]		AFLD SITE SEL TRNG AREA	Y	AN AIRFIELD SITE SELECTION TRAINING AREA IS CLEARED LAND USED TO TRAIN SOLDIERS IN THE FUNDAMENTALS OF SELECTING AND SECURING A SITE SUITABLE FOR TAKEOFFS AND PARKING OF ROTARY-WING AIRCRAFT.
17926	1792	S	AC	[EA]		AERIAL GUNNERY RANGE	Y	AN AERIAL GUNNERY RANGE IS DESIGNED TO SUPPORT THE TRAINING AND QUALIFICATION REQUIREMENTS OF HELICOPTER GUNNERY. THIS RANGE IS USED TO TRAIN AND TEST HELICOPTER CREWS ON THE SKILLS NECESSARY TO DETECT, IDENTIFY, ENGAGE, AND HIT STATIONARY ARMOR AND INFANTRY TARGETS IN A TACTICAL ARRAY.
17930	1767	S		[EA]		SURFACE PROJECTILE RANGE	N	THIS CODE IS FOR RANGES SUPPORTING SURFACE-LAUNCHED PROJECTILES AS OPPOSED TO RANGES FOR AIR-LAUNCHED PROJECTILES WHICH ARE CODED AS CATEGORY CODE 179 10. CRITERIA ARE NOT PRESENTLY AVAILABLE FOR SURFACE PROJECTILE RANGE REQUIREMENTS.
17931	1742	S	AC	[EA]		MED HVY EQUIP TRNG AREA	Y	A MEDIUM HEAVY EQUIPMENT TRAINING AREA IS AN UNIMPROVED AREA FOR TRAINING IN PLACEMENT, COMPACTION, AND GRADING OF FILL, AND TRAINING IN CONSTRUCTION OF DRAINAGE STRUCTURES.
17932	1790	S	AC	[EA]		DECON TRAINING SITE	Y	A DECONTAMINATION TRAINING SITE IS AN AREA CONSISTING OF A PIT FILLED WITH ROCK WITH AN ATTACHED ROCK-FILLED SUMP TO A DRAIN BED. THIS STRUCTURE IS USED PRIMARILY FOR VEHICLE DECONTAMINATION TRAINING.
17933	1790	S	AC	[EA]		POL TRAINING AREA	Y	A POL TRAINING AREA IS A MATERIALS HANDLING AREA FOR TRAINING PERSONNEL IN THE PROPER HANDLING OF PETROLEUM, OILS, AND LUBRICANTS. ALSO USED FOR ASSEMBLY AND TRAINING IN VARIOUS POL STORAGE AND DISTRIBUTION SYSTEMS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17935	1734	S		[EA]		WEAPONS RANGE OPS TOWER	N	RANGE OPERATIONS TOWERS ARE USED AT GUNNERY, BOMBING, AND ROCKET RANGES TO PROVIDE AN UNOBSTRUCTED VIEW OF TARGET AREAS FOR PURPOSES OF CONTROL AND SPOTTING IMPACTS.
17936	1793	S	AC	[EA]		CLOSE AIR SUPPORT RANGE	N	A CLOSE AIR SUPPORT RANGE IS DESIGNED TO SUPPORT THE TRAINING AND QUALIFICATION REQUIREMENTS OF CLOSE AIR SUPPORT AIRCRAFT. THIS RANGE IS USED TO TRAIN AND TEST AIRCRAFT CREWS ON THE SKILLS NECESSARY TO PROVIDE AIR SUPPORT TO GROUND FORCES UNDER VARYING CONDITIONS.
17937	1793	S	AC	[EA]		AERIAL BOMBING RANGE	N	AN AERIAL BOMBING RANGE IS DESIGNED TO SUPPORT THE TRAINING AND QUALIFICATION REQUIREMENTS FOR FIXED-WING AIRCRAFT DROPPING THEIR ORDNANCE. THIS RANGE IS USED TO TRAIN AND TEST AIRCRAFT CREWS ON THE SKILLS NECESSARY TO DETECT AND SUPPRESS ENEMY TARGETS IN A TACTICAL ARRAY.
17940	1750	S		[EA]	FP	SMALL ARMS RANGE - OUTDOOR	Y	A SMALL ARMS RANGE PROVIDES AN AREA FOR TRAINING IN THE USE OF PISTOLS, SMALL CALIBER RIFLES, AND SMALL CALIBER MACHINE GUNS. RANGES MUST BE AVAILABLE ALL YEAR TO PROVIDE CONTINUAL TRAINING AND RETRAINING FOR PERSONNEL WHO MUST BE PROFICIENT IN THE USE OF SMALL ARMS.
17941	1794	S	AC		[FP]	AIR DEF MISSILE FRNG RANGE	Y	AN AIR DEFENSE MISSILE FIRING RANGE IS DESIGNED TO MEET TRAINING AND QUALIFICATION REQUIREMENTS OF AIR DEFENSE (LAAD/STINGER) UNITS. THIS RANGE IS USED TO TRAIN AND TEST CREWS ON THE SKILLS NECESSARY TO EMPLOY GROUND TO AIR ANTI-AIRCRAFT MISSILES AGAINST BALLISTIC AERIAL TARGET SYSTEMS (BATS).

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17945	1790	S		[EA]		TRAINING MOCK-UPS	Y	THIS CODE INCLUDES MOCKUP STRUCTURES REPRESENTING ALL OR PARTS OF SHIPS, AIRCRAFT, TANKS, OR BUILDINGS FOR TRAINING PERSONNEL IN SKILLS SUCH AS DISASTER CONTROL, FIRE FIGHTING, AND EQUIPMENT HANDLING.
17950	1741	S	AC	[EA]		TRAINING COURSE	N	THIS CODE INCLUDES AREAS DESIGNATED FOR PERSONNEL TRAINING IN VARIOUS SKILLS UNDER ACTUAL OPERATIONAL CONDITIONS. TABLE 17950-1 OUTLINES THE FACILITIES OF THIS GROUP AND APPROXIMATE REQUIREMENTS.
17951	1795	S	AC	[EA]		FF AND RESCUE TRNG AREA	Y	A FIRE FIGHTING AND RESCUE TRAINING AREA IS A STRUCTURE CONSISTING OF A MOCKUP OF A MULTISTORY BUILDING OR AN AIRCRAFT FOR TRAINING IN FIRE CONTAINMENT, LADDER USE, ESCAPE, AND RESCUE FROM BUILDINGS.
17955	1725	S		[EA]	ME	COMBAT TRAIN'G POOL/TANK	Y	A COMBAT TRAINING POOL/TANK IS PLANNED FOR INSTRUCTIONS IN SWIMMING AND SURVIVAL UNDER COMBAT CONDITIONS. THE SWIMMING POOL/TANK MAY BE PROVIDED ONLY AS REQUIRED FOR TRAINING PURPOSES,
17960	1745	S	AC	[EA]		PARADE AND DRILL FIELD	N	THIS FACILITY PROVIDES SPACE FOR FORMATION DRILLS, PARADE AND REVIEW FUNCTIONS, AND HONOR CEREMONIES. SUCH A FIELD MAY BE PLANNED FOR STATIONS HAVING INDEPENDENT COMMAND FUNCTIONS.
17961	1790	S	AC	[EA]		COMBAT IN CITIES FACILITY	Y	A COMBAT IN CITIES FACILITY IS A NON-STANDARD TRAINING FACILITY THAT TYPICALLY INCLUDES THE BUILDINGS, ROADS, AND SIDEWALKS NORMALLY FOUND IN AN URBAN ENVIRONMENT, AND WHICH IS USED TO TRAIN AND SUSTAIN UNIT PROFICIENCY IN AN URBAN ENVIRONMENT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17962	1790	S	AC	[EA]		MOUT COLLECTIVE(SMALL)	Y	A MOUT COLLECTIVE TRAINING FACILITY (SMALL) IS DESIGNED TO MEET THE TRAINING REQUIREMENTS OF AN INFANTRY COMPANY-SIZED UNIT IN AN URBAN ENVIRONMENT. THIS STRUCTURE CONTAINS 24 BUILDINGS OR LESS AND IS USED TO TRAIN UNIT COLLECTIVE TASKS ASSOCIATED WITH URBAN TERRAIN.
17963	1796	S	SF	[EA]		MOUT COLLECTIVE (LARGE)	Y	A MOUT COLLECTIVE TRAINING FACILITY (LARGE) IS DESIGNED TO MEET THE TRAINING REQUIREMENTS OF AN INFANTRY BATTALION-SIZED UNIT IN AN URBAN ENVIRONMENT. THIS STRUCTURE CONTAINS MORE THAN 24 BUILDINGS AND IS USED TO TRAIN UNIT COLLECTIVE TASKS ASSOCIATED WITH URBAN TERRAIN.
17970	1790	S		[EA]		RADAR BOMB SCORING RANGE	N	A RADAR BOMB SCORING FACILITY (RBS) IS USED TO MEASURE, ELECTRONICALLY, AIRCRAFT SIMULATED-BOMBING RESULTS AND TO PRODUCE GRAPHIC FLIGHT PATH TRACKING DATA AND OTHER PERTINENT AIRCRAFT TARGET SCORING INFORMATION.
17971	1790	S		[EA]		ELECTRONIC WAR TRNG RNGE	N	TRAINING RANGE FOR USING REMOTE CONTROLLED EQUIPMENT SUCH AS ROBOTS FOR EOD TRAINING.
17972	1790	S		[EA]		UNDWTR TRACKG/TRNG RNGE	Y	THE UNDERWATER TRACKING RANGE IS USED TO SUPPORT SURFACE AND SUBSURFACE WEAPON SYSTEM ACCURACY TRIALS AND DEVELOPMENT, TEST, AND EVALUATION PROJECTS. PLANNING FACTORS, STANDARDS, AND GUIDES FOR COMPUTING REQUIREMENTS FOR FACILITIES UNDER THIS CATEGORY ARE EXCLUDED FROM THIS PUB BECAUSE OF THE SPECIAL PROVISIONS AND VARIANCES IN THE APPLICATION OF CRITERIA FOR PLANNING UNDERWATER TRACKING RANGES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
17981	1798	S	AC	[EA]	FP	INFILTRATION COURSE	Y	AN INFILTRATION COURSE IS DESIGNED FOR TRAINING INDIVIDUAL INFILTRATION AND COMBAT MOVEMENT TECHNIQUES AND THEN EXECUTING THEM WHILE SUBJECT TO LIVE FIRE.
17991	1799	S	AC	[EA]		CONFIDENCE COURSE	Y	A CONFIDENCE COURSE IS DESIGNED FOR DEVELOPING INDIVIDUAL SOLDIER CONFIDENCE AND STRENGTH THROUGH A SERIES OF OBSTACLES. NO AUTOMATION IS REQUIRED FOR THIS FACILITY.
17992	1799	S	AC	[EA]		OBSTACLE COURSE	Y	AN OBSTACLE COURSE IS A FACILITY CONTAINING NUMEROUS OBSTACLES DESIGNED FOR DEVELOPING AND MEASURING INDIVIDUAL SOLDIER SPEED, AGILITY, AND COORDINATION UTILIZING VARIOUS OBSTACLES IN AN EFFORT TO REACH THE OBJECTIVE.
200						MAINT AND PRODUCTION FAC		
210						MAINTENANCE FACILITIES		
211						MAINTENANCE-AIRCRAFT		

Facilities for the maintenance and repair of Navy and Marine Corps aircraft and related spares, including airframes, aircraft engines, aircraft weapons systems, avionics systems, and other related aircraft equipment.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21101	2114	B	[SF]	EA		AIRCRAFT ENGINE TEST BLDG	Y	A BUILDING OR UTILIZATION IN A BUILDING USED AS AN ENGINE TEST CELL FOR EITHER IN-FRAME OR OUT-OF-FRAME ENGINE TESTING. SOMETIMES REFERRED TO AS A "HUSH HOUSE."
21103	2113	B	[SF]			CORROSION CONTROL HANGAR	Y	THIS HANGAR PROVIDES SPACE FOR WASHING, RINSING, PAINT STRIPPING, CORROSION REMOVAL, PROTECTIVE COATING AND PAINTING OF AIRCRAFT AT THE INTERMEDIATE AND ORGANIZATIONAL MAINTENANCE LEVELS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21104	2111	B	[SF]			PRE-ENGIN MAINTENCE HANGAR	Y	THIS PRE-ENGINEERED MAINTENANCE HANGAR PROVIDES A FACILITY FOR AN ORGANIZATIONAL LEVEL MAINTENANCE OF NAVY AND MARINE CORPS AIRCRAFT. ITS INTENDED USE IS PRIMARILY AT OVERSEAS LOCATIONS FOR THE SUPPORT OF A DETACHMENT SIZE UNIT OF FROM THREE TO FIVE AIRCRAFT.
21105	2111	B	[SF]			MAINT HANGAR-O/H SPACE	Y	MAINTENANCE HANGARS ARE REQUIRED TO PROVIDE WEATHER-PROTECTED SHELTER FOR THE SERVICING AND REPAIR OF NAVY AND MARINE CORPS AIRCRAFT AT THE ORGANIZATIONAL LEVEL AND EMERGENCY SHELTER FOR OPERABLE AIRCRAFT.
21106	2112	B	[SF]			MAINT HANGAR-01 SPACE	Y	(01) IN ADDITION TO PROVIDING A WEATHER-PROTECTED SHELTER FOR THE SERVICING AND REPAIR OF NAVY AND MARINE CORPS AIRCRAFT AT THE ORGANIZATIONAL LEVEL AND EMERGENCY SHELTER FOR OPERABLE AIRCRAFT, IT ALSO CONTAINS SPACE FOR CREW AND EQUIPMENT.
21107	6100	B	[SF]			MAINT HANGAR-02 SPACE	Y	(02) IN ADDITION TO PROVIDING A WEATHER-PROTECTED SHELTER FOR THE SERVICING AND REPAIR OF NAVY AND MARINE CORPS AIRCRAFT AT THE ORGANIZATIONAL LEVEL AND EMERGENCY SHELTER FOR OPERABLE AIRCRAFT, IT ALSO CONTAINS ADMINISTRATIVE SPACE.
21108	2112	B	[SF]			AIRFRAMES SHOP (NON-DEPOT)	Y	AN INTERMEDIATE MAINTENANCE LEVEL IS REQUIRED AT NAVY AND MARINE CORPS AIR INSTALLATIONS FOR THE TESTING, MAINTENANCE AND REPAIR OF AIRFRAMES COMPONENTS. THIS SECTION PROVIDES THE METHOD FOR DETERMINING THE SPACE REQUIREMENTS FOR THIS DIVISION. THE PRIMARY FUNCTION OF THE AIRFRAMES SHOP IS TO REPAIR AIRCRAFT BOTH STRUCTURAL AND HYDRAULIC.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21109	1791	S		[EA]		AIRCRAFT BORESIGHT RANGE	Y	ONE AIRCRAFT BORESIGHT RANGE IS REQUIRED AT NAVY AND MARINE CORPS AIR INSTALLATIONS THAT SERVICE AIRCRAFT EQUIPPED WITH FIXED GUNS OR GUN PODS. A TAXIWAY, CATEGORY CODE 112 10 IS REQUIRED FOR ACCESS TO THIS FACILITY. AN AIRCRAFT PARKING APRON WITH TIE-DOWNS, CATEGORY CODE 113 20 IS REQUIRED TO PARK AND SECURE THE AIRCRAFT DURING GUN ALIGNMENT.
21110	2116	B	[SF]			A/C OVERHAUL & REPAIR SHOP	Y	AN AIRCRAFT OVERHAUL AND REPAIR SHOP IS REQUIRED FOR THE AIRFRAME PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). THERE ARE GENERALLY TWO TYPES OF AIRCRAFT OVERHAUL AND REPAIR SHOPS. ONE SUPPORTS AIRCRAFT OVERHAUL AND REPAIR OF TRAINER AIRCRAFT, FIGHTER AIRCRAFT, AND HELICOPTERS AND ONE SUPPORTS AIRCRAFT OVERHAUL AND REPAIR OF CARGO, TRANSPORT, AND PATROL AIRCRAFT.
21111	2116	B	[SF]			COROSION CONTRL-CLEAN SHOP	Y	THIS SHOP IS REQUIRED TO PROVIDE SPACE FOR AIRCRAFT CORROSION CONTROL AND DECONTAMINATION FACILITIES DESIGNED FOR CLEANING, PAINT STRIPPING, ETC., OF THE COMPLETE AIRCRAFT FOR THE AIRFRAME PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT).
21112	2116	B	[SF]			PAINT & FINISHING HANGAR	Y	THIS HANGER IS REQUIRED FOR THE AIRFRAME PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). THIS FACILITY PROVIDES SPACE TO REPAINT AN ENTIRE AIRCRAFT.
21113	2116	B	[SF]			A/C NON-DESTRUCT TEST SHP	Y	THIS SHOP IS REQUIRED TO PROVIDE SPACE FOR THE NON-DESTRUCTIVE INSPECTION OF AIRFRAMES FOR THE AIRFRAME PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT).

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21114	2116	B	[SF]			AIRCRAFT REWORK SHOP	Y	THIS IS THE AIRFRAME PRODUCTION SHOP OF THE NAVAL AIR DEPOT, WHICH INCLUDES AN AIRFRAME DEDICATED MACHINE SHOP, WELDING SHOP, PLATING SHOP, EXAMINATION AND EVALUATION, PRE-SHOP ANALYSIS, EXAMINATION AND INSPECTION SHOP, MAINTENANCE DOCK, QUICK ENGINE CHANGE SHOP ¿ (USED FOR QUICK ENGINE CHANGE AND ENGINE BUILD-UP INCLUDING DIESEL AND RESEAL OPERATIONS AND FUEL SYSTEMS MAINTENANCE FACILITIES).
21115	2112	B	[SF]			LINE MAINTENANCE SHELTER	N	LINE MAINTENANCE SHELTERS ARE REQUIRED IN SUPPORT OF AIRCRAFT LOCATED ON AIRCRAFT PARKING APRONS AND AT AIRCRAFT BORESIGHT RANGES (CATEGORY CODE 21109).
21116	2116	B	[SF]			AC INTERM MAINT MGMT	Y	FACILITY FOR THE CONTROL, MONITORING, AND ADMINISTRATION OF THE INTERMEDIATE MAINTENANCE ACTIVITY (IMA). IT INCLUDES ADMINISTRATION AND SUPERVISION OF THE MAINTENANCE; PRODUCTION, QUALITY, AND MATERIAL CONTROL, FINANCIAL ACCOUNTING, TRAINING, PERSONNEL, ADMINISTRATION, TECHNICAL PUBLICATIONS LIBRARY, DATA ANALYSIS, AND TOOL CONTROL FOR COMMON AND SPECIAL TOOLS AND TEST EQUIPMENT.
21117	2116	B	[SF]			REG AC SERVICE FAC	Y	FACILITY PROVIDES SPACE TO PERFORM AIRCRAFT IN-SERVICE REPAIR (ISR), INTEGRATED MAINTENANCE (IMC/IMP), MODIFICATIONS (MOD) AND OTHER PROGRAM WORK THAT MAY CONCURRENTLY INVOLVE DEPOT, INTERMEDIATE, AND ORGANIZATIONAL LEVEL WORK ON AIRCRAFT BY SQUADRON, IMA, NAVAL AIR DEPOT (NAVAIR DEPOT), AND/OR CONTRACTOR PERSONNEL.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21120	2116	B	[SF]			A/C ENGINE OVERHAUL SHOP	Y	PROVIDES SPACE ASSOCIATED WITH PROCESSING JET, TURBOJET, AND RECIPROCATING TYPE AVIATION ENGINES IN TERMS OF OVERHAUL, LOW TIME REPAIR, COMPLETE REPAIR, AND MAJOR INSPECTION. THE WORK FUNCTIONS PERFORMED WITHIN THIS SPACE INCLUDE UNCANNING, DISASSEMBLY, CLEANING, MATERIAL EXAMINATION, PARTS RECONDITIONING, SUBASSEMBLY, FINAL ASSEMBLY AND PRESERVATION.
21121	2112	B	[SF]			ENGINE MAINTENANCE SHOP	Y	PROVIDES SPACE FOR ALL WORK CENTERS WITHIN THE POWER PLANTS DIVISION OF AN INTERMEDIATE LEVEL MAINTENANCE ACTIVITY (IMA).
21122	2116	B	[SF]			ENGINE PREPARATON & STORGE	Y	PROVIDES SPACE USED IN PREPARING ENGINES FOR TEST, STORAGE OR SHIPMENT FOR THE ENGINE PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT).
21123	2116	B	[SF]			ENGINE EXAM & EVALUATON SH	Y	ENGINE EXAMINATION AND EVALUATION SHOP OF THE NAVAL AIR DEPOT OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: ENGINE NON-DESTRUCTIVE TESTING SHOP; AND ENGINE EXAMINATION AND EVALUATION, PRE-SHOP ANALYSIS, EXAMINATION AND INSPECTION SHOP.
21124	2116	B	[SF]			DED A/C ENG OH	Y	DEDICATED AIRCRAFT ENGINE OVERHAUL ¿ GENERAL PROCESS SHOP TO SUPPORT THE ENGINE PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: ENGINE DEDICATED CLEANING SHOP; ENGINE DEDICATED PAINT SHOP; ENGINE DEDICATED MACHINE SHOP; ENGINE DEDICATED PLATING SHOP; ENGINE DEDICATED WELDING SHOP; AND ENGINE DEDICATED MODIFICATION AND REPAIR SHOP.
21125	2116	B	[SF]			JET ENGINE OVERHAUL SHOP	Y	JET ENGINE OVERHAUL SHOP SUPPORTS THE ENGINE PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT).

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21126	2116	B	[SF]			RECIPROCAT ENGINE OVERHAUL	Y	RECIPROCATING ENGINE OVERHAUL SHOP SUPPORTS THE ENGINE PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT).
21127	2116	B	[SF]			TURBINE ENGINE OVERHAUL SH	Y	TURBINE ENGINE OVERHAUL SHOP SUPPORTS THE ENGINE PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT).
21130	2116	B	[SF]			A/C & ENGINE ACCES OVERHAL	Y	PROVIDES SPACE FOR THE OVERHAUL AND TESTING OF MISCELLANEOUS ACCESSORIES SUCH AS CONTROL ASSEMBLIES, ENGINE FUEL SYSTEM COMPONENTS, AND ACCESSORIES GEAR DRIVE FOR THE ACCESSORIES AND COMPONENTS PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT).
21131	2116	B	[SF]			DED A/C & ENG AC OH GEN PR	Y	DEDICATED AIRCRAFT AND ENGINE ACCESSORIES OVERHAUL SHOP INCLUDES THE FOLLOWING DEDICATED SHOPS: CLEANING, PAINT, MACHINE, PLATING, WELDING, EXAMINATION AND EVALUATION, PRE-SHOP ANALYSIS, EXAMINATION AND INSPECTION, HAZARDOUS TEST SHOP.
21132	2116	B	[SF]			METAL COMPONENTS SHOP	Y	ACCESSORIES AND COMPONENTS PRODUCTION SHOP OF THE NAVAIR DEPOT INCLUDES THE FOLLOWING SHOPS: TANK AND RADIATOR REPAIR; SHEET METAL; METAL SURFACE; SEAT REPAIR, METAL BONDING, AND CONTAINER RECLAMATION.
21133	2116	B	[SF]			NON-METAL COMPONENTS SHOP	Y	NON-METALS COMPONENTS SHOP OF THE NAVAIR DEPOT INCLUDES THE FOLLOWING SHOPS: LIFE RAFT REPAIR; RUBBER REPAIR SHOP; PARACHUTE REPAIR SHOP; FABRIC AND UPHOLSTERY SHOP; TIRE REPAIR SHOP; PLASTIC AND FIBERGLASS SHOP; AND COMPOSITE REWORK SHOP.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21134	2116	B	[SF]			DYNAMIC COMPONENTS SHOP	Y	ACCESSORIES AND COMPONENTS PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NADEP). INCLUDED WITHIN THIS CATEGORY CODE ARE: PROPELLER AND PROPELLER CONTROL OVERHAUL SHOP; ROTOR HEAD OVERHAUL SHOP; ROTOR BLADE OVERHAUL SHOP; TRANSMISSION/GEARBOX OVERHAUL SHOP; AND DYNAMIC DRIVE SYSTEM OVERHAUL SHOP.
21135	2116	B	[SF]			HYDRAULIC COMPONENTS SHOP	Y	HYDRAULIC COMPONENTS SHOP OF THE NAVAIR DEPOT. INCLUDED WITHIN THIS CATEGORY CODE ARE: HYDRAULIC COMPONENTS OVERHAUL SHOP; BEARINGS SHOP; AND AIRCRAFT LANDING GEAR SHOP.
21136	2116	B	[SF]			ELECTRICAL COMPONENTS SHOP	Y	ELECTRICAL COMPONENTS SHOP OF THE NAVAIR DEPOT. INCLUDED WITHIN THIS CATEGORY CODE ARE: ALTERNATOR DRIVE OVERHAUL SHOP; ELECTRICAL ACCESSORIES OVERHAUL AND TEST SHOP; BATTERY SHOP; CONSTANT SPEED DRIVE SHOP; AND ELECTRO-MECHANICAL COMPONENTS SHOP.
21137	2116	B	[SF]			TURBINE ACCESSORIES SHOP	Y	TURBINE ACCESSORIES SHOP OF THE NAVAIR DEPOT. INCLUDED WITHIN THIS CATEGORY CODE ARE: TURBINE ACCESSORIES OVERHAUL SHOP; TURBINE ACCESSORIES TEST SHOP; GENERAL PURPOSE UNITS SHOP; GENERAL PURPOSE UNITS TESTS SHOP; RAM/AIR TURBINE ACCESSORIES OVERHAUL SHOP; AND RAM/AIR TURBINE ACCESSORIES TEST SHOP.
21138	2116	B	[SF]			PNEUMATIC OXYGEN SHOP	Y	PNEUMATIC OXYGEN SHOP SUPPORTS THE ACCESSORIES AND COMPONENTS PRODUCTION SHOP OF THE NAVAIR DEPOT. INCLUDED WITHIN THIS CATEGORY CODE ARE: PNEUMATIC COMPONENTS OVERHAUL SHOP; CRYOGENICS SHOP; AND OXYGEN EQUIPMENT SHOP.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21139	2116	B	[SF]			OPTICAL & PHOTOGRAPHIC COM	Y	OPTICAL AND PHOTOGRAPHIC COMPONENTS SHOP SUPPORTS THE ACCESSORIES AND COMPONENTS PRODUCTION SHOP OF THE (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: PHOTOGRAPHIC EQUIPMENT REPAIR SHOP AND OPTICAL COMPONENT REPAIR SHOP.
21140	2116	B	[SF]			ELECTRON,COMM & ARM SYS SH	Y	A SHOP THAT PROVIDES SPACE ASSOCIATED WITH PROCESSING AIRBORNE COMMUNICATION AND NAVIGATION EQUIPMENT, INSTRUMENTS, AIRBORNE DATA COMPUTERS, FIRE CONTROL AND BOMBING SYSTEM EQUIPMENT, GYROSCOPES, INERTIAL GUIDANCE SYSTEMS, AND OTHER AVIONICS EQUIPMENT.
21141	2116	B	[SF]			DED ELEC,COM & ARM GEN PRO	Y	SPECIALIZED SHOP THAT SUPPORTS THE ELECTRONIC, COMMUNICATION, AND ARMAMENT SYSTEMS PRODUCTION SHOP OF THE NAVAIR DEPOT. INCLUDED WITHIN THIS CATEGORY CODE ARE ELECTRONICS, COMMUNICATION, AND ARMAMENT SYSTEMS DEDICATED: CLEANING SHOP; PAINT SHOP; MACHINE SHOP; WELDING SHOP; PLATING SHOP; BEARINGS SHOP; AND INSTRUMENT OVERHAUL SHOP.
21142	2116	B	[SF]			ELECTRONIC SYS COMPONENTS	Y	SPECIALIZED SHOP THAT SUPPORTS ELECTRONIC, COMMUNICATION, AND ARMAMENT SYSTEMS PRODUCTION SHOP OF THE NAVAIR DEPOT. INCLUDED WITHIN THIS CATEGORY CODE ARE: ARMAMENT AND AVIONICS SHOP; AIRBORNE SYSTEMS SOFTWARE SHOP; NAVIGATIONAL AIDS REPAIR SHOP; AND AVIONICS TESTING SHOP.
21143	2116	B	[SF]			INERTIAL QUAL INSTRU OH SH	Y	INERTIAL QUALITY INSTRUMENT OVERHAUL SHOP OF THE NAVAIR DEPOT. INCLUDED WITHIN THIS CATEGORY CODE ARE: INERTIAL QUALITY GYROSCOPE OVERHAUL SHOP AND INERTIAL GUIDANCE SYSTEM OVERHAUL AND CALIBRATION SHOP.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21144	2116	B	[SF]			NON-INERTIAL QUAL INSTR OH	Y	SPECIALIZED SHOP THAT SUPPORTS THE ELECTRONIC, COMMUNICATION, AND ARMAMENT SYSTEMS PRODUCTION SHOP OF THE NAVAIR DEPOT. INCLUDED WITHIN THIS CATEGORY CODE ARE: ELECTRONIC INSTRUMENT OVERHAUL SHOP; MECHANICAL INSTRUMENT OVERHAUL SHOP; NON-INERTIAL GYROSCOPE OVERHAUL SHOP; AND MAGNETIC INSTRUMENT OVERHAUL AND TEST SHOP.
21145	2112	B	[SF]			AVIONICS SHOP (NON-DEPOT)	Y	AVIONICS DIVISION INTERMEDIATE MAINTENANCE LEVEL SHOP IS USED FOR THE TESTING, MAINTENANCE AND REPAIR OF AVIONICS SYSTEMS. IT UTILIZES STANDARD SIZE WORK CENTERS, VARIABLE SIZE WORK CENTERS AND SUPPORT SPACES.
21150	2116	B	[SF]			A/C ARMAMENT/MISILE REWORK	Y	AIRCRAFT ARMAMENT/MISSILE REWORK SHOP IS REQUIRED TO PROVIDE SPACE ASSOCIATED WITH PROCESSING AIRCRAFT WEAPONS INCLUDING GUNS, MISSILES, BOMB RACKS, WEAPON PYLONS, ETC.
21151	2116	B	[SF]			DED A/C ARM/MISSL GEN PURP	Y	A DEDICATED AIRCRAFT ARMAMENT/MISSILE REWORK ¿ GENERAL PURPOSE SHOP SUPPORTS THE ARMAMENT PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE ARMAMENT DEDICATED: CLEANING SHOP; PAINT SHOP; MACHINE SHOP; WELDING SHOP; PLATING SHOP; WEAPON OVERHAUL AND TEST SHOP; ORDNANCE EQUIPMENT SHOP; AND WEAPON ACCESSORIES REPAIR SHOP.
21152	2116	B	[SF]			A/C WEAPON OVERHAUL & TEST	Y	A SHOP IS REQUIRED TO PROVIDE SPACE FOR THE REPAIR OF AIR LAUNCHED MISSILES FOR THE ARMAMENT PRODUCTION SHOP OF THE NAVAIR DEPOT. INCLUDED WITHIN THIS CATEGORY CODE ARE: AIRCRAFT WEAPON OVERHAUL AND TEST SHOP; ORDNANCE EQUIPMENT SHOP; AND WEAPON ACCESSORIES REPAIR SHOP.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21153	2116	B	[SF]			AIR LAUNCHED MISSILE REWRK	Y	AIR LAUNCHED MISSILE REWORK SHOP IS REQUIRED TO PROVIDE SPACE FOR THE REPAIR OF AIR LAUNCHED MISSILES FOR THE ARMAMENT PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT).
21154	2112	B	[SF]			AVIATION ARMAMENT SHOP	Y	INTERMEDIATE MAINTENANCE LEVEL SHOP USED TO SUPPORT AIRCRAFT CAPABLE OF BEING ARMED. ALTHOUGH MISSILES AND ROCKETS ARE HANDLED AT THE MISSILE MAINTENANCE SHOP OR ROCKET ASSEMBLY AND LOADING AREAS, MAINTENANCE OF REUSABLE OR NON-EXPENDABLE TYPE ROCKET LAUNCHERS CLASSIFIED AS AMMUNITION ITEMS AND MAINTENANCE AND STORAGE OF MISSILE LAUNCHERS ARE HANDLED IN THE ARMAMENT SHOP.
21155	4412	S	[SF]			AVIATION ARM EQUIP SHED	N	FOR MARINE CORPS ACTIVITIES, AN AVIATION ARMAMENT SUPPORT EQUIPMENT HOLDING SHED IS PLANNED IN CONJUNCTION WITH THE CATEGORY CODE 211 54. THE SHED PROVIDES COVER FOR WEAPONS TRAILERS, BOMB CRADLES, SHORT AIRFIELD AND TACTICAL SUPPORT (SATS) TENTS, AND OTHER ARMAMENT SUPPORT EQUIPMENT AND IS AN INTEGRAL PART OF MARINE CORPS HEADQUARTERS AND MAINTENANCE SQUADRONS¿ ORDNANCE DIVISIONS
21160	2116	B	[SF]			SUPPORT EQUIP REWORK SHOP	Y	A SUPPORT EQUIPMENT REWORK SHOP IS REQUIRED TO PROVIDE SPACE ASSOCIATED WITH PROCESSING AVIATION GENERAL AND SPECIAL SUPPORT EQUIPMENT AND AEROSPACE GROUND SUPPORT EQUIPMENT.
21161	2116	B	[SF]			DED SUP EQUIP REWRK GEN PR	Y	SPECIALIZED SHOP USED TO SUPPORT THE SUPPORT EQUIPMENT PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE SUPPORT EQUIPMENT DEDICATED: CLEANING SHOP; PAINT SHOP; MACHINE SHOP; PLATING SHOP; AND WELDING SHOP.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21162	2116	B	[SF]			SUPPORT EQUIP CALIBRATION	Y	SPECIALIZED SHOP USED TO SUPPORT THE SUPPORT EQUIPMENT PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: AERONAUTICAL ELECTRONIC SUPPORT EQUIPMENT SHOP; ELECTRONIC TEST SYSTEMS REPAIR SHOP; AND PRECISION MEASUREMENT EQUIPMENT SHOP .
21163	2116	B	[SF]			GROUND SUPPORT EQUIP REWK	Y	A GROUND SUPPORT EQUIPMENT REWORK SHOP IS REQUIRED FOR THE SUPPORT EQUIPMENT PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: GSE MAINTENANCE SHOP, TRAINING DEVICES SHOP, HYDROSTATICS SHOP. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21164	2116	B	[SF]			GROUND SUP EQUIP HOLD SHED	Y	A GROUND SUPPORT EQUIPMENT HOLDING SHED IS REQUIRED FOR THE SUPPORT EQUIPMENT PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21165	2112	B	[SF]			WEAPONS EQUIPMENT SHOP	Y	AN AIRBORNE WEAPONS SUPPORT EQUIPMENT SHOP IS REQUIRED FOR THE SUPPORT EQUIPMENT PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21170	2116	B	[SF]			MANUFACTUING & REPAIR SHOP	Y	A MANUFACTURING AND REPAIR SHOP IS REQUIRED TO PROVIDE SPACE FOR AIRCRAFT REPAIR OPERATIONS BY SUCH WORK FUNCTIONS AS PARTS CLEANING AND PAINTING, PLATING AND METAL PROCESSING SHOP. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21171	2116	B	[SF]			DED MANUF & REPR GEN PURP	Y	A MANUFACTURING AND REPAIR - GENERAL PURPOSE SHOP IS REQUIRED FOR THE MANUFACTURE AND REPAIR PRODUCTION SHOP (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: WELDING SHOP, FOUNDRY SHOP, PEENING AND BLASTING SHOP, NON-DESTRUCTIVE INSPECTION ¿ MAGNETIC PARTICLE, DYE PENETRANT, ETC, PARTS CLEANING SHOP, PARTS PAINTING SHOP, THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21172	2116	B	[SF]			METAL FABRICATION/MANUFACT	Y	A METAL FABRICATION/MANUFACTURING SHOP IS REQUIRED FOR THE MANUFACTURE AND REPAIR PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: MACHINE SHOP, GRINDING SHOP, NC MACHINE SHOP, METAL PARTS FABRICATION SHOP. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21173	2116	B	[SF]			METAL TREATMENT SHOP	Y	A METAL TREATMENT SHOP IS REQUIRED FOR THE MANUFACTURE AND REPAIR PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: METAL PROCESSING SHOP, PLATING SHOP, HEAT TREATING SHOP. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21174	2116	B	[SF]			NON-METAL FABRICA/MANUF SH	Y	A NON-METAL FABRICATION/MANUFACTURING SHOP IS REQUIRED FOR THE MANUFACTURE AND REPAIR PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: PLASTIC FABRICATION SHOP, PATTERN SHOP, DECAL (GRAPHIC ARTS) SHOP, WOODWORKING SHOP, RUBBER FABRICATION SHOP. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21175	2184	B	[SF]			PARACHUTE & SURVL EQUIPT	Y	AN AVIATION LIFE SUPPORT SYSTEMS SHOP IS REQUIRED AT NAVY AND MARINE CORPS AIR INSTALLATIONS FOR INSPECTING, REPAIRING, AND REPACKING OF PARACHUTES, FLOTATION DEVICES, OXYGEN AND OTHER LIFE SUPPORT EQUIPMENT.
21176	2116	B	[SF]			MISC PARTS/COMPNT REPR	Y	A MISCELLANEOUS PARTS/COMPONENTS REPAIR SHOP IS REQUIRED FOR THE MANUFACTURE AND REPAIR PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). INCLUDED WITHIN THIS CATEGORY CODE ARE: TUBING SHOP, CABLE SHOP, CORDAGE (FLIGHT CONTROLS) SHOP, ELECTRICAL CABLE/HARNESS SHOP. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21180	2116	B	[SF]			TEST AND CALIBRATION SHOP	Y	A TEST AND CALIBRATION SHOP IS REQUIRED TO PROVIDE SPACE DEDICATED TO TEST, TRIM, OR CALIBRATE ENGINES, ELECTRONICS, COMMUNICATIONS OR ARMAMENT SYSTEMS. THIS IS THE MAIN CATEGORY CODE USED FOR THE TEST AND CALIBRATION PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NADEP). THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21181	2118	S	[SF]	EA		ENGINE TEST CELL	Y	AN ENGINE TEST CELL PROVIDES AN ACOUSTICALLY ATTENUATED AND FULLY INSTRUMENTED ENCLOSURE IN WHICH UNINSTALLED TURBOJET AND TURBOFAN ENGINES ARE TESTED AT INSTALLATIONS WHERE INTERMEDIATE LEVEL MAINTENANCE ENGINE REPAIR WORK IS PERFORMED.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21182	2116	B	[SF]			A/C WEAPONS ALIGNMENT SHEL	Y	A MINIMUM OF ONE AIRCRAFT WEAPONS ALIGNMENT SHELTER IS REQUIRED AT NAVY AND MARINE CORPS AIR INSTALLATIONS HAVING FIGHTER OR ATTACK AIRCRAFT WEAPONS SYSTEMS REQUIRING ALIGNMENT, WHICH IS THE PROCESS OF MECHANICALLY AND ELECTRICALLY ALIGNING AIRCRAFT WEAPONS ELECTRONIC SYSTEMS TO A COMMON AIRCRAFT AXIS.
21183	2118	S	[SF]	EA		ENGINE TEST CELL	Y	AN ENGINE TEST CELL IS REQUIRED FOR THE TEST AND CALIBRATION PRODUCTION SHOP OF THE (NAVAIR DEPOT). INCLUDED WITHIN THIS CATCODE ARE: VARIOUS JET ENGINE TEST CELLS, JET ENGINE TEST STAND, VARIOUS RECIPROCATING ENGINE TEST CELLS, RECIPROCATING ENGINE TEST STAND, AND TURBO SHAFT, TURBO FAN AND PNEUMATIC GAS/AIR TURBINE TEST CELLS. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21184	2116	B	[SF]			HELICOPTER BLADE TEST FAC	Y	A HELICOPTER BLADE TEST FACILITY IS REQUIRED FOR THE TEST AND CALIBRATION PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21185	2116	B	[SF]			RADOME TEST FACILITY	Y	A RADOME TEST FACILITY IS REQUIRED FOR THE TEST AND CALIBRATION PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21186	2116	B	[SF]	EA		RADAR/ANTENNA TEST FAC	Y	A RADAR/ANTENNA TEST FACILITY IS REQUIRED FOR THE TEST AND CALIBRATION PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.

Report Date: 27-JUN-2019 08:33:51

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21187	2116	B	[SF]	EA		A/C WEAPON ALIGN/BORESIGHT	Y	AN AIRCRAFT WEAPONS ALIGNMENT/BORESIGHT FACILITY IS REQUIRED FOR THE TEST AND CALIBRATION PRODUCTION SHOP OF THE NAVAL AIR DEPOT (NAVAIR DEPOT). THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21188	2118	S		[EA]		POWER CK PAD W/ SOUND SUPP	Y	POWER CHECK PADS WITH SOUND SUPPRESSION, ARE PROVIDED WITH FIXED OR PORTABLE SOUND SUPPRESSORS, TO MEET DESIRED NOISE CRITERIA.
21189	2118	S		[EA]		POWER CK PAD W/O SOUND SUP	Y	THE POWER CHECK PAD IS USED TO TEST AND ADJUST ENGINES MOUNTED IN THE AIRCRAFT FOR IN-FRAME TESTING.
21190	2116	B	[SF]			OTHER SUPPORT FACILITIES	Y	THE OTHER SUPPORT FACILITIES ARE THOSE AREAS USED TO PERFORM PRODUCTIVE NAVAIR DEPOT WORK THAT HAVE NOT BEEN PREVIOUSLY IDENTIFIED. THIS INCLUDES RAMP, APRON, AND AIRCRAFT STORAGE SITES. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21191	2118	S	[SF]		EA	UNCOVERED RAMP	Y	UNCOVERED RAMP IS REQUIRED TO PERFORM NAVAIR DEPOT-SPECIFIC MAINTENANCE AND PRODUCTION FUNCTIONS. INCLUDED WITHIN THIS CATEGORY CODE ARE: AIRCRAFT REWORK APRON, RECLAMATION APRON, ARMAMENT AND DISARMAMENT PAD, PREDOCK/POSTDOCK APRON, AIRCRAFT CORROSION CONTROL FACILITY, GROUND CHECK/FLIGHT TEST SUPPORT. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21192	2116	B	[SF]			COVERED GRND CK/FLIHT TEST	Y	A COVERED GROUND CHECK/FLIGHT TEST FACILITY IS REQUIRED FOR THE NAVAL AIR DEPOT (NAVAIR DEPOT).

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21193	2116	B	[SF]			ENGINEERING LABORATORY	Y	AN ENGINEERING LAB IS REQUIRED TO PROVIDE SPACE TO SUPPORT NAVAIR DEPOT-SPECIFIC MAINTENANCE AND PRODUCTION FUNCTIONS. INCLUDED WITHIN THIS CATEGORY CODE ARE: MATERIAL HANDLERS/PARTS EXPEDITERS, MATERIAL CONTROL LABORATORY, STANDARDS LABORATORY, PROGRAMMER¿S ¿ AUTOMATIC TEST EQUIPMENT AND NUMERICAL CONTROLLED MACHINE. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21194	2118	S	[SF]	EA		AIRCRAFT POWER CHECK FAC	Y	AIRCRAFT POWER CHECK FACILITIES ARE REQUIRED TO PERFORM NAVAIR DEPOT-SPECIFIC MAINTENANCE AND PRODUCTION FUNCTIONS. INCLUDED WITHIN THIS CATEGORY CODE ARE: POWER CHECK PADS WITH AND WITHOUT SUPPRESSION, PROPELLOR AIRCRAFT, HELICOPTER AIRCRAFT AND VSTOL AIRCRAFT POWER CHECK PADS.
21195	2116	B	[SF]			MATERIAL & EQUIP STAG/STOR	Y	A MATERIAL AND EQUIPMENT STAGING/STORAGE FACILITY FOR NAVAL AIR DEPOT (NAVAIR DEPOT) IS REQUIRED TO PROVIDE SPACE FOR PACKAGING AND PRESERVATION OF MATERIAL. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21196	2116	B	[SF]			MAINT AC SPARE / STOR	Y	AIRCRAFT PARTS/SPARES STORAGE FACILITY.
21197	2116	B	[SF]			PLANT SERVICES FOR A/C OH	Y	AIRCRAFT OVERHAUL FACILITY IS USED FOR FUNCTIONS SUCH AS MANAGEMENT, SUPERVISION, ENGINEERING, CLERICAL FUNCTIONS, PLANT MAINTENANCE, CENTRAL OR GENERAL STORAGE, QUALITY ASSURANCE, AND MATERIALS TESTING. THIS CATCODE INCLUDES OFFICES, CAFETERIAS, SUPERVISORS¿ WORK SPACE, SHOP PARTS STORAGE AREAS, DISPATCHING FACILITIES, INSPECTION FACILITIES, STAIRWELLS, AUXILIARY EQUIPMENT ROOMS, WALLS, ETC.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21198	2116	B	[SF]	EA	A/C ACOUSTICAL ENCLOSURE	Y	THE AIRCRAFT ACOUSTICAL ENCLOSURE, SOMETIMES REFERRED TO AS A HUSH HOUSE, IS A TOTAL ENCLOSURE FOR FIXED WING AIRCRAFT DESIGNED TO ABATE NOISE DURING IN-FRAME RUN-UP OF JET ENGINES. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.
21199	4413	B	[SF]		HAZARDOUS MATERIAL STORE	Y	A HAZARDOUS MATERIAL STOREHOUSE FOR NAVAL AIR DEPOT (NAVAIR DEPOT) IS REQUIRED TO PROVIDE SPACE FOR THE STORAGE OF HAZARDOUS SUBSTANCES AND MATERIALS. THERE ARE NO SPECIFIC CRITERIA DEVELOPED FOR THIS CATEGORY CODE.

212 MAINT - GUIDED MISSILES

Facilities and shops for maintenance and repair of guided missile systems, ground handling, and launching equipment. Under certain circumstances, the maintenance and storage for these missiles are integrated and the missiles are maintained where they are stored.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21210	2121	B	[SF]		GUIDED MISSILE INTEGRA FAC	Y	THE PURPOSE OF THIS FACILITY IS TO ASSEMBLE NEW-PRODUCTION COMPONENTS OF AIR LAUNCHED GUIDED MISSILES AND PERFORM ANY REQUIRED MAINTENANCE ON FLEET RETURNED ALL-UP-ROUND (AUR) MISSILES OR COMPONENTS.
21220	2123	B	[SF]		MISSILE EQUIP MAINT SHOP	Y	MISSILE EQUIPMENT MAINTENANCE SHOP.
21230	2121	B	[SF]		MISSILE ASSBLY & TEST BLDG	Y	THIS FACILITY IS REQUIRED FOR INTERMEDIATE LEVEL MAINTENANCE OF SURFACE LAUNCHED GUIDED MISSILES.
21240	2124	S		[EA]	MISSILE COMPT SLING TESTER	N	THIS FACILITY IS USED TO TEST THE TENSILE STRENGTH OF ALL FORMS OF WEAPONS HANDLING EQUIPMENT SUCH AS SLINGS, BEAMS, BARS, ETC. IT IS USED IN TESTING DEVELOPMENTAL EQUIPMENT AND THE PERIODIC TESTING OF HANDLING EQUIPMENT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21250	2126	B	[SF]			SUB BAL MISSILE PROCES FAC	Y	THESE FACILITIES ARE REQUIRED TO RECEIVE COMPONENTS; CHECKOUT, ASSEMBLE, REFURBISH, AND REPAIR SUBMARINE LAUNCHED BALLISTIC MISSILES. NO PLANNING FACTORS ARE CURRENTLY AVAILABLE FOR THIS FACILITY.
21277	2121	B	[SF]			MISSILE/SPARE STRG(MISC)	Y	THESE FACILITIES ARE STORAGE FACILITIES FOR MISCELLANEOUS EQUIPMENT OR GOODS RELATED TO GUIDED MISSILES. THERE ARE NO CRITERIA FOR THIS TYPE OF FACILITY.

213 MAINT - SHIPS/SPARES

Facilities for maintenance of vessels of all types. These facilities include graving dry docks, fixed cranes, marine railways, ship repair shops, and amphibian vehicle maintenance shops. For waterfront operational facilities, see Category Group 150. For administrative facilities, see Facility Class 600.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21310	2131	S	[SF]	LF	DS	DRYDOCK	Y	A DRY DOCK IS A LONG NARROW BASIN SITED IN THE FORESHORE OF A HARBOR. ITS ENTRANCE IS CLOSED BY A MOVABLE CAISSON OR BY GATES. THE BASIN IS SO CONSTRUCTED THAT A VESSEL MAY BE PLACED IN IT AND THE WATER REMOVED, ALLOWING THE VESSEL TO SETTLE ON SUPPORTS LOCATED ON THE DOCK FLOOR.
21320	2132	S		[EA]	TN	MARINE RAILWAY	Y	THE FUNCTION OF A MARINE RAILWAY IS TO BRING A VESSEL OUT OF THE WATER FOR THE PURPOSE OF MAKING ALL PARTS AVAILABLE FOR OVERHAUL, AND TO RETURN THE VESSEL TO THE WATER WHEN THE WORK IS FINISHED.
21330	2133	B	[SF]			SHORE INTERMED MAINT FCTY	Y	THIS FACILITY (SIMA) PROVIDES SPACE FOR THE FLEET INTERMEDIATE LEVEL MAINTENANCE OPERATIONS. A SIMA HAS TWO BASIC COMPONENTS: MAINTENANCE SHOPS AND ADMINISTRATION.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21340	2137	S		[EA]	TN	FIXED CRANE STRUCTURES	Y	THE PRINCIPAL TYPES OF FIXED CRANES ARE PILLAR, PILLAR-JIB, AND JIB. THE HAMMERHEAD AND TOWER CRANES ARE ALSO CLASSED AS STATIONARY WHEN MOUNTED ON FIXED TOWERS.
21341	2133	B	[SF]			CENTRAL TOOL SHOP	Y	THE CENTRAL TOOL SHOP IS RESPONSIBLE FOR THE DESIGN, DEVELOPMENT, MANUFACTURE AND MAINTENANCE OF PROTOTYPE AND CONVENTIONAL TOOLING SUCH AS CUTTING MACHINES, DIES, MOLDS, CLEANLINESS PLUGS, CUTTERS, JIGS, FIXTURES, AND SPECIAL TOOLS.
21342	2133	B	[SF]			SHIPFITTING SHOP	Y	THE SHIPFITTING SHOP IS RESPONSIBLE FOR THE BACK-SHOP MODIFICATION, FABRICATION, REPAIR, AND ASSEMBLY OF VARIOUS METAL STRUCTURAL PARTS OF THE SHIP¿S HULL, SUPERSTRUCTURE AND INTERIOR SHIP STRUCTURE BY USING SHIPFITTING EQUIPMENT.
21343	2133	B	[SF]			SHEET METAL SHOP	Y	THE SHEET METAL SHOP IS RESPONSIBLE FOR DEVELOPING, FABRICATING, AND INSTALLING VENTILATION AND AIR CONDITIONING DUCTWORK; WORKSHOP AND STOWAGE FACILITIES, OUTFITTING THE GALLEY, LABEL PLATES, SOME BERTHING, BULKHEAD AND PARTITIONS AND HABITABILITY AND OFFICE SPACE FITTINGS FOR VESSELS.
21344	2133	B	[SF]			FORGE & HEAT TRT SP	Y	THE FORGE AND HEAT TREATING SHOP IS RESPONSIBLE FOR HOT-FORGING, HEAT TREATING, INSPECTING, CLEANING, AND REPAIRING VARIOUS METAL STRUCTURAL PARTS OF A SHIP¿S HULL, SUPERSTRUCTURE, INTERIOR SHIP STRUCTURE, MECHANICAL SYSTEMS, MACHINERY SYSTEMS, ANCHOR CHAIN, AND SHIP¿S PROPELLERS

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21345	2133	B	[SF]			WELDING SHOP	Y	THE WELDING SHOP IS RESPONSIBLE FOR ALL OF THE WELDING, FLAME CUTTING, CARBON ARC GAUGING, AND RELATED PROCESSES REQUIRED BY THE VARIOUS SHOPS OF THE OPERATIONS AND PRODUCTION RESOURCES DEPARTMENTS OF THE SHIPYARD AND THE PUBLIC WORKS CENTER LOCATED AT THE SHIPYARD.
21348	2133	B	[SF]			QUALITY ASSUR OFF	Y	THE QUALITY ASSURANCE OFFICE IS RESPONSIBLE FOR INSPECTION AND TESTS TO DETERMINE COMPLIANCE WITH SPECIFICATIONS, PLANS, ORDERS, DIRECTIVES, AND SOUND SHOP AND MARINE PRACTICES; NON-DESTRUCTIVE TESTING SERVICES; AND TECHNICAL DIRECTION, CONSULTING AND ADVISORY SERVICES ON THOSE PROCESSES, MATERIALS, AND SYSTEMS FOR FABRICATION AND REPAIR TO SHOPS.
21349	2133	B	[SF]			INSIDE MACH SHOP	Y	THE INSIDE MACHINING SHOP IS RESPONSIBLE FOR PERFORMING HORIZONTAL BORING, VERTICAL BORING, PLANING AND HEAVY LATHE WORK IN MANUFACTURING, ALTERING, AND REPAIRING SHIP MACHINERY AND SHIPYARD MANUFACTURED ITEMS.
21350	2133	B	[SF]			OPTICAL SHOP	Y	OPTICAL SHOP.
21351	2133	B	[SF]			WEAPONS SHOP	Y	THE WEAPONS SHOP IS RESPONSIBLE FOR THE REPAIR, OVERHAUL, ALIGNMENT, INSTALLATION, CHECKING OUT, TESTING AND CALIBRATION OF ALL WEAPONS AND INTEGRATED SYSTEMS.
21352	2133	B	[SF]			MARINE MACH SHOP	Y	THE MARINE MACHINING SHOP IS RESPONSIBLE FOR THE INSTALLATION AND TESTING OF ALL MAIN PROPULSION MACHINERY, AUXILIARIES, RUDDERS, SHAFTING, SEA VALVES, DECK MACHINERY, LAUNDRY AND GALLEY EQUIPMENT, ARRESTING GEAR, AND CATAPULTS ON SHIPS UNDERGOING REPAIR AND CONVERSION.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21353	2133	B	[SF]			BOILERMAKING SHOP	Y	THE BOILERMAKING SHOP IS RESPONSIBLE FOR THE REPAIR, CONVERSION, AND BUILDING OF STEAM GENERATING EQUIPMENT USED TO FURNISH STEAM TO MAIN AND AUXILIARY MACHINERY.
21354	2133	B	[SF]			ELECTRICAL SHOP	Y	THE ELECTRICAL SHOP IS RESPONSIBLE FOR ACCOMPLISHING THE INSTALLATION, REPAIR, MAINTENANCE, ALTERATION, TROUBLESHOOTING, AND TEST OF ALL POWER, LIGHTING, AND INTERIOR COMMUNICATION SYSTEMS AND EQUIPMENT ABOARD NAVAL SHIPS AND SUBMARINES;
21355	2133	B	[SF]			PIPEFITTING SHOP	Y	THE PIPEFITTING SHOP IS RESPONSIBLE FOR ACCOMPLISHING THE LAYOUT, FABRICATION, INSTALLATION, DISMANTLING, REPAIR, CLEANING, TESTING, AND INSPECTION OF PIPING SYSTEMS AND GASKETS ON BOTH NUCLEAR AND NON-NUCLEAR SYSTEMS IN THE SHOP AS WELL AS ONBOARD SHIPS AND SUBMARINES;
21356	2133	B	[SF]			WOODWORKING SHOP	Y	THE WOODWORKING SHOP IS RESPONSIBLE FOR ACCOMPLISHING OPERATIONS PERFORMED BY BOAT BUILDERS, WOODCRAFTSMEN, AND SHIPWRIGHTS TO CONSTRUCT AND REPAIR WOODEN AND PLASTIC BOATS, WOODEN PORTABLE BUILDINGS AND SHELTERS, HOLLOW BOOMS, WOODEN TANK, PRACTICE TORPEDOES, AND FLIGHT DECK PANELS; AS WELL AS REPAIR AND MAINTENANCE OF ANY WOOD OR WOOD RELATED ITEMS ABOARD SHIP.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21357	2133	B	[SF]			ELECTRONICS SHOP	Y	THE ELECTRONICS SHOP IS RESPONSIBLE FOR ACCOMPLISHING INSTALLATION, REPAIR, OVERHAUL, MODIFICATION CHECK-OUT, ADJUSTMENT, TEST, AND CALIBRATION OF RADAR, SONAR, COMMUNICATIONS, CRYPTOGRAPHIC DATA PROCESSING, ANTENNAS, NAVIGATION, AND ELECTRONIC COUNTERMEASURE EQUIPMENT AND SYSTEMS ON AND FOR SURFACE SHIPS, SUBMARINES, AND SHORE STATIONS.
21358	2133	B	[SF]			BOAT SHOP	Y	OPERATIONAL BOAT SHOP.
21359	2133	B	[SF]			ABRASIVE BLAST FACILITY	Y	ABRASIVE BLAST FACILITY.
21360	2133	B	[SF]			PAINT & BLASTNG SHP	Y	THE PAINT AND BLASTING SHOP IS RESPONSIBLE FOR SURFACE PREPARATION, INCLUDING ABRASIVE BLASTING, FOR THE APPLICATION OR INSTALLATION OF PROTECTIVE, DECORATIVE, AND FUNCTIONAL PAINTS, COATINGS, FILMS, AND FOR INSTALLATION OF DECK, FLOOR, AND WALL COVERINGS.
21361	2133	B	[SF]			RIGGING SHOP	Y	THE RIGGING SHOP IS RESPONSIBLE FOR OPERATIONS PERFORMED BY RIGGERS, SAILMAKERS, TANK AND COMPONENT CLEANERS, LABORERS, UPHOLSTERERS, FABRIC WORKERS, AND DIVING OPERATIONS REQUIRED FOR REPAIR, OVERHAUL, CONVERSION, AND CONSTRUCTION OF NAVAL VESSELS AND EQUIPMENT.
21362	2133	B	[SF]			SAIL LOFT	Y	SAIL LOFT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21363	2133	B	[SF]			FOUNDRY	Y	THE FOUNDRY IS RESPONSIBLE FOR MANUFACTURING CORES FOR IRON, STEEL, AND NON-FERROUS CASTING IN THE CORE UNIT; PREPARING AND MIXING SAND, PROCESSING AND MAKING MOLDS, STEEL CASTINGS, POURING STEEL FROM FURNACES, MELTING, AND MANUFACTURING STEEL, AND SHAKING OUT STEEL CASTINGS FROM MOLDS AFTER POURING IN THE STEEL FOUNDRY UNIT
21364	2133	B	[SF]			PATTERNMAKING SHOP	Y	THE PATTERNMAKING SHOP IS RESPONSIBLE FOR THE MANUFACTURE, REPAIR, AND ALTERATION OF WOOD PATTERNS REQUIRED TO PRODUCE CASTINGS; MANUFACTURE OF METAL PARTS FOR WOOD AND PLASTIC PATTERNS AND METAL PATTERNS AND MANUFACTURE OF MOCK-UPS FOR PATTERNS.
21365	2136	B	[SF]			NUCLEAR REPAIR SHOP	Y	THE NUCLEAR REPAIR SHOP IS RESPONSIBLE FOR THE REPAIR OF REACTOR PLANT COMPONENTS FOR NUCLEAR SHIPS.
21366	2133	B	[SF]			TEMP SERVICES SHOP	Y	THE TEMPORARY SERVICES SHOP IS RESPONSIBLE FOR ELECTRICAL, PIPING, AND VENTILATION SYSTEMS AS RELATED TO TEMPORARY SERVICES.
21367	2134	B	[SF]			PUMPHOUSE, DRYDOCKS	Y	THE DRY DOCK PUMPHOUSE IS USED TO HOUSE DRY DOCK DEWATERING PUMPS AND ASSOCIATED EQUIPMENT.
21368	2134	B	[SF]			DIVE SHOP	Y	DIVE SHOP
21370	2134	B	[SF]			SHP SVCS SUPT BLDG	Y	A SHIP SERVICES SUPPORT BUILDING IS USED TO PROVIDE OFFICE AND SHOP SPACE IN DIRECT SUPPORT OF MAINTENANCE AND REPAIR WORK FOR SURFACE SHIPS AND SUBMARINES.
21373	2135	S		[EA]		LANDING CRAFT WASH RACK	Y	THE PRIMARY FUNCTION OF THIS FACILITY IS TO WASH DOWN LANDING CRAFT AIR CUSHIONS (LCAC) VEHICLES AFTER EVERY MISSION IN ORDER TO REMOVE SAND AND SALT SPRAY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21375	2134	B	[SF]			AMPHIB VEHICLE MAINT SHOP	Y	THE AMPHIBIAN VEHICLE MAINTENANCE SHOP PROVIDES SPECIAL WORK AREAS FOR PERFORMING ALL ORGANIZATIONAL MAINTENANCE FUNCTIONS ON THE AMPHIBIAN VEHICLES OF THE MARINE CORPS AMPHIBIOUS TRACTOR BATTALION AND IN THE CASE OF THE NAVY, ALL ORGANIZATIONAL AND INTERMEDIATE LEVEL MAINTENANCE ON LANDING CRAFT AIR CUSHION (LCAC) VEHICLES.
21377	4421	B	[SF]			MAINT SHPS/SPRS STRG	Y	STORAGE FACILITIES FOR MISCELLANEOUS EQUIPMENT OR GOODS RELATED TO SHIP MAINTENANCE

214 MAINT - TANK/AUTOMOTIVE

Facilities for maintenance and repair of combat and noncombat motorized vehicles. For weapons, see Category Code series 215; for tracked amphibious vehicles see Category Code series 213; for construction equipment see Category Code series 218.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21410	2141	B	[SF]			COMBAT VEHICLE MAINT SHOP	Y	THIS FACILITY PROVIDES SPECIALIZED WORK AREAS, EQUIPMENT, AND STORAGE FOR OVERHAUL OF COMBAT VEHICLES SUCH AS SELF-PROPELLED GUN CARRIAGES AND TANKS.
21420	2141	B	[SF]			AUTO VEHICLE MAINT NONCOMB	Y	AUTOMOTIVE VEHICLE MAINTENANCE FACILITIES ARE REQUIRED TO PROVIDE COVERED WORK AREAS FOR INSPECTION, MAINTENANCE, AND REPAIR OF ALL TRANSPORTATION EQUIPMENT ASSIGNED TO AN INSTALLATION, AND AS APPLICABLE, ITS SUPPORTED ACTIVITIES.
21430	2141	B	[SF]			REFUELING VEHICLE SHOP	Y	AIRCRAFT REFUELER TRUCKS AND OTHER PORTABLE FUEL DISPENSING EQUIPMENT ARE NOT SERVICED OR REPAIRED IN THE AUTOMOTIVE VEHICLE MAINTENANCE SHOP BECAUSE OF THE EXPLOSIVE HAZARD INVOLVED. ACCORDINGLY, A SEPARATE EXPLOSION PROOF AND FIRE-RESISTANT MAINTENANCE/REPAIR FACILITY IS PROVIDED.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21440	1444	B	[SF]			VEHICLE HOLDG SHED	Y	THIS FACILITY IS A PART OF THE AUTOMOTIVE VEHICLE MAINTENANCE SHOP WITH THE MAIN PURPOSE OF PROVIDING A COVERED AREA FOR HOLDING DEADLINED EQUIPMENT AWAITING REPAIRS.
21451	2141	B	[SF]			AUTO ORGANIZATIONAL SHOP	Y	THIS FACILITY PROVIDES WORK AREAS FOR FLEET MARINE FORCE (FMF) UNITS TO PERFORM MAINTENANCE ON ITEMS OF ORGANIZATIONAL EQUIPMENT.
21453	2141	B	[SF]			FLD MAINT SHOP	Y	THIS FACILITY PROVIDES SPECIALIZED WORK AREAS FOR PERFORMING 3RD AND 4TH ECHELON MAINTENANCE FUNCTIONS ON ITEMS OF TACTICAL EQUIPMENT INVOLVING PRIMARILY ROLLING STOCK ITEMS OF MOTOR TRANSPORT AND ENGINEER EQUIPMENT.
21455	2145	S	SF	[EA]		VEHICLE WASH PLATFORM	N	VEHICLE WASH PLATFORMS EQUIPPED WITH HOSE CONNECTIONS SHOULD BE PROVIDED ON THE BASIS OF ONE VEHICLE WASHING SPACE FOR EACH 50 VEHICLES ASSIGNED TO THE MOTOR POOL.
21456	2145	S	SF	[EA]		GREASE RACK	N	GREASE RACK.

215 MAINT - WEAPONS,SPARES

Facilities for maintenance of small arms, automatic weapons, mortars, artillery guns, launchers, flamethrowers, torpedo tubes, harbor protective nets, and non-electronic equipment. See UFC 4-229-01N for design criteria. For missile maintenance facilities, see Category Group 212.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21510	2152	B	[SF]			SMALL ARMS SHOP	Y	A SMALL ARMS SHOP IS USED TO SUPPORT SMALL ARMS MAINTENANCE AND REPAIR FOR VARIOUS MARINE CORPS ACTIVITIES OR UNITS.
21520	2152	B	[SF]			LIGHT GUN(20MM/5IN) SHOP	Y	LIGHT GUN (20 MM TO 5 IN) SHOP.
21530	2152	B	[SF]			HEAVY-GUN (6/16IN) SHOP	Y	HEAVY GUN (6 IN TO 16 IN) SHOP.
21540	2134	B	[SF]			HARBOR PROTECT NET SHOP	N	HARBOR PROTECTIVE NET SHOP.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21550	2152	B	[SF]			LAUNCHR&PROJCTR MAINT SHOP	Y	LAUNCHER AND PROTECTIVE MAINTENANCE SHOP.
21560	2151	B	[SF]			FLD MAINT SHOP (ORDNANCE)	Y	THIS FIELD MAINTENANCE SHOP PROVIDES SPECIALIZED WORK AREAS FOR PERFORMING 3RD AND 4TH ECHELON MAINTENANCE ON ALL ITEMS OF ORDNANCE EQUIPMENT AUTHORIZED REPAIRED BY THE FORCE SERVICE SUPPORT GROUP (FSSG).

216 MAINT - AMMO/EXPLSV/TOXICS

Facilities for maintenance of ammunition, rockets, bombs, mines, grenades, torpedoes, depth charges, demolition materials, pyrotechnics, missile fuels, and related chemicals.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21605	2162	B	[SF]		PN	CHANGE / RELIEF HOUSE	N	THIS IS A BUILDING, TYPICALLY ASSOCIATED WITH EXPLOSIVES OPERATING BUILDING(S), CONTAINING FACILITIES FOR EMPLOYEES TO CHANGE TO AND FROM WORK CLOTHES.
21610	2162	B	[SF]			AMMO REWORK AND O/H SHOP	Y	OVERHAULING AMMUNITION INCLUDES DETERMINING THE SERVICEABILITY OF THE PRIMARY COMPONENTS OF AN ITEM, AND PERFORMING EXTERIOR MAINTENANCE AS REQUIRED TO RENDER THE ITEM FULLY SERVICEABLE.
21620	2162	B	[SF]			ROCKET REWORK AND O/H SHOP	Y	OVERHAULING ROCKETS INCLUDES DETERMINING THE SERVICEABILITY OF THE PRIMARY COMPONENTS OF AN ITEM, AND PERFORMING EXTERIOR MAINTENANCE AS REQUIRED TO RENDER THE ITEM FULLY SERVICEABLE.
21630	2162	B	[SF]			MINE&DEPTH CHG REWORK SHOP	Y	OVERHAULING MINES AND DEPTH CHARGES INCLUDES DETERMINING THE SERVICEABILITY OF THE PRIMARY COMPONENTS OF AN ITEM, AND PERFORMING EXTERIOR MAINTENANCE AS REQUIRED TO RENDER THE ITEM FULLY SERVICEABLE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21640	2162	B	[SF]			TORPEDO SHOP	Y	TORPEDO SHOP FUNCTIONS INCLUDE, BUT ARE NOT LIMITED TO: PREVENTIVE AND CORRECTIVE MAINTENANCE AS WELLS AS HARDWARE AND OPERATIONAL SOFTWARE UPGRADES ON TORPEDO WARSHOT AND EXERCISE CONFIGURATIONS.
21650	2153	B	[SF]			SPECIAL WEAPONS SHOP	Y	SPECIAL WEAPONS SHOP FUNCTIONS INCLUDE, BUT ARE NOT LIMITED TO, DETERMINING THE SERVICEABILITY OF THE PRIMARY COMPONENTS OF AN ITEM, AND PERFORMING EXTERIOR MAINTENANCE AS REQUIRED TO RENDER THE ITEM FULLY SERVICEABLE.
21655	2161	B	[SF]			AIR/UNDRWTR WPNS SHOP	Y	THE AUW SHOP CONTAINS SPACE AND EQUIPMENT FOR THE STORAGE, TEST, CHECK, ASSEMBLY, AND LIMITED MAINTENANCE OF AIRBORNE TORPEDOES AND OTHER AIRDROP WEAPONS.
21660	2162	B	[SF]			QUALITY EVALUATION LAB	Y	A QUALITY EVALUATION LABORATORY (QEL) SUPPORTS THE QE PROGRAM BY PERFORMING ANALYSIS AND TESTS TO DETERMINE AND MAINTAIN QUALITY ASSURANCE OF AMMUNITION, EXPLOSIVES AND TOXINS.
21677	2162	B	[SF]			AMMO/EXPLSV MAINT STORAGE	Y	STORAGE FACILITIES FOR MISCELLANEOUS EQUIPMENT RELATED TO AMMUNITION/EXPLOSIVES MAINTENANCE FACILITIES

217						MAINT - ELECNX/COMM EQUIP		

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Facilities and shops for maintenance and repair of radio and radar equipment, antennas, radiation aids, sonar equipment, transmission and reception equipment, and guided bombs.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21710	2171	B	[SF]			ELECNX/COMMS MAINT SHOP	Y	ELECTRONICS MAINTENANCE SHOPS PROVIDE FACILITIES FOR MAINTENANCE AND REPAIR OF NON-AIRBORNE EQUIPMENT. IT CONTAINS OFFICE AND SUPPORT SPACES FOR THE EQUIPMENT MAINTENANCE OFFICER (EMO) AND THE EMO STAFF, EQUIPMENT MAINTENANCE AND TRAINING AREAS, AND A SMALL STORAGE AREA FOR PARTS AND SUPPLIES DIRECTLY UNDER THE CONTROL OF THE EMO.
21720	2173	S		[EA]		COLLIMATION TOWER	N	COLLIMATION FACILITIES ARE REQUIRED AT SHIPYARDS FOR ELECTRONIC AND OPTICAL ALIGNMENT OF FIRE CONTROL AND RADAR EQUIPMENT ABOARD SHIPS.
21730	2171	B	[SF]			FLD MAINT SHOP(ELEC/COMMS)	Y	THIS FIELD MAINTENANCE SHOP PROVIDES SPECIALIZED WORK AREAS FOR PERFORMING 3RD AND 4TH ECHELON MAINTENANCE ON ALL ITEMS OF COMMUNICATIONS/ELECTRONICS EQUIPMENT AUTHORIZED REPAIRED BY THE SERVICE BATTALION OF THE MARINE DIVISION AND THE FORCE SERVICE REGIMENT. THE SHOP SPACE INCLUDES ADMINISTRATIVE AND TRAINING AREAS AS WELL AS STORAGE SPACE FOR TOOLS, PARTS, AND MAINTENANCE FLOAT EQUIPMENT.
21740	2173	S		[EA]		ANTENNA TEST RANGE	N	THIS FACILITY IS FOR TESTING ELECTRONIC EQUIPMENT AND COMMUNICATION ANTENNAS AFTER COMPLETION OF MAINTENANCE, REPAIR AND OVERHAUL WORK.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21750	2173	S		[EA]		SENSOR ACCURACY CHECK SITE	Y	THE PRIMARY PURPOSE OF THIS FACILITY IS TO MEASURE THE PERFORMANCE OF SHIPBOARD SENSORS IN AN IN-PORT ENVIRONMENT ON COMPLETION OF OVERHAUL OR DURING NORMAL PORT UPKEEP OF NAVY SHIPS. MAJOR COMPONENTS ARE: MOVEABLE AND PILE MOUNTED TRANSDUCERS, MOORING SYSTEM, SLIP SERVICES, ECHO SOUNDER TEST ARRAY AND A AUTOMATIC SHIP¿S HEAD MEASURING SYSTEM
21777	2171	B	[SF]			ELECTRNCS SPRES/MISC STRG	Y	ELECTRONICS PARTS STORAGE FACILITY.

218 MAINT - MISC MATL & EQUIPT

Facilities for maintaining/repairing equipments/material not coded in the 211 through 217 and the 219 series.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21810	2182	B	[SF]			CONTAINER REPAIR/TEST BLDG	Y	A CONTAINER REPAIR AND TEST FACILITY SERVICES ONLY EMPTY CONTAINERS.
21820	2182	B	[SF]			CONSTR/WT HNDLG EQUIP SHOP	Y	SEPARATE FACILITY FOR THE MAINTENANCE AND REPAIR OF CONSTRUCTION/WEIGHT-HANDLING EQUIPMENT FOR AREAS WHERE COMBINED AUTOMOTIVE, WEIGHT-HANDLING, RAILROAD AND/OR CONSTRUCTION EQUIPMENT MAINTENANCE FACILITIES ARE NOT A PART OF CATEGORY CODE 214 20, AUTOMOTIVE VEHICLE MAINTENANCE SHOP.
21825	2181	B	[SF]			MAR AIR BASE SQDN FAC	Y	MARINE AIR BASE SQUADRON (MABS) FACILITY.
21830	2182	B	[SF]			DRUM RECONDITIONING PLANT	Y	THE DRUM RECONDITIONING PLANT IS USED TYPICALLY FOR THE RECONDITIONING OF 55 GAL DRUMS. PROCESSES INCLUDE: WASHING, DE-DENTING, INTERNAL CHAINING, EXTERNAL WIRE BRUSHING, CHIME ROLLING, TESTING, WELDING, INTERNAL PRESERVATION AND PAINTING.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21835	2182	B	[SF]			CABLE REPAIR HOUSE	Y	CABLE REPAIR FACILITY.
21840	2183	B	[SF]			RAILROAD EQUIPMENT SHOP	Y	THE RAILROAD EQUIPMENT MAINTENANCE FACILITY IS A SPECIAL SHOP TO HOUSE MATERIAL AND EQUIPMENT FOR THE SERVICE AND MAINTENANCE OF RAILROAD LOCOMOTIVES AND LOCOMOTIVE CRANES.
21845	2182	B	[SF]			INSTRUMNT CALIBRATION SHOP	Y	THIS SHOP PERFORMS CALIBRATION, REPAIR, AND CERTIFICATION OF ALL MEASUREMENT INSTRUMENTS ASSIGNED TO AN ACTIVITY. SPACES WITHIN INCLUDE: CALIBRATION LAB, CLEANING ROOM, UTILITIES ROOM, STORAGE AREA, ADMINISTRATION AREA.
21850	2181	B	[SF]			BATTERY SHOP	Y	A BATTERY SHOP IS REQUIRED TO SERVICE AND CHARGE BATTERIES.
21851	2181	B	[SF]			BATTERY RECHARGING SHOP	Y	THIS CATEGORY CODE IS FOR USE AT ACTIVITIES WHICH HAVE A REQUIREMENT TO RECHARGE BATTERY POWERED EQUIPMENT SUCH AS FORKLIFT TRUCKS USED AT SUPPLY CENTERS.
21860	2181	B	[SF]			GRND SUPPRT EQUIP SHP	Y	THE INTERMEDIATE LEVEL MAINTENANCE OF AIRCRAFT GROUND SUPPORT EQUIPMENT (GSE) IS PERFORMED IN THIS SHOP. GROUND SUPPORT EQUIPMENT, OFTEN REFERRED TO AS YELLOW GEAR, INCLUDES SUCH ITEMS AS TOW TRACTORS, TRUCKS, FORK LIFTS, TRAILERS, COMPRESSORS, POWER GENERATORS, MAINTENANCE STANDS, JACKS AND OTHER GROUND EQUIPMENT WHICH SUPPORT AIRCRAFT OPERATIONS.
21861	2181	B	[SF]			GRND SUPPRT EQUIP HOLDING	Y	THE GROUND SUPPORT EQUIPMENT (GSE) HOLDING SHED PROVIDES PROTECTIVE COVER FOR GSE GEAR AWAITING AND UNDERGOING INTERMEDIATE LEVEL MAINTENANCE AND IS AN INTEGRAL PART OF THE GSE SHOP COMPOUND.
21862	2182	B	[SF]			SHIPBD ACFT SUPP EQUIP FAC	Y	SHIPBOARD AIRCRAFT SUPPORT EQUIPMENT FACILITY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21865	2182	B	[SF]			EQUIP HOLD SHED FOR 218-20	Y	THIS FACILITY IS REQUIRED IN CONJUNCTION WITH CONSTRUCTION/WEIGHT-HANDLING EQUIPMENT SHOP, CATEGORY CODE 218 20 FOR THE PURPOSE OF PROTECTION OF EQUIPMENT AWAITING REPAIRS.
21868	2182	B	[SF]			PROD EQUIP MAINT SHOP	Y	PRODUCTION EQUIPMENT MAINTENANCE SHOP.
21870	2182	B	[SF]			OFFICE EQUIP/APPL REPAIR	Y	APPROPRIATE FACILITIES MAY BE PROVIDED TO PERFORM MAINTENANCE AND REPAIR OF OFFICE EQUIPMENT AND SMALL APPLIANCES.
21871	2182	B	[SF]			DENTAL EQUIP MAINT BLDG	Y	DENTAL EQUIPMENT MAINTENANCE BUILDING.
21877	2182	B	[SF]			REPAIR SHOP STORAGE	Y	REPAIR SHOP STORAGE FACILITY.
21880	2182	B	[SF]			FLD MAINT SHOP(GENL SUPPL)	Y	THIS FIELD MAINTENANCE SHOP PROVIDES SPECIALIZED WORK AREAS FOR FLEET MARINE FORCE (FMF) UNITS PERFORMING 3RD AND 4TH ECHELON MAINTENANCE ON ALL ITEMS OF GENERAL SUPPLY EQUIPMENT.
21890	2182	B	[SF]			AVIA SUP EQUIP SHOP (NALC)	Y	AVIATION SUPPORT EQUIPMENT SHOP.
21891	2181	B	[SF]			MOBILE VAN SHOP (NALC)	Y	MOBILE VAN SHOP (NALC).
21892	2182	B	[SF]			AVIA SUPT/FEED SHOP (NALC)	Y	AVIATION SUPPORT/FEEDER SHOP (NALC).

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

This basic category includes maintenance shops for repair and overhaul of installation facilities (public works and public utilities), including installed shop and other and other equipment, and utility distribution systems, used in support of maintenance operations at military and/or industrial installations. The maintenance and repair of vehicles and weight-handling and construction equipment, utility plant, and maintenance shops are not included in this category. For the former, see Category Code series¿ 214 and 218, and the latter, see Category Code series 811.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21910	2191	B	[SF]			PUBLIC WORKS SHOP	Y	THIS FACILITY SUPPORTS THE MAINTENANCE DIVISION OF THE PUBLIC WORKS DEPARTMENT. THIS DIVISION IS RESPONSIBLE FOR MANAGEMENT OF THE PREVENTIVE, MAINTENANCE INSPECTION (PMI) PROGRAM AND IS TASKED TO PERFORM MAINTENANCE ON ALL BUILDINGS, UTILITIES PLANTS AND DISTRIBUTION SYSTEMS, HEATING, AIR-CONDITIONING AND REFRIGERATION SYSTEMS, INTERNAL COMMUNICATIONS AND ALARM SYSTEMS AND ROADS AND TRACKAGE.
21920	4422	S	[SF]			PAVMT/GRNDS EQUIP SHED	Y	THE PAVEMENT AND GROUNDS EQUIPMENT SHOP WILL PROVIDE HOLDING SPACE AND MINOR MAINTENANCE SPACE FOR TRACTORS, LAWNMOWERS, SNOWPLOWS, AND OTHER MISCELLANEOUS EQUIPMENT USED FOR ROADS AND GROUND MAINTENANCE.
21925	2191	B	[SF]			PW EXPENDBL/WORK IN PROCES	Y	THE PUBLIC WORKS SHOPS EXPENDABLE/WORK-IN-PROCESS STORE HOLDS THE READY-ISSUE ITEMS FOR PUBLIC WORKS DAILY MAINTENANCE, JOB ORDER MATERIALS FOR THE MAINTENANCE OF STATION FACILITIES AND MATERIALS THAT ARE CONSIDERED CRITICAL ITEMS FOR EMERGENCIES/SERVICE.
21930	2191	B	[SF]			PAINTG & RELTD OPNS BLDG	Y	THE FUNCTION OF THE PAINTING AND RELATED OPERATIONS BUILDING IS TO PROVIDE SPACE FOR PAINTING AND OTHER OPERATIONS WHICH MAY NOT BE FUNCTIONALLY COMPATIBLE OR HAZARDOUS TO THE BUILDING OR TYPES OF OPERATION CONDUCTED IN THE PUBLIC WORKS SHOP, CATEGORY CODE 219 10.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
21931	2192	S		[EA]		PAINTG & RELTD OPNS STRC	N	THE PAINTING AND RELATED OPERATIONS STRUCTURE IS A FACILITY USED FOR PAINTING AND THOSE OPERATIONS WHICH ARE NOT SUITABLE TO BE CARRIED ON IN CATEGORY CODE 219 30, PAINTING AND RELATED OPERATIONS BUILDING. THIS CODE MAY INCLUDE STRUCTURES LIKE A SANDBLAST SCAFFOLD, PAINT SPRAY BOOTH, PRESERVATION DIP TANK, PICKLING TANK, SANDHOPPER, SANDBLASTING FACILITIES, OPEN PAINT CANOPY, SAND HANDLING BIN.
21940	2192	S		[EA]		SEWAGE HOSE STORAGE FAC	Y	SEWAGE HOSE STORAGE FACILITY. FOR INVENTORY PURPOSES ONLY.
21977	2191	B	[SF]			PW MAINTENANCE STORAGE	Y	THIS FACILITY IS A GENERAL WAREHOUSE FOR THE STORAGE OF ITEMS AND MATERIALS REQUIRED FOR THE MAINTENANCE OF STATION BUILDINGS AND GROUNDS.

220 PRODUCTION

The production facility is part of the production system that processes raw materials, components and labor into finished goods.1 Production facilities are typically ¿one-of-a-kind¿ therefore space requirements should be developed ¿from the ground up¿; first for the individual workstations; then departmental requirements by summing the workstations within the department. Applying industrial engineering practices and methods would provide sufficient and accurate space requirements. Accurate future product demand forecasts are necessary so the facility can be sized for future growth. The facility should be sized for forecasted production growth 5 to 10 years beyond initial operating capability.

221 PRODUCTION - AIRCRAFT

Facilities for constructing and assembling new components, air frames and related assemblies and spares, aircraft engines and related spares, and aircraft equipment and spares.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
22110	2211	B	[SF]			ACFT ENGINE ASSEMBLY PLANT	Y	AIRCRAFT ENGINE ASSEMBLY PLANT.
22120	2211	B	[SF]			AIRFRAME ASSEMBLY PLANT	Y	AIRFRAME ASSEMBLY PLANT.
22130	2211	B	[SF]			ACFT ACCESSORY ASSEMBLY	Y	AIRCRAFT ACCESSORIES ASSEMBLY PLANT.

222 PROD - GUIDED MISSILES

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Facilities for constructing and assembling new components, guided missile systems and parts, ground handling and launching equipment.

22210	2221	B	[SF]			MISSILE ASSEMBLY PLANT	Y	MISSILE ASSEMBLY PLANT THAT ACCOMODATES MOTOR FINISHING, PARTS STORAGE, ADMIN, CONTROL HOUSE, SHIPPING, INGREDIENT SCREENING, PROPELLANT STORAGE, TOOL STORAGE, BURNING CAGE, BLENDING, GRINDING, DARKROOM, UTILITY STORAGE ETC.
22220	2221	B	[SF]			MISSILE HANDL LAUNCH EQUIP	Y	MISSILE HANDLING LAUNCH EQUIPMENT PLANT.

223 PRODUCTION - SHIPS, SPARES

Ship-ways, ground ways, graving docks, marine railways, appurtenant shipyard facilities for the construction of vessels of all types, of floating cranes and dry docks, and of tracked amphibious vehicles. Does not include facilities principally for use in ship maintenance and repair which fall in other categories.

22310	2231	B	[SF]			FABRICATION/ASSEMBLY BLDG	Y	FABRICATION AND ASSEMBLY BUILDING THAT ACCOMODATES FABRICATION, PROTOTYPE ASSEMBLY, TECH LAB STORAGE, CONSTRUCTION WOOD SHOP, SAND BLAST FACILITY, TECHNICAL SERVICES, AND PROTOTYPE FABRICATION.
22330	2233	S	SF	[EA]	LF	SHIP BUILDING DRYDOCKS	Y	SHIP-BUILDING DRYDOCKS.

224 PROD - TANK-AUTOMOTIVE

Facilities for constructing and assembling new components, combat vehicles, non-combat vehicles and related components, self-propelled gun carriages, ambulances, and other motorized vehicles. Excludes production facilities for weapons (225 series), tracked amphibious vehicles (223 series), and construction equipment (228 series.)

22410	2241	B	[SF]			COMBAT VEHICL ASSEMBL PLT	Y	COMBAT VEHICLE ASSEMBLY PLANT
22420	2241	B	[SF]			AUTO VEHICL ASSEMBL PLT	Y	AUTOMOTIVE VEHICLE ASSEMBLY PLANT.

225 PROD - WEAPONS/SPARES

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Facilities for constructing and assembling new components, small arms, automatic weapons, mortars, artillery, guns, launchers, projectors (for arming ships, vehicles, and aircraft,) flame throwers, torpedo tubes, harbor protective nets, non-eletronic equipment and related components, Use Basic Category 222 for facilities for producing guided missile equipment.

22510	2251	B	[SF]			SMALL ARMS PLANT	Y	SMALL ARMS PLANT.
22520	2251	B	[SF]			LIGHT GUN (20MM/5IN) PLANT	Y	LIGHT GUN PLANT.
22530	2251	B	[SF]			HEAVY GUN(6/16IN) PLANT	Y	HEAVY GUN PLANT.
22540	2251	B	[SF]			HARBOR PROTECT NET PLANT	Y	HARBOR PROTECTIVE NET PLANT.
22550	2251	B	[SF]			LAUNCHER/PROJECTOR PLANT	Y	LAUNCHER AND PROJECTOR PLANT.
22560	2251	B	[SF]			ARMOR PLATE PLANT	Y	ARMOR PLATE PLANT.

226 PROD - AMMO/EXPLSV/TOXICS

Facilities for constructing and assembling new components, ammunition, rockets, bombs, mines, grenades, torpedoes, depth charges, demolition materials, pyrotechnics, ATO units, guided missile fuels, ammunition parts and related components and chemicals. For facilities for producing guided bombs use Basic category 227; for commercial-type petroleum products use basic category 228.

22610	2261	B	[SF]			BAG CHARGE FILLING PLANT	Y	BAG CHARGE FILLING PLANT.
22615	2261	B	[SF]			CASE FILLING PLANT	Y	CASE FILLING PLANT.
22620	2261	B	[SF]			CASE O/H TANK REPAIR FAC	Y	CASE OVERHAUL TANK REPAIR FACILITY.
22625	2261	B	[SF]			40MM LOADING PLANT	Y	40MM-LOADING PLANT.
22630	2261	B	[SF]			20MM LOADING PLANT	Y	20MM-LOADING PLANT.
22635	2261	B	[SF]			MAJ-CAL PROJECTL LOAD PLT	Y	LARGE CALIBER PROJECTILES LOADING FACILITY.
22640	2261	B	[SF]			MED-CAL PROJECTL LOAD PLT	Y	MEDIUM CALIBER PROJECTILE LOADING FACILITY.
22645	2261	B	[SF]			LARGE CAL ROCKET LOAD PLT	Y	LARGE CALIBER ROCKET MOTOR LOADING PLANT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
22650	2261	B	[SF]			MED CAL ROCKET LOAD PLT	Y	MEDIUM CALIBER ROCKET LOADING PLANT.
22655	2261	B	[SF]			CAST HI EXPLOS FILL PLT	Y	CAST HIGH EXPLOSIVES FILLING PLANT.
22656	2262	S	SF	[EA]		CAST HI EXPLOS FILL FAC	N	CAST HIGH EXPLOSIVES FILLING FACILITY.
22660	2261	B	[SF]			SPECIAL WEAPONS PLANT	Y	SPECIAL WEAPONS PLANT.
22665	2261	B	[SF]			PROPELLANT CHEMICAL PLT	Y	PROPELLANT AND RELATED CHEMICAL PLANT.
22666	2262	S	SF	[EA]		PROPELLANT CHEMICAL FAC	N	PROPELLANT AND RELATED CHEMICAL FACILITY.
22670	2261	B	[SF]			READY AMMO BELTING PLT	Y	READY AMMUNITION BELTING PLANT.
22675	2261	B	[SF]			UNDRWTR DEMO EQUIP PLT	Y	UNDERWATER DEMOLITION EQUIPMENT PLANT.
22680	2261	B	[SF]			AMMUNITION LOADING PLANT	Y	AMMUNITION LOADING PLANT.
22681	2264	B	[SF]			DEMILITARIZATION BUILDING	Y	DEMILITARIZATION BUILDING.
22682	2265	S		[EA]		DEMILITARIZATION FACILITY	N	DEMILITARIZATION FACILITY.
22685	2261	B	[SF]			FUSE ASSEMBLY PLANT	Y	FUZE ASSEMBLY PLANT.
22686	2261	B	[SF]			MINE ASSEMBLY PLANT	Y	MINE ASSEMBLY PLANT.
22688	2261	B	[SF]			PYROTECHNIC PRODUCTION FAC	Y	PYROTECHNIC PRODUCTION FACILITY.

227 PROD - ELECNX/COMM EQUIPT

Facilities for constructing and assembling new components radio and sonar equipment, radiation aids, sonar equipment, transmission and reception equipment, guided bombs and related components.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
22710	2271	B	[SF]			RADIO/RADAR EQUIP PLT	Y	RADIO AND RADAR EQUIPMENT PLANT.
22720	2271	B	[SF]			SONAR EQUIPMENT PLANT	Y	SONAR EQUIPMENT PLANT.
22730	2271	B	[SF]			GUIDANCE EQUIPMENT PLANT	Y	GUIDANCE EQUIPMENT PLANT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
22735	2271	B	[SF]			PRINTED CIRCUIT SHOP	Y	PRINTED CIRCUIT SHOP.
228						PROD - MISC MATL & EQUIPT		
22810	2281	B	[SF]			PARACHUTE/SURVVL EQUIP PLT	Y	PARACHUTE AND SURVIVAL EQUIPMENT SHOP.
22820	2281	B	[SF]			CONSTRUCTION EQUIP PLT	Y	CONSTRUCTION EQUIPMENT PLANT.
22830	2281	B	[SF]			RAILROAD EQUIPMENT PLANT	Y	RAILROAD EQUIPMENT PLANT.
22835	5302	B	[SF]			OPHTHALMIC SUPPORT BUILDIN	Y	OPTHALMIC SUPPORT BUILDING.
229						PROD - DOD MNT,REP & OP		

Plants and facilities for production and processing in support of the maintenance, repair, and operation function at military or industrial installations.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
22910	2291	S		[EA]	TH	ASPHALT PLANT	Y	ASPHALT BATCH PLANT.
22920	2291	S		[EA]	TH	CONCRETE BATCHING PLANT	Y	CONCRETE BATCH PLANT.
22930	2291	S		[EA]	TH	ROCK CRUSHER PLANT	Y	ROCK CRUSHER PLANT.
22950	6103	B	[SF]	EA		PRINTING PLANT	Y	PRINTING PLANT.
22977	2281	B	[SF]			MAINT/PROD STRG (MISC)	Y	MAINTENANCE PRODUCTION STORAGE-READY ISSUE FACILITY.
22980	2281	B	[SF]			CONTAINER ASSEMBLY BLDG	Y	CONTAINER (CONEX) ASSEMBLY BUILDING.
300						RDT&E - FACILITIES		

Research, development, acquisition, test and evaluation facilities include the buildings and other scientific structures and facilities used directly in theoretical and/or applied research, development, acquisition, test and evaluation operations.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
310						SCIENCE LABORATORIES		

Category Code Report (All Series)

Buildings used directly in theoretical or applied research, development and testing operations related to basic research such as chemistry, materials, medical, biological, sonic, physics, geophysics, etc.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31010	6100	B	[SF]			RDAT&E ADMINISTRATIVE OFC	Y	BUILDINGS USED DIRECTLY IN THEORETICAL OR APPLIED RESEARCH, DEVELOPMENT AND TESTING OPERATIONS RELATED TO BASIC RESEARCH SUCH AS CHEMISTRY, MATERIALS, MEDICAL, BIOLOGICAL, SONIC, PHYSICS, GEOPHYSICS, ETC.
31011	3101	B	[SF]			ASTRONOMY/ASTROPHYSICS LAB	Y	A FACILITY REQUIRED TO SUPPORT THE INVESTIGATION OF RADIO ASTRONOMY EQUIPMENT, SATELLITE RESEARCH, AND DEVELOPMENT FOR NAVIGATIONAL AND COMMUNICATION PROGRAMS.
31013	3101	B	[SF]			CHEMISTRY/TOXICOLOGY LAB	Y	THE FACILITY REQUIRED TO SUPPORT THE CONDUCTING OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION IN THE AREAS OF PHYSICAL, ORGANIC, INORGANIC, NUCLEAR, AND BIOLOGICAL CHEMISTRY, DIRECTED TOWARDS PROBLEMS OF FUELS, LUBRICANTS, CORROSION, PROTECTIVE COATINGS, ELECTROCHEMISTRY, SUBMARINE ATMOSPHERE PURIFICATION, PROTECTION AGAINST BIOLOGICAL AND CHEMICAL WARFARE AGENTS, AND RELATED PROGRAMS.
31015	3101	B	[SF]			MATERIALS LABORATORY	Y	THIS FACILITY IS USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF STATIC, PNEUMATIC NON-DESTRUCTIVE AS WELL AS DESTRUCTIVE TESTING OF COMPONENTS AND ASSEMBLIES FOR NAVY WEAPONS, VEHICLES, ENGINES, SHIPS AND AIRCRAFT.
31017	3101	B	[SF]			OPTICS LABORATORY	Y	THIS FACILITY IS USED IN CONDUCTING RESEARCH, DEVELOPMENT, TEST AND EVALUATION PROGRAMS IN QUANTUM OPTICS, OPTICAL PROPAGATION, LASER PHYSICS, OPTICAL MATERIALS AND OPTICAL WARFARE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31019	3101	B	[SF]			PHYSICS LABORATORY	Y	THIS FACILITY IS USED IN RESEARCH, DEVELOPMENT, TEST AND EVALUATION STUDIES IN THE APPLIED SCIENCE OF MATTER AND ENERGY. IT INCLUDES RESEARCH IN SUCH AREAS AS ACOUSTICS, MECHANICS, LIGHT, THERMODYNAMICS, ELECTROMAGNETISM, ATOMIC AND NUCLEAR PHYSICS, CRYOGENICS, SOLID STATE PHYSICS, PARTICLE PHYSICS AND PLASMA PHYSICS, ETC.
31021	3101	B	[SF]			RADIATION EFFECTS LAB	Y	THIS FACILITY IS USED IN CONDUCTING RESEARCH, DEVELOPMENT, TEST AND EVALUATION ON RADIATION CHARACTERISTICS OF VARIOUS DEVICES AND THEIR EFFECT ON PERFORMANCE OF VARIOUS SYSTEMS IN THE AIR AND IN THE OCEAN ENVIRONMENT. IT IS ALSO USED IN THE STUDY OF EFFECTS OF RADIATION ON PEOPLE AND MARINE LIFE AND THE ACCOMPLISHMENT OF STUDIES TO DETERMINE RELIABLE METHODS FOR DETECTING RADIATION SOURCES.
31023	3101	B	[SF]			COMBINED RESEARCH LAB	Y	THIS FACILITY IS USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF NAVAL SYSTEMS WHICH UTILIZED SEVERAL OF THE SCIENCES IN A COMBINED SYSTEM APPLIED DIRECTLY TO A FLEET PROBLEM OR AREA OF RDAT&E. IT IS ALSO USED TO SUPPORT RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF NAVAL SYSTEMS WHICH DO NOT LOGICALLY FIT THE OTHER CATEGORIES OF RDAT&E.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31025	3101	B	[SF]			BIOLOGICAL LABORATORY	Y	THIS FACILITY IS USED IN RESEARCH, DEVELOPMENT, TEST AND EVALUATION IN TERRESTRIAL AND MARINE BIOLOGY AS RELATED TO STRUCTURE CAPABILITIES, FUNCTIONING HABITAT, HEALTH, GROWTH ENVIRONMENTAL INDICATORS, ECOLOGICAL RELATIONSHIPS OF LIVING ORGANISMS AND ASSOCIATION OF BIOLOGICAL PHENOMENON TO MAN'S EXISTENCE AND OPERATIONS IN THE LAND, OCEAN AND SPACE ENVIRONMENT.
31027	3101	B	[SF]			ENVIRONMENTAL LABORATORY	Y	THIS FACILITY IS USED TO SUPPORT THE RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF INSTRUMENTATION AND COMPUTER SYSTEMS FOR MEASUREMENT AND ANALYSIS OF THE EVALUATION OF ENVIRONMENTAL EFFECTS ON VARIOUS EQUIPMENT, WEAPONS SYSTEMS, FACILITIES, ETC.
31029	3101	B	[SF]			ANIMAL APPLICATIONS LAB	Y	THIS FACILITY IS USED TO SUPPORT THE RDT+E ON NON-HUMAN ANIMALS IN PURE RESEARCH AND OCEAN SUPPORT APPLICATIONS. INCLUDING THE USE OF WHALES AND DOLPHINS AS TRAINED DEEP SEA DIVERS, SEALS FOR TOOL RECOVERY AND DOGS AS SENTRIES. IT ALSO INCLUDES R+D IN APPLICATION AND KNOWLEDGE OF ANIMAL CAPABILITIES IN SENSING, HOMING AND IDENTIFICATION TO IMPROVE THE OPERATION OF MAN-MADE OCEAN DEVICES.
31031	3102	B	[SF]			MEDICAL LABORATORY	Y	THIS FACILITY IS USED IN CONDUCTING RESEARCH TOWARD METHODOLOGY FOR DIAGNOSIS, TREATMENT, OR PREVENTION OF DISEASE OR DAMAGE TO THE BODY OR MIND.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31033	3101	B	[SF]			COMPUTATION/ANALYSIS LAB	Y	THIS FACILITY SUPPORTS RESEARCH, DEVELOPMENT, TEST AND EVALUATION IN THE AREAS OF INFORMATION PROCESSING AND DATA HANDLING, ESPECIALLY WHEN CONCERNED WITH IDENTIFICATION OF CONDITIONS RESPONSIBLE FOR GIVEN DATA CONFIGURATIONS. MATHEMATICAL DATA ANALYSIS UTILIZING BOTH DIGITAL AND ANALOG COMPUTERS TO RESEARCH, DEVELOP, TEST AND EVALUATE NEW NAVAL SYSTEMS
31037	3101	B	[SF]			OCEAN SCIENCES LABORATORY	Y	THIS FACILITY IS USED TO ACCOMPLISH RDT+E IN MARINE BIOSYSTEMS, ENVIRONMENTAL PROTECTION AND MANAGEMENT, DEVELOPMENT OF ANALYTICAL SYSTEMS FOR EVALUATION OF THE OCEAN ENVIRONMENT, STUDIES OF WAVE DYNAMICS, CURRENT FLOW, THERMOCLINES, CHEMICAL VARIANCES, AS WELL AS DEVELOPMENT OF NEW TECHNIQUES AND EQUIPMENT TO INCREASE MAN'S KNOWLEDGE AND UTILIZATION OF THE TOTAL OCEAN ENVIRONMENT.
31039	3103	B	[SF]			LEVEL III BIOSAFETY LAB	Y	THIS TYPE OF LABORATORY APPLIES TO CLINICAL, DIAGNOSTIC, AND TEACHING, RESEARCH, OR PRODUCTION FACILITIES FOR WORK INVOLVING INDIGENOUS OR EXOTIC AGENTS THAT HAVE THE POTENTIAL TO TRANSMIT INFECTION THROUGH THE RESPIRATORY SYSTEM, WHICH MAY CAUSE SERIOUS AND POTENTIALLY LETHAL INFECTION.
31040	3104	B	[SF]			LEVEL IV BIOSAFETY LAB	Y	THIS TYPE OF LABORATORY IS ASSOCIATED WITH WORK ON DANGEROUS AND EXOTIC AGENTS THAT POSE A HIGH INDIVIDUAL RISK OF LIFE-THREATENING DISEASE, AEROSOL TRANSMISSION, OR RELATED AGENT WITH UNKNOWN RISK OF TRANSMISSION.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
Buildings used directly in the research, development and testing of air frames and related assemblies and spares, and other aircraft equipment.								
31105	3111	B	[SF]			RDAT&E MAINT HGR	Y	A BUILDING USED FOR THE RESEARCH, DEVELOPMENT, AND TESTING OF AIR FRAMES, RELATED ASSEMBLIES, AND OTHER AIRCRAFT EQUIPMENT. THE FACILITY INCLUDES HIGH BAY/HANGER SPACES, CREW AND EQUIPMENT SPACES, AND ADMIN SUPPORT SPACES.
31106	2112	B	[SF]			RDAT&E MAINT HGR-01 SPC	Y	RDAT&E MAINTENANCE HANGAR CREW AND EQUIPMENT AREA.
31107	2112	B	[SF]			RDAT&E MAINT HGR-02 SPC	Y	RDAT&E MAINTENANCE HANGAR ADMINISTRATIVE AREA.
31110	3111	B	[SF]			AIRCRAFT/FLIGHT EQUIP LAB	Y	THIS FACILITY IS UTILIZED IN CONDUCTING RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF AERODYNAMIC DESIGN OF AIRCRAFT AND WEAPONS SYSTEMS AND NAVIGATIONAL SYSTEMS.
31120	3111	B	[SF]			AIRCRAFT GRD SUP EQUIP LAB	Y	THIS FACILITY IS USED TO RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF AIRCRAFT GROUND SUPPORT EQUIPMENT, SYSTEMS AND TECHNIQUES FOR THE TAKEOFF, RECOVERY, MAINTENANCE, AND TEST OF AIRCRAFT.
31125	3111	B	[SF]			AIRCRAFT SYS INTEGRAT LAB	Y	THIS FACILITY IS USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF VARIOUS GROUPINGS AND COLLECTIONS OF INTERACTING AIRCRAFT SYSTEMS SUCH AS THE EFFECTS OF AIRFRAME, STRUCTURE, FLIGHT CONTROL, ELECTRICAL, ENVIRONMENTAL CONTROL, FUEL, HYDRAULIC, MECHANICAL, PNEUMATIC, PROPULSION, GUN, LIFE SUPPORT AND RELATED GROUND SUPPORT SYSTEMS ON ECM, AIR TO AIR MISSILE LAUNCH, ETC.
312						MISSILE AND SPACE		

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Buildings used directly in the research, development and testing of missiles, missile system, related ground handling, and launching equipment, and other aerospace equipment.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31210	3121	B	[SF]			GUIDED MISSILE LAB	Y	THIS FACILITY IS USED IN SUPPORT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ADVANCE SIMULATION, INSTRUMENTATION, ENVIRONMENTAL TEST TECHNIQUES AND IMPROVED SERVICEABILITY AND RELIABILITY CHARACTERISTICS OF GUIDED MISSILE WEAPON SYSTEMS. IT INCLUDES ASSEMBLY, DISASSEMBLY, TEST MODIFICATION AND ANALYSIS OF TEST FIRING RESULTS OF GUIDED MISSILES.
31220	3121	B	[SF]			MISSILE SUPPORT EQUIP LAB	Y	THIS FACILITY IS USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF EQUIPMENT AND TECHNIQUES FOR THE LAUNCHING, RECOVERY, MAINTENANCE, TRANSPORT AND TESTING OF MISSILES AND GUIDED MISSILE SUPPORT EQUIPMENT.
31225	3121	B	[SF]			SPACECRAFT / SATELLITE LAB	Y	THIS FACILITY SUPPORTS RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF SPACECRAFT, SATELLITES OR COMPONENTS OF EACH NOT OTHERWISE CLASSIFIED AS A MISSILE WEAPON SYSTEM. THIS FACILITY WOULD INCLUDE RELATED GROUND SUPPORT/LAUNCHING EQUIPMENT.
31230	3121	B	[SF]			MISSILE SYS INTEGRAT LAB	Y	THIS FACILITY IS USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF RELATED AND INTERCONNECTED SYSTEMS THAT ARE NECESSARY FOR LAUNCHING, AND IN DIRECT SUPPORT OF GUIDED MISSILE SYSTEMS.

313						SHIP AND MARINE EQUIPMENT		

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Facilities used directly in the research, development and testing of ships and marine equipment and tracked amphibious vehicles.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31310	3131	B	[SF]			SHIP AND MARINE LAB	Y	THIS FACILITY IS USED IN CONDUCTING RESEARCH, DEVELOPMENT, TEST AND EVALUATION ON SHIPS, BY USE OF MODELS IN HIGH AND LOW SPEED TOW TANKS, MANEUVERING AND SEAKEEPING BASINS, WATER TUNNELS, CIRCULATING WATER CHANNELS, FLUID PHENOMENON BASINS, ETC.
31320	3131	B	[SF]			SHIPS/MARINE EQUIPMENT LAB	Y	THIS FACILITY IS USED TO CONDUCT RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF SHIPS AND MARINE SUPPORT REQUIREMENT. THIS INCLUDES REPAIR AND MAINTENANCE EQUIPMENT AS WELL AS EQUIPMENT FOR DIRECT SUPPORT AND OPERATION OF SHIPS AND MARINE VESSELS SUCH AS PERISCOPES, TOWED ARRAYS, ETC.
31325	3131	B	[SF]			SHIPS/MAR SYS INTEGRAN LAB	Y	THIS FACILITY IS USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF RELATED AND INTERCONNECTED SHIPS AND MARINE SYSTEMS SUCH AS THE SHIP PLATFORM INTEGRATED WITH THE WEAPONS SYSTEMS, COMMUNICATION SYSTEMS, COMMAND AND CONTROL SYSTEMS, SURVEILLANCE SYSTEMS, NAVIGATION SYSTEMS, ETC.

314 TANK AND AUTOMOTIVE

Facilities used directly in the research, development and testing of tank and other automotive equipment.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31410	3141	B	[SF]			GROUND TRANSPORT EQUIP LAB	Y	THIS FACILITY IS USED IN CONDUCTING RESEARCH, DEVELOPMENT, TEST AND EVALUATION IN THE FIELD OF AUTOMOTIVE DESIGN AS APPLIED TO TANKS, APC'S, AND RELATED MILITARY AUTOMOTIVE EQUIPMENT.

315 WEAPONS AND WEAPON SYSTEMS

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Facilities used directly in the research, development and testing of small arms, automatic weapons, mortars, artillery, guns, launchers, projectors (for arming ships, vehicles, and aircraft,) flame throwers, torpedo tubes, harbor protrction, and non-electronic equipment. RDAT&E facilities for guided missiles and related items are included under Category Code series 312.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31510	3151	B	[SF]			AIRCRAFT WEAPON SYS LAB	Y	THIS FACILITY SUPPORTS THE RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF AIRCRAFT WEAPON SYSTEMS INCLUDING PROJECTILES, MINES AND BOMBS, AND DEFENSIVE COUNTERMEASURES DEVICES/WEAPONS.
31515	3151	B	[SF]			SHIP WEAPON SYSTEM LAB	Y	THIS FACILITY IS USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF WEAPONS AND WEAPON SYSTEMS DEPLOYED FROM A SURFACE SHIP. THIS WOULD INCLUDE GUNS, FIRE CONTROL, ETC. THIS DOES NOT INCLUDE AIRCRAFT OR MISSILE SYSTEMS.
31520	3151	B	[SF]			UNDERWATER WEAPON SYS LAB	Y	THIS FACILITY IS USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF UNDERSEA WEAPONRY SUCH AS MINES AND TORPEDOES. THIS WOULD INCLUDE SUBMARINE MOUNTED GUNS BUT NOT SUBMARINE LAUNCHED MISSILES. KEY PLATFORM COMPONENTS INCLUDE SONAR, COMBAT CONTROL, UNDERWATER SUBMARINE WARFARE (USW) WEAPONS TARGETS, UNMANNED UNDERWATER VEHICLES (UUVS), AND FLEET TRAINING SYSTEMS.
31525	3151	B	[SF]			GROUND WEAPON SYSTEM LAB	Y	THIS FACILITY IS USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF WEAPONRY IN USE ON OR DEPLOYED FROM A GROUND BASE PLATFORM AND WOULD INCLUDE SMALL ARMS, AUTOMATIC WEAPONS, MORTARS, ARTILLERY, FLAME THROWERS, ETC.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31530	3151	B	[SF]			WEPS SYS INTEGRTN LAB	Y	THIS FACILITY IS USED TO ACCOMPLISH RESEARCH, DEVELOPMENT, TEST AND EVALUATION ASSOCIATED WITH THE INTEGRATION OF WEAPON SYSTEMS WITH THE WEAPONS PLATFORM AND WITH OTHER INTERFACES BETWEEN OTHER WEAPONS SYSTEMS, GUIDANCE SYSTEMS, SURVEILLANCE SYSTEMS, ETC.

316 AMMO,EXPLOSIVES & TOXICS

Facilities used directly in the research, development and testing of ammunition, rockets, bombs, mines, grenades, torpedoes, depth charges, demolition materials, pyrotechnics, ATO units, ammunition parts and related components and chemicals. This Category Code does not include facilities for guided missiles, guided bombs, or commercial type petroleum products.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31610	3161	B	[SF]			AMMO,EXPLOSIVE & TOXIC LAB	Y	THIS FACILITY IS USED TO SUPPORT THE RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF AMMUNITION, ROCKETS, BOMBS, MINES, GRENADES, TORPEDOES, DEPTH CHARGES, DEMOLITION MATERIALS, PYROTECHNICS, AT0 UNITS, RELATED CHEMICALS, AND THEIR COMPONENTS AND MATERIALS. THIS CATEGORY CODE DOES NOT INCLUDE FACILITIES FOR GUIDED MISSILES, GUIDED BOMBS, OR COMMERCIAL TYPE PETROLEUM PRODUCTS.

317 ELECTRON,COMM & ELEC EQUIP

Buildings used directly in the research, development and testing or radio and radar equipment, signal equipment, radiation aids, electrical equipment and its controls, transmitting and receiving equipment, avionics equipment, sonar, and guided bombs.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31710	3171	B	[SF]			COMMUNICATIONS SYSTEM LAB	Y	THIS FACILITY IS USED IN CONDUCTING RESEARCH, DEVELOPMENT, TEST AND EVALUATION IN THE AREAS OF RADIO COMMUNICATION, INSTRUMENTATION, SATELLITE COMMUNICATION, ELECTROMAGNETIC PROPAGATION, RADIO ANTENNAS, UNDERWATER SOUND SYSTEMS, OPTICAL SYSTEMS (INFRARED), ETC.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31715	3171	B	[SF]			DETECTION SYSTEMS LAB	Y	THIS IS USED IN CONDUCTING RESEARCH, DEVELOPMENT, TEST AND EVALUATION IN BASIC PHYSICAL PHENOMENA OF IMPORTANCE TO RADAR, SONAR, AND RELATED SENSORS, ALSO THE DEVELOPMENT OF SYSTEMS ANALYSIS AND EVAL. OF THE SENSORS USED IN SATELLITES, SHIPS, SUBMARINES, AND AIRCRAFT, ETC. IT INCLUDES SURVEILLANCE FOR DETECTION, IDENTIFICATION AND CLASSIFICATION OF SURFACE, AEROSPACE AND SUB-SURFACE OBJECTS.
31720	3171	B	[SF]			ELEC & ELECTRONICS SYS LAB	Y	THIS FACILITY IS USED IN CONDUCTING RDT+E IN THE AREAS OF ELECTRICAL POWER AND ITS CONTROL, MAGNETIC FIELDS AND SHIP'S CONTROL SYSTEMS. RESEARCH IN THIS AREA INVOLVES DEVELOPMENT OF MOTORS AND GENERATORS, FREQUENCY CONVERTERS, VOLTAGE AND CURRENT CONTROL DEVICES, AND SHIPBOARD POWER DISTRIBUTION SYSTEMS.
31725	3171	B	[SF]			ELEC/COMM SYS INTEGRAT LAB	Y	THIS FACILITY IS USED TO ACCOMPLISH RESEARCH, DEVELOPMENT, TEST AND EVALUATION ASSOCIATED WITH THE INTEGRATION OF RELATED SYSTEMS AND SUBSYSTEMS OF ELECTRICAL, ELECTRONICS AND COMMUNICATIONS SYSTEMS WITH THE PLATFORM (AIR, SEA, GROUND, ETC.) UPON WHICH THEY WILL OPERATE AND TO VERIFY INTERFACE CONSIDERATION WITH OTHER SYSTEMS OPERATING ON THE RESPECTIVE PLATFORM.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Facilities used directly to support research, development, testing and evaluation of propulsion hardware and appurtenances thereto and propellant type fuels.

31810	3181	B	[SF]			PROPULSION SYS LAB	Y	THIS FACILITY IS USED TO SUPPORT RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF PROPULSION SYSTEMS IN ORDER TO DETERMINE OPERATIONAL CAPABILITIES AND IN STUDYING THE ACOUSTICS AND ELECTROMAGNETIC NOISE EFFECTS ON PERFORMANCE AND EFFICIENCY OF DRIVE UNITS.
31815	3181	B	[SF]			PROPULSION FUEL LAB	Y	THIS FACILITY IS USED TO SUPPORT RESEARCH, DEVELOPMENT, TEST, AND EVALUATION OF PROPULSION FUELS IN ORDER TO MAXIMIZE A PROPULSION SYSTEM'S OPERATIONAL CHARACTERISTICS. THIS FACILITY WOULD ALSO SUPPORT INVESTIGATION INTO NEW FUELS AND PROPULSIVE ENERGY SYSTEMS INCLUDING CONTROLLED NUCLEAR ENERGY.

319 MISC ITEMS & EQUIP

Facilities used directly to support research, development, testing and evaluation of miscellaneous military equipment such as clothing, survival equipment, landing mats, military type bridging, hand tools, construction equipment, valves (e.g. safety, pressure reducing, fuel regulating), and hyperbaric facilities not appropriate in another category code, etc.

31910	3191	B	[SF]			MISC EQUIP & ITEMS LAB	Y	THIS FACILITY SUPPORTS RESEARCH, DEVELOPMENT, TEST, AND EVALUATION OF MISCELLANEOUS MILITARY EQUIPMENT SUCH AS LANDING MATS, VALVES (E.G. SAFETY, PRESSURE REDUCING, FUEL REGULATING), AND HYPERBARIC FACILITIES NOT APPROPRIATE IN ANOTHER CATEGORY CODE.
31915	3191	B	[SF]			RDT&E STORAGE	Y	THIS BUILDING IS A STORAGE FACILITY FOR RESEARCH, DEVELOPMENT, TEST, AND EVALUATION EQUIPMENT AND MATERIALS DIRECTLY RELATED TO RDAT&E PROGRAMS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
31920	3191	B	[SF]			CIVIL ENGINEERING LAB	Y	THIS FACILITY IS USED TO SUPPORT RESEARCH, DEVELOPMENT, TEST AND EVALUATION IN THE AREA OF CIVIL ENGINEERING. THIS WOULD INCLUDE MILITARY TYPE BRIDGING, HAND TOOLS, CONSTRUCTION EQUIPMENT, CONSTRUCTION TECHNIQUES, ON LAND, IN AND UNDER THE OCEAN.
31925	3191	B	[SF]			HUMAN FACTORS LAB	Y	THIS FACILITY IS USED TO DETERMINE THE EFFECTS OF WARTIME ATMOSPHERE AND MATERIAL ON MILITARY PERSONNEL AND NON-COMBATANTS. THIS FACILITY WOULD ALSO DEAL WITH MAN-MAN INTERFACING (MORALE, COMMAND CONTROL, AND THE LIKE) AND MAN-MACHINE INTERFACING (CONSOLE DESIGN, PAYLOAD DESIGN, WORK AREA REQUIREMENTS, ETC.)
31930	3191	B	[SF]			SURVIVAL EQUP/CLOTHING LAB	Y	THIS FACILITY SUPPORTS RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF PILOT'S AND SAILOR'S NEED FOR SPECIAL EQUIPMENT, CLOTHING AND TECHNIQUES FOR SURVIVAL IN VARIOUS HOSTILE ENVIRONMENTS.
31935	3191	B	[SF]			METROLOGY & CALIBRATON LAB	Y	THIS FACILITY WILL BE USED IN DIRECT SUPPORT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION PROGRAMS WHERE PRECISE WEIGHTS AND MEASURES ARE REQUIRED IN CALIBRATING RDAT&E EQUIPMENT. THIS FACILITY WOULD INCLUDE THE METROLOGY AND CALIBRATION EQUIPMENT AND SPACE FOR CALIBRATING APPLICABLE EQUIPMENT.
31940	3191	B	[SF]			RANGE OPERATON & INSTR LAB	Y	THIS FACILITY IS USED IN SUPPORT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF RANGE OPERATIONS TO INCLUDE COMMAND CENTER, COMMUNICATIONS, SURVEILLANCE, INSTRUMENTATION, DATA COLLECTION/REDUCTION/DISPLAY, ETC.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
Facilities used directly in the research, development and testing of underwater equipment.								
32010	3201	B	[SF]			UNDERWATER EQUIPMENT LAB	Y	THIS FACILITY IS USED IN CONDUCTING RESEARCH DEVELOPMENT, TEST AND EVALUATION OF UNDERWATER ACOUSTICS, SHIP VIBRATIONS AND VARIOUS TYPES OF UNDERWATER DEVICES TO INCREASE MAN'S CAPABILITIES IN THE OCEAN.
32020	3201	B	[SF]			UNDERWATER SYS INTEGRA LAB	Y	THIS FACILITY WILL BE USED FOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF VARIOUS INTERACTING UNDERWATER SYSTEMS, EQUIPMENT, TOOLS, TECHNIQUES AND OPERATORS WORKING TOGETHER IN AN UNDERWATER ENVIRONMENT. THE INTEGRATION OF SEVERAL SYSTEMS TO ACCOMPLISH A GREATER TOTAL EFFORT WILL BE ACCOMPLISHED IN THIS FACILITY.
321						TECHNICAL SERVICES		
Buildings used directly in RD&T manufacturing or reverse engineering of one-of-a-kind models and parts for systems or subsystems from wood, plastic, fiberglass and other materials by molding, casting, extruding and machining.								
32110	3211	B	[SF]			TECHNICAL SERVICES LAB	Y	BUILDINGS USED DIRECTLY IN RD&T MANUFACTURING OR REVERSE ENGINEERING OF ONE-OF-A-KIND MODELS AND PARTS FOR SYSTEMS OR SUBSYSTEMS FROM WOOD, PLASTIC, FIBERGLASS AND OTHER MATERIALS BY MOLDING, CASTING, EXTRUDING AND MACHINING.
371						RANGE FACILITIES		
Structures used directly in research, development and testing of small arms, artillery, weapons systems, avionics, protection equipment, shelters,								
37110	3712	S		[EA]		SCIENCE SYS RANGE FACILITY	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 310.
37111	3712	S		[EA]		AIRCRAFT SYS RANGE FACILTY	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 311.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
37112	3712	S		[EA]		MISILE & SPACE SYS RGE FAC	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 312.
37113	3712	S		[EA]		SHIPS/MARINE SYS RANGE FAC	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 313.
37114	3712	S		[EA]		TANK & AUTO SYS RANGE FAC	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 314.
37115	3712	S		[EA]		WEAPONS/WEAP SYS RANGE FAC	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 315.
37116	3712	S		[EA]		AMMO,EXPLOSIVE & TOXIC FAC	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 316.
37117	3712	S		[EA]		ELEC,COMM/ELE SYS RNGE FAC	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 317.
37118	3712	S		[EA]		PROPULSION SYS RANGE FAC	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 318.
37119	3712	S		[EA]		MISC ITEM & EQUIP RNGE FAC	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 319.
37120	3712	S		[EA]		UNDERWATER SYS RANGE FAC	N	FACILITIES USED IN THE CONDUCT OF TESTS AND EVALUATIONS OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 320.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Scientific structures and facilities other than buildings used directly in theoretical or applied research, development, and test operations related to such items as test tracks, wind tunnels, etc. Do not include structures and buildings used for normal maintenance, repair, and overhaul purposes.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
39010	3901	S		[EA]		SCIENCE SYSTEMS FACILITY	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 310.
39011	3901	S		[EA]		AIRCRAFT SYSTEMS FACILITY	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 311.
39012	3901	S		[EA]		MISSILE & SPACE SYSTEM FAC	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 312.
39013	3901	S		[EA]		SHIPS & MARINE SYSTEMS FAC	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 313.
39014	3901	S		[EA]		TANK @ AUTOMOTIVE SYS FAC	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 314.
39015	3901	S		[EA]		WEAPONS & WEAPONS SYS FAC	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 315.
39016	3901	S		[EA]		AMMO,EXPLOSVES & TOXIC FAC	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 316.
39017	3901	S		[EA]		ELEC,COMM/ELE SYS RNGE FAC	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER CATEGORY CODE SERIES 317.
39018	3901	S		[EA]		PROPULSION SYSTEMS FAC	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER THE CATEGORY CODE SERIES 318.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
39019	3901	S		[EA]		MISC ITEMS & EQUIP FAC	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER THE CATEGORY CODE SERIES 319.
39020	3901	S		[EA]		UNDERWATER SYSTEM FACILITY	N	FACILITIES USED IN THE CONDUCT OF RESEARCH, DEVELOPMENT, TEST AND EVALUATION OF ITEMS IDENTIFIED UNDER THE CATEGORY CODE SERIES 320.
400						SUPPLY FACILITIES		
410						LIQUID STRG - FUEL/NONPRPL		
411						LIQUID FUEL STORAGE - BULK		

Depot, terminal, and bulk storage for POL, fuel oil, aviation gas, and other liquid fuel including accessory piping, fire protection and berns.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
41110	4111	S		[BL]		SHIP FUEL STR 10K-100K BL	Y	OPERATIONAL SHIP FUEL STORAGE TANKS WITH CAPACITIES BETWEEN 10K AND 100K BARRELS.
41111	4112	S		[BL]		SHIP FUEL STRG > 100K BL	Y	BULK SHIP FUEL STORAGE TANKS ABOVE 100K BARREL CAPACITY.
41112	4113	S		[BL]		CUT & COVER SHIP FUEL STRG	Y	SHIP FUEL STORAGE WITH EARTH COVER FOR USE IN POTENTIALLY HOSTILE ENVIRONMENTS.
41120	4111	S		[BL]		AVTN FUEL STR 10K-100K BL	Y	OPERATIONAL AVIATION FUEL STORAGE TANKS WITH CAPACITIES BETWEEN 10K AND 100K BARRELS.
41121	4112	S		[BL]		AVTN FUEL STRG > 100K BL	Y	BULK AVIATION FUEL STORAGE TANKS ABOVE 100K BARREL CAPACITY.
41122	4113	S		[BL]		CUT & COVER AVTN FUEL STRG	Y	AVIATION FUEL STORAGE WITH EARTH COVER FOR USE IN POTENTIALLY HOSTILE ENVIRONMENTS.
41130	4111	S		[BL]		DSL FUEL STR 10K-100K BL	Y	OPERATIONAL DIESEL FUEL STORAGE TANKS WITH CAPACITIES BETWEEN 10K AND 100K BARRELS.
41131	4112	S		[BL]		DIESEL FUEL STRG > 100K BL	Y	BULK DIESEL FUEL STORAGE TANKS ABOVE 100K BARREL CAPACITY.
41132	4113	S		[BL]		CUT& COVER DIESEL FUEL STR	Y	DIESEL FUEL STORAGE WITH EARTH COVER FOR USE IN POTENTIALLY HOSTILE ENVIRONMENTS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
41140	4111	S		[BL]		MTR GAS STRG 10K-100K BL	Y	OPERATIONAL MOTOR GASOLINE STORAGE TANKS WITH CAPACITIES BETWEEN 10K AND 100K BARRELS.
41141	4112	S		[BL]		MOTOR GAS STRG > 100K BL	Y	MOTOR GASOLINE FUEL STORAGE TANKS ABOVE 100K BARREL CAPACITY.
41142	4113	S		[BL]		CUT & COVER MOTOR GAS STRG	Y	MOTOR GASOLINE STORAGE WITH EARTH COVER FOR USE IN POTENTIALLY HOSTILE ENVIRONMENTS.
41150	4111	S		[BL]		JET FUEL STRG 10K-100K BL	Y	OPERATIONAL JET FUEL STORAGE TANKS WITH CAPACITIES BETWEEN 10K AND 100K BARRELS.
41151	4112	S		[BL]		JET ENGNE FL STR > 100K BL	Y	JET FUEL STORAGE TANKS ABOVE 100K BARREL CAPACITY.
41152	4113	S		[BL]		CUT&CVER JET ENGN FUEL STR	Y	JET FUEL STORAGE WITH EARTH COVER FOR USE IN POTENTIALLY HOSTILE ENVIRONMENTS.
41155	4114	S		[GA]		BULK/READY FUEL ADDTV STRG	N	STORAGE TANKS FOR FUEL ADDITIVES SUCH AS DEICING CHEMICALS.
41160	1244	S		[BL]	GA	LIQ PETROLM FUEL GAS STRG	Y	THIS CATCODE IS FOR THE STORAGE OF LIQUEFIED PETROLEUM GAS, COMMONLY KNOWN AS LPG, FOR HEATING, METAL CUTTING, BRAZING, IN DENTAL LABORATORIES, ABOARD SHIPS, AND IN SIMILAR INSTALLATIONS. LPG CONSISTS PREDOMINANTLY OF PROPANE, PROPYLENE, WITH MINOR AMOUNTS OF BUTANE, ISOBUTENE, AND BUTYLENES.
41182	4111	S		[BL]		CONTAMINATED FUEL STORAGE	Y	THIS CATCODE IS FOR FUEL STORAGE FACILITY TEMPORARY STORAGE FOR OFF-SPECIFICATION (CONTAMINATED) FUEL.
41184	4111	S		[BL]		BULK HEATING FUEL STRG	Y	THIS CATCODE IS FOR HEATING FUEL OIL STORAGE FACILITIES AND IT MAY INCLUDE STORAGE TANKS FOR KEROSENE AND SEVERAL DIFFERENT GRADES OF DIESEL OIL.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

This group includes tank storage, accessories and piping for organic liquids such as cottonseed, linseed or soybean oils and other non-fuel liquids such as lubricants, ballast, or waste oils. Historical data should be available to determine rate of delivery and storage requirement. For waste liquids and oils, methods and schedule of disposals should be considered when determining storage requirement.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
41215	4121	S		[GA]		ROAD OIL STORAGE	N	STORAGE FACILITIES FOR ROAD OIL. ROAD OIL IS OIL USED TO CONTROL DUST IN CERTAIN UNPAVED ROADWAY SITUATIONS.
41225	4121	S		[GA]		LUBRICANT STORAGE	N	THIS CATCODE IS FOR THE STORAGE OF LUBRICATING OIL.
41235	4121	S		[GA]		BALLAST AND SLUDGE STORAGE	N	THIS CATCODE IS FOR THE STORAGE OF BALLAST AND SLUDGE LIQUIDS.
41240	4121	S		[GA]		ORGANIC OIL STORAGE	N	THIS CATCODE IS FOR THE STORAGE OF ORGANIC OILS.
41245	4121	S		EA	[GA]	MISC LIQUID STORAGE	N	THIS CATCODE IS FOR THE STORAGE OF MISCELLANEOUS LIQUIDS.
41250	4121	S		[GA]		INDUS/POL WASTE STORGE FAC	N	THIS CATCODE IS FOR THE STORAGE OF INDUSTRIAL WASTE/POL LIQUIDS.

420 AMMUNITION STORAGE

Ammunition storage utilizes magazines, general purpose and refrigerated storehouses, tanks, open storage pads and associated stationary equipment for storage of Ammunition, Inert Ammunition Components, Liquid Propellants and Weapon-Related Batteries.

421 AMMUNITION STRG DEP/INSTLN

Above/underground ammunition and ammunition component magazines and storehouses (including their explosion barriers.)

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
42122	4211	B	[SF]		CF	HIGH EXPLOSIVE MAGAZINE	Y	A HIGH-EXPLOSIVE MAGAZINE IS USED FOR THE STORAGE OF HAZARD CLASS 1 DIVISION 1 (CH/D 1.1) ENERGETIC MATERIALS. EXAMPLES OF CH/D 1.1 MATERIALS ARE: BOMBS, MISSILES, WARHEADS, NAVAL MINES, DEMOLITION CHARGES. HC/D 1.3 AND 1.4 ENERGETICS MAY ALSO BE STORED IN A HIGH EXPLOSIVE MAGAZINE WHEN THE UTILIZATION REQUIRES IT AND COMPATIBILITY ALLOWS IT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
42132	4211	B	[SF]		CF	INERT STOREHOUSE	Y	THESE STOREHOUSES ARE USED FOR THE STORAGE OF SUCH NON-EXPLOSIVE ITEMS AS BOMB TAILS, MACHINE GUN LINKS, EMPTY CARTRIDGE CASES, AND PACKING MATERIALS.
42135	4221	B	[SF]		CF	READY MAGAZINE	Y	THIS CATEGORY CODE IS USED SPECIFICALLY FOR ORDNANCE REQUIRED TO BE STORED IN A READY SERVICE CAPACITY AND IS USED TO CAPTURE READY SERVICE MAGAZINES. THIS DOES NOT INCLUDE READY SERVICE LOCKERS AND SIMILAR ITEMS OF EQUIPMENT, WHICH ARE NOT CAPTURED IN INFADS.
42142	4211	B	[SF]		CF	SMOKEDRUM STOREHOUSE	Y	THIS CATCODE IS FOR THE STORAGE OF CHEMICAL AND SMOKE PRODUCING MIXTURES.
42148	4211	B	[SF]		CF	SMALL ARMS/PYROTECHNIC MAG	Y	THIS MAGAZINE MAY BE USED TO STORE CLASS 1 DIVISION 3 AND 4 AMMUNITION. PREDOMINANTLY SMALL ARMS AMMUNITION AND PYROTECHNICS.
42162	4211	B	[SF]		CF	SPECIAL WEAPONS MAGAZINE	Y	THE SPECIAL WEAPONS MAGAZINE IS SIMILAR TO THE HIGH EXPLOSIVE MAGAZINE BUT IS USED FOR THE STORAGE OF DIFFERENT TYPES OF ORDNANCE. FOR MORE DETAILS, REFER TO FC 2-000-05N.
42182	4211	B	[SF]			SUB BALLISTIC MSL STO FAC	Y	THIS CATCODE IS PRIMARILY FOR THE STORAGE OF SUBMARINE LAUNCHED BALLISTIC MISSILES

422

423 AMMUNITION STRG LIQ PRPLNT

Facilities for receipt of bulk storage in tanks, and dispensing from storage of liquid propellants under explosive safety distances criteria including tanks, pipes, valves, valve chambers and similar appurtenant equipment and facilities.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
42310	4231	S		[GA]		LIQUID PROPELLANT STORAGE	Y	THIS CATCODE IS FOR THE STORAGE OF LIQUID PROPELLANTS
42320	1221	S		OL	[GM]	LIQ PROPELLANT DISPENS FAC	Y	THIS CATCODE IS FOR LIQUID PROPELLANT STORAGE AND DISPENSING FACILITIES

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
424						WPN-RELATED BATTERY STRG		

Weapon-related storage utilizes refrigerated warehouses that are capable of maintaining at least subfreezing temperatures. This code is not to be used for other cold storage facilities.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
42410	4241	B	[SF]	NS	SH	WPN-RELATED BATTERY STRG	Y	THIS CATCODE IS FOR FACILITIES RELATED TO THE STORAGE OF WEAPONS RELATED BATTERIES.
425						OPEN AMMUNITION STORAGE		

Includes open hardstands (pavements or prepared/stabilized surfaces) for ammunition storage and excludes all other hardstands.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
42510	4251	S	[SY]			OPEN AMMUNITION STRG PAD	Y	THIS CATCODE IS FOR FACILITIES RELATED TO AN OPEN AMMUNITION STORAGE PAD
42511	4251	S	[SY]			EXPLOSIVE STORAGE SITE PAD	N	A CONCRETE OR ASPHALT PAD, CONSTRUCTED AS A BASE ON WHICH TO PLACE NON-PERMANENT ORDNANCE STORAGE CONTAINERS SUCH AS READY SERVICE LOCKERS (RSLS) AND GOLANS. THE PADS CAN BE NEW OR A PORTION OF AN EXISTING PAVEMENT SUCH AS AN AIRCRAFT APRON OR SIMILAR.
42520	4251	S	[SY]			CONTAINR HOLDG YARD (EMPT)	Y	THIS CATCODE IS FOR FACILITIES RELATED TO AN EMPTY ISO CONTAINER-HOLDING YARD.
42530	4251	S	[SY]			BARRICADED MODULE	Y	A BARRICADED MODULE IS A BARRICADED AREA COMPRISING OF A SERIES OF CONNECTED CELLS WITH HARD SURFACE STORAGE PADS SEPARATED FROM EACH OTHER BY BARRICADES.
430						COLD STORAGE		
431						COLD STORAGE		

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Cold storage warehouses for preserving the quality of perishable foods and general supply materials that require refrigeration. The warehouse will include freeze and chill space and normal processing facilities and mechanical areas. The space requirements are applicable to cold storage facilities of all sizes whether built as separate structures or in conjunction with other buildings.

43110	4311	B	[SF]	TC	SH	COLD STORAGE WAREHOUSE	Y	A COLD STORAGE WAREHOUSE IS PLANNED TO PRESERVE THE QUALITY OF PERISHABLE FOODS AND GENERAL SUPPLY MATERIALS THAT REQUIRE REFRIGERATION. THE WAREHOUSE WILL INCLUDE FREEZE AND CHILL SPACE AND NORMAL PROCESSING FACILITIES AND MECHANICAL AREAS.

432

440 GENERAL SUPPLY BUILDINGS

This category group consists of supply-oriented covered storage and/or storage support facilities that are assigned to the Supply/Material Department or assigned for storage of operational mount-out stocks. Requirements allowance guidance can be found in the General Supply Planning Guidance under Requirements Determination.

441 GEN SUPPLY STRG DEP/INSTLN

Navy buildings assigned to/required by Supply/Materials Departments including any space assigned for storage of operational mount-out stocks . 2. Marine Corps buildings required for storage of "out-of-stores" material, or organic mount out stocks. 3. Marine Corps buildings at activities designated as Remote Storage Activities (RSA), or Direct Support Stock Control activities. 4. Excludes buildings not assigned to the Supply/Material Department or for storage of operational mount-out stocks. also, excluded are facilities for operational hazardous flammable storage, storage of aircraft maintenance materials, storage of public works equipments and material, and commissary and exchange materials.

44110	4421	B	[SF]	TC	SH	GENERAL PURP WAREHOUSE	Y	THIS CODE INCLUDES GENERAL WAREHOUSES WITH THE FOLLOWING CHARACTERISTICS: HEATED OR UNHEATED AND WITH/WITHOUT HEAVY-DUTY (OVERHEAD CRANE) CAPABILITY, SPRINKLER SYSTEMS AND/OR ALARM SYSTEMS.
44111	4421	B	[SF]	TC	SH	GENERAL WAREHOUSE MARCORPS	Y	THIS CATEGORY CODE INCLUDES REQUIREMENTS FOR MARINE CORPS GROUND ACTIVITIES WHICH HAVE BEEN DESIGNATED BY MARINE CORPS ORDERS AS DIRECT SUPPORT STOCK CONTROL ACTIVITIES OR WHICH HAVE SPECIALIZED DSSC FUNCTIONS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
44112	4421	B	[SF]	TC	SH	STG AIR/GRD ORG UTS MARCOR	Y	THIS CATEGORY CODE INCLUDES GENERAL PURPOSE STORAGE FACILITIES ASSIGNED TO MARINE CORPS BASES, AIR INSTALLATIONS AND FLEET MARINE FORCE (FMF) UNITS FOR ORGANIC REQUIREMENTS TO INCLUDE DIVISION/WING, BATTALION/GROUP AND COMPANY/SQUADRON STORAGE AREAS, SPECIAL SERVICE STOREROOMS, BASE SHIPPING AND RECEIVING FUNCTIONS AND ANY OTHER ORGANIC STORAGE REQUIREMENTS.
44113	4411	B	[SF]	TC	SH	MARCOR LOGSUPBASE WRHSE	Y	THIS FACILITY INCLUDES GENERAL-PURPOSE WAREHOUSES DESIGNATED AS STORAGE AREAS FOR MARINE CORPS OWNED MATERIAL IN SUPPORT OF LOGISTIC SUPPORT BASE MISSION AS INTEGRATED MATERIAL MANAGERS. ALSO INCLUDED IS THE SPACE UTILIZED IN SUPPORT OF PRE-POSITIONED WAR RESERVE STOCKS.
44114	4411	B	[SF]	TC	SH	MARCOR SASSY WAREHOUSE	Y	THIS FACILITY INCLUDES GENERAL-PURPOSE WAREHOUSES DESIGNATED FOR SUPPORT OF THE SUPPORTED ACTIVITY SUPPLY SYSTEM (SASSY) MANAGEMENT UNITS TO INCLUDE GENERAL AND MOUNT OUT ACCOUNTS AND CONSOLIDATED ISSUE POINT ASSETS.
44120	4424	B	[SF]	TC	SH	CONTROLLED HUMIDITY WRHSE	Y	A CONTROLLED HUMIDITY WAREHOUSE IS SIMILAR TO A GENERAL WAREHOUSE (441 10) IN EVERY RESPECT EXCEPT THAT IT IS CONSTRUCTED WITH APPROPRIATE VAPOR BARRIERS AND CONTAINS HUMIDITY CONTROL EQUIPMENT TO MAINTAIN HUMIDITY AT DESIRED LEVELS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
44130	4423	B	[SF]	TC	SH	HAZARDOUS/FLAMMABL STRHSE	Y	A HAZARDOUS MATERIALS WAREHOUSE IS REQUIRED FOR THE STORAGE AND HANDLING OF MATERIALS SUCH AS FLAMMABLE AND COMBUSTIBLE LIQUIDS, ACIDS, ETC. AS SAFE STORAGE OF SUCH MATERIALS LIES IN THEIR SEPARATION FROM INCOMPATIBLE MATERIALS, A HAZARDOUS AND FLAMMABLES STOREHOUSE IS REQUIRED AS MUCH FOR ADEQUATE MATERIAL SEPARATION AS FOR THEIR STORAGE AND HANDLING.
44135	4422	S	[SF]	TC	SH	GENERAL STORAGE SHED	Y	THE GENERAL SHED IS A ROOFED STRUCTURE WITHOUT COMPLETE SIDE AND/OR END WALLS AND WITH OR WITHOUT SPRINKLER AND/OR ALARM SYSTEMS.
44140	4421	B	[SF]	TC	SH	UNDERGROUND STORAGE	Y	THIS CATEGORY CODE PERTAINS TO UNDERGROUND STORAGE; WHERE IT IS NECESSARY, BECAUSE OF POTENTIAL SABOTAGE OR ENEMY ACTION TO PROTECT SUPPLIES EITHER BY DISPERSAL OR PROTECTIVE CONSTRUCTION, INSTEAD OF PROGRAMMING NEW PROTECTIVE CONSTRUCTION, EXISTING MINES MAY BE USED.
44170	4421	B	[SF]	NS	SH	DISPOSL/SALVAGE/SCRAP BLDG	Y	THIS FACILITY IS PRIMARILY TO PROVIDE COVERED SPACE FOR THE RECEIPT, PROCESSING, STAGING AND ISSUE OF MATERIAL THAT HAS BEEN DEEMED EXCESS TO NAVY NEEDS AND IS AWAITING SOME RESALE OR FINAL DISPOSAL.
44171	4421	B	[SF]	TC	SH	INTEGRATE LOG OH & OUTFIT	Y	THIS FACILITY PROVIDES COVERED SUPPLY SPACE USED FOR PROCESSING MATERIALS OFFLOADED FROM OR ASSEMBLED FOR LOADING ABOARD SHIPS. IT INCLUDES SPACE REQUIRED FOR RECEIVING, SORTING, IDENTIFYING AND PROCESSING MATERIALS OFF-LOADED AS WELL AS PROCESSING AND ASSEMBLY OF OUTFITTING MATERIALS TO BE LOADED ABOARD FLEET UNITS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
44172	4421	B	[SF]	TC	SH	SERVMART	Y	A SERVMART PROVIDES COVERED SUPPLY FACILITIES USED FOR DISPLAY AND SALE OF SUPPLY SYSTEMS MATERIALS FOR SELF-SERVICE REQUISITIONING BY END USERS. IT INCLUDES AREAS USED TO DISPLAY ITEMS ON SHELVES OR GONDOLAS, CHECKOUT COUNTERS AND ADMINISTRATIVE FUNCTIONS.
44173	4421	B	[SF]	TC	SH	MTIS BUILDING	Y	A MATERIAL TURNED INTO STORE (MTIS) FACILITY PROVIDES COVERED SUPPLY SPACE USED FOR PROCESSING MATERIALS TURNED INTO SUPPLY FOR REDISTRIBUTION OR DISPOSAL. IT INCLUDES SPACE USED FOR RECEIPT, SCREENING, IDENTIFICATION, ASSEMBLY AND STAGING FOR RETURN TO STORAGE AREAS.
442								
450						STORAGE OPEN		
451						STORAGE-OPEN DEPOT/INSTLN		

This category group consists of non-covered storage areas, paved or otherwise established, for storage of General Supply Materials. Several of the excluded types of functions include miscellaneous materials coded under other basic category codes (e.g., ammunition on open pad coded under 425-10 and open storage areas for non-supply oriented functions coded under 852-35). This code also refers to open areas primarily to provide space for the receipt, processing, staging and issue of material that has been deemed excess to Navy needs and is awaiting some resale or final disposal and whose value is not significantly impacted by uncovered exposure to the environment. This code may also be used for such open yards required for staging or storage of items being held for their scrap value to ongoing missions or systems.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
45110	4521	S	[SY]	NS		OPEN STORAGE AREA	Y	THIS CATEGORY GROUP CONSISTS OF NON-COVERED STORAGE AREAS, PAVED OR OTHERWISE ESTABLISHED, FOR STORAGE OF GENERAL SUPPLY MATERIALS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
45170	4521	S	[SY]	NS		EXTRAORDY SUP DISPL STG AR	Y	THIS CODE REFERS TO OPEN AREAS PRIMARILY TO PROVIDE SPACE FOR THE RECEIPT, PROCESSING, STAGING AND ISSUE OF MATERIAL THAT HAS BEEN DEEMED EXCESS TO NAVY NEEDS AND IS AWAITING SOME RESALE OR FINAL DISPOSAL AND WHOSE VALUE IS NOT SIGNIFICANTLY IMPACTED BY UNCOVERED EXPOSURE TO THE ENVIRONMENT.
452								
500						HOSPITAL-MEDICAL FACILITY		
510						MEDICAL CENTER/HOSPITAL		

Facilities that provides general and specialized medical care for authorized personnel, with both inpatient and outpatient services. This facility will also normally contain clinics, such as Medical, surgical, pediatrics, obstetrical, ICU and CCU. The facility will have a Pharmacy, ambulance, and administrative area. This facility will admit for more than 24-hour stay.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
51010	5100	B	SF	[BD]	LC	HOSPITAL	Y	A HEALTHCARE FACILITY THAT PROVIDES GENERAL AND SPECIALIZED MEDICAL CARE FOR AUTHORIZED PERSONNEL, WITH BOTH INPATIENT AND OUTPATIENT SERVICES. THIS FACILITY WILL ALSO NORMALLY CONTAIN CLINICS, SUCH AS MEDICAL, SURGICAL, PEDIATRICS, OBSTETRICAL, ICU AND CCU.
51011	5100	B	[SF]	LC	BD	MEDICAL CENTER	Y	A REGIONAL MEDICAL CENTER. THESE FACILITIES SUPPORT BOTH INCREASED SURGICAL CAPABILITIES AND A SURGICAL GRADUATE EDUCATION PROGRAM, NOT REQUIRED IN SMALLER HOSPITALS. APPLIES TO BETHESDA, PORTSMOUTH AND SAN DIEGO (BALBOA).
51012	5306	B	SF	[EA]		PREPOS FLT HOSP WAREHOUSE	Y	FLEET (DEPLOYABLE) HOSPITAL STORAGE FACILITY.
51015	5100	B	SF	[BD]	LC	HOSPITAL BR/ANEX	Y	HOSPITAL FACILITY ASSOCIATED WITH A MAIN HOSPITAL BUT IN A SEPARATE LOCATION.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
51016	6100	B	[SF]			MEDICAL ADMIN	Y	ADMINISTRATIVE FUNCTIONS ASSOCIATED WITH A HOSPITAL OR MEDICAL CENTER. CAN BE WITHIN A MEDICAL FACILITY ITSELF, OR IN A STANDALONE ADMIN FACILITY ASSOCIATED WITH A HOSPITAL OR MEDICAL CENTER.
51020	5100	B	[SF]			HOSPITAL LAUNDRY	Y	LAUNDRY FACILITIES LOCATED WITHIN A HOSPITAL (CATCODE 510 10), USED FOR LAUNDERING OF HOSPITAL LINENS AND OTHER NECESSARY ITEMS.
51077	5306	B	[SF]			HOSPITAL/MED STRG(MISC)	Y	SPACE USED FOR STORAGE OF MEDICAL SUPPLIES WITHIN THE HOSPITAL FACILITY.

530 LABORATORIES

Laboratory, veterinary, preventive medicine and other ancillary facilities.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
53010	5500	B	[SF]			DISP & OUT PATIENT CLINIC	Y	FREE STANDING CLINIC, OUTPATIENT CLINIC, WHICH OCCUPIES A BUILDING OR PART OF A BUILDING, BUT IS NOT PHYSICALLY LOCATED WITH A HOSPITAL OR MEDICAL CENTER THAT PROVIDES ROUTINE AND EMERGENCY CARE TO AUTHORIZED PERSONNEL.
53020	5302	B	[SF]			MEDICAL LABORATORY	Y	A FACILITY, DETACHED FROM A HOSPITAL THAT PROVIDES LABORATORY SUPPORT TO THE HOSPITAL AND/OR OTHER MEDICAL ACTIVITIES. THE ANALYSIS AND DIAGNOSTIC LABORATORY INCLUDES CHEMISTRY, DIAGNOSTICS AND MICROBIOLOGY TESTING SECTIONS AND A QUALITY ASSURANCE AND TECHNICAL SUPPORT SECTION.
53025	5500	B	[SF]			NAVY MEDICAL PHARMACY	Y	A DETACHED FACILITY THAT PROVIDES ROUTINE AND EMERGENCY HEALTH CARE TO AUTHORIZED PERSONNEL.
53030	5303	B	[SF]			MORGUE	Y	A FACILITY, EITHER DETACHED OR WITHIN A HOSPITAL, FOR THE IDENTIFICATION, PREPARATION, AND HOLDING OF HUMAN REMAINS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
53040	5304	B	[SF]		VIVARIUM CLINIC	Y	THE VIVARIUM CLINIC IS A MEDICAL RESEARCH LABORATORY FOR KEEPING AND RAISING ANIMALS AND PLANTS UNDER NATURAL CONDITIONS FOR OBSERVATION AND RESEARCH.
53045	5304	B	[SF]	EA	VET TREATMENT FAC	Y	THIS FACILITY IS USED TO PROVIDE FOOD SAFETY AND QUALITY ASSURANCE, CARE FOR GOVERNMENT OWNED ANIMALS (WORKING DOGS AND HORSES), AND ANIMAL DISEASE PREVENTION AND CONTROL. VETERINARY SERVICES ARE TO EXAMINE, IMMUNIZE AND TREAT FOR THE PREVENTION AND CONTROL OF DISEASES OR CONDITIONS THAT ARE TRANSMISSIBLE TO HUMANS OR ANIMALS, OR MAY CONSTITUTE A MILITARY COMMUNITY HEALTH PROBLEM.
53050	5302	B	[SF]		ENVIRONMNTL PREVNTV MED LB	Y	MEDICAL LABORATORY OPERATING IN SUPPORT OF A HOSPITAL OR MEDICAL CENTER.
53060	5306	B	[SF]		MEDICAL WAREHOUSE	Y	A STORAGE FACILITY FOR MEDICAL EQUIPMENT AND SUPPLIES THAT IS CONTINUOUSLY WITHDRAWN AND REPLENISHED. STORAGE OF WAR RESERVE MEDICAL SUPPLIES IS INCLUDED IN DEPOT STORAGE FACILITIES.
53070	5307	B	[SF]		AMBUL SHELTER	Y	A COVERED SPACE USED TO SHIELD THE AMBULANCE, ITS DRIVER AND ITS PATIENTS FROM EXPOSURE TO THE ELEMENTS.

540 DENTAL CLINICS

A dental clinic is an oral health care service facility equipped and staffed to perform dental procedures for general practices, a specialty, or a grouping of specialties. A dental facility will normally include treatment areas, administrative, support and storage areas.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
54010	5400	B	SF	[OU]	DENTAL CLINIC	Y	A DENTAL CLINIC IS AN ORAL HEALTH CARE SERVICE FACILITY EQUIPPED AND STAFFED TO PERFORM DENTAL PROCEDURES FOR GENERAL PRACTICES, A SPECIALTY, OR A GROUPING OF SPECIALTIES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
550						DISPENSARIES/CLINICS		

Facilities primarily intended to provide emergency treatment and ambulatory services. A primary care clinic may be referred by various names (troop medical clinic, adult clinic, family practice clinic, OCC Health, Outpatient, and others). A primary care clinic provides the office, examination and treatment space for ¿primary care managers¿.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
55010	5500	B	[SF]			PRIM CARE CLINIC	Y	A PRIMARY CARE CLINIC MAY BE REFERRED BY VARIOUS NAMES (TROOP MEDICAL CLINIC, ADULT CLINIC, FAMILY PRACTICE CLINIC, OCC HEALTH, OUTPATIENT, AND OTHERS). A PRIMARY CARE CLINIC PROVIDES THE OFFICE, EXAMINATION AND TREATMENT SPACE FOR ¿PRIMARY CARE MANAGERS¿.
55020	5501	B	[SF]		BD	AMBULATORY CARE CENTER	Y	A HEALTH CARE FACILITY CAPABLE OF PERFORMING OUTPATIENT SURGICAL PROCEDURES AND OTHER MEDICAL TREATMENT, NOT REQUIRING EXTENSIVE PATIENT CONVALESCENCE OR OVERNIGHT OBSERVATION.
55030	5500	B	[SF]			SUBSTANCE ABUSE REHAB PRGM	Y	THIS FACILITY WILL PROVIDE THE NECESSARY ADMINISTRATION, COUNSELING, TRAINING, BERTHING, AND RECREATION FOR REHABILITATION OF ELIGIBLE NAVY, MARINE CORPS AND OTHER PERSONNEL SUFFERING FROM ALCOHOLISM, DRUG DEPENDENCY AND/OR COMPULSIVE OVEREATING.
552						AMBU CARE CLINICS		

A health care facility capable of performing outpatient surgical procedures and other medical treatment, not requiring extensive patient convalescence or overnight observation.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
600						ADMINISTRATIVE FACILITIES		
610						ADMIN BUILDINGS		

Category Code Report (All Series)

These are headquarters and office-type buildings accommodating administrative and professional activities, business and data-processing machines, records, files, and administrative supplies for normal operations. For bulk storage of administrative records and supplies, see the 400 series.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
61010	6100	B	[SF]			ADMINISTRATIVE OFFICE	Y	THIS FACILITY ACCOMMODATES THE EXECUTIVE AND STAFF FUNCTIONS OF THE STATION OR OF A PARTICULAR DEPARTMENT. THE FUNCTIONS PERFORMED IN AN ADMINISTRATIVE OFFICE ARE PRIMARILY LOGISTICAL AND PERSONNEL MANAGEMENT AS DISTINGUISHED FROM TACTICAL AND STRATEGIC ACTIVITIES.
61030	6100	B	[SF]		PH	CLASSMATTER INCINERTR BLD	Y	A STAND ALONE FACILITY SOLELY FOR THE PURPOSE OF DESTRUCTION OF CLASSIFIED MATERIALS EITHER THROUGH INCINERATION OR SHREDDING.
61040	6100	B	[SF]			LEGAL SERVICES FACILITY	Y	NAVAL LEGAL SERVICE OFFICES (NLSO), REGIONAL LEGAL SERVICE OFFICES (RLSO), JUDICIARY OFFICES, AND CLAIMS CENTERS PROVIDE COMPREHENSIVE LEGAL SERVICES TO COMMAND AND INDIVIDUAL CLIENTS. THESE SERVICES INCLUDE SAFE AND SECURE TRIALS BY COURT-MARTIAL, ADMINISTRATIVE DISCHARGE PROCEEDINGS AND OTHER PERSONNEL ACTIONS, ADJUDICATION OF CLAIMS, LEGAL ASSISTANCE, AND COMMAND ADVICE.
61050	6100	B	[SF]			AUSTERE ADMIN FACILITY	Y	AUSTERE ADMIN. FACILITIES ACCOMMODATE THE EXECUTIVE AND STAFF FUNCTIONS AT DESIGNATED AUSTERE NAVAL INSTALLATIONS. THE FUNCTIONS PERFORMED IN AN ADMIN. OFFICE ARE PRIMARILY LOGISTICAL AND PERSONNEL MANAGEMENT. THEY ARE INTENDED TO PROVIDE THE MINIMUM FOOTPRINT AREA AND FINISH SUPPORTING ADMIN. FUNCTIONS WHILE PROVIDING MINIMAL UP FRONT AND TOTAL COSTS IN COMPARISON TO NON-AUSTERE FACILITIES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
61070	6102	B	[SF]			DIVISION/WING HQ (MARCOR)	Y	THIS CATEGORY CODE IS FOR A FLEET MARINE FORCE (FMF) FACILITY AND PROVIDES THE NECESSARY ADMINISTRATIVE SPACE TO CONDUCT THE DAY-TO-DAY OPERATIONS OF A MARINE DIVISION HEADQUARTERS OR A MARINE AIRCRAFT WING HEADQUARTERS.
61071	6102	B	[SF]			REGMT/GROUP HQ (MARCOR)	Y	THIS CATEGORY CODE IS FOR A FLEET MARINE FORCE (FMF) FACILITY AND PROVIDES THE NECESSARY ADMINISTRATIVE SPACE TO CONDUCT THE DAY-TO-DAY OPERATIONS OF A MARINE REGIMENTAL HEADQUARTERS OR A MARINE AIRCRAFT GROUP HEADQUARTERS.
61072	6102	B	[SF]			BATTLN SQUADRN HQ (MARCOR)	Y	THIS CATEGORY CODE IS FOR A FLEET MARINE FORCE (FMF) FACILITY AND PROVIDES THE NECESSARY ADMINISTRATIVE SPACE TO CONDUCT THE DAY-TO-DAY OPERATIONS OF A MARINE BATTALION OR A SQUADRON HEADQUARTERS.
61073	6101	B	[SF]			COMPANY/BATTERY HQ(MARCOR)	Y	THE CATEGORY CODE IS FOR A FLEET MARINE FORCE (FMF) FACILITY AND IS INTENDED FOR THOSE FMF UNITS OF COMPANY OR BATTERY SIZE WHICH REQUIRE SEPARATE ADMINISTRATIVE FACILITIES.
61074	6102	B	[SF]			GARRISON AID STA, MARCOR	Y	A GARRISON AID STATION PROVIDES MEDICAL CARE AT THE LOCAL LEVEL FOR THE MARINE CORPS AND GENERALLY WILL BE COLLOCATED WITH THE BATTALION AND REGIMENTAL HQ FACILITIES. THE FUNCTIONS PERFORMED IN THIS FACILITY ARE BOTH ADMIN AND CLINICAL IN NATURE WHICH REQUIRES SPACE FOR THE MEDICAL PERSONNEL ASSIGNED AT THE BATTALION, SQUADRON, AND REGIMENTAL LEVELS TO WORK AND SPACE FOR MEDICAL FILE STORAGE.
61077	6100	B	[SF]			ADMIN STORAGE (MISC)	Y	STORAGE FACILITIES FOR MISCELLANEOUS EQUIPMENT OR GOODS RELATED TO ADMINISTRATIVE FACILITY SUPPORT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
620						ADMIN FACILITIES UNDERGRND		
62010	6200	B	[SF]			ADMIN FACILITY UNDERGROUND	Y	UNDERGROUND ADMINISTRATIVE FACILITY, UTILIZED WHERE SECURITY PROVIDED BY UNDERGROUND LOCATION IS WARRANTED AND APPROVED BY HIGHER HEADQUARTERS.
62077	6200	B	[SF]			UNDERGRND ADMIN STRG(MISC)	Y	UNDERGROUND ADMINISTRATIVE STORAGE FACILITY, UTILIZED WHERE SECURITY PROVIDED BY UNDERGROUND LOCATION IS WARRANTED AND APPROVED BY HIGHER HEADQUARTERS.
690						OTHER ADMINISTRATIVE FAC		

Miscellaneous administrative facilities not included in the 610 and 620 category code series. Excludes community facilities coded in the 700 category code series, and all facilities coded in the 800 series.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
69010	6900	S		[EA]		FLAGPOLE/BILLBD/ MARKER	N	NO PLANNING FACTORS ARE AVAILABLE. PROVIDE FACILITIES AS REQUIRED.
69015	6900	S		[EA]		SALUTING BATTERY GUN MOUNT	N	NO PLANNING FACTORS ARE AVAILABLE. PROVIDE FACILITIES AS REQUIRED.
69025	6900	S		[EA]		REVIEWING STAND	N	NO PLANNING FACTORS ARE AVAILABLE. PROVIDE FACILITIES AS REQUIRED.
69030	6900	S		[EA]	PH	CLAS MATERIAL INCIN/NO BLD	N	A FACILITY SIMILAR TO 610 30, THAT IS LOCATED INSIDE ANOTHER BUILDING INSTEAD OF A STAND ALONE STRUCTURE.
700						HOUSING AND COMMUNITY FAC		
710						FAMILY HOUSING		
711						FAMILY HOUSING-DWELLINGS		

Buildings to be used as family quarters including attached private garages.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
71120	7110	B	SF	[FA]	NF	WHERRY HSG	N	WHERRY HOUSING, ALL RANKS
71125	7110	B	SF	[FA]	NF	CAPEHT HSG	N	CAPEHART HOUSING, THRU O6.
71129	7110	B	SF	[FA]	NF	CAPEHT HSG,O-7/O-10	N	CAPEHART HOUSING, O7-O10.
71130	7110	B	SF	[FA]	NF	FAM HSG THRU O6	N	FAMILY HOUSING THRU O6
71134	7110	B	SF	[FA]	NF	FAM HSG O7 - O10	N	FAMILY HOUSING O7 - O10

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
71135	7110	B	SF	[FA]	NF	LEASED HSG	N	LEASED HOUSING THRU O6
71139	7110	B	SF	[FA]	NF	LEASED HSG,O-7/O-10	N	LEASED HOUSING, O7-O10.
71145	7120	B	SF	[FA]	NF	RELOCATABLE HSG	N	RELOCATABLE HOUSING, ALL RANKS.
71150	7110	B	SF	[FA]	NF	SURP COMMDTY HSG	N	SURPLUS COMMODITY HOUSING, ALL RANKS.
71155	7110	B	SF	[FA]	NF	FOREIGN SOURCE HSG THRU 06	N	FOREIGN SOURCE HOUSING THRU O6
71159	7110	B	SF	[FA]	NF	FOR'N SOURCE HSG,O-7/O-10	N	FOREIGN SOURCE HOUSING, O7-O10.

712 SUBSTNRD TRAILERS-FAM HSG

Mobile homes with government ownership are an emergency expedient. They are not considered in basic planning.

713 FAMILY HOUSING-TRAILR SITE

Single and/or double wide manufactured housing parking sites with appurtenant utility connections; roads; walks; storage sheds; laundry and community buildings; and recreational facilities.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
71311	7130	LS	SY	[FA]	SI	TRAILER SITE,PRVT TRAILERS	N	THIS GROUP INCLUDES SINGLE AND/OR DOUBLE WIDE MANUFACTURED HOUSING PARKING SITES WITH APPURTENANT UTILITY CONNECTIONS; ROADS; WALKS; STORAGE SHEDS; LAUNDRY AND RECREATIONAL FACILITIES.

714 FAMILY HOUSING-DETACHD FAC

Detached facilities are structures separated from family quarters, but available to the occupants.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
71410	7141	B	[SF]	VE		DETACHED GARAGES	N	DETACHED GARAGES ARE BUILDINGS SEPARATED FROM FAMILY QUARTERS, BUT AVAILABLE TO THE OCCUPANTS.
71420	7147	S	[SF]	VE		DETACHED CARPORTS	N	DETACHED CARPORTS ARE ALSO PROVIDED ON THE BASIS OF ONE PER LIVING UNIT AND A SPACE ALLOWANCE OF ONE VEHICLE PER CARPORT.
71430	7143	B	[SF]			FAMILY HSG OTHER DET BLDG	N	THESE CODES ARE FOR INVENTORY PURPOSES ONLY AND ARE TO BE USED FOR MINOR DETACHED BUILDINGS DIRECTLY RELATING TO A PARTICULAR FAMILY DWELLING.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
71431	7143	B	SF	[EA]		FAMILY HSG OTHER DET FAC	N	THESE CODES ARE FOR INVENTORY PURPOSES ONLY AND ARE TO BE USED FOR MINOR DETACHED FACILITIES DIRECTLY RELATING TO A PARTICULAR FAMILY DWELLING.
71432	7440	B	[SF]			COMMUNITY CENTER	N	A FAMILY HOUSING COMMUNITY CENTER (FHCC) PROVIDES SPACE FOR SOCIAL AND RECREATIONAL PROGRAMS AT FAMILY HOUSING PROJECTS WHERE COMPARABLE NAVY OR NON-NAVY FACILITIES ARE NOT REASONABLY ACCESSIBLE.
71433	6100	B	[SF]			HOUSING WELCOME CTR (HWC)	N	A FAMILY HOUSING WELCOME CENTER (HWC) PROVIDES SPACE FOR ADMINISTRATIVE AND SERVICE FUNCTIONS ASSOCIATED WITH THE PROVISIONS OF GOVERNMENT AND PRIVATE SECTOR HOUSING. THE ESTABLISHMENT OF A HWC MUST BE AUTHORIZED BY DIRECTOR, SHORE READINESS DIVISION (OPNAV N46) OR COMMANDANT OF THE MARINE CORPS (LFF-3).
71477	7142	B	[SF]			HOUSING,MISC STRG	N	STORAGE FACILITIES IN SUPPORT OF FAMILY HOUSING.
720						UNACOMP PERSONNEL HOUSING		
721						UNACOMP PERS HOUS-ENL PERS		

Unaccompanied Enlisted Quarters refers to apartment style, hotel style, dormitory style living quarters and the open bay barracks for recruits. If messing facilities are attached, use category code numbers 721-11 through 721-40 for the quarters portion as appropriate and category code number 721-45 for the mess hall portion. For detached mess halls, use category group 722.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
72111	7210	B	SF	[PN]		UNACC ENL HSG	Y	UNACCOMPANIED ENLISTED HOUSING
72114	7213	B	SF	[PN]		STUDENT BARRACKS	Y	UNACCOMPANIED QUARTERS FOR 'A' SCHOOL STUDENTS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
72115	7218	B	SF	[PN]		RECRUIT BARRACKS	Y	OPEN BAY DESIGN BARRACKS. THESE WILL BE CONSTRUCTED ONLY FOR RECRUITS, RECEIVING BARRACKS, AND USMC SCHOOL OF INFANTRY. RECRUIT QUARTERS ARE OPEN BAY, CENTRAL HEAD FACILITIES WITH NET LIVING AREA SIZED AS ONE EQUAL SHARE OF THE OPEN BAY SLEEPING AREA.
72127	7212	B	[SF]			AUSTERE QTRS MISSION ESSN	Y	AUSTERE QUARTERS ARE LODGING FACILITIES LOCATED AT DESIGNATED ENDURING NAVAL INSTALLATIONS. THE CURRENT AUSTERE FACILITY GUIDANCE PROVIDES FOR STANDARDIZED ROOM MODULES WITH CENTRALIZED SHOWER/TOILET FACILITIES FOR ACTIVE DUTY PERSONNEL AND RESERVISTS.
72140	7312	B	SF	[PN]		DISCIPLINARY HOUSING	Y	THIS FACILITY IS TO BE USED FOR BERTHING PERSONNEL IN DISCIPLINARY HOLDING OF RESTRICTED STATUS.
72141	7214	B	[SF]	PN		UDP HOUSING M.E.(ENLISTED)	Y	UNIT DEPLOYMENT PROGRAM (UDP) PERSONNEL HOUSING FOR MISSION ESSENTIAL (ENLISTED)
72145	7220	B	SF	[PN]		GALLEY/MESS BUILT-IN/ATTD	Y	A FACILITY, WITH CAFETERIA STYLE DINING OPERATIONS, FOR UNACCOMPANIED PERSONNEL AND OTHER AUTHORIZED PERSONS THAT IS BUILT INTO OR ATTACHED TO THE UH.
72146	7210	B	SF	[PN]		RESIDENTIAL CARE FACILITY	Y	BERTHING FOR RETIRED NAVY PERSONNEL ON A LONG TERM BASIS.
72147	7215	B	[SF]			WNDED WRS HSG	Y	A FACILITY DESIGNED TO PROVIDE TEMPORARY AND PERMANENT HOUSING FOR UNACCOMPANIED PERSONNEL IN A WOUNDED WARRIOR/WARRIOR IN TRANSITION STATUS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Dining facilities for unaccompanied personnel and conference centers operated by Unaccompanied Housing that are located in, or adjacent to, Unaccompanied Housing facilities. For clubs and open mess facilities, see the appropriate codes in 740 series. For additional information see design criteria UFC 4-722-01, "Dining Facilities".

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
72210	7220	B	SF	[PN]		GALLEY/MESS HALL	Y	THIS GROUP INCLUDES DINING FACILITIES FOR UNACCOMPANIED PERSONNEL.
72235	7220	B	[SF]	PN		AUSTERE GALLEY	Y	AUSTERE GALLIES PROVIDE CORE DINING, FOOD PREPARATION, AND SUPPORT AREAS FOR LOCATIONS DETERMINED AUSTERE BY CNIC. THESE FACILITIES ARE INTENDED TO PROVIDE THE MINIMUM FOOTPRINT AREA AND FINISHES TO SUPPORT GALLEY FUNCTIONS WHILE PROVIDING MINIMAL UP FRONT AND TOTAL OWNERSHIP COSTS IN COMPARISON TO NON-AUSTERE LOCATIONS.
72250	7233	B	[SF]	NS	SH	COLD STOR DET GALLEY/MESS	N	THIS CODE IS FOR INVENTORY PURPOSES ONLY IN CASES WHERE COLD STORAGE FACILITIES ARE DETACHED FROM THE GALLEY PROPER.
72260	6100	B	[SF]			CONFERENCE CENTER	N	THIS CATEGORY CODE IS FOR INVENTORY PURPOSES ONLY, AND INCLUDES ONLY THOSE CONFERENCE ROOMS LOCATED IN UNACCOMPANIED HOUSING.

723 UNACOMP PERS HOUS-DET FACS

Facilities appurtenant to unaccompanied personnel housing such as latrines, unit adimistrative and storage facilities and other facilities which are normally included as an integral part or permanent unaccompanied personnel housing but are usuallu provided as separate appurtenances to semi-permanent and temporary personnel housing.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
72320	7234	B	[SF]	PN		LATRINE, DETACHED	N	LATRINE FACILITIES ARE PLANNED AS PART OF THE UNACCOMPANIED HOUSING. CODES ARE LISTED FOR INVENTORY PURPOSES ONLY.
72330	7342	B	[SF]			LAUNDRY, DETACHED	N	LATRINE AND LAUNDRY FACILITIES ARE PLANNED AS PART OF THE UNACCOMPANIED QUARTERS. CODES ARE LISTED FOR INVENTORY PURPOSES ONLY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
72340	7232	B	SF	[VE]		GARAGE, DETACHED UH	N	INDIVIDUAL GARAGES WILL NOT BE PLANNED IN CONJUNCTION WITH TROOP HOUSING. THIS CATEGORY CODE SHOULD BE USED FOR INVENTORY PURPOSES ONLY.
72350	7235	S		[EA]		WASH RACK, DETACHED	N	WASH RACKS FOR GALLEY GARBAGE CONTAINERS, AND WASH RACKS FOR UNACCOMPANIED RESIDENT'S VEHICLES ARE PLANNED AS PART OF GALLEYS AND UNACCOMPANIED HOUSING. THIS CATEGORY CODE SHOULD BE USED FOR INVENTORY PURPOSES ONLY.
72360	7231	B	[SF]			TROOP HSG OTHER DET BLDG	N	THESE CODES ARE FOR INVENTORY PURPOSES ONLY AND ARE TO BE USED FOR MINOR DETACHED BUILDINGS DIRECTLY RELATING TO UNACCOMPANIED HOUSING FUNCTIONS.
72361	7235	S		[EA]		TROOP HSG OTHER DET FAC	N	THESE CODES ARE FOR INVENTORY PURPOSES ONLY AND ARE TO BE USED FOR MINOR DETACHED FACILITIES DIRECTLY RELATING TO UNACCOMPANIED HOUSING FUNCTIONS.
72377	4421	B	[SF]			TROOP HSG STRG(MISC)	Y	STORAGE FACILITIES FOR MISCELLANEOUS EQUIPMENT AN/OR GOODS RELATED TO UNACCOMPANIED HOUSING SUPPORT WILL BE PROVIDED ONLY WHERE IT CAN BE INDIVIDUALLY JUSTIFIED.

724 UNACOMP PERS HOUS-OFF QTRS

Public housing for unaccompanied officers and comparable civilians excluding club and club messing.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
72411	7240	B	SF	[PN]		UNACCOMPANIED OFF HSG	Y	UNACCOMPANIED OFFICER HOUSING, ALL RANKS
72415	7214	B	[SF]	PN		UDP HOUSING M.E. (OFFICER)	Y	HOUSING FOR UNIT DEPLOYED PERSONNEL (UDP) HOUSING - MISSION ESSENTIAL - OFFICER

725 UNACOMP PERS HOUS-EMERGNCY

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Hutments (quonset and similar) and tent frames and floors for troop or civilian emergency housing. Excludes detached facilities coded in the 723 series.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
72510	7250	B	[SF]	PN		TROOP HSG EMERGENCY BLDG	Y	THESE MAY BE HUTMENTS (QUONSETS), TENT FRAMES WITH FLOORS AND MAY BE PERMANENT, SEMI-PERMANENT, OR TEMPORARY TYPES OF BUILDINGS. CODES ARE LISTED FOR INVENTORY PURPOSES ONLY.
72511	7251	S	SF	[EA]		TROOP HSG EMERGENCY FAC	N	THESE MAY BE HUTMENTS (QUONSETS), TENT FRAMES WITH FLOORS AND MAY BE PERMANENT, SEMI-PERMANENT, OR TEMPORARY TYPES OF FACILITIES. NO CRITERIA FOR THESE FACILITIES ARE CURRENTLY AVAILABLE. CODES ARE LISTED FOR INVENTORY PURPOSES ONLY.

730 COMMUNITY FAC-PERS SUPPORT

Municipal type facilities for support of the personnel component. Excludes morale, welfare, and recreation facilities in the 740 and 750 series.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
73010	7311	B	[SF]			FIRE STATION	Y	THIS CRITERIA APPLIES TO FIRE STATIONS WITH STRUCTURAL AND BRUSH FIRE MISSIONS AND IS TO BE USED AS A GUIDELINE FOR PLANNING FIRE STATIONS WITH AIR CRASH RESCUE OPS AND COMBINED STRUCTURAL FIRE AND RESCUE OPS. FIRE STATIONS CONSIST OF AN ALARM COM CENTER, TRAINING FACILITIES, LIVING QUARTERS, RECREATION/DINING FACILITIES, ADMIN OFFICES, AN EQUIPMENT MAINTENANCE AREA, AND AN APPARATUS ROOM.
73011	7311	B	SF	[EA]		FIRE HOSE DRYING STRUCTURE	N	CATEGORY CODE 730 11 AND 12 ARE FOR INVENTORY PURPOSES ONLY IN CASES WHERE THESE FACILITIES ARE PROVIDED IN A SEPARATE BUILDING OR STRUCTURE. FOR PLANNING PURPOSES, THEY ARE TO BE CONSIDERED AS PART OF THE FIRE STATION, CODE 730 10.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
73012	7311	B	[SF]			FIRE CART/HOSE DRYING FAC	N	CATEGORY CODE 730 11 AND 12 ARE FOR INVENTORY PURPOSES ONLY IN CASES WHERE THESE FACILITIES ARE PROVIDED IN A SEPARATE BUILDING OR STRUCTURE. FOR PLANNING PURPOSES, THEY ARE TO BE CONSIDERED AS PART OF THE FIRE STATION, CODE 730 10.
73013	7343	B	[SF]			ISSU/RETAIL CLOTHING/UNIFM	N	THIS IS A RETAIL OUTLET FOR MILITARY CLOTHING AND ACCESSORIES. THIS FACILITY IS OPERATED BY THE NAVY AND MARINE CORPS EXCHANGE SERVICE.
73015	7312	B	[SF]	PN		BRIG	Y	THIS CODE IS TO BE USED FOR FACILITIES WHOSE PRIMARY PURPOSE IS THE CONFINEMENT OF PERSONNEL.
73020	7313	B	[SF]			SEC BUILDING	Y	A SECURITY BUILDING WHICH HOUSES THE SHORE PATROL AND MILITARY OR CIVILIAN POLICE FORCES MAY VARY IN USE FROM A STANDARD POLICE STATION TO A LARGE SECURITY DEPARTMENT PROVIDING COUNTER-TERRORISM FUNCTIONS AND INVESTIGATIVE SERVICES.
73021	1498	B	[SF]			DEFENSIVE FIGHTING POS	Y	AN ELEVATED DEFENSIVE FIGHTING POSITION LOCATED AT ECP'S AND OTHER AREAS NEEDING ADDITIONAL ENTRY SECURITY.
73025	1498	B	[SF]			GATE / SENTRY HOUSE	Y	THE GATE/SENTRY HOUSE MAY VARY IN SIZE FROM A SIMPLE SENTRY SHELTER TO A BUILDING HOUSING A GATE GUARD OFFICE, CLERICAL OFFICE, AND WAITING ROOM; OR A TRUCK INSPECTION BUILDING.
73030	7321	B	[SF]			BAKERY	Y	THE ESTABLISHMENT OF BAKERIES IS GOVERNED BY PROVISIONS OF DOD INSTRUCTION 4100.33 ? COMMERCIAL OR INDUSTRIAL ACTIVITIES ? OPERATION OF. NORMALLY A BAKERY WILL BE AUTHORIZED WHERE COMMERCIAL SOURCES ARE NOT AVAILABLE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
73035	7382	B	[SF]	PN		LOCKER ROOM	Y	THIS FACILITY PROVIDES LOCKER SPACE FOR THE BELONGINGS OF MILITARY PERSONNEL WHO MUST VACATE THEIR QUARTERS FOR EXTENDED PERIODS OF TIME, FOR THOSE WHOSE ALLOTTED STORAGE SPACE IS NOT SUFFICIENT, AND FOR OTHER USES AS DEEMED JUSTIFIED BY THE COMMANDING OFFICER.
73036	7332	B	[SF]			LUNCH/LOCKER ROOM	Y	THIS FACILITY IS GENERALLY PROVIDED ONLY TO SUPPORT INDUSTRIAL OPERATIONS WHERE OTHER MESSING FACILITIES ARE NOT AVAILABLE AND REQUIRES SPECIFIC JUSTIFICATION.
73040	7342	B	[SF]			LAUNDRY/DRY CLEANING PLT	Y	LAUNDRY AND DRY CLEANING PLANTS. THE ESTABLISHMENT OF THESE FACILITIES IS GOVERNED BY PROVISIONS OF DOD INSTRUCTION 4100.33 - COMMERCIAL OR INDUSTRIAL ACTIVITIES - OPERATION OF. NORMALLY THEY WILL BE AUTHORIZED ONLY IN LOCATIONS WHERE COMMERCIAL FACILITIES ARE NOT AVAILABLE.
73061	7352	B	[SF]		PN	DEP SCHOOL - CONSOLIDATED	Y	DEPENDENT SCHOOL GRADES K-12. THE PLANNING AND PROGRAMMING FOR DEPENDENT SCHOOL FACILITIES OVERSEAS IS CURRENTLY UNDER THE COGNIZANCE OF DEPARTMENT OF DEFENSE EDUCATION ACTIVITY (DODEA). DEPENDENT SCHOOLS PROVIDE EDUCATION FOR DEPENDENTS OF MILITARY PERSONNEL.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
73065	7383	B	[SF]	PN		FALLOUT SHELTER	N	THERE ARE TWO KINDS OF FALLOUT SHELTERS: DUAL-PURPOSE AND SINGLE-PURPOSE. A DUAL-PURPOSE FALLOUT SHELTER HAS A PRIMARY PURPOSE AND SATISFIES SOME OTHER BASIC REQUIREMENT SUCH AS HOUSING, ADMINISTRATIVE, STORAGE, ETC., BUT IS DESIGNATED TO PROVIDE FALLOUT PROTECTION IN EMERGENCIES. A SINGLE-PURPOSE FALLOUT SHELTER IS A BUILDING OR PART OF A BUILDING WHOSE SINGULAR PURPOSE IS FALLOUT PROTECTION.
73066	7384	S	[SF]			MISC PERS WEATHER SHELTERS	Y	SHELTERS MAY BE ESTABLISHED AT BUS STOPS OR OTHER LOCATIONS AS REQUIRED. PROVIDE 0.5 SQ.M. (5 SF) PER PERSON.
73067	7341	B	[SF]			BUS STATION	Y	A BUS STATION IS A TERMINAL WITH SPACE FOR A WAITING ROOM AND BUS TICKET SALES. IT MAY BE PLANNED AS REQUIRED.
73074	7449	B	[SF]			KENNEL - MWR OPERATED	N	A TEMPORARY BOARDING FACILITY FOR DOGS AND CATS OPERATED BY MWR.
73075	7385	B	[SF]	PN		PUBLIC TOILET	N	USE THIS CODE FOR INVENTORY OF ALL DETACHED COMFORT STATIONS, SUCH AS THOSE AT BALL FIELDS AND PICNIC AREAS, EXCEPT FOR THOSE IN THE UNACCOMPANIED HOUSING AREA. USE CATEGORY CODE 723 20 LATRINE FOR THE UNACCOMPANIED HOUSING AREA.
73076	1445	B	[SF]			KENNEL	Y	USE THIS CATEGORY CODE FOR MILITARY WORKING DOG (MWD) KENNELS AND QUARANTINE FACILITIES OPERATED BY THE SECURITY DEPARTMENT.
73077	4421	B	[SF]			PERSONNEL SUPPT STRG(MISC)	Y	STORAGE FACILITIES FOR MISCELLANEOUS GOODS RELATED TO PERSONNEL SUPPORT FACILITIES.
73078	7322	B	[SF]			DAIRY PLANT	Y	A FACILITY FOR THE RECEIVING AND PROCESSING OF MILK AND MILK PRODUCTS.
73082	8331	S	[SF]		EA	RECYCLING CTR	Y	THIS FACILITY SERVES AS A COLLECTION, SORTING, STORAGE, AND SHIPPING CENTER FOR RECYCLABLE MATERIALS AND PRODUCTS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
73083	7361	B	[SF]		SE	RELIGIOUS MINISTRY FAC	Y	RELIGIOUS MINISTRY FACILITY (RMF) IS A GENERIC TERM FOR FACILITY ASSETS USED TO SUPPORT COMMAND RELIGIOUS PROGRAMS. RMFS MUST THEREFORE ACCOMMODATE THE RELIGIOUS RIGHTS AND NEEDS OF A MULTI-FAITH, INTER-GENERATIONAL, CULTURALLY DIVERSE MILITARY POPULATION.
73085	7344	B	[SF]			POST OFFICE	Y	FACILITY FOR HANDLING AND DISTRIBUTING US MAIL TO AN INSTALLATION, EITHER AS A STANDALONE FACILITY OR PART OF ANOTHER FACILITY UNDER A DIFFERENT CATEGORY CODE.
731								
732								
733								
734								
735						EDUCATION FAC MISC		
736								
737								
738								
740						COMM FAC-MOR,WEL&REC INTR		

Indoor, athletic, recreation, and exchange facilities.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74001	7346	B	[SF]			EXCHANGE RETAIL STORE	Y	THE EXCHANGE RETAIL STORE IS PLANNED AS PART OF AN AUTHORIZED NAVY OR MARINE CORPS EXCHANGE. THE STORE INCLUDES SALES AREA, IMMEDIATE BACK-UP STOCK AREA, STORE OFFICE, TOILETS AND CIRCULATION SPACE.
74003	7387	B	[SF]			EXCHGE CENTRL ADMIN	Y	THIS IS SPACE REQUIRED FOR THE GENERAL ADMINISTRATIVE EFFORT OF AN EXCHANGE SUCH AS ACCOUNTING, PAYROLL, PERSONNEL, PURCHASING OR WAREHOUSING.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74004	7331	B	[SF]			EXCHANGE / MWR FOOD SVC	Y	THESE FACILITIES INCLUDE: CAFETERIAS, SPECIALTY SHOPS SIMILAR TO DELI, FAST FOOD AND PIZZA, BAKE SHOPS, ICE CREAM SHOPS, ETC. FOOD SERVING FACILITIES OPERATED IN AND FOR THE SOLE CONVENIENCE OF NON-EXCHANGE ACTIVITIES SUCH AS BOWLING ALLEYS, THEATERS, AIR TERMINALS AND SIMILAR, IS ALREADY INCLUDED IN THE BASIC SPACE ALLOWANCE FOR SUCH ACTIVITIES.
74009	7346	B	[SF]			EXCHANGE SERVICE OUTLETS	Y	EXCHANGES ARE NAVY EXCHANGE SERVICEC COMMAND (NEXCOM) AUTHORIZED OUTLETS FOR BASIC SERVICES IN CONJUNCTION WITH THE RETAIL STORE, SUCH AS BARBER SHOP, TAILOR/UNIFORM SHOP, RADIO/TV REPAIR SHOP, PORTRAIT STUDIO, WATCH REPAIR SHOP, OPTICAL SHOP, BEAUTY SALON, AND PERSONAL SERVICES.
74011	7346	B	[SF]			NEX DEPOT (SERVMART)	Y	NEX DEPOTS ARE SIMILAR TO TRADITIONAL NAVY SERVMARTS, AND OFFER THE SAME TYPE OF INVENTORY, IN A MORE CONVENIENT SETTING. AN NEX DEPOT MAY BE PROVIDED AS DICTATED BY NEXCOM.
74012	6100	B	[SF]			RED CROSS/NAVY RELIEF	Y	SPACE PROVIDED WITHIN OTHER FACILITIES FOR THE RED CROSS AND NAVY RELIEF ORGANIZATIONS.
74013	7342	B	[SF]			EXCHANGE LAUNDRY DRY CL	Y	DRY CLEANING PLANT AND COIN LAUNDRY FACILITY OPERATED BY THE NAVY EXCHANGE SERVICE COMMAND (NEXCOM).
74016	7387	B	[SF]			EXCHANGE MAINTENANCE SHOP	Y	AN EXCHANGE MAINTENANCE SHOP MAY BE PROVIDED FOR THE LOCAL REPAIR OF EXCHANGE EQUIPMENT, FIXTURES REPAIR OF REFRIGERATION EQUIPMENT AND VENDING MACHINES, AND TO PROVIDE SHOP SPACE FOR FACILITY MAINTENANCE CREWS AND PERSONNEL.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74018	7347	B	[SF]			BANK	Y	BANKS MAY BE ESTABLISHED ONLY WHEN THEY ARE AUTHORIZED BY THE U.S. TREASURY DEPARTMENT. NORMALLY THERE WILL BE ONLY ONE BANKING FACILITY AT EACH INSTALLATION.
74019	7347	B	[SF]			CREDIT UNION	Y	CREDIT UNIONS ARE PRIVATE COOPERATIVE SAVINGS AND LOAN ORGANIZATIONS. FACILITIES FOR A PROPERLY CHARTERED CREDIT UNION MAY BE PROVIDED TO SERVE MILITARY PERSONNEL, THEIR DEPENDENTS, AND OTHER PERSONNEL AS PERMITTED IN THE BYLAWS OF THE CREDIT UNION.
74020	7441	B	[SF]			PCS OFFICIAL LODGING	N	THESE FACILITIES ARE LODGING PROVIDED AT A COST TO PERSONNEL WHO ARE WITHOUT HOUSING DUE TO EXECUTING PERMANENT CHANGE OF STATION (PCS) ORDERS. THESE FACILITIES MAY BE USED BY TEMPORARY DUTY OR LEISURE TRAVELERS. WHERE NEW CONSTRUCTION IS AUTHORIZED, CONSTRUCT MOTEL TYPE FACILITIES WITH BATH AND WITH KITCHENETTES. LIVING UNITS SHALL CONTAIN NO MORE THAN 450 SQUARE FEET OF LIVING AREA. APPROPRIATE CIRCULATION, ADMINISTRATION, MECHANICAL AND SERVICE SPACE WILL BE PROVIDED.
74021	7440	B	[SF]			VISITOR RECEPTN (RECRUIT)	Y	A VISITOR¿S RECEPTION CENTER IS LIMITED TO INSTALLATIONS PERFORMING BASIC TRAINING. IT SERVES AS A POINT OF CONTACT BETWEEN TRAINEES AND VISITING RELATIVES OR FRIENDS.
74023	7349	B	[SF]			COMMISSRY INC BACKUP STRG	Y	FACILITY USED FOR THE SALE OF PERISHABLE GOODS AND OTHER GROCERIES AND FOODSTUFFS. OPERATED BY THE DEFENSE COMMISSARY AGENCY (DECA).
74024	4321	B	[SF]		CF	COMMISSARY COLD STRG,DET	Y	DETACHED FACILITY USED FOR COLD STORAGE OF PERISHABLE ITEMS STOCKED FOR THE COMMISSARY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74025	7372	B	[SF]			FAMILY SERVICES CNTR	Y	THE FAMILY SERVICES CENTER (FSC) FACILITY SUPPORTS THE PROGRAMS THAT PROVIDE THE INFORMATION AND FAMILY SERVICES NECESSARY TO SUPPORT QUALIFIED SINGLE AND MARRIED DEPARTMENT OF DEFENSE (DOD) PERSONNEL AND THEIR FAMILY MEMBERS IN MEETING THE UNIQUE DEMANDS OF THE MILITARY LIFESTYLE, AS DEFINED BY DOD INSTRUCTION 1342.22, FAMILY CENTERS.
74027	1441	B	[SF]			ARMED FORCES RADIO/TV STA	Y	A RADIO AND/OR TV STATION IS NORMALLY ESTABLISHED IN OVERSEAS LOCATIONS TO PROVIDE U.S. INSTALLATION POPULATION WITH ENTERTAINMENT AND NEWS COVERAGE. AS A RULE, THE COVERAGE RADIUS IS LIMITED TO THE INSTALLATION AND IMMEDIATE VICINITY AND THE FACILITIES ARE RESTRICTED FOR TRANSMISSION OF PRERECORDED PROGRAM MATERIAL.
74028	7417	B	[SF]			AMUSEMENT CTR / REC MALL	Y	AMUSEMENT CENTERS ARE RECREATIONAL FACILITIES WHICH CATER LARGELY TO THE LEISURE NEEDS OF YOUNGER ACTIVE-DUTY PERSONNEL AND YOUTH FROM MILITARY FAMILIES.
74030	7345	B	[SF]		OL	EXCHGE AUTO REPAIR STA	Y	THIS FACILITY PROVIDES SPACE FOR GASOLINE AND OIL SALES, AUTOMOTIVE PARTS AND ACCESSORIES SALES, EMERGENCY SERVICE AND AUTOMOTIVE REPAIR SERVICE.
74032	7348	B	[SF]			EXCHANGE CAR WASH	Y	AN EXCHANGE OPERATED CAR WASH MAY BE PROVIDED AS DICTATED BY THE NAVY EXCHANGE SERVICE COMMAND. THE NAVY EXCHANGE NORMALLY OPERATES AUTOMATED, DRIVE-THRU CAR WASHES. FOR MWR (SELF SERVICE) CAR WASHES SEE CCN 740-91.
74034	7340	B	[SF]			THRIFT SHOP	Y	THIS IS A NONPROFIT FACILITY FOR THE SALE AND PURCHASE BY MILITARY PERSONNEL OF USED APPAREL, FURNISHINGS AND EQUIPMENT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74036	7411	B	[SF]			HOBBY SHOP - CRAFTECH	N	THIS FACILITY IS USED FOR THE PURSUIT OF WOODWORKING, PICTURE FRAMING, CERAMICS AND OTHER HOBBY PASTIMES. THIS CCN IS FOR INVENTORY PURPOSES ONLY.
74037	7446	B	[SF]			MWR OUTDOOR REC CTR	Y	THIS CATEGORY CODE APPLIES TO THREE TYPES OF FACILITIES: OUTDOOR ADVENTURE CENTERS (OAC), RENTAL CENTERS (RC), AND OUTDOOR CENTERS & OTHER RENTALS (OCOR). GENERALLY, OAC, RC, AND OCORS ARE FACILITIES THAT RENT AND/OR SELL GOODS THAT ARE ASSOCIATED WITH OUTDOOR ACTIVITIES AND OUTDOOR RECREATION PROGRAMS (ORP).
74038	7412	B	[SF]			MWR AUTO SKILLS CTR	Y	THE MISSION OF AUTOMOTIVE SKILLS CENTER IS TO PROVIDE THEIR CUSTOMERS WITH A QUALITY, VALUE-BASED PROGRAM FOR THE MAINTENANCE, REPAIR, MODIFICATION AND IMPROVEMENT OF THEIR OWN VEHICLES INCLUDING CARS, TRUCKS, TRAILERS, MOTORCYCLES, AND BICYCLES.
74040	7415	B	[SF]		LA	BOWLING CENTER	Y	BOWLING CENTERS ARE RECREATIONAL FACILITIES WHICH ACCOMMODATE BOWLING AND RELATED FUNCTIONS, WHICH MAY INCLUDE: OPEN BOWLING, LEAGUES, TOURNAMENTS, YOUTH BOWLING, INSTRUCTION, EXHIBITIONS, AND SUPPORT ACTIVITIES SUCH AS EQUIPMENT SALES AND RENTAL, FOOD AND BEVERAGE SERVICE, ELECTRONIC AND TABLE GAMES, AND MEETINGS.
74042	7417	B	[SF]			COMMUNITY REC CTR	Y	FORMERLY "FLEET REC CENTER". THESE ARE A CONSOLIDATION OF MULTIPLE CATEGORY B MWR ACTIVITIES INTO ONE FACILITY WHICH ALLOWS FOR REDUCED FOOTPRINT, OVERHEAD, AND STAFFING COSTS WHILE PROVIDING MORE CONVENIENT ACCESS TO A VARIETY OF RECREATIONAL PROGRAMS, SERVICES, AND FACILITIES FOR THE INSTALLATION COMMUNITY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74044	7421	B	[SF]			INDOOR PHYSICAL FIT CTR	Y	PHYSICAL FITNESS FACILITIES PROVIDE FACILITIES AND SUPPORT SERVICES TO MEET THE INDIVIDUAL PHYSICAL FITNESS, COORDINATION, SKILLS DEVELOPMENT, RECREATION AND TRAINING NEEDS OF MILITARY PERSONNEL.
74045	7421	B	[SF]			FITNESS ROOM	N	FITNESS ROOMS ARE STAND ALONE GYMNASIUM FACILITIES, USUALLY CARDIO EQUIPMENT AND WEIGHT MACHINES OR FREE WEIGHTS, IN A SINGLE AREA OF ROOMS WITHIN A FACILITY OF A DIFFERENT CCN. THIS CCN IS PRIMARILY FOR INVENTORY PURPOSES,
74046	7418	B	[SF]			ROLLER / ICE SKATING RINK	Y	THIS FACILITY SERVES AS A ROLLER/ICE SKATING RINK REQUIRING A HARD SURFACE FLOOR WITH POTENTIAL FOR MULTIPURPOSE USE.
74047	7446	B	[SF]			INFO, TKT TRAVEL OFFICE	Y	THE MISSION OF THE RECREATION INFORMATION, TICKETS AND TRAVEL (ITT) OFFICE IS TO SERVE THE MILITARY COMMUNITY'S LEISURE NEEDS BY PROVIDING INFORMATION ON WHAT TO SEE AND DO LOCALLY, OFFERING TOURS TO NEARBY ATTRACTIONS, SELLING TICKETS FOR MUSICAL AND THEATRICAL PERFORMANCES, AND OTHER SPECIAL EVENTS, AND PROVIDING OPTIONS FOR LEISURE TRAVEL (THIS MAY INCLUDE CRUISE AND AIRLINE TICKET SERVICE).
74049	7421	B	[SF]			AUSTERE FITNESS CENTER	Y	AUSTERE PHYSICAL FITNESS FACILITIES PROVIDE FACILITIES AND SUPPORT SERVICES TO MEET THE INDIVIDUAL PHYSICAL FITNESS, COORDINATION, SKILLS DEVELOPMENT, RECREATIONAL AND TRAINING NEEDS OF MILITARY PERSONNEL STATIONED IN DESIGNATED AUSTERE OPERATING ENVIRONMENTS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74052	7448	B	[SF]			GUN/SKEET/TRAP BLDG	Y	THIS FACILITY IS FOR SUPPORT OF THE RESPECTIVE RANGES AND CONTAINS OPERATOR'S OFFICE, STORAGE, SALES AREA, GUN MAINTENANCE SHOP, TOILETS AND LOUNGE.
74053	7422	B	[SF]		ME	SWIMMING POOL - INDOOR	Y	THE PRIMARY PURPOSE OF SWIMMING POOLS IS TO SUPPORT PHYSICAL READINESS PROGRAMS AS WELL AS INSTRUCTIONAL, INFORMAL AND INTRAMURAL ACTIVITIES, AND TO SERVE THE RECREATIONAL NEEDS OF ACTIVE-DUTY MILITARY PERSONNEL AND THEIR SPOUSES AND CHILDREN, RETIREES AND DOD AUTHORIZED CIVILIANS.
74054	7417	B	[SF]			MWR MIL REC CENTER	Y	THE MWR MILITARY RECREATION CENTER (MRC) HAS INCORPORATED THE FEATURES AND FUNCTIONS OF THE FLEET RECREATION CENTER IN ORDER TO DEFINE A FACILITY THAT SERVES THE RECREATIONAL NEEDS OF BOTH SHIP-BASED ENLISTED PERSONNEL AS WELL AS THOSE LIVING IN BACHELOR ENLISTED QUARTERS. THEY CONSIST OF SERVICES, FACILITIES, AND PROGRAMS INTENDED TO PROVIDE ALCOHOL-FREE AND TOBACCO-FREE RECREATIONAL ALTERNATIVES FOR 17- TO 25-YEAR OLDS. ALSO KNOWN AS LIBERTY OR SINGLE SAILOR CENTERS.
74055	7417	B	[SF]			YOUTH & SAC (6-18 YRS)	Y	THE YOUTH CENTER IS A SOCIAL AND RECREATIONAL CENTER PRIMARILY FOR USE BY CHILDREN AGES 6 TO 18 IN SUPPORT OF A YOUTH PROGRAM. THE YOUTH CENTER SUPPORTS OPPORTUNITIES FOR YOUTH TO DEVELOP THEIR PHYSICAL, SOCIAL, EMOTIONAL, AND COGNITIVE ABILITIES AND TO EXPERIENCE ACHIEVEMENT, LEADERSHIP, ENJOYMENT, FRIENDSHIP, AND RECOGNITION.
74056	7431	B	[SF]		SE	THEATER	Y	THIS CATCODE IS FOR A FACILITY FOR THE SHOWING OF MOVIES AND THE PRESENTATION OF STAGE PRODUCTIONS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74067	7333	B	[SF]			ALL HANDS CLUB	Y	THIS CODE IS USED TO PLAN THE SPACE REQUIREMENTS FOR A SINGLE FACILITY TO ACCOMMODATE ON-BASE FACILITIES, SURROUNDING COMPETITIVE ENVIRONMENT AND SIZE OF THE SUPPORTING POPULATION. IT MAY INCLUDE ONE OR MORE OF THE FOLLOWING COMPONENTS: TABLE SERVICE RESTAURANT, QUICK SERVICE RESTAURANT, BANQUET/CATERING ROOM, CAFETERIA, GAMING ROOM (OCONUS, NON-US), BEVERAGE LOUNGE WITH OR WITHOUT ENTERTAINMENT.
74068	7333	B	[SF]			MWR CATERING FACILITY	Y	THIS FACILITY MAY BE STAND ALONE OR COMBINED WITH AN OFFICERS CLUB, ENLISTED CLUB, ALL HANDS CLUB, BOWLING CENTER, MARINA CLUBHOUSE, OR GOLF CLUBHOUSE. THE CATERING FACILITY OFTEN INCLUDES BINGO OPERATIONS IN AT LEAST ONE ROOM.
74071	7346	B	[SF]			NEX PACKAGE STORE	Y	THIS FACILITY PROVIDES FOR RETAIL SALES TO AUTHORIZED CUSTOMERS AND THE TRANSFER (WHOLESALE) OF ALCOHOLIC BEVERAGES TO CLUBS AND OPEN MESSES. A SELECT FEW LOCATIONS HAVE PACKAGE STORES OPERATED BY MWR AS PERMITTED BY CONGRESS.
74074	7371	B	[SF]			CHILD DEVELOPMT CENTER	Y	CHILD DEVELOPMENT CENTERS PROVIDE CHILD CARE/DEVELOPMENT FOR CHILDREN AGES 6-WEEKS TO 6 YEARS OLD FOR FULL-DAY, PART-DAY, AND HOURLY CARE.
74075	7414	B	[SF]			NAVY FLYING CLUB FACILITY	Y	THE NAVY FLYING CLUB IS A RECREATIONAL FLYING ACTIVITY LOCATED ON OR NEAR MILITARY INSTALLATIONS USED BY AUTHORIZED PERSONNEL AND APPROVED BY THE DEPARTMENT CONCERNED.
74076	7416	B	[SF]			LIBRARY	Y	THIS FACILITY IS FOR RECREATIONAL READING AND STUDY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74077	4421	B	[SF]			MWR READY STOR	Y	STORAGE FACILITIES FOR MISCELLANEOUS EQUIPMENT AND/OR GOODS RELATED TO COMMUNITY SUPPORT WILL BE PROVIDED ONLY WHERE THEY CAN BE INDIVIDUALLY JUSTIFIED. THERE ARE NO CRITERIA FOR THIS TYPE OF FACILITY.
74078	7531	S	[SF]			RECREATION PAVILION	Y	THE PURPOSE OF THIS FACILITY IS TO SUPPORT RECREATION AREAS SUCH AS PARKS, PLAYGROUNDS, PICNIC AREAS, BEACHES, ETC. THIS FACILITY MAY INCLUDE LOUNGE, TOILETS, BATHHOUSES, STORAGE AREAS, SNACK BARS, AND/OR CONCESSION STAND FOR LIMITED AND RELATED ITEMS AS REQUIRED.
74079	7444	B	[SF]			RIDING STABLES	Y	PROVIDES SPACE FOR SINGLE STALLS, BOX OR DOUBLE STALLS, TREATMENT STALLS, QUARANTINE AREAS, QUARTERS FOR ONE OPERATOR, HAY STORAGE AREA, GRAIN ROOM, TACK LOCKERS, SWEAT PAD AND BLANKET DRYING AREA, OFFICE, AND TOILETS.
74080	7413	B	[SF]			GOLF CLUBHOUSE	Y	THIS FACILITY ACTS AS THE MAIN SERVICE AREA FOR THE GOLF COURSE. FOODSERVICE AND GOLF EQUIPMENT SALES ARE THE TWO PRIMARY FUNCTIONS OF THE CLUBHOUSE.
74081	7442	B	[SF]	EA		MWR RENTAL ACCOMMODATIONS	Y	MWR RENTAL ACCOMMODATIONS ARE PERMANENT, STAND-ALONE, OR MULTIPLEX BUILDINGS. THEY MAY TAKE THE FORM OF MODERN MOTELS, MULTI-LEVEL HOTELS, PRIMITIVE CAMPING CABINS WITH NO UTILITY CONNECTIONS, OR ALMOST ANYTHING IN BETWEEN, DEPENDING ON THE GEOGRAPHY, THE MARKET BEING SERVED, AND DEMAND.
74082	7448	B	[SF]			GOLF STOR MAINT FAC	Y	A GOLF STORAGE/MAINTENANCE FACILITY PROVIDES SPACE FOR MAINTENANCE,STORAGE, AND SUPPORTING SPACES ASSOCIATED WITH INSTALLATION GOLF COURSES OF NINE OR MORE HOLES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74085	7388	B	[SF]			EXCHGE DIST CTR (WRHSE)	Y	THIS TYPE WAREHOUSE MAY BE PROVIDED FOR BULK BACK-UP STORAGE (EXCHANGE STOCK AND OPERATING SUPPLIES) TO SUPPORT ALL EXCHANGE OPERATIONS WITHIN A GEOGRAPHICAL AREA AS DETERMINED BY NEXCOM OR MARINE CORPS EXCHANGE SERVICES.
74086	7388	B	[SF]			EXCHANGE INSTALLATION WHSE	Y	THIS CATCODE IS FOR THE TOTAL STORAGE SPACE THAT MAY BE PROVIDED IN INSTALLATION EXCHANGE WAREHOUSES TO ACCOMMODATE BACK-UP STORAGE FOR EXCHANGE RETAIL ACTIVITIES FOR THAT INSTALLATION.
74087	7445	B	[SF]			MARINA SUPPT BLDG	Y	THIS FACILITY PROVIDES SPACE FOR OFFICE, EQUIPMENT CHECK-OUT, REPAIR, AND STORAGE. IT DOES NOT INCLUDE DOCKS, MARINA SLIPS, AND WALKWAYS WHICH ARE LISTED UNDER CODE 750 60. THIS IS A SPECIAL FACILITY WHICH IS REQUIRED ONLY AT OUTDOOR RECREATION AREAS WHICH HAVE WATERFRONT FACILITIES AVAILABLE FOR BOATING ACTIVITIES.
74088	7351	B	[SF]			EDUCATIONAL SRVCS OFFICE	Y	THIS FACILITY IS INTENDED TO PROVIDE FACILITIES FOR THE ADVANCEMENT OF THE ACADEMIC, TECHNICAL, AND VOCATIONAL EDUCATION OF MILITARY PERSONNEL OF ALL GRADES AND RANKS IN ORDER TO ENHANCE THEIR POTENTIAL TO THE SERVICE.
74089	7385	B	[SF]			BATHHOUSE	Y	THE PRIMARY PURPOSE OF A BATHHOUSE IS TO PROVIDE A FACILITY FOR POOL AND BEACH USERS TO STORE THEIR BELONGINGS WHILE USING THE RECREATIONAL FACILITY, TO CLEAN UP, AND HAVE A PLACE TO USE THE RESTROOM. IN ADDITION, THE BATHHOUSE CONTAINS THE OFFICES FOR THE ADMINISTRATIVE STAFF AND LIFEGUARDS.
74090	7448	B	[SF]			MWR EQUIP MAINT SHOP	Y	AN MWR EQUIPMENT MAINTENANCE SHOP IS WHERE NAF VEHICLES AND GROUNDS MAINTENANCE EQUIPMENT (NON-GOLF), IS MAINTAINED.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74091	7348	B	[SF]			MWR CAR WASH	Y	A COIN OPERATED STAND ALONE CAR WASH AND VACUUM ISLAND OPERATED BY MWR.
74092	7443	B	[SF]			MWR RV SUPPORT BLDG	Y	RECREATIONAL RV PARKS PROVIDE THE MILITARY COMMUNITY WITH OUTDOOR RECREATION OPPORTUNITIES AT LOCATIONS WITH ATTRACTIVE NATURAL RESOURCES. TO COMPLEMENT THE CAMPING EXPERIENCE, AND DEPENDING ON LOCATION, RECREATIONAL RV PARKS MAY OFFER ACTIVITIES SUCH AS BOATING, CANOEING, FISHING, HIKING, HUNTING, SKIING AND SWIMMING.
74093	7384	S	SF	[EA]		SMOKING GAZEBO	N	SMOKING GAZEBO¿S ARE PROVIDED AS DESIGNATED SMOKING AREAS OUTSIDE OF NAVY AND MARINE CORPS FACILITIES. SIZE IS STANDARD. THIS CCN IS FOR INVENTORY PURPOSES.
74094	7441	B	[SF]	PN		TDY OFFICIAL LODGING	Y	THESE FACILITIES PROVIDE TEMPORARY LIVING ACCOMMODATIONS THAT INCLUDES IN-ROOM HOUSEKEEPING SERVICES AND AMENITIES SIMILAR TO A MID-GRADE HOTEL. SERVICE CHARGES ARE ASSESSED TO TDY TRAVELERS TO MANAGE OPERATIONAL AND RECAPITALIZATION REQUIREMENTS. TDY OFFICIAL LODGING MAY BE USED BY PERMANENT CHANGE OF STATION AND LEISURE TRAVELERS
74095	7441	B	[SF]	PN		LIM SVC OFFICIAL LODGING	Y	LIMITED SERVICE LODGING PROVIDES TRANSIENT FACILITIES FOR ACTIVE DUTY AND RESERVE MEMBERS (REGARDLESS OF RANK) OF DEPLOYED UNITS AT AN INSTALLATION OTHER THAN THE UNITS' HOMEPORT. THESE FACILITIES PROVIDE LIMITED IN-ROOM HOUSEKEEPING SERVICES AND AMENITIES COMMENSURATE WITH THE UNIT'S LENGTH OF STAY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
74097	7441	B	[SF]			FISHER HOUSE	N	DON FISHER HOUSES PROVIDE TEMPORARY, CONVENIENT, AND AFFORDABLE LODGING TO NAVY MEDICAL TREATMENT FACILITY (MTF) PATIENTS (¿WOUNDED WARRIORS¿), MEMBERS OF THE FAMILIES OF SUCH PATIENTS, AND OTHERS PROVIDING THE EQUIVALENT OF FAMILIAL SUPPORT FOR SUCH PATIENTS.
74098	6100	B	[SF]	PN		NGIS-OPERATED CONF CTR	N	CONFERENCE CENTERS OPERATED BY NAVY GATEWAY INNS AND SUITES
741								
742								
743								
744								
750						COMMUNITY FAC-MW&R-EXTER		

Outdoor, athletic, recreation, and exchange facilities.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
75010	7521	S		[EA]		OUTDOOR PLAYING COURTS	Y	OUTDOOR PLAYING COURTS PROVIDE FACILITIES AND SUPPORT SERVICES TO MEET THE INDIVIDUAL PHYSICAL FITNESS AND RECREATION NEEDS OF MILITARY PERSONNEL. THE FACILITIES MAY ALSO SERVE DEPENDENTS, RETIREES AND AUTHORIZED CIVILIANS.
75020	7522	S		[EA]		PLAYING FIELDS	Y	PLAYING FIELDS PROVIDE FACILITIES AND SUPPORT SERVICES TO MEET THE INDIVIDUAL PHYSICAL FITNESS, COORDINATION, SKILLS DEVELOPMENT, TRAINING AND RECREATION NEEDS OF MILITARY PERSONNEL. THE FACILITIES MAY ALSO SERVE DEPENDENTS, RETIREES AND AUTHORIZED CIVILIANS. ACTIVITIES WHICH MAY BE ACCOMMODATED IN PLAYING FIELDS INCLUDE: BASEBALL, FOOTBALL, SOCCER, SOFTBALL, TRACK AND FIELD, ETC.
75021	7521	S	SF	[EA]		BATTING CAGE	N	A SMALL ENCLOSED AREA WITH A PITCHING MACHINE OR OTHER PROVISION FOR PITCHING TO A BATTER TO ALLOW BATTING PRACTICE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
75022	7523	S		[MI]	EA	JOGGING TRACK	N	JOGGING TRACKS MAY BE PAVED OR A NATURAL SURFACE AND ARE PROVIDED FOR THE INDIVIDUAL PHYSICAL FITNESS AND RECREATION OF MILITARY PERSONNEL. JOGGING TRACKS ARE PROVIDED AND SIZED AS REQUIRED.
75023	7542	S		[MI]	EA	GO-CART TRACK	N	SMALL OVAL OR OTHER SHAPED PAVED TRACKS WHERE PARTICIPANTS RACE GASOLINE POWERED GO-CARTS.
75030	7512	S	SF	EA	[ME]	OUTDOOR SWIM POOL	Y	OUTDOOR POOLS MAY INCLUDE WATER PARK FEATURES AND SPRAY PARKS.
75033	7542	S		[EA]		DETACHED POOL FACILITY	N	THIS CATCODE IS USED IN THOSE CASES WHERE SUCH FACILITIES ARE LOCATED IN A BUILDING SEPARATE FROM THE MAIN POOL HOUSE.
75034	7512	S		[EA]		WADING POOL / SPLASH PL	N	WADING POOLS ARE SMALL SHALLOW POOLS GENERALLY FOR TODDLERS AND SMALL CHILDREN. THESE ARE NORMALLY PLANNED AS ADJUNCTS TO MAIN POOLS (SEE CC 740 53 SWIMMING POOL¿INDOOR). THIS CODE IS FOR INVENTORY PURPOSES AND ONLY IN THOSE CASES WHERE WADING POOLS ARE DETACHED FROM THE MAIN FACILITY.
75036	1351	LS		EA	[MI]	TV COMM LINES	N	CATEGORY CODES 750 35 AND 750 36 ARE FOR INVENTORY PURPOSES ONLY. SUCH FACILITIES ARE PROVIDED ONLY AT REMOTE INSTALLATIONS WHERE CENTRAL TV RECEPTION AND LOCAL DISTRIBUTION SYSTEMS CAN BE INDIVIDUALLY JUSTIFIED.
75037	7542	S		[EA]		OUTDR ADVENTR AREA	N	INCLUDES ROPES COURSES, NATURAL RECREATION FEATURES (ROCK CLIMBING, HIKING TRAILS, MOUNTAIN BIKE TRAILS, PAINTBALL RANGES, MOTOCROSS/BMX AREAS).
75038	4521	S	[SY]		EA	OUTDR MWR EQUIP RNTL STO	Y	OUTDOOR FENCED AREA WITH LIGHTING FOR STORAGE OF MWR RENTAL EQUIPMENT (NOT ENCLOSED). FACILITY SHOULD BE CO-LOCATED WITH THE OUTDOOR RECREATION CENTER CCN 740-37, IF THERE IS ONE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
75039	8523	LS	[SY]		EA	MWR VEH/ RV/ BOAT STO CPD	Y	THIS CATCODE IS FOR FENCED IN AREA FOR THE STORAGE OF PERSONAL WATER CRAFT, BOATS, TRAILERS, CAMPERS, MOTOR HOMES, ETC. AND OPERATED BY MWR.
75040	7513	S		EA	[HO]	GOLF COURSE	Y	GOLF COURSES ARE RECREATIONAL FACILITIES WHICH MAY ACCOMMODATE: RECREATIONAL GOLFING, PRACTICE, INSTRUCTION, TOURNAMENTS, EXHIBITIONS, SPECIAL EVENTS, AND WINTER RECREATIONAL ACTIVITIES SUCH AS CROSS-COUNTRY SKIING, ICE SKATING, SLEDDING AND TOBOGGANING.
75050	7532	S		EA	[SE]	OUTDOOR THEATER	Y	AN OUTDOOR THEATER MAY EITHER BE DRIVE OR WALK IN, AND IS USED PREDOMINANTLY TO SHOW FILMS.
75052	7542	S		[EA]		SKEET AND/OR TRAP RANGE	Y	A SHOOTING RANGE TO ENGAGE IS THE SPORTS OF SKEET AND TRAP SHOOTING. A BUILDING MAY BE INCLUDED IF THE FACILITY CAN BE SELF SUSTAINING.
75054	7531	S	SF	[EA]		BAND STAND	N	A RAISED PLATFORM USED BY BANDS OR FOR OTHER PUBLIC ENTERTAINMENT ACTIVITIES.
75056	7514	S		[EA]		GOLF DRIVING RANGE	Y	USUALLY ASSOCIATED WITH A GOLF COURSE, THIS FACILITY ALLOWS THE GOLFER TO PRACTICE HITTING GOLF BALLS.
75057	7516	S		[EA]		MWR REC GRNDS	Y	THIS FACILITY INCLUDES PARKS, PLAYGROUNDS, OR PICNIC AREAS AND RECREATION PAVILIONS (CODE 740 78). OPERATED BY MWR.
75058	7541	S	AC	[EA]		REC CAMPGRND TENT	Y	PLEASE SEE CCN 750-59 FOR GENERAL DESCRIPTION OF CAMPGROUND. THIS CCN WILL BE USED FOR TENT CAMPING, NO VEHICLE PADS ARE REQUIRED.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
75059	7541	S	[AC]		EA	REC CAMPGROUND - RV	Y	RECREATIONAL CAMPGROUNDS PROVIDE THE MILITARY COMMUNITY WITH OUTDOOR RECREATION OPPORTUNITIES AT LOCATIONS WITH ATTRACTIVE NATURAL RESOURCES. TO COMPLEMENT THE CAMPING EXPERIENCE, AND DEPENDING ON LOCATION, RECREATIONAL CAMPGROUNDS MAY OFFER ACTIVITIES SUCH AS BOATING, CANOEING, FISHING, HIKING, HUNTING, SKIING AND SWIMMING.
75060	7518	S		[EA]		MARINA/BOAT RAMP	Y	THIS CATCODE IS FOR A WATERFRONT FACILITY PROVIDING RENTAL BOATS, A BOAT LAUNCH, AND OTHER WATERFRONT AMENITIES. OPERATED BY MWR.
75061	7517	S		[EA]	LF	RECREATIONAL PIER	Y	THIS CCN IS USED FOR STAND-ALONE RECREATIONAL PIER FACILITIES (E.G. FISHING PIERS) WHERE THERE IS NO EXISTING MARINA.
751						OUTDOOR RECREATION FAC		
75110	7511	S		[EA]		PLAYGROUNDS	N	PLAYGROUNDS ARE OUTDOOR ACTIVITY AREAS PROVIDED FOR CHILDREN AND ARE AN INTEGRAL PART OF THE FUNCTIONS ASSOCIATED WITH SCHOOLS, FAMILY HOUSING AREAS, OUTDOOR ATHLETIC AND RECREATIONAL AREAS, AND CHILD DEVELOPMENT, SCHOOL AGE CARE AND YOUTH CENTERS.
752								
75240	7524	S		[EA]		ATHLETIC STADIUM	N	A SPORTS ARENA USED FOR ATHLETIC ACTIVITIES AND INCLUDES AN ATHLETIC FIELD AND PERMANENTLY CONSTRUCTUED FEATURES THAT CAN INCLUDE SPECTATOR SEATING, GRANDSTANDS, PRESS BOXES/ANNOUNCER BOOTHS, CONCESSIONS STANDS AND SUPPORTING FEATURES BASED ON THE ACTIVITY TYPE. LIGHTING AND FENCING ARE CAPTURED UNDER OTHER CCNS.
753								
754								

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
760						MUSEUMS AND MEMORIALS		
76010	7601	B	[SF]	EA		MUSEUMS / MEMORIAL BLDG	Y	NO SPECIFIC PLANNING FACTORS ARE AVAILABLE FOR THIS GROUP. REQUIREMENTS FOR EACH OF THE ABOVE FACILITIES WILL BE ESTABLISHED BASED ON INDIVIDUAL STUDIES AND SUPPORTING JUSTIFICATION. MUSEUMS MUST BE APPROVED BY SECNAV.
76020	7602	S		[EA]		OUTDOOR MONUMENT/MEMORIAL	N	THIS CATCODE IS FOR STATUES, MONUMENTS, PLAQUES ETC. COMMEMORATING SPECIAL EVENTS, LOCATIONS OR PEOPLE. THE OFFICE OF THE COMPTROLLER OF THE NAVY HAS RULED THAT THE USE OF APPROPRIATED FUNDS (INCLUDING OM&N FUNDS) FOR THE CONSTRUCTION AND MAINTENANCE OF MEMORIALS IS RESTRICTED TO THOSE MEMORIALS SPECIFICALLY APPROVED BY CONGRESSIONAL AUTHORITY.
76030	7603	S	AC	[EA]		CEMETERY	N	NO SPECIFIC PLANNING FACTORS ARE AVAILABLE FOR THIS GROUP. REQUIREMENTS FOR EACH OF THE ABOVE FACILITIES WILL BE ESTABLISHED BASED ON INDIVIDUAL STUDIES AND SUPPORTING JUSTIFICATION. SECNAV APPROVAL WILL BE REQUIRED.
800						UTILITIES & GROUND IMPRVMT		
810						ELECTRIC POWER		
811						ELECTRIC POWER-SOURCE		

Category Code Report (All Series)

Electric power for base facilities operation is normally derived from local commercial sources. Where commercial sources are used, transformer substations are required to transform the electrical energy to satisfy the station's load requirement. Where commercial electricity is not available, power plants will be planned. Standby generator plants are planned to provide adequate uninterrupted power supply in emergencies. Planning for power plants will include the building, the power generating equipment, and supporting appurtenances such as fuel storage for plant operation, auxiliary power, and switching stations.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
81109	8910	B	[SF]			ELECTRIC POWER PLANT BLDG	N	THIS CATEGORY CODE IS USED FOR BUILDINGS ASSOCIATED WITH AN ELECTRIC POWER PLANT INCLUDING CATEGORY CODES 811 10, 811 25, 811 45, 811 46, AND 81150.
81110	8111	S		[KW]		ELECTRIC PWR PLNT - DIESL	N	A CENTRAL PLANT FOR THE PRODUCTION OF ELECTRICITY USING DIESEL GENERATORS.
81125	8111	S		[KW]		ELECTRIC POWER PLANT-STEAM	N	A CENTRAL PLANT FOR THE PRODUCTION OF ELECTRICITY USING STEAM TURBINE GENERATORS.
81145	8111	S		[KW]		ELECTRIC POWER PLT-GAS TUR	N	A CENTRAL PLANT FOR THE PRODUCTION OF ELECTRICITY USING GAS FIRED TURBINE GENERATORS.
81146	8114	S		[KW]		WIND TURBINE	N	A SOURCE FOR THE PRODUCTION OF ELECTRICITY USING WIND TURBINES.
81150	8115	S		[KW]		ELEC POWER PHOTO SYSTM	N	A SOURCE FOR THE PRODUCTION OF ELECTRICITY USING PHOTOVOLTAIC PANELS.
81159	8910	B	[SF]			STANDBY GENERATOR BLDG	N	THIS CATEGORY CODE IS USED FOR BUILDINGS ASSOCIATED WITH A STANDBY GENERATOR PLANT (811 60).
81160	8112	S		[KW]		STANDBY GENERATOR PLANT	N	STANDBY GENERATORS ARE USED TO PROVIDE ELECTRICAL POWER WHEN THE NORMAL SOURCE OF POWER IS NOT AVAILABLE.

812 ELECT TRANSMSN/DISTR LINES

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Distribution and transmission lines are required to supply electricity to buildings, street lighting, floodlighting, and perimeter lighting. Lines may be either overhead or underground and will include poles, ductbanks, and controls to distribute electrical energy from the source to each using facility. Planning for distribution and transmission lines will require engineering calculation of critical power demand loads and future load growth. Airfield pavement lighting is planned as described under Category Code 136.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
81209	8910	B	[SF]			ELECTRIC DISTRBN BLDG	N	THIS CATEGORY CODE SHOULD BE USED FOR BUILDINGS ASSOCIATED WITH ELECTRIC DISTRIBUTION SYSTEM THAT ARE NOT INCLUDED UNDER SWITCHING STATION/SUBSTATION BUILDINGS, CATEGORY CODE 813 10.
81212	8133	S			[KV]	TRANSFORMERS	N	TRANSFORMERS TRANSFORM ELECTRICAL POWER ON THE PRIMARY SIDE TO A LOWER OR HIGHER VOLTAGE ON THE SECONDARY SIDE TO SERVE A FACILITY OR SEVERAL FACILITIES.
81220	8122	S		[LF]	EA	EXT LIGHTING, POLE MT	N	UNIFORM POLE MOUNTED ILLUMINATION AT INSTALLATIONS, INCLUDING PERIMETER AND INTERIOR LIGHTING.
81231	8121	LS			[LF]	OVERHD ELEC DIST LINES	N	THE OVERHEAD LINES ARE FOR THE TRANSMISSION OF ELECTRICAL POWER BETWEEN SOURCE, SUBSTATIONS AND SWITCHING STATIONS, AND END USERS.
81232	8123	LS			[LF]	UNDERGRD ELEC DIST LINES	N	THE UNDERGROUND LINES ARE FOR THE TRANSMISSION OF ELECTRICAL POWER BETWEEN SOURCE, SUBSTATIONS AND SWITCHING STATIONS, AND END USERS.

813 ELECTRIC PWR-SUB/SWTCH STA

This Category Code is used for the buildings associated with a substation or switching station (813 20 or 813 30). These are the buildings that contain the switchgear, batteries, charging panels and other equipment located within the substation or switching station.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
81310	8910	B	[SF]			SWITCHG SUB/SUBSTA BLDG	N	THIS CATEGORY CODE IS USED FOR THE BUILDINGS ASSOCIATED WITH A SUBSTATION OR SWITCHING STATION (813 20 OR 813 30).

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
81320	8131	S		[KV]		SUBSTATIONS	N	DISTRIBUTION SUBSTATIONS, NORMALLY CONSISTING OF TRANSFORMERS AND THEIR ASSOCIATED SWITCHGEAR, STRUCTURES, BUSES, GROUNDING SYSTEMS, AND PROTECTIVE DEVICES; TRANSFORM ELECTRICAL POWER TO A LOWER OR HIGHER VOLTAGE AND PUT IT ON THE DISTRIBUTION SYSTEM.
81330	8132	S		[KV]	EA	SWITCHG STA/SECT DIST CIRC	N	A SWITCHING STATION IS EQUIPMENT IN AN ELECTRIC DISTRIBUTION SYSTEM WHERE ELECTRIC POWER IS SWITCHED WITHOUT TRANSFORMATION. SWITCHING STATIONS ARE LOCATED AT POINTS WHERE IT IS NECESSARY TO BRANCH OFF FROM A MAIN FEEDER OR FEEDERS WITH SMALLER COMPONENTS DUE TO PHYSICAL LOCATION OF THE FACILITIES TO BE SERVED OR TO ISOLATE PORTIONS OF FEEDERS FOR MAINTENANCE OR REPAIR.
81340	8134	S		[EA]		LGHTNG PROT SYS	N	STANDALONE LIGHTNING PROTECTION SYSTEMS ARE THOSE THAT ARE NOT INCLUDED AS PART OF A SPECIFIC FACILITY'S INSTALLED EQUIPMENT. THESE ARE USUALLY CONSTRUCTED TO PROTECT A COMPOUND, A SINGLE BUILDING (WHERE THE SYSTEM IS CONSTRUCTED OF MASTS AND IS NOT A PART OF THE FACILITY) OR SERIES OF BUILDINGS. UM IS "EA", WHICH CONSTITUTES UP TO FOUR LIGHTNING PROTECTION MASTS/STRUCTURES. FOR SYSTEMS WITH MORE THAN FOUR, INCREASE UM QUANTITY ACCORDINGLY.
820						HEAT & REFRIGERATION(A/C)		
821						HEAT-SOURCE		

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

The source of heat from steam or high temperature water (HTW) includes a complete central plant and associated fuel storage. The source of heat and steam/HTW are coded to indicate the type of fuel used by the plant. A central heating plant will include a structure, piping, equipment, controls, fuel, storage, and all equipment necessary to make a complete usable facility. Central heating plants are justified only when the total owning and operating costs for central plants and distribution systems are less than similar costs for heating systems in individual buildings. Central heating plants are also justified when the overall energy use for providing heat from extraction steam in a steam-electric-power plant would be less than a central plant plus purchased electricity. The type of fuel for the plant, whether an electric power generating plant with by-product heat and steam, or a heating plant, will be selected on the basis of an economic analysis. The heating plant capacity will be based on BTU rating, and this rating will be determined from an engineering analysis of the need for steam, heat, and hot water at the station.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
82109	8910	B	[SF]			HEATING PLANT BUILDING	N	THIS CATEGORY CODE IS USED FOR BUILDINGS ASSOCIATED WITH A HEATING PLANT INCLUDING CATEGORY CODES 821 12, 821 22, OR 821 30.
82112	8211	S		[BH]		HTG PLNT - OIL/GAS	N	THIS CATEGORY CODE IS USED FOR A PLANT THAT UTILIZES OIL OR GAS FOR THE PRODUCTION AND DISTRIBUTION OF HEAT. THIS INCLUDES STEAM, HOT WATER, HIGH PRESSURE/LOW PRESSURE, ETC., SERVING MORE THAN ONE SEPARATE FACILITY.
82122	8211	S		[BH]		HTG PLNT-COAL	N	THIS CATEGORY CODE IS USED FOR A PLANT THAT UTILIZES COAL FOR THE PRODUCTION AND DISTRIBUTION OF HEAT. THIS INCLUDES STEAM, HOT WATER, HIGH PRESSURE/LOW PRESSURE, ETC., SERVING MORE THAN ONE SEPARATE FACILITY.
82130	8211	S		[BH]		NON-FOSL FUEL HTG PLT	N	THIS CATEGORY CODE IS USED FOR A PLANT THAT UTILIZES A NON-FOSSIL FUEL FOR THE PRODUCTION AND DISTRIBUTION OF HEAT. THIS INCLUDES STEAM, HOT WATER, HIGH PRESSURE/LOW PRESSURE, ETC., SERVING MORE THAN ONE SEPARATE FACILITY.

Report Date: 27-JUN-2019 08:33:51

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
82140	8211	S		[BH]		NUCLEAR STEAM PLANT-ALL	N	THIS CATEGORY CODE IS USED FOR A PLANT THAT UTILIZES NUCLEAR FUEL FOR THE PRODUCTION AND DISTRIBUTION OF HEAT. THIS INCLUDES STEAM, HOT WATER, HIGH PRESSURE/LOW PRESSURE, ETC., SERVING MORE THAN ONE SEPARATE FACILITY.
82150	8211	S		[BH]		NON-NUCLEAR STEAM PLANT	N	TO BE DELETED
82160	1244	S		[GA]		DISTILATE HEATING FUEL OIL	N	THIS CATEGORY CODE IS USED FOR FUEL OIL TANKS USED FOR HEATING BUILDINGS, GENERATION OF STEAM, POWER PLANT REQUIREMENTS, AND FOR OTHER HEAT GENERATING FACILITIES AS REQUIRED.
82161	1244	S		[GA]		RESIDUAL HEATING OIL STG	N	THIS CATEGORY CODE IS USED FOR FUEL OIL TANKS USED FOR HEATING BUILDINGS, GENERATION OF STEAM, POWER PLANT REQUIREMENTS, AND FOR OTHER HEAT GENERATING FACILITIES AS REQUIRED. NO. 4 FUEL OIL, NO. 5 FUEL OIL AND NO. 6 FUEL OIL ARE VARIOUSLY REFERRED TO AS RESIDUAL FUEL OILS.

822 HEAT-TRNSMSN/DISTR LINES

This basic category encompasses the transmission and distribution lines for steam and associated hot water lines throughout an installation. In temperate and tropical climates and at locations where the water table is high, steam lines will be aboveground. Routing of steam or hot water lines requiring underground installation under runways and taxiways should be held to a minimum to avoid interference by maintenance and repair operations. Adequate clearances shall be provided above roads, railroads, streets, walks, and tow-ways.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
82209	8910	B	[SF]			STEAM DIST SYSTEM BLDG	N	BUILDINGS ASSOCIATED WITH A HEATING DISTRIBUTION SYSTEM (CATEGORY CODES 822 12, 822 14, 822 16 OR 822 26). THE REQUIREMENT FOR STEAM AND CONDENSATE OR HOT WATER PIPELINES IS DETERMINED FROM AN ENGINEERING STUDY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
82210	8924	S		[EA]		COND RETURN PUMP STATION	N	PUMP STATIONS ARE UTILIZED TO PUMP CONDENSED STEAM (CONDENSATE) BACK TO THE STEAM PLANT OR OTHER FACILITY.
82212	8221	LS		[LF]		STEAM LINES	N	THIS CATEGORY CODE CONTAINS ALL DISTRIBUTION SYSTEM PIPES THAT CONVEY STEAM. THE REQUIREMENT FOR STEAM AND CONDENSATE OR HOT WATER PIPELINES IS DETERMINED FROM AN ENGINEERING STUDY.
82214	8221	LS		[LF]		CONDENSATE LINE	N	THIS CATEGORY CODE CONTAINS ALL COLLECTION SYSTEM PIPES THAT CONVEY CONDENSATE. THE REQUIREMENT FOR STEAM AND CONDENSATE OR HOT WATER PIPELINES IS DETERMINED FROM AN ENGINEERING STUDY.
82216	8221	LS		[LF]		HOT WATER LINES	N	THIS CATEGORY CODE CONTAINS ALL PIPES THAT CONVEY HOT WATER LESS THAN 250 DEGREES. THE REQUIREMENT FOR STEAM AND CONDENSATE OR HOT WATER PIPELINES IS DETERMINED FROM AN ENGINEERING STUDY.
82226	8221	LS		[LF]		HIGH TEMP HOT WTR LINES	N	THIS CATEGORY CODE CONTAINS ALL PIPES THAT CONVEY HOT WATER HEATED ABOVE 250 DEGREES. THE REQUIREMENT FOR STEAM AND CONDENSATE OR HOT WATER PIPELINES IS DETERMINED FROM AN ENGINEERING STUDY.

823 HEAT, GAS - SOURCE

This basic category includes a central plant for generation of gas and related facilities including connected fuel storage for plant operation and storage of gas for direct heating or as a fuel for central plants. An engineering study is needed to determine the requirements for receipt, storage, distribution and vaporizing capacities of Liquefied Petroleum Gases (LPG).

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
82309	8910	B	[SF]			GAS GENERATING BUILDING	N	THIS CATEGORY CODE CONTAINS BUILDINGS ASSOCIATED WITH A GAS GENERATING PLANT.
82310	8231	S		[BH]	CM	GAS GENERATING PLANT	N	THIS CATEGORY CODE CONTAINS PLANT EQUIPMENT THAT GENERATES GAS FOR USE IN THE UTILITY SYSTEM.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
82315	8910	B	[SF]			GAS METER BLDG	N	THIS CATEGORY CODE CONTAINS BUILDINGS ASSOCIATED WITH GAS METERING.
82320	8232	S		EA	[CF]	GAS STORAGE TANKS	N	THIS CATEGORY CODE CONTAINS TANKS FOR THE STORAGE OF LIQUID NATURAL GAS AND/OR PROPANE CONNECTED TO A GAS DISTRIBUTION SYSTEM SERVING MULTIPLE FACILITIES.

824 HEAT, GAS - TRANSMISSION

This basic category applies to exterior lines, mains, and systems for transmission of gas for direct heating or as fuel for central plants.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
82410	8241	LS		[LF]		GAS MAINS	N	THIS CATEGORY CODE IS FOR THE MAIN GAS LINES (PIPES) THAT CARRY THE BULK OF THE GAS TO AND FROM FACILITIES AT AN INSTALLATION.

826 REFRIGERATION/AIR CONDTNG

This category code group is for chilled water and air conditioning plants Exclude cold storage facilities (see Category Code 430 series).

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
82610	8910	B	[SF]	TN		COOLING SYS PLANT BLDG	N	BUILDINGS ASSOCIATED WITH A COOLING SYSTEM PLANT (CATEGORY CODE 826 20).
82620	8261	S		[TR]		COOLING SYSTEM PLANT	N	A PLANT FOR THE PRODUCTION AND DISTRIBUTION OF A CHILLED FLUID FOR MORE THAN ONE SEPARATE FACILITY.

827 C/W-A/C TRNSMSN/DISTRBN

This basic category encompasses the transmission/distribution of chilled water from a central refrigeration/air conditioning plant to buildings throughout an installation for space air conditioning with water being returned to the plant. Routing of chilled water lines under runways, taxiways, and buildings should be held to a minimum to avoid interference by maintenance and repair operations to the chilled water lines. If lines are located above ground, adequate clearances shall be provided above roads, railroads, walks and tow-ways.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
82710	8910	B	[SF]			COOLING SYS VALVE BLDG	N	BUILDINGS ASSOCIATED WITH A COOLING DISTRIBUTION SYSTEM (CATEGORY CODE 827 20).
82720	8271	LS		[LF]		CHILLED FLUID LINES	N	THIS CATEGORY CODE INCLUDES ASSETS PREVIOUSLY CONTAINED IN CCN 827 25.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
830						SEWAGE AND WASTE		

Category group 830 describes the facilities required for the collection, transportation, treatment, and disposal of sewage and industrial waste, and disposal of storm drainage water in storm and sanitary sewer systems. Components of sewage and refuse facilities include sewage treatment plants, outfall sewer lines, septic tanks, septic tank drain fields, sanitary sewers, sewage pumping stations, and incinerators. Certain industrial waste must be kept separately and treated separately from the sanitary sewage. In planning for sewage and waste facilities cognizance shall be taken of the Federal Water Pollution Control Act as amended, applicable to municipalities, industries, and others that may contribute to the pollution of surface and underground waters in the United States.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
831						SEWAGE-IND WASTE TRTMT&DSP		

Plant Buildings, and sanitary sewage treatment plant will be necessary to provide for the processing of sanitary sewage for ultimate disposal. Disposal of sewage is usually in a stream or other body of water or on land by subsurface irrigation or by direct absorption into the soil. A sewage treatment plant may include aeration tanks or trickling filters, settling basins, sump or storage wells, dry wells, pumps, screens, and accessories. The type and capacity of sewage treatment plant is determined by an engineering study that considers planned population, number of family quarters, and industrial peak loads.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
83109	8910	B	[SF]			SWGE TRMT BLDG	N	THIS CATEGORY CODE INCLUDES THE BUILDINGS ASSOCIATED WITH THE SEWAGE TREATMENT PLANT (CATEGORY CODE 831 10).
83110	8311	S		[KG]		SWGE TRMT PLT	N	THIS CATEGORY CODE IS USED FOR ALL TYPE OF SEWAGE TREATMENT PLANTS; PRIMARY, SECONDARY, OR TERTIARY.
83111	8313	S		[KG]		BALLAST CONTAMTN SKMR	N	A FACILITY TO REMOVE GREASE, OIL, AND OTHER CONTAMINENTS FROM THE WATER REMOVED FROM SHIP BALLAST TANKS.
83114	8910	B	[SF]			INDUSTRY WAST TREATMT BLDG	N	THIS CATEGORY CODE IS USED FOR BUILDINGS ASSOCIATED WITH AN INDUSTRIAL WASTEWATER TREATMENT PLANT (CATEGORY CODE 831 15).

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
83115	8312	S		[KG]		INDUSTRY WAST TREATMT FAC	N	THIS CAT CODE IS USED FOR A DEDICATED INDUSTRIAL WASTEWATER TREATMENT PLANT. ALL THE PLANT EQUIPMENT; EQUALIZATION, PRELIMINARY TREATMENT, CLARIFICATION, HOLDING TANKS, BIOLOGICAL TREATMENT, CHEMICAL TREATMENT, FILTRATION, DISINFECTION, DEWATERING, DIGESTION, SLUDGE DISPOSAL, ELECTRICAL SYSTEM, CONTROLS, COMPRESSED AIR, STORAGE, AND COMS, IS INCLUDED AS A SINGLE WASTEWATER TREATMENT PLANT.
83116	8313	S			[KG]	OIL / WATER SEPARATOR	N	THIS CATEGORY CODE IS USED FOR OIL/WATER SEPARATORS THAT DISCHARGE TO THE SANITARY SEWER OR INDUSTRIAL WASTE COLLECTION SYSTEM. OIL/WATER SEPARATORS BELONG TO THE FACILITY WHICH IT SERVES.
83120	8321	LS		[KG]	LF	OUTFALL SEWER LINE	N	AN OUTFALL SANITARY SEWER LINE RECEIVES THE SEWAGE FROM A COLLECTING SYSTEM OR THE EFFLUENT FROM A SANITARY SEWAGE PLANT AND CARRIES IT TO A POINT OF FINAL DISCHARGE. PLANNING FOR OUTFALL SEWER LINES WILL INCLUDE LAND ACQUISITION.
83130	8314	S		KG	[GA]	SEPTIC TANK/DRAIN FIELD	N	A SEPTIC TANK AND DRAIN FIELD FACILITY PROVIDES SEWAGE TREATMENT FOR HUMAN WASTE AT ISOLATED FACILITIES WHERE AN EXTENSION OF THE CENTRAL SEWER COLLECTION SYSTEM WOULD NOT BE ECONOMICALLY FEASIBLE. A SEPTIC TANK AND DRAIN FIELD WILL INCLUDE A CONCRETE OR PROTECTED STEEL TANK, A DRAIN FIELD SYSTEM INCLUDING HEADERS, LATERALS, OPEN JOINT CLAY OR CONCRETE PIPE, GRAVEL, DITCHING, AND LAND ACQUISITION.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
83131	8315	S		GA	[KG]	SEPTIC LAGOON &/OR POND	N	A STRUCTURE USED FOR COLLECTING AND HOLDING SEWAGE TO ALLOW FOR SETTLEMENT AND EVAPORATION. THESE STRUCTURES ARE TYPICALLY CONCRETE ENCASED.
83139	8910	B	[SF]			RADIOACTV WASTE HANDL BLDG	N	RADIOACTIVE WASTE HANDLING BUILDING.
83140	8926	S		[EA]		RADIOACTV WASTE HANDL FAC	N	RADIOACTIVE WASTE HANDLING FACILITY.
83141	8926	S	[SF]		EA	HAZARD WSTE STOR & TRANSFR	N	A STORAGE FACILITY FOR THE CONTAINMENT AND SHIPMENT OF HAZARDOUS WASTES. CAN BE SHORT TERM (HW STORAGE LESS THAN 90 DAYS) OR LONG TERM (HW STORAGE 90 DAYS OR MORE).
83142	8926	S	[SY]		EA	HAZARD WASTE STORAGE AREA	N	AN EXTERIOR LAYDOWN AREA FOR THE STORAGE OF HAZARDOUS WASTE MATERIALS THAT DO NOT POSE ANY THREATS TO THE ENVIRONMENT VIA CONTAMINATED RUNOFF.
83143	4423	B	[SF]			HAZ WASTE BLDG	Y	A BUILDING THAT HAS BEEN PROPERLY CERTIFIED TO STORE SUBSTANCES THAT CANNOT LEGALLY BE DISPOSED OF IN A NORMAL SANITARY LANDFILL OR INTO A REFUSE INCINERATOR DESIGNATED TO HANDLE MUNICIPAL TYPE REFUSE, OR CANNOT BE DISCHARGED INTO A SANITARY SEWERAGE SYSTEM.

832 SEWAGE/IND WASTE COLLECTN

This basic category includes collection systems and lines including pumping stations for sewage and industrial waste and collection of storm drainage in combined storm and sanitary sewer systems. Planning for the sanitary sewer system will include piping, fittings, pumps, lift stations, and accessories. A sanitary sewer collection system will be required at all Naval installations and it will be based primarily on the population. The requirements will be determined by an engineering survey.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
83210	8321	LS		[LF]		SANITARY SEWER LINE	N	ALL DISTRIBUTION SYSTEM PIPES THAT COLLECT AND TRANSPORT SANITARY SEWAGE. TYPES INCLUDE GRAVITY OR FORCED MAIN SYSTEMS.
83220	8321	LS		[LF]		COMBINED SEWER LINE	N	ALL DISTRIBUTION PIPES THAT COLLECT AND TRANSPORT BOTH SANITARY SEWAGE AND STORM WATER.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
83229	8910	B	[SF]			SEWAGE PUMP STA BLDG	N	BUILDINGS ASSOCIATED WITH A SEWAGE PUMP STATION. THE PRIMARY UNIT OF MEASURE IS SQUARE FEET (SF).
83230	8316	S		EA	[GM]	SEWAGE WASTE PUMPG STA	N	A SEWAGE PUMPING STATION IS A FACILITY USED TO MOVE SEWAGE THROUGH MAINS TO A TREATMENT PLANT, TO SERVE WHERE A GRAVITY SYSTEM IS NOT FEASIBLE, AND/OR TO LIFT SEWAGE FROM ONE LEVEL TO ANOTHER IN A GRAVITY SYSTEM.
83231	8316	S		[EA]		SEWAGE LIFT STATIONS	N	A SEWAGE LIFT STATION IS A FACILITY USED TO MOVE SEWAGE THROUGH MAINS TO A TREATMENT PLANT, TO SERVE WHERE A GRAVITY SYSTEM IS NOT FEASIBLE, AND/OR TO LIFT SEWAGE FROM ONE LEVEL TO ANOTHER IN A GRAVITY SYSTEM.
83240	8321	LS		[LF]		INDUSTRIAL WASTEWTR LN	N	THIS CATEGORY CODE INCLUDES ALL DISTRIBUTION SYSTEM PIPES THAT COLLECT AND TRANSPORT INDUSTRIAL WASTEWATER. TYPES INCLUDE GRAVITY OR FORCED MAIN.
83241	8316	S		[EA]		IND WASTE WATER PUMP STAT	N	FACILITIES USED TO TRANSPORT WASTE STREAMS TO HOLDING TANKS OR INDUSTRIAL WASTE TREATMENT PLANTS, TO SERVE WHERE A GRAVITY SYSTEM IS NOT FEASIBLE, AND/OR TO LIFT WASTE STREAMS FROM ONE LEVEL TO ANOTHER IN A GRAVITY SYSTEM.
833						SOLID WASTE HANDLING FAC		
83309	8332	S	SF	[TH]		INCINRTR BLDG & INCINRTR	N	BUILDINGS ASSOCIATED WITH AN INCINERATOR. AN INCINERATOR IS A FACILITY FOR BURNING COMBUSTIBLE REFUSE TO REDUCE IT TO STABLE GASES AND INERT SOLIDS.
83310	8332	S		[TH]		INCINERATOR - EXTERIOR	N	AN INCINERATOR IS A FACILITY FOR BURNING COMBUSTIBLE REFUSE TO REDUCE IT TO STABLE GASES AND INERT SOLIDS. AN EXTERIOR INCINERATOR IS ONE THAT IS NOT ENCLOSED IN A STRUCTURE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
83315	8333	S	AC	[EA]		SANITARY/CUT-FIL DISP AREA	N	LANDFILLS ARE LINED (USUALLY WITH CLAY) EXCAVATIONS IN WHICH SOLID WASTES ARE BURIED, COVERED AND MONITORED. LANDFILLING SOLID WASTE IS THE TECHNOLOGY OF LAST RESORT. CONSULT EPA AND STATE REGULATIONS AND THE LATEST SOLID WASTE TEXT BOOKS FOR ENGINEERING PRINCIPLES AND PRACTICES IN SITING AND SCOPING A LANDFILL.
83320	8331	S	SF	[TN]	EA	GARBAGE GRINDER BLDG	N	A GARBAGE GRINDER FACILITY THAT IS FULLY ENCLOSED BY A BUILDING.
83321	8331	S		[TN]	EA	GARBAGE GRINDER	N	A GARBAGE GRINDER FACILITY THAT IS PARTIALLY ENCLOSED BY AN OPEN STRUCTURE.
83330	8526	LS	SY	[EA]		GARBAGE STAND	N	AN OPEN STRUCTURE USED TO PARTIALLY ENCLOSE TRASH RECEPTACLES, USUALLY DUMPSTERS.
83340	8910	B	[SF]			GARBAGE/RECYCLE BUILDING	N	SMALL BUILDING USED FOR TEMPORARY STORAGE OF TRASH OR RECYCLABLES PRIOR TO REMOVAL AND PROCESSING BY A COLLECTION SERVICE.

840 WATER

Water facilities at naval installations shall provide sufficient quantities of potable water for domestic and industrial use; purification of raw water from deep wells, lakes, and rivers; storage of water in bulk storage tanks or reservoirs; and distribution of water to demand areas. Facilities included are Wells, pre-treatment supply mains, pumping, treatment and filtration plants, plant buildings, tanks, and storage for potable water. For separate fire protection systems, see basic category code 843.

841 POTABLE WATER-SUP/TMT/STRG

Category Code Report (All Series)

Planning for the treatment of water will include, as applicable, screening, settling, coagulation and sedimentation, filtration, disinfection, softening, and aeration. The water treatment systems are normally planned in millions of gallons (MG) per day capacity and distribution is in linear feet (LF). The systems must be adequate to meet the domestic and industrial requirements and to provide fire protection if a separate fire protection system is not provided. If separate demand (see Code 843). Planning requirements for water treatment facilities will be based on the results of an engineering survey and an economic analysis to determined sources of water versus commercial or municipal supply.nonpotable water protective systems are not provided, the capacity of the water supply system will be determined by the fire flow

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
84109	8910	B	[SF]			WATER TREATMENT FAC BLDG	N	THIS CATEGORY CODE INCLUDES BUILDINGS ASSOCIATED WITH A WATER TREATMENT PLANT (841 10), DESALINIZATION PLANT (841 25), OR WELLS - POTABLE WATER (841 50).
84110	8412	S		[KG]		WATER TREATMENT FACILITIES	N	A WATER TREATMENT PLANT IS A FACILITY THAT TREATS WATER TO MAKE IT SAFE FOR HUMAN CONSUMPTION (POTABLE). THIS CATEGORY CODE INCLUDES THE STRUCTURES, EQUIPMENT, AND PROCESSES REQUIRED TO TREAT POTABLE WATER. WATER TREATMENT PLANT BUILDINGS ARE CLASSIFIED AS 841 09.
84115	8412	S		[KG]		NUCL WATER TREATMT FAC	N	NO CRITERIA FOR THIS FACILITY ARE CURRENTLY AVAILABLE.
84120	8421	LS		[LF]	GM	WATER SUPPLY LINE	N	THE PIPE THAT CONVEYS WATER FROM SOURCE TO POINT OF TREATMENT OR TO THE POINT OF CONSUMPTION. A PRESSURE MAIN WILL BE NEEDED IF THE WATER IS PUMPED. HOWEVER, IF TOPOGRAPHY PERMITS, A GRAVITY SYSTEM IS PLANNED.
84125	8415	S		[KG]		DESALINIZATION PLANT	N	A WATER TREATMENT PLANT THAT UTILIZES A PROCESS, SUCH AS DISTILLATION, REVERSE OSMOSIS, OR ELECTRO DIALYSIS, THAT REMOVES DISSOLVED MINERAL SALTS AND OTHER DISSOLVED SOLIDS FROM WATER.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
84130	8413	S			[GA]	ELEVTD POTABLE WATER TANK	N	WATER STORAGE TANKS FOR POTABLE WATER ARE ELEVATED OR GROUND-LEVEL STRUCTURES USED TO STORE BULK QUANTITIES OF POTABLE WATER. ELEVATED TANKS FOR POTABLE WATER PROVIDE BOTH STORAGE AND STATIC PRESSURE FOR THE DISTRIBUTION SYSTEM. GROUND-LEVEL TANKS ACCOMMODATE PEAK DEMAND REQUIREMENTS WITHOUT AFFECTING THE CAPABILITY OF THE SOURCE.
84140	8413	S			[GA]	GRND LVL POTABL WATER TANK	N	WATER STORAGE TANKS FOR POTABLE WATER ARE ELEVATED OR GROUND-LEVEL STRUCTURES USED TO STORE BULK QUANTITIES OF POTABLE WATER. ELEVATED TANKS FOR POTABLE WATER PROVIDE BOTH STORAGE AND STATIC PRESSURE FOR THE DISTRIBUTION SYSTEM. GROUND-LEVEL TANKS ACCOMMODATE PEAK DEMAND REQUIREMENTS WITHOUT AFFECTING THE CAPABILITY OF THE SOURCE.
84150	8414	S		[KG]	GM	WATER WELLS - POTABLE	N	EQUIPMENT THAT PUMPS WATER FROM UNDERGROUND SOURCES TO TREATMENTS PLANTS OR DIRECTLY TO DISTRIBUTION WITH MINOR TREATMENT.
84151	8443	S			[MG]	RESERVOIR - POTABLE WATER	N	AN OPEN BODY OF WATER FOR THE COLLECTION AND STORAGE OF WATER USED BY A WATER TREATMENT FACILITY OR WATER DISTRIBUTION SYSTEM.
84152	8442	S	SY	LF	[GA]	WATER CATCHMENT STRUCTURE	N	A MAN-MADE STRUCTURE DESIGNED TO CAPTURE OR COLLECT RAINWATER AND USED TO PRODUCE POTABLE WATER.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

Potable water will be transmitted from a storage tank or a treatment plant to all station demand points through a pipeline. An engineering study of the pressures and quantities of water required at the demands points will serve as the basis for planning the sizes and lengths of pipe required for the water distribution pipelines. Planning for a potable water distribution pipeline will include requirements for piping, valves, pumps, connections, excavation, and backfilling. The pipeline shall be listed in linear feet (LF). Requirements will be determined by an engineering study.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
84209	8910	B	[SF]			WATER DISTRIBTN BLDG, PTBL	N	ALL BUILDINGS ASSOCIATED WITH THE DISTRIBUTION OF POTABLE WATER. POTABLE WATER WILL BE TRANSMITTED FROM A STORAGE TANK OR A TREATMENT PLANT TO ALL STATION DEMAND POINTS THROUGH A PIPELINE. THIS CATEGORY CODE INCLUDES BUILDINGS ASSOCIATED WITH THE DISTRIBUTION OF POTABLE WATER, TYPICALLY HOUSING DISTRIBUTION PUMPS AND EQUIPMENT.
84210	8421	LS		[LF]		WATER DISTBTN LINE, POTBL	N	ALL PIPES THAT CONVEY POTABLE WATER FROM THE TREATMENT PLANT TO THE END USER.
84215	8422	S		KG	[GM]	PUMP STATION - POTABLE	N	THIS CATEGORY CODE WILL INCLUDE THE PUMP(S) AND APPURTENANT PIPING, VALVES, AND OTHER MECHANICAL AND ELECTRICAL EQUIPMENT FOR PUMPING WATER IN THE POTABLE WATER SYSTEM.

843 WATER, FIRE PROTECTION

Fire protection requirements often dominate the plans of a water supply system. When the supply of fresh water is not adequate, salt water may be used. Since fire flow demands are usually greater than either the domestic or industrial demands, the capacity of the system will generally be determined by the fire flow demands. Fire flows are expressed in gallons per minute and are separate from the other water requirements.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
84310	8432	LS		[LF]		FIRE PROTECTION LINES	N	FIRE PROTECTION PIPELINES ARE USED EXCLUSIVELY IN THE TRANSMISSION OF WATER FOR FIRE PROTECTION, NOT DOMESTIC USE.
84320	8434	S		KG	[GM]	FIRE PROTECTION PUMPG STA	N	A FIRE PROTECTION PUMPING STATION IS A COLLECTION OF PUMPS AND SUPPORTING EQUIPMENT USED TO INCREASE THE PRESSURE IN THE FIRE PROTECTION SYSTEM.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
84330	8435	S		MG	[GA]	FIRE PROTECTION WATER TANK	N	TANKS THAT PROVIDE FIRE PROTECTION WATER STORAGE TO ACCOMMODATE PEAK DEMAND REQUIREMENTS.
84335	8433	S			[MG]	FIRE PROTECTION RESERVOIR	N	THIS CATEGORY CODE IS FOR A RESERVOIR THAT HAS A CAPACITY GREATER THAN OR EQUAL TO ONE MILLION GALLONS AND TYPICALLY PROVIDES A SUFFICIENT QUANTITY OF WATER IN RESERVE TO INSURE AN UNINTERRUPTED FLOW FOR FIRE PROTECTION.
84340	8431	S			[GM]	FIRE PROTECTION WATER WELL	N	THIS CATEGORY CODE IS FOR EQUIPMENT THAT PUMPS WATER FROM UNDERGROUND SOURCES TO THE FIRE PROTECTION SYSTEM.
84350	8910	B	[SF]			FIRE PROTECTION BLDG	N	THIS CATEGORY CODE INCLUDES BUILDINGS ASSOCIATED WITH THE DISTRIBUTION OF FIRE PROTECTION WATER, TYPICALLY HOUSING DISTRIBUTION PUMPS AND EQUIPMENT.

844 WATER SUPPLY/STRG-NONPOTBL

The water from these facilities will be used primarily for industrial purposes or as an emergency supply should there be a failure of the principal source. When a requirement for nonpotable water source exists, firefighting water requirements usually will be combined with this group. Requirements for this facility group are similar to that for Category Group 841 and 843.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
84410	8910	B	[SF]			WATER DIST BLDG, NONPOTB	N	THIS CATEGORY CODE INCLUDES ALL BUILDINGS ASSOCIATED WITH THE SUPPLY OR DISTRIBUTION OF NONPOTABLE WATER, TYPICALLY HOUSING DISTRIBUTION PUMPS AND EQUIPMENT.
84420	8441	S		[KG]		WELLS - NONPOTABLE WATER	N	THIS CATEGORY CODE INCLUDES EQUIPMENT THAT PUMPS WATER FROM UNDERGROUND SOURCES TO A DEDICATED NONPOTABLE WATER DISTRIBUTION SYSTEM.
84430	8452	S		[KG]		PUMP STA - NONPOTBL	N	THIS CATEGORY CODE INCLUDES THE COLLECTION OF PUMPS AND SUPPORTING EQUIPMENT USED TO SUPPLY WATER TO THE NONPOTABLE WATER SYSTEM

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
84440	8442	S			[GA]	STORAGE TANKS-NONPOTBL WTR	N	THIS CATEGORY CODE INCLUDES TANKS THAT PROVIDE NONPOTABLE WATER STORAGE TO ACCOMMODATE PEAK DEMAND REQUIREMENTS.
84450	8443	S			[MG]	RESERVOIRS-NONPOTBL WATER	N	THIS CATEGORY CODE INCLUDES A RESERVOIR THAT HAS A CAPACITY GREATER THAN OR EQUAL TO ONE MILLION GALLONS AND TYPICALLY PROVIDES A SUFFICIENT QUANTITY OF WATER IN RESERVE TO INSURE AN UNINTERRUPTED FLOW FOR NONPOTABLE WATER REQUIREMENTS.

845 WATER-DISTRBN SYS NONPOTBL

Facilities in this group support non-potable water supply systems and are similar to those described under Category Group 842.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
84520	8451	LS		[LF]		PIPELINE-NONPOTABLE WATER	N	THIS CATEGORY CODE INCLUDES ALL PIPES THAT TRANSMIT WATER IN A DEDICATED NONPOTABLE WATER DISTRIBUTION SYSTEM.

850 ROADS AND STREETS

851 ROADS

Roads, streets, and I ncidental parking area, curbs and gutters and culverts for vehicular traffic, including highway and vehicular bridges.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
85110	8511	LS	[SY]	MI		ROADS	N	ROADS, STREETS, AND BRIDGES ARE GENERALLY PLANNED TO CONFORM TO THE STANDARDS AND PRACTICES OF THE AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS (AASHO), BUREAU OF PUBLIC ROADS (BPR), AND STATE AND LOCAL GOVERNMENTS.
85111	8512	LS	[SY]		MI	ROADS, UNSURFACED	N	VEHICULAR ROADWAYS THAT DO NOT HAVE A PERMANENT/IMPERVIOUS SURFACE SUCH AS ASPHALT OR CONCRETE.
85115	8928	S	[SF]	EA		LOAD / UNLOAD RAMP	N	A RAMP, USUALLY CONCRETE OR STEEL/IRON THAT IS UTILIZED TO ASSIST IN THE LOADING OF TRUCKS AND RAILCARS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
85120	8513	S	[SY]	LF		VEHICULAR BRIDGES	N	BRIDGES ARE GENERALLY USED TO CROSS AREAS OF DIFFERING ELEVATIONS. GENERALLY THEY ARE PLANNED TO CONFORM TO THE STANDARDS AND PRACTICES OF THE AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS (AASHO), BUREAU OF PUBLIC ROADS (BPR), AND STATE AND LOCAL GOVERNMENTS.
85121	8522	LS	[SY]			VEH. PARK, UNSURFACED	Y	AN AREA FOR PARKING PRIVATE AND/OR GOVERNMENT OWNED VEHICLES AND EQUIPMENT THAT DO NOT HAVE A PERMANENT/IMPERVIOUS SURFACE SUCH AS ASPHALT OR CONCRETE.
85122	8523	LS	[SY]			VEHICLE STAGING AREA	N	AN AREA, PAVED OR UNPAVED, THAT IS FOR TEMPORARY STORAGE OF VEHICLES PRIOR TO SHIPMENT OR FURTHER DEPLOYMENT.
85123	8541	S		[EA]		TRAFFIC CONTROL SIGNALS	N	DEVICES USED FOR DIRECTING PEDESTRIAN, VEHICULAR OR RAIL TRAFFIC BY MEANS OF POWER-OPERATED CONTROLS. COSTS INCLUDE SIGNAL DEVICES, NECESSARY SUPPORTS, AND ELECTRIC POWER CABLES AND ARE COUNTED PER INTERSECTION.
85125	8514	LS			[LF]	VEHICULAR TUNNEL	N	VEHICULAR TUNNELS ARE USED FOR SLOPE STABILIZATION AND AUTOMOBILE ACCESS IN AREAS WHERE STEEP SLOPES LIMIT DEVELOPMENT AND REQUIRE INNOVATIVE ACCESS SOLUTIONS. THESE TUNNELS SERVE VEHICULAR AND PEDESTRIAN TRAFFIC AS WELL AS HOUSING UTILITY RUNS.

852 SIDEWALKS & OTHER PAVEMENT

Walks and stairs for pedestrian traffic including pedestrian bridges, separate parking lots, and paved or stabilized areas for vehicular use and work or service areas.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
85210	8521	LS	[SY]			PARKING AREA	Y	THE PAVED AND/OR STABILIZED AREA WITHIN AN ORGANIZATIONAL MOTOR POOL AND PARKING LOT,
85215	7384	S	[SF]			BICYCLE SHELTER	Y	A STRUCTURE USED FOR TEMPORARY PARKING OF BICYCLES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
85220	8524	S	[SY]			SIDEWALK	N	A PATHWAY CONSTRUCTED TO SUPPORT PEDESTRIAN TRAFFIC. CONSTRUCTION IS OF CONCRETE, ASPHALT, PAVING BLOCKS, GRAVEL, OR THE LIKE.
85230	8525	S	[SY]	LF		PEDESTRIAN BRIDGES	N	BRIDGES THAT SUPPORT WALKWAY CROSSING OF A RIVER, UNDERPASS, OR SIMILAR GAP.
85235	8526	LS	[SY]			OTHER PAVED AREA	N	THIS CODE IS FOR MISCELLANEOUS VEHICULAR PAVEMENTS NOT CAPTURED IN OTHER 100 OR 400 SERIES CATEGORY CODES.
85240	8526	LS	[SY]			MISC OPEN STRG/LAYDOWN	N	THIS CODE IS FOR OPEN STORAGE AREAS OTHER THAN THOSE USED FOR GENERAL SUPPLY OPERATIONS (CATEGORY CODE 451 10). IT INCLUDES PUBLIC WORKS OPEN STORAGE FACILITIES.
85241	8526	LS	SY	[EA]		BLDG/TRLR PAD W/ UTIL CNCT	N	PAVED SURFACE CONSTRUCTED TO SUPPORT A TEMPORARY FACILITY OR TRAILER. UTILITY CONNECTIONS ARE PART OF THE TRAILER PAD REQUIREMENTS AND ALLOW TEMPORARY FACILITIES (OFTEN CLASS 3 PROPERTY) TO BE EASILY INSTALLED.

853 PARKING BLDG

A structure or building designed for parking private and/or government owned vehicles and equipment in individual parking spots/locations. The facility may be above ground or underground. The parking building should be justified by land restrictions and economic considerations. Allow 33 m2/ 40 SY for each passenger vehicle.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
85310	8531	S	[SF]	VE		PARKING BLDG	Y	A STRUCTURE OR BUILDING DESIGNED FOR PARKING PRIVATE AND/OR GOVERNMENT OWNED VEHICLES AND EQUIPMENT IN INDIVIDUAL PARKING SPOTS/LOCATIONS. THE FACILITY MAY BE ABOVE GROUND OR UNDERGROUND. THE PARKING BUILDING SHOULD BE JUSTIFIED BY LAND RESTRICTIONS AND ECONOMIC CONSIDERATIONS.

854

860 RAILROADS

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION

This category group covers all two-rail tracks including spurs, sidings, yards, turnouts, with accessories and appurtenances such as barricades. It includes trackage on ship repair facilities, marine railways and portal crane structures.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
86010	8601	LS		[MI]		RAILROAD TRACKAGE	N	RAIL TRACK TO INCLUDE SPURS, SIDINGS, YARDS, AND TURNOUTS. TRACK INCLUDES TWO PARALLEL RAILS, CROSSTIES, AND ROADBED.
86020	1495	S		[EA]		EXPLOSV BARICD,TRUCK/CAR	N	A CONCRETE AND EARTHEN STRUCTURE PLACED ALONGSIDE A SUSPECT CARGO SITE FOR TRUCKS AND RAILCARS CONTAINING AMMUNITION OR EXPLOSIVES THAT ARE SUSPECTED OF BEING IN A HAZARDOUS CONDITION.
86030	8611	S		[MI]	LF	RR BRIDGE&TRESTLE	N	BRIDGES THAT SUPPORT RAILROAD TRACK CROSSING OF A RIVER, ROAD UNDERPASS, OR SIMILAR GAP.
86040	8601	LS		[MI]		CRANE TRACKAGE	N	TRACKAGE USED IN OPERATIONAL AREAS TO ALLOW CRANE TRAVEL BETWEEN OPERATIONAL FACILITIES OR WATERFRONT AREAS SUCH AS PIERS AND WHARVES.
86041	8923	S	[SF]	EA		RAILROAD SCALEHOUSE	N	A RAILROAD SCALEHOUSE IS A FACILITY DESIGNED TO WEIGH RAIL CARGO. TYPICALLY, TRACKS ARE LAID TO ALLOW RAILCARS TO BE PULLED THROUGH THE SCALEHOUSE.

861

870 GROUND IMPROVEMENT STRC

This category group includes drainage and storm sewer systems, bo

871 GROUNDS, DRAINAGE

Drainage and storm sewer systems including appurtenant dykes, dams, and retaining walls. For combined storm and sanitary sewer systems, use basic category codes 831 and 832.

CATEGORY CODE	FAC CODE	RPA TYPE	AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
87110	8321	LS		[LF]		STORM SEWER	N	STORM SEWERS ARE COMPONENTS OF A STORM DRAINAGE SYSTEM THAT COLLECTS THE SURFACE RUNOFF WATER AND CONVEYS IT TO OUTLET POINTS.
87111	8313	S		[KG]		OIL/WATER SEPARATOR-RUNOFF	N	OIL/WATER SEPARATOR USED FOR SEPARATING PETROLEUM CONTAMINANTS FROM STORMWATER PRIOR TO BEING REINTRODUCED INTO THE NATURAL ENVIRONMENT.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
87115	8452	S		[EA]	KG	STORM WATER PUMPING STA	N	PUMP STATION FACILITY USED FOR MOVING STORMWATER RUNOFF FROM ONE ELEVATION/LOCATION TO ANOTHER.
87116	8715	S			[MG]	STORM WATER POND	N	A STORM WATER RETENTION POND IS UTILIZED TO CONTAIN AND CONTROL STORM WATER RUNOFF AT A PREDETERMINED RATE.
87120	8711	LS		[LF]		DRAIN DITCH,EXC ROAD DITCH	N	DRAINAGE DITCHES SERVE THE SAME PURPOSE AS STORM SEWERS. THEY ARE PREFERABLE TO COVERED STRUCTURES TO MINIMIZE CONSTRUCTION, TO CONSERVE MATERIALS, AND TO FACILITATE MAINTENANCE.
87125	8714	S		[LF]	EA	DYKE / DAM	N	A DAM IS AN ARTIFICIAL OR NATURAL BARRIER USUALLY CONSTRUCTED ACROSS A STREAM CHANNEL TO IMPOUND WATER.
87126	8714	S		LF	[EA]	LEVEE &/OR DIKE	N	A LEVEE IS A TYPE OF DAM THAT RUNS ALONG THE BANKS OF A RIVER OR CANAL. LEVEES REINFORCE THE BANKS AND HELP PREVENT FLOODING.
87130	8451	LS		EA	[LF]	IRRIGATION FACILITY	N	THESE FACILITIES ARE USED TO SUPPLY WATER TO AREAS THAT NEED WATER ABOVE THE AMOUNT OF NATURAL RAINFALL. THEY CAN CONSIST OF A SERIES OF PUMPS, PIPES AND OTHER ASSOCIATED EQUIPMENT.
87135	8712	S		[LF]		RETAINING WALL	N	A STRUCTURE CONSTRUCTED TO RESTRICT OR PREVENT THE HORIZONTAL MOVEMENT OF EARTH.
87145	8714	S		EA	[LF]	DREDGED SPOIL HNDLG FAC	N	FACILITY FOR STORAGE OF DREDGE SPOILS PRIOR TO PROCESSING AND REMOVAL.
872						FENCING/WALLS/GUARD TOWERS		

Category Code Report (All Series)

This basic category provides boundary security in the form of fencing, walls, gates, watch towers, guard walks, and guard shelters. The type and amount of security planned is a function of the security classification required, and the economical utilization of security guards.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
87210	8721	LS		[LF]		SECURTY/PERIMTR FENCE/WALL	N	SECURITY FENCING AND WALLS DEFINE THE LIMITS OF SECURITY AREAS AND FACILITATE THE EFFECTIVE AND ECONOMICAL USE OF SECURITY PERSONNEL. FENCING IS PLANNED ON THE BASIS OF A STUDY OF THE SECURITY CLASSIFICATION REQUIREMENTS OF THE INSTALLATION.
87211	8722	LS			[LF]	HARDENED SEC FENCE	N	A LINEAR STRUCTURE INTENDED TO RESTRICT ACCESS TO A SPECIFIC AREA OR TO RESTRICT AND DIRECT THE FLOW OF TRAFFIC. THESE STRUCTURES INCLUDE HARDENING OR SPECIAL CHARACTERISTIC BEYOND STANDARD FENCES AND WALLS SUCH AS INTRUSION DETECTION, RAZOR WIRE, OR BARRIER IMPACT/PENETRATION RESISTANCE MEASURES.
87215	8721	LS		[LF]		INTERIOR FENCE*EXC 87210*	N	MISCELLANEOUS FENCING INTERIOR TO AN INSTALLATION PERIMETER FENCE. THIS CATEGORY CODE IS FOR INVENTORY PURPOSES ONLY.
87220	1734	S	SF	[EA]		GUARD AND WATCH TOWERS	N	WHERE AUTHORIZED, GUARD OR WATCHTOWERS SHOULD BE CONSTRUCTED AT LOCATIONS THAT WILL PROVIDE THE BEST OBSERVATION OF SECURITY AREAS.
87230	1458	S			[EA]	MECH SEC BARRICADE	N	MECHANICALLY OPERATED BARRICADE CONSISTING OF POP-UP BOLLARDS, RISING ROAD PLATES, OR WEDGES DESIGNED TO CONTROL VEHICLULAR OR OTHER TRAFFIC. UNIT OF MEASURE IS EA AND INCLUDES DEVICES USED FOR A SINGLE TRAFFIC LANE.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
This basic category includes separate integral signal systems such as fire alarm, watch reporting, and security. Telephone reporting systems are planned with telephone systems (see Code 130).								
88010	1351	LS		[MI]		FIRE ALARM COMM LINES	N	THIS CATEGORY CODE IS USED TO CAPTURE THE FIRE ALARM REPORTING SYSTEM RELATED COMMUNICATION LINES THAT ARE EXTERIOR TO THE BUILDINGS THEY SERVE. FACILITY FIRE ALARM EQUIPMENT AND RELATED BUILDING INFRASTRUCTURE ARE EITHER RPIE OR PPE AND ARE NOT INCLUDED IN THIS CATEGORY CODE.
88020	1351	LS		[MI]		WATCH RPTG SYSTEM LINES	N	A WATCH REPORTING SYSTEM PROVIDES A METHOD FOR THE AUTOMATIC AND NON-AUTOMATIC DETECTION OF FIRE AND FOR SECURITY PROTECTION (INTRUSION DETECTION SYSTEM) THROUGHOUT DESIGNATED AREAS, BUILDINGS, AND STRUCTURES. THE WATCH REPORTING SYSTEM PROVIDES LOCAL ALARMS AND CENTRAL STATION ALARMS TO BUILDING OCCUPANTS AND TO STATION SECURITY AND FIREFIGHTING PERSONNEL.
88030	1351	LS		[MI]		BASE ALERT SYSTEMS LINES	N	BASE ALERT SYSTEMS SHALL BE PLANNED FOR ALL NAVY INSTALLATIONS. THE SYSTEM MAY ALERT BASE PERSONNEL TO AIR RAIDS, CHEMICAL/BIOLOGICAL ATTACKS OR ANY OTHER TYPE OF TERRORIST ATTACK. HORNS OF HIGH-POWER TYPE MAY BE USED AS SIGNAL DEVICES.
88040	1351	LS		[MI]		AIR CRASH/ALERT COMM LINES	N	ALARM SYSTEM INTENDED TO ALERT IN THE EVENT OF AN AIR CRASH
881								
882								
883								
890						MISCELLANEOUS UTILITIES		

Category Code Report (All Series)

This Category Code is used for structures associated with public works utilities shops and other miscellaneous utility buildings. If a utility building cannot be classified under one of the other utility type buildings, this Category Code should be used.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
89009	8910	B	[SF]			MISC UTILITY BLDG	N	THIS CATEGORY CODE IS USED FOR BUILDINGS ASSOCIATED WITH PUBLIC WORKS UTILITIES SHOPS AND OTHER MISCELLANEOUS UTILITY BUILDINGS. IF A UTILITY BUILDING CANNOT BE CLASSIFIED UNDER ONE OF THE OTHER UTILITY TYPE BUILDINGS, THIS CATEGORY CODE SHOULD BE USED.
89011	8930	LS		[LF]		ACETYLENE DISTRBTN SYSTEM	N	THE DISTRIBUTION SYSTEM FOR ACETYLENE GAS GENERATED BY THE ACETYLENE PLANT IN CCN 89010.
89015	8921	S		[EA]		NITROGEN PLANT	N	NITROGEN IS USED WHERE AN INERT GAS IS REQUIRED. A NITROGEN PLANT IS REQUIRED FOR THE PROVISION OF LARGE QUANTITIES OF NITROGEN FOR SPECIAL APPLICATIONS.
89018	8927	S		[EA]		UTILITY VAULT	N	A UTILITY VAULT IS AN ENCLOSED STRUCTURE GENERALLY MADE OF CONCRETE THAT CONTAINS UTILITY EQUIPMENT, CONNECTIONS AND/OR LINES. A UTILITY VAULT IS TYPICALLY AN UNDERGROUND STRUCTURE.
89020	8921	S		[EA]		COMPRESSED AIR PLANT	N	COMPRESSED AIR IS USED BY THE NAVY IN NUMEROUS APPLICATIONS, SUCH AS FOR PNEUMATIC TOOLS, LAUNDRY EQUIPMENT, INSTRUMENTATION AND CONTROL EQUIPMENT, AND IN HOSPITALS AND LABORATORIES.
89021	8930	LS		[LF]		COMPD AIR DISTRBTN SYSTEM	N	COMPRESSED AIR IS USED BY THE NAVY IN NUMEROUS APPLICATIONS, SUCH AS FOR PNEUMATIC TOOLS, LAUNDRY EQUIPMENT, INSTRUMENTATION AND CONTROL EQUIPMENT, AND IN HOSPITALS AND LABORATORIES.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
89025	8921	S		[EA]		CARBON DIOXIDE PLANT	N	A CARBON DIOXIDE PLANT AT A NAVAL ACTIVITY PROVIDES SPACE FOR THE STORAGE AND TRANSFER OF CARBON DIOXIDE. THE SPACE CONTAINS A STORAGE TANK AND A DISTRIBUTION SYSTEM USED FOR REFILLING CARBON DIOXIDE FIRE EXTINGUISHERS.
89027	7322	B	SF	[TR]		ICE-MAKING PLANT	N	FACILITY FOR THE CREATION AND DISTRIBUTION OF ICE.
89030	8921	S		[EA]		INDUSTRIAL OXYGEN PLANT	N	FACILITY USED TO GENERATE OXYGEN (NON-BREATHABLE) FOR INDUSTRIAL USE WHERE IT IS OTHERWISE UNAVAILABLE.
89031	8930	LS		[LF]		OXYGEN DISTRIBUTION SYSTEM	N	PUMPS, PIPES AND LINES ASSOCIATED WITH THE DISTRIBUTION OF INDUSTRIAL OXYGEN PRODUCED BY THE INDUSTRIAL OXYGEN PLANT IN CCN 89030.
89045	8910	B	[SF]			VALVE HSE,OTHER ENCLOSURE	N	THIS CATEGORY CODE IS USED FOR ANY ENCLOSURE USED FOR HOUSING VALVES OR OTHER UTILITY EQUIPMENT THAT IS NOT CONTAINED IN ANY OTHER CCN.
89046	8931	LS		[LF]		UTILITY TUNNEL	N	THIS CATEGORY CODE IS USED FOR A TUNNEL IN WHICH UTILITY SYSTEMS ARE ROUTED. THERE MAY BE MULTIPLE UTILITY SYSTEMS IN A SINGLE TUNNEL NETWORK.
89050	1351	LS		[MI]		ICS COMM LINES	N	This CCN applies to the communication links portion of an Industrial Control System (ICS). An ICS manages and moves data to provide real-time operational capability, real time consumption, demand management, energy reduction and maintenance savings opportunities, and increases the reliability and efficiency associated with building and utility systems at shore installations.
89051	8910	B	[SF]			ICS MON STA	Y	AN ICS MONITORING STATION IS USED TO MONITOR AND CONTROL MECHANICAL SYSTEMS OF FACILITIES AT REMOTE LOCATIONS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
89056	8923	S		[EA]		WEIGHTING FACILITY	N	VEHICULAR SCALES TYPICALLY USED FOR WEIGHING TRANSPORT TRUCKS AND CONTAINERS AT AN INSTALLATION.
89077	8910	B	[SF]			UTILITY SYSTEM STRG(MISC)	Y	THIS CATEGORY CODE IS USED FOR INVENTORY PURPOSES ONLY. USE CATEGORY CODE 890 09 FOR MISCELLANEOUS UTILITY BUILDINGS.
891								
892								
89210	1499	S		[EA]		MONITORING WELLS	N	WELLS INSTALLED AROUND A SITE IN ORDER TO DETECT THE DISCHARGE OF ANY LEACHATE. SAMPLES FROM THE WELLS SHOULD BE ANALYZED PRIOR TO THE DISPOSAL OF ANY WASTE IN ORDER TO ESTABLISH BASELINE DATA.
893						MISCELLANEOUS UTILITIES-LF		
89320	8932	LS		[LF]		UTILITY CHANNEL	N	A UTILITY CHANNEL IS AN ENCLOSED UNDERGROUND CHANNEL FOR UTILITY, COMMUNICATION OR OTHER LINES THAT BOTH PROTECTS THE LINES, AND PROVIDES RELATIVELY EASY ACCESS FOR THEIR MAINTENANCE.
895								
900						REAL ESTATE		
910						LAND - GOVERNMENT OWNED		
911						LAND PURCH,COND,DONA/ TRANS		

This basic category includes lands acquired in fee purchase, condemnation, donation, exchange or transfer, which is owned in fee by the Federal Government, and under custody and accountability of the Department of the Navy.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	UNITS OF MEASURE OTHER	UNITS OF MEASURE ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
91110	9110	L	[AC]			LAND - PURCHASE	N	LAND ACQUIRED IN FEE BY PURCHASE IS A NEGOTIATED SALE OF THE PROPERTY FROM PRIVATE OWNERS TO THE FEDERAL GOVERNMENT BY CONVEYANCE OF DEED.
91120	9110	L	[AC]			LAND - DONATION	N	LAND ACQUIRED IN FEE BY DONATION USUALLY CONSISTS OF A CONVEYANCE OF FEE TITLE BY THE DONOR WITHOUT MONETARY CONSIDERATION.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
91130	9110	L	[AC]			LAND - TRANSFER	N	TRANSFERS OF FEDERAL GOVERNMENT-OWNED LAND AMONG DEPARTMENTS AND AGENCIES OF THE FEDERAL GOVERNMENT
91140	9110	L	[AC]			LAND - CONDEMNATION	N	LAND IS ACQUIRED BY CONDEMNATION WHERE LAND IS ESSENTIAL FOR A PROJECT WHICH AFFECTS NATIONAL DEFENSE OR SECURITY, AND THE CONSIDERATION FOR PURCHASE CANNOT BE MUTUALLY AGREED UPON BETWEEN THE OWNER AND THE NAVY.
91150	9110	L	[AC]			LAND - EXCHANGE	N	LAND ACQUIRED BY EXCHANGE IS SIMILAR IN PRINCIPLE TO ACQUISITIONS BY PURCHASE EXCEPT THAT THE CONSIDERATION IS BY LAND VALUE RATHER THAN CASH.

912 LAND-PUB DOMAIN WITHDRAWAL

The Navy Department may acquire land by withdrawal from public domain under jurisdiction of the Department of the Interior. Withdrawals of less than 5,000 acres are made by Public Land Order. Withdrawal of more than 5,000 acres for any one project must be approved by Act of Congress. In addition to securing authorization from the Armed Services Committees of Congress, a bill must be introduced in the Committees on Public Land and Insular Affairs for acquisition of public domain lands in excess of 5,000 acres.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
91210	9120	L	[AC]			LAND - PUB DOMAIN,PERM	N	FEDERAL GOVERNMENT LAND PERMANENTLY EXCLUDED FROM SOME OR ALL FORMS OF ENTRY, USE, SALE, OR OTHER DISPOSAL UNDER THE PUBLIC LANDS LAWS AS SPECIFIED IN THE PUBLIC LAND ORDER, EXECUTIVE ORDER, OR ACT OF CONGRESS AND THOSE LANDS THAT ARE RESERVED FOR A SPECIFIED DEPARTMENT OR AGENCY FOR A SPECIFIC PUBLIC PURPOSE.
91215	9111	L	[AC]			LAND - SET ASIDE- HAWAII	N	FEDERAL GOVERNMENT LAND RESERVED THROUGH LAND TRUST IN STATE OF HAWAII

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
91220	9120	L	[AC]			LAND-PUB DOMAIN,TEMPORY	N	FEDERAL GOVERNMENT LAND EXCLUDED FROM SOME OR ALL FORMS OF ENTRY, USE, SALE, OR OTHER DISPOSAL UNDER THE PUBLIC LANDS LAWS AS SPECIFIED IN THE PUBLIC LAND ORDER, EXECUTIVE ORDER, OR ACT OF CONGRESS AND THOSE LANDS THAT ARE RESERVED FOR A SPECIFIC PUBLIC PURPOSE FOR A SPECIFIED PERIOD OF TIME.

913 LAND - LICENSE OR PERMIT

Land is acquired for temporary use under license or permit. The license or permit is a privilege, revocable at will, to use the property of the licenser, for a specified purpose and period of time. Land from Public Domain used under temporary permit is obtained under agreement between the Navy Department, and the Department of the Interior. The temporary permit implies no use detrimental to the land such as contamination.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
91310	9130	L	[AC]			LAND-TEMP USE,LIC,PMT,AGMT	N	THIS LAND IS ACQUIRED FOR TEMPORARY USE UNDER LICENSE OR PERMIT. THE LICENSE OR PERMIT IS A PRIVILEGE, REVOCABLE AT WILL, TO USE THE PROPERTY OF THE LICENSER, FOR A SPECIFIED PURPOSE AND PERIOD OF TIME.
91320	9130	L	[AC]			LAND-PUB DOMAIN -TEMP/PMT	N	LAND FROM PUBLIC DOMAIN USED UNDER TEMPORARY PERMIT IS OBTAINED UNDER AGREEMENT BETWEEN THE NAVY DEPARTMENT, AND THE DEPARTMENT OF THE INTERIOR. THE TEMPORARY PERMIT IMPLIES NO USE DETRIMENTAL TO THE LAND SUCH AS CONTAMINATION.

914 PUBLIC LAND- TERRIT & POSS

Land from U.S. possessions is acquired for temporary or long-term use by Executive Order or permit agreement for a limited specific use. This includes public land of U.S. possessions acquired and used under long-term agreements or temporary agreements, and public land of U.S. possessions assigned to the Navy on temporary permit.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
91410	9140	L	[AC]			LAND-PUBLIC- TEMPO/LNG TERM	N	THIS CODE IS USED FOR PUBLIC LAND OF U.S. POSSESSIONS ACQUIRED AND USED UNDER LONG-TERM AGREEMENTS OR TEMPORARY AGREEMENTS.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
91420	9140	L	[AC]			LAND-PUBLIC-TEMP PERMIT	N	THIS CODE IS USED TO DESIGNATE PUBLIC LAND OF U.S. POSSESSIONS ASSIGNED TO THE NAVY ON TEMPORARY PERMIT.
920						LAND - OTHER RIGHTS		
921						LAND - EASEMENT		

An easement is a conveyance of interest in real property for particular purposes and needs of the Navy. An easement is acquired by deed for a term of years or in perpetuity. The grantor of an easement may continue to use the land within the stipulations of the easement.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA	OTHER	ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
92110	9210	L	[AC]			LND-AVTN EASEMENT-PURCHASE	N	AN AVIATION EASEMENT IS PURCHASED TO CONVEY CERTAIN PROPERTY RIGHTS FROM THE PRIVATE OWNER TO THE FEDERAL GOVERNMENT. THIS IS DONE BY CONVEYANCE OF DEED. EASEMENTS ARE ACQUIRED TO INSURE FREE AND UNOBSTRUCTED AIRCRAFT PASSAGE THROUGH THE AIRSPACE. THE EASEMENT PROVIDES THE RIGHT TO LIMIT STRUCTURE HEIGHT AND NATURAL GROWTH.
92120	9210	L	[AC]			LND-AVTN EASEMT-CONDEMN	N	THIS CODE VARIES FROM 921 10 ONLY IN THE METHOD OF ACQUISITION. POSSESSION IS OBTAINED BY CONDEMNATION ONLY WHEN THE PURCHASE PRICE CANNOT BE MUTUALLY AGREED UPON BETWEEN THE OWNER AND THE NAVY.
92130	9210	L	[AC]			LAND-OTH EASEMENT-PURCHASE	N	EASEMENTS OTHER THAN FOR NAVIGATION ARE ACQUIRED BY NEGOTIATED SALE. THESE EASEMENTS PROVIDE RIGHTS-OF-WAY FOR TYPICAL UTILITY LINES AND ACCESS ROADS AS WELL AS MANY OTHER PURPOSES, INCLUDING RESTRICTIONS ON USE.
92140	9210	L	[AC]			LAND-OTH EASEMENT-CONDEMNA	N	THIS IS SIMILAR TO 921 30 BUT DIFFERS IN THAT AGREEMENT ON A NEGOTIATED EASEMENT CANNOT BE REACHED, AND THE EASEMENT IS OBTAINED BY CONDEMNATION FOR REASON OF NATIONAL DEFENSE OR SECURITY.

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
92150	9210	L	[AC]	LAND-OTH EASEMENT-EXCHANGE	N	THIS IS SIMILAR TO 92130 BUT DIFFERS IN THAT CONSIDERATION IS LAND VALUE RATHER THAN CASH.

922 LAND - IN-LEASE

An in-lease is a conveyance of a possessory interest in real property for a term of years for rent or other consideration. Leased property is categorized under three groups as follows: Land is leased from private owners for periods under 25 years, land is leased from State and local governments for periods under 25 years, and Land in-lease for 25 years or more is categorized as "long-term". The land may be leased from private enterprise, or State or local governments.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
92210	9220	L	[AC]	LAND-IN-LEASE-PRIV ENTERPR	N	THIS LAND IS LEASED FROM PRIVATE OWNERS FOR PERIODS UNDER 25 YEARS.
92220	9220	L	[AC]	LAND- IN-LEASE-STAT&LOC	N	THIS LAND IS LEASED FROM STATE AND LOCAL GOVERNMENTS FOR PERIODS UNDER 25 YEARS.
92230	9220	L	[AC]	LAND-IN LEASE-LONG TERM	N	LAND IN-LEASE FOR 25 YEARS OR MORE IS CATEGORIZED AS "LONG-TERM". THE LAND MAY BE LEASED FROM PRIVATE ENTERPRISE, OR STATE OR LOCAL GOVERNMENTS.

923 LAND - FOREIGN RIGHTS

Land under custody and accountability of the Navy Department comprising a Navy installation in a foreign country except land under easement, Code 921. The method of acquisition or use of real property in a foreign country depends upon, and is accomplished by, diplomatic agreement and subsidiary military agreements or, where applicable, by lease or other agreement. Fee simple title to real property in a foreign country is not acquired. The extent of interest which may be acquired in such property depends upon the agreement. Acquisition or use of real property in an occupied country is accomplished by requisition or other local arrangements.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
92310	9230	L	[AC]	LAND-FOREIGN 99 YR LEASE	N	LAND - FOREIGN, 99-YEAR LEASE
92320	9230	L	[AC]	LAND-FOREIGN, BASE RIGHTS	N	LAND - FOREIGN, BASE RIGHTS
92330	9230	L	[AC]	LAND-FOREIGN RECIP AID	N	LAND - FOREIGN, RECIPROCAL AID
92340	9230	L	[AC]	LAND - FOREIGN, OCC AREA	N	LAND - FOREIGN, OCCUPIED AREA
92350	9230	L	[AC]	LAND-FOREIGN, IN-LEASE	N	LAND - FOREIGN, IN-LEASE
92360	9230	L	[AC]	LAND-FOREIGN,MISC	N	LAND - FOREIGN, MISCELLANEOUS

Category Code Report (All Series)

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
930				IMPROVEMENTS		
931				BUILDINGS		

This code is to be used for budgeting purposes and for reporting buildings on land at the time land is acquired. Such facilities are carried under this code for the balance of the fiscal year when such land or buildings are acquired, then inventoried as appropriate in the 100 through 800 series of Category Codes.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
932				SITE IMPROVEMENT		

Site improvements which are not associated with a specific building or structure within its own category code such as clearing, grading, landscaping, erosion control, and similar.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
933				DEMOLITION		

This group is for demolition of buildings, structures, or utilities and removal of debris performed primarily to make usable or disposable an otherwise unusable site. Demolition directly related to a construction project is assigned the same code as for the project.

CATEGORY CODE	FAC CODE	RPA TYPE	UNITS OF MEASURE AREA OTHER ALT	TITLE	RQMTS RPTG IND.	DESCRIPTION
939				OTHER SITE IMPROVEMENTS		

Units Of Measure
And Their Symbols

AC	ACRES	BD	HOSPITAL BEDS, NORMAL CAPACITY
BH	BTU PER HOUR	BL	BARRELS (42 GALS EACH)
BX	BOXES	CF	CUBIC FEET
CM	CUBIC FEET/MINUTE	CP	CANDLE POWER
CY	CUBIC YARDS	DS	DEPTH OF WATER OVERSILL @ HIGH TIDE
DW	DEPTH OF WATER OVERSILL @ LOW TIDE	EA	EACH
FA	FAMILY UNITS (HOUSING)	FB	LINEAR FEET OF BERTHING
FP	FIRING POINT (FIRING RANGES)	GA	GALLONS
GM	GALLONS PER MINUTE	HO	HOLES (GOLF COURSE)
IN	INCHES	KG	THOUSANDS OF GALLONS PER DAY
KV	KILOVOLT AMPERES	KW	KILOWATTS
LA	LANES (BOWLING)	LC	LIGHT CARE, HOSPITAL SPACE
LF	LINEAR FEET	LN	SET OF FIRING POINTS
MB	MILLIONS OF BTU PER HOUR	ME	METERS
MG	MILLIONS OF GALLONS	MI	STATUTE MILES
MW	MEGAWATTS	NF	NET SQUARE FEET (HOUSING)
NS	NET SQUARE FEET (STORAGE)	OL	OUTLETS, NUMBER OF
OU	OPERATING UNITS	PH	POUNDS PER HOUR
PN	PERSONS, DESIGN CAPACITY	SE	SEATS, NUMBER OF
SF	SQUARE FEET	SH	STACKING HEIGHT
SI	SITES	SP	STARTING POINT
SY	SQUARE YARDS	TC	TOTAL CUBIC FEET
TH	TONS PER HOUR	TN	TONS
TR	TONS, REFRIGERATION	VE	NUMBER OF VEHICLES

UNIT OF MEASURE CODES & DESCRIPTIONS

Unit of Measure Code	Description
AC	ACRES
BD	HOSPITAL BEDS, NORMAL CAPACITY
BL	BARRELS (42 GALS EACH)
BX	BOXES
CF	CUBIC FEET
CM	CUBIC FEET/MINUTE
CP	CANDLE POWER
CY	CUBIC YARDS
DS	DEPTH OF WATER OVERSILL @ HIGH TIDE
DW	DEPTH OF WATER OVERSILL @ LOW TIDE
EA	EACH
FA	FAMILY UNITS (HOUSING)
FB	LINEAR FEET OF BERTHING
FP	FIRING POINT (FIRING RANGES)
GA	GALLONS
GM	GALLONS PER MINUTE
HO	HOLES (GOLF COURSE)
IN	INCHES
KG	THOUSANDS OF GALLONS PER DAY
KV	KILOVOLT AMPERES
KW	KILOWATTS
LA	LANES (BOWLING)
LC	LIGHT CARE, HOSPITAL SPACE
LF	LINEAR FEET
LN	SET OF FIRING POINTS
MB	MILLIONS OF BTU PER HOUR
ME	METERS
MG	MILLIONS OF GALLONS
MI	STATUTE MILES
MW	MEGAWATTS
NF	NET SQUARE FEET (HOUSING)
NS	NET SQUARE FEET (STORAGE)
OL	OUTLETS, NUMBER OF
OU	OPERATING UNITS
PH	POUNDS PER HOUR
PN	PERSONS, DESIGN CAPACITY
SE	SEATS, NUMBER OF
SF	SQUARE FEET
SH	STACKING HEIGHT
SI	SITES
SP	STARTING POINT
SY	SQUARE YARDS
TC	TOTAL CUBIC FEET
TH	TONS PER HOUR
TN	TONS
TR	TONS, REFRIGERATION
VE	NUMBER OF VEHICLES

[Home | Table of Contents | Foreword | Introduction | Category Codes for Military Real Property Investment Category Codes | Deleted Category Codes (For Reference Only) | Index]

FACILITY PLANNING FACTORS FOR NAVAL SHORE ACTIVITIES

Appendix C

Runway Capacity Handbook-Fixed Wing

NAVFAC P-80.1
JUNE 1972

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
WASHINGTON, D. C. 20390

DISTRIBUTION:

SNDL PART I (one copy each except as indicated)

List	21A	Fleet Commanders in Chief
	23A	Force Commanders (2 copies)
	24A	Naval Air Force Commanders (2 copies)
	27C	Sea Frontier Commanders
	42A	Fleet Air Commands (2 copies)
	42B	Fleet Air Wings
	50A	Unified Commands
	50B	Specified Commands

SNDL PART II (one copy each except as indicated)

List	A1	Immediate Office of the Secretary:S02 only (5 copies)
	A2A	Independent Offices: Comptroller and ONR only
	A3	Chief of Naval Operations: 03, 03EG, 09BF, 098, 82, 90, 96, 513, 514, 515 (1 copy each) 405, 442 (3 copies each)
	A4A	Chief of Naval Material (2 copies)
	A6	Headquarters, U.S. Marine Corps MC-COA only (10 copies)
	B1	Secretary of Defense: DASD(I&L) only
	B2	Joint Chiefs of Staff: FCS-F4 only (3 copies)
	B3	Colleges
	FA5	Air Facility LANT
	FA6	Air Station LANT
	FA7	Station LANT: Argentia, Charleston, Keflavik, Mayport, Roosevelt Road only
	FA25	Public Works Center LANT
	FB6	Air Facility PAC
	FB7	Air Station PAC
	FB8	Auxiliary Air Station PAC
	FB9	Air Support Unit
	FB10	Station PAC: Adak, Guam, Midway Island only
	FC4	Air Facility NAVEUR
	FC7	Station NAVEUR
	FF1	Naval District Commandants
	FG11	Training Command - Morocco
	FJ60	Naval War College
	FKA1A	Air Systems Command Hq. AIR 4012 only (11 copies)
	FKA6B1	Air Facility CNM
	FKN1	Facilities Engineering Command Division (10 copies)
	FKN2	Construction Battalion Center (4 copies)
	FKN3	Construction O in C
	FKN5	Public Works Center NAVFACENGCOM (3 copies)
	FKR1A	Air Station NAVAIRSYSCOM
	FKR4B	Missile Range Facility
	FKR7A	Air Systems Command Representative
	FR1	Air Reserve (4 copies)
	FR2	Air Station NAR
	FT1	Chief of Naval Training (4 copies)
	FT2	Chief of Naval Air Training (4 copies)
	FT3	Chief of Naval Advanced Air Training (4 copies)

FT6	Air Station CNT
FT7	Air Facility CNT
FT20	Construction Training Unit (5 copies)
FT37	Scol CEC Officers (55 copies)
FT40	Schools Command
FT42	Scol Construction
FT62	Training Publications Center (3 copies)
V3	Marine Corps Air Base Commanders
V5	Marine Corps Air Station
V11	Marine Corps Institute
V12	Marine Corps Development and Education Command (6 copies)
V15	Marine Corps District
V16	Marine Corps Base
V22	Marine Air Reserve Training Unit

Stocked: Naval Publications and Forms Center
5801 Tabor Avenue
Philadelphia, Pa. 19120

FOREWORD

This appendix to NAVFAC P-80 provides planning procedures to determine and evaluate practical hourly and daily capacity of various runway/taxiway configurations at Naval and Marine Corps Air Installations supporting fixed wing aircraft. The procedures developed herein are not applicable to helicopter or joint use (Navy-Marine Corps/Civilian) installations.

Procedures, examples and worksheets are provided for the computation of capacities for Instrument Flight Rules (IFR), Visual Flight Rules (VFR) and Carrier Practice Landings (CPL).

TABLE OF CONTENTS

****

LIST OF FIGURES AND TABLES

****

Note: Figures and Tables used in Section III (EXAMPLES) are not listed above.

Section I. INTRODUCTION

This Appendix describes the procedures necessary to compute the hourly and daily aircraft handling capacity of an air station's runway system. The following basic factors are considered in the process:

- Type of aircraft (Not including Helicopters)
- Type of operations performed
- Runway/taxiway design
- Use of runways
- IFR Capability

This procedure does not consider such items as personnel support, fueling requirements, ramp/gate/apron size, civilian landing OPS at joint use installations (will require special studies), etc. These factors could be a limiting constraint on an air station's ability to accommodate a specific aircraft demand and would have to be considered in an overall station capacity evaluation.

It should be recognized that there is a range of capacity values for any given station depending on the number of individual or combinations of runways that can be used. Runway use at any one time is related to the runway layout as well as operational factors including wind direction and velocity (crosswind and tailwind limitations), prevailing visibility and ceiling (VFR and IFR conditions), available runway lengths, location of arresting gear, position of navigational facilities, environmental considerations (noise abatement procedures) and applicable air traffic control rules and regulations.

Typical air station runway layouts showing possible runway uses (operating configurations) are included on Figure 1-1. The selection of all possible operating configurations is necessary to calculate the range of capacities associated with a station. However, the selection of the primary operating configuration may be sufficient for study purposes in some cases.

Throughout the capacity procedures, reference is made to aircraft class (I, II, and III). These classes have been developed for capacity calculation purposes. A description of the classes and aircraft type they represent are shown on Table 1-1.

Capacity procedures are separately described for three types of operations; namely,

- Under VFR conditions
- Under IFR conditions
- Carrier Practice Landing (CPL) procedures

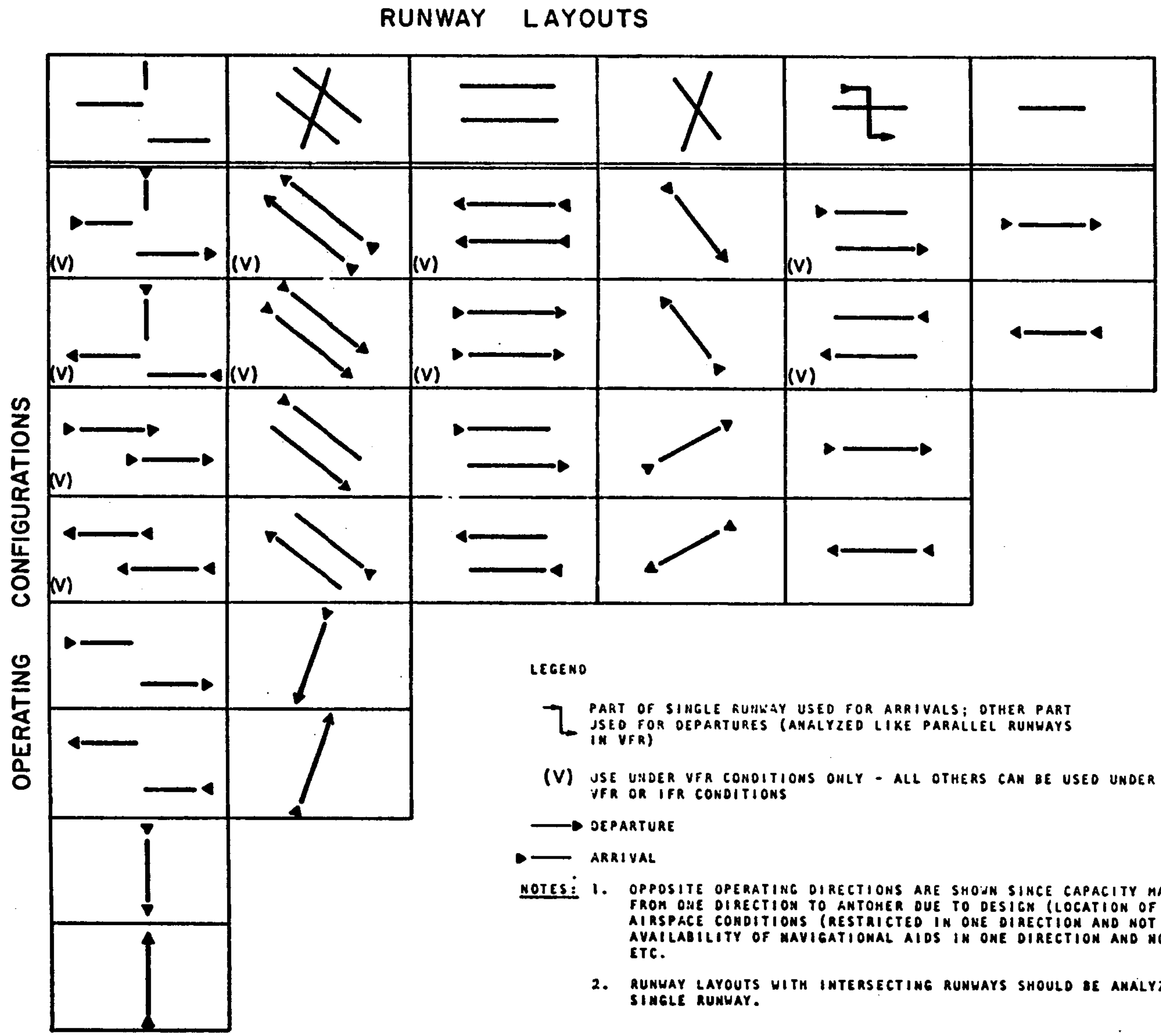
As applicable, these procedures should be followed for each individual runway operating configuration for which capacity is required.

In order to calculate capacity, a forecast of aircraft activity has to be developed. Where an existing station with its current activity is being analyzed, a field survey can be used to develop forecast data. Where aircraft traffic changes are contemplated for an existing station or a new station is being planned for, other forecast techniques will have to be employed. For each analysis the forecast activity should be grouped into the three aircraft classes shown on Table 1-1. A further breakdown may then be required with respect to number of aircraft landing, taking off, performing touch and go's, taking off in pairs (side by side; not formations of two aircraft), and/or operating in formations of two, three or four. It should be noted that the forecast activity breakdown may differ significantly between VFR, IFR and CPL operating conditions.

Helicopter operations are not treated in these capacity procedures. At installations which support both helicopter and fixed wing aircraft on the same runway, consideration shall be given to providing a separate helicopter landing area before any evaluation is made as to the need for an additional fixed wing runway.

Figure 1-1

TYPICAL RUNWAY LAYOUTS AND OPERATING CONFIGURATIONS



LEGEND

PART OF SINGLE RUNWAY USED FOR ARRIVALS; OTHER PART USED FOR DEPARTURES (ANALYZED LIKE PARALLEL RUNWAYS IN VFR)

(V) USE UNDER VFR CONDITIONS ONLY - ALL OTHERS CAN BE USED UNDER VFR OR IFR CONDITIONS

DEPARTURE

ARRIVAL

NOTES:

1. OPPOSITE OPERATING DIRECTIONS ARE SHOWN SINCE CAPACITY MAY VARY FROM ONE DIRECTION TO ANTOHER DUE TO DESIGN (LOCATION OF EXITS), AIRSPACE CONDITIONS (RESTRICTED IN ONE DIRECTION AND NOT ANOTHER), AVAILABILITY OF NAVIGATIONAL AIDS IN ONE DIRECTION AND NOT ANOTHER, ETC.

2. RUNWAY LAYOUTS WITH INTERSECTING RUNWAYS SHOULD BE ANALYZED AS SINGLE RUNWAY.

Table 1-1

U. S. NAVY AIRCRAFT CLASSES
FOR CAPACITY CALCULATIONS

Class	Description	Final Approach Speed (Knots)	Type
I	Jet Aircraft	100-150	A4, A6, A7, F4, F8, T-1, T-2, T-33, F9, F-10, T-39, C-141, A-3, A-5, A-2
II	Turbo-Prop and Piston Aircraft	100-150	C-54, C-118, T-29, C-130, C-121, P-2, P-3, C-119, C-131
III	Turbo-Prop and Piston Aircraft	Less than 100	C-47, C-117, C-45, T-28, T-34, U11A, OV-10, S-2, C-1, E-1, U-6

Section II. CAPACITY PROCEDURES

This section describes the procedures necessary to calculate VFR, IFR, Carrier Landing Practice and Daily Capacities.

1. DEFINITIONS. Before proceeding, the following definitions should be reviewed:

   a. Hourly Arrival Capacity (HAC): the hourly aircraft movement rate which can be sustained at a reasonable average delay imposed on aircraft using a runway for arrivals only.

   b. Hourly Departure Capacity (HDC): the hourly aircraft movement rate which can be sustained at a reasonable average delay imposed on aircraft using a runway for departures only.

   c. Hourly Mixed Capacity (HMC): the hourly aircraft movement rate which can be sustained at a reasonable average delay imposed on aircraft using a runway for arrivals and departures at the same time.

   d. Hourly Total Capacity (HTC): the summation of all available hourly capacities. In the case of a single runway used for arrivals and departures at the same time, HTC = HMC; where multiple runways are used for arrivals (only) and departures (only), HTC = the sum of HAC and HDC.

   e. Daily Capacity: number of aircraft that can be accommodated on a daily basis on an air station's runway system.

only necessary to forecast the extent to which any of these operations are likely or planned to occur, during any period of interest such as an hour, two hours, half day, etc., in order to determine a runway capacity appropriate for the intended use. VFR Runway Capacity Analysis Work Sheets with provisions for logging the forecast of aircraft activity and calculations of HDC, HAC and HMC are presented on Tables 2-3, 2-4 and 2-5 respectively. Instructions for application of these Tables follow later in this Section.

b. Aircraft Takeoff Considerations. A runway used exclusively for takeoff will have a capacity dependent on the class of aircraft using the runway, and on the extent to which takeoffs are conducted singly, in formations or paired. When aircraft of a given class are operated singly, an average hourly departure capacity (HDC) can be established which is typical for VFR operations of the class from most any runway. This movement rate is largely controlled by average speed and the separation required for aircraft of the particular class and are noted below:

HDC - Hourly Departure Capacity-Movements Per Hour

Class of Aircraft	HDC
I	49
II	63
III	90

If some of the takeoffs are conducted in formations or in pairs (side-by-side), then the number of aircraft which can be accommodated in a given time is increased.

2. VFR RUNWAY CAPACITY ANALYSIS. This paragraph describes the procedures to determine hourly capacity of a runway used for normal air station operations in VFR conditions. For procedures to determine the capacity of the same runway in IFR conditions, or when it is used for CLP - see paragraphs 3 or 4 respectively.

These procedures should be repeated for each runway for which a capacity determination is required. A single analysis may be applicable to both directions of a runway if the operations are forecast to be identical, and the runway is symmetrical in terms of effective landing length and turnoffs available, for either landing direction.

a. Forecast of Aircraft Activity. The capacity of a runway for accommodating aircraft operations depends significantly on how the runway is used, specifically in consideration of the following:

(1) The degree of mixing of various aircraft classes.

(2) Whether it is used for takeoffs only, landings only, or the degree to which they are mixed on a single runway.

(3) The type of takeoff operations, namely, made singly, in formations, or paired (side by side).

(4) The type of landing operations, namely, singly, in formations, performing touch-and-go's, or at reduced separation.

These procedures allow for accountability of these variables normally encountered in air station operations. In application of the procedures to a given runway it is then

Stated another way, the time required to handle each aircraft in formation, or paired, is less than the equivalent of one movement when aircraft takeoff singly.

The runway capacity analyses uses procedures which consider the effect of formations and paired takeoffs by converting this activity to "equivalent" single aircraft movements, i.e. two aircraft taking off paired equal one equivalent movement (equivalent movement factor equals 0.50); ten Class I aircraft taking off in formations of two equals six equivalent movements (equivalent movement factor equals 0.60). A breakdown of takeoff equivalent movement factors are listed below:

TAKEOFF EQUIVALENT MOVEMENT FACTOR

	Class of Aircraft		
Type of Takeoff	I	II	III
Single	1.00	1.00	1.00
Formation of 2	.60	.63	.69
Formation of 3	.47	.51	.59
Formation of 4	.41	.45	.54
Pairs	.50	.50	.50

The takeoff factors appropriate for the various classes of aircraft and number of aircraft in each formation are also shown on the appropriate Analysis Work Sheets.

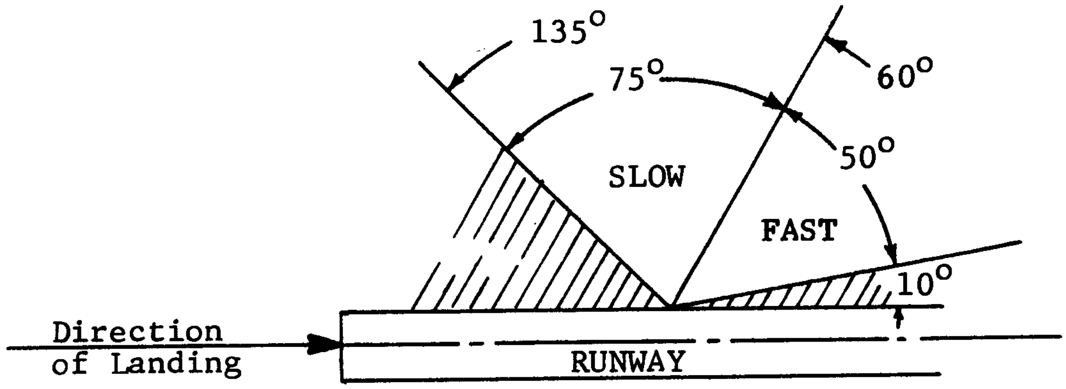
When more than one class of aircraft is using the same runway, the hourly departure capacity (HDC) will be influenced by the relative amount each class of aircraft contributes to the total operations during the period under consideration. The Work Sheets describe the steps necessary to properly account for the mix of aircraft by class. A weighted HDC is computed for each class and totaled for the mix of operations forecast for the runway analysis.

c. Runway Rating. A runway used for landing, either exclusively or mixed with takeoff operations, will have a capacity influenced by the length of time that landing aircraft occupy the runway. Subsequent arriving or departing aircraft must wait until a landing aircraft has cleared the runway at an exit (or is a sufficient distance along the runway if reduced runway separation criteria are in use).

Average runway occupancy time (Runway Rating) will be influenced by landing speed (Class of Aircraft), field elevation, length of runway and by the number, type and location of turnoffs (exits) available along the runway.

Turnoffs which will contribute most to a favorable Runway Rating are those which are located along the runway close to the point where landing aircraft will have slowed to a safe turnoff speed in a normal deceleration. Turnoffs too close to the threshold will not be usable for fast aircraft. Turnoffs far down the runway will require a time consuming rollout. The contribution of each turnoff may thus vary depending on the speed class of aircraft using the runway.

The type of turnoff will also influence Runway Rating. A low angled turnoff in the direction of landing may normally be used at higher speed than one requiring close to a 90° turn. For purposes of determining Runway Rating, the types of usable turnoffs will be classified as follows:



Note: Shaded areas outside usable turnoff range.

The usability of each available runway exit should be considered when determining the number of equivalent usable turnoffs which contribute to the Runway Rating. For example, one class of aircraft destined for a parking area on one side of the runway cannot reasonably use a turnoff leading to the opposite side, and some turnoffs may lead to conflict with takeoffs or other ground traffic.

A chart for use in determining Runway Rating for each aircraft class is provided on Figure 2-1. Examples illustrating use of the Runway Rating chart are included in Section III of this Handbook. When using the chart the following considerations should be kept in mind.

> Usable turnoffs are in terms of equivalent "slow" turnoffs. A "fast" turnoff within the "Range of Usable Turnoffs" should be counted as two "slow" turnoffs.

- Turnoffs which are located outside the "Range of Usable Turnoffs" on the chart should not be used in determining Runway Ratings.
- "Fast" turnoffs which are located outside the "fast" range but are in the "slow" range on the chart should be counted as equivalent to only one "slow" turnoff.
- When no usable turnoffs exist except at the end of the runway use the "End Only" line on the chart.
- If only one turnoff exists (before the end of the runway) and it is located beyond the "Range of Usable Turnoffs" on the chart, use the "0" line to determine Runway Rating.

When "Reduced Separation" is authorized for any class of aircraft, the average time interval between landings will no longer be controlled by Runway Rating. An effective Runway Rating of 25 seconds is used for all operations of aircraft using "Reduced Separation".

d. Aircraft Landing Considerations. A runway used exclusively for landing will have a capacity dependent on the class of aircraft using the runway, and the extent to which landings are conducted singly, in formations or as touch-and-go's. When aircraft of a given class are operated singly, an average hourly arrival capacity (HAC) can be established for each Runway Rating, which is typical for VFR operations of the class onto most any runway with the same rating. Intermittent low approaches are considered as touch-and-go's. HAC values for each class of aircraft for a range of Runway Ratings are presented in Table 2-1.

Similar considerations as those used for takeoff are included in the runway capacity analysis procedure. Landings in formation and touch-and-go's are converted to "equivalent" single aircraft movements. The "equivalent movement factors" to be used for the conversion of aircraft landings to equivalent movements will vary with HAC, since a formation interval or touch-and-go, takes the same amount of time regardless of aircraft class or Runway Rating.

The landing equivalent movement factors appropriate for the various classes of aircraft and number of aircraft in each formation are presented on Table 2-2.

When more than one class of aircraft is using the same runway, the total hourly arrival capacity (HAC) will be influenced by the relative amount each class of aircraft contributes to the total operations during the period under consideration. To properly account for the mix of aircraft by class, the Work Sheet include the steps necessary to compute weighted HAC.

e. Mixed Takeoff and Landing Considerations. Runways used for mixed takeoffs and landings will have an average hourly mixed capacity (HMC) dependent on the mix of aircraft by class and on the mix of operations between takeoffs and landings. Aircraft types are designated by class depending on their typical terminal area operating speeds. When more than one class of aircraft is using a runway, a fast aircraft may follow a slow one, and vice versa, in landing or takeoff. The efficiency with which runways and airspace can be used decreases when speed classes are mixed.

When takeoffs and landings are mixed, the runway capacity will vary depending on the percent of total operations, during the period under consideration, which are reserved for landings, considering that landing operations will most always be given priority. A typical runway may display variations in HMC as the percent of landings changes as shown in the following example:

% Landings	HMC
0%	49 (HDC)
25	42
50	43
75	39
100	32 (HAC)

To properly account for the mix of aircraft by class and the mix of operations by percent of landings, the Work Sheet includes the steps necessary to compute the equivalent takeoff and landing movements by class, and the percent of equivalent movements which are landing.

A chart showing the relationship of Runway Rating, mix of aircraft classes, and percent landings, is presented on Figure 2-2. This chart is used in conjunction with the procedures outlined on the Work Sheet to determine HMC for the appropriate aircraft and operating mix.

f. Aircraft Capacity. The values of HDC - hourly departure capacity; HAC - hourly arrival capacity, and HMC - hourly mixed capacity, determined by these procedures, calculates the number of equivalent single aircraft movements which could take place on the runway being analyzed considering the factors described above under "Forecast of Aircraft Activity"; these capacities are identified on the Work Sheets with a subscript "E", for example, $(HAC)_E$. The procedures also then allow for conversion of the "equivalent" capacities into a value representative of the actual number of aircraft involved, that is, a pair equals two aircraft and a formation of 2, 3 and 4, equals 2, 3 and 4 aircraft; the actual capacity is identified on the Work Sheet with a subscript "A", for example, $(HAC)_A$. It is noted that throughout these procedures, touch-and-go traffic are considered arrivals only and are not counted twice (an arrival and takeoff) as is the normal control tower traffic counting procedures. Therefore the forecast of touch-and-go traffic must count such operations as arrivals only.

g. Use of Capacity Analysis Work Sheets. As applicable, the following three work sheets are to be used for the calculation of hourly capacity:

(1) Table 2-3: "VFR Hourly Departure Capacity (HDC) Analysis Work Sheet" - used to calculate the capacity of a runway used for departures only.

(2) Table 2-4: "VFR Hourly Arrival Capacity (HAC) Analysis Work Sheet" - used to calculate the capacity of a runway used for arrivals only.

(3) Table 2-5: "VFR Hourly Mixed Capacity (HMC) Analysis Work Sheet" - used to calculate the capacity of a runway used for arrivals and departures (at the same time).

Each Work Sheet provides step by step procedures requiring either simple arithmetic computations or use of specified tables or charts. The following items regarding use of these tables are noted:

(1) Most steps require use of previously computed values (from prior steps) and the "procedure" identifies the applicable steps and process.

(2) Where "boxes" are shown below each step adjacent to sub-total and grand total lines, the appropriate addition of values should be made and entered; subsequent steps require use of sub-total and grand total values and are denoted in the procedures with subscripts "S" and "G" respectively.

(3) Some values are constants and have therefore been pre-printed on the Work Sheets.

3. IFR CAPACITY PROCEDURES. Determination of an air station's IFR capability is dependent primarily upon the availability of radar ATC services. Such services may be provided by D.O.D. or F.A.A. ATC facilities or a combination of military and civil units in a joint operation. In joint facilities the F.A.A. normally is responsible for the radar approach control function while the military operates the Precision Approach Radar (PAR) positions of Ground Controlled Approach (GCA) facilities.

At those airfields not provided with their own radar facilities, surveillance radar service for departures and arrivals may be provided by adjacent F.A.A. or D.O.D. terminal radar air traffic control units or by the enroute Air Route Traffic Control Center (ARTCC) of the area.

Stations without terminal radar services may operate IFR with conventional air traffic control service provided by the ARTCC or by the NAS control tower.

a. The following variables must be determined to compute IFR capacity:

- Forecast of Activity in terms of Aircraft Class (I, II, III); if more than one class is involved, capacity is computed by weighting individual class capacity by percent distribution of each class.
- Availability of radar service
- Type Approach Aid: PAR (single or multiple); Conventional (VOR, TACAN, NDB).
- Airspace Limitations:
  Restrictive - single departure path
  Unrestrictive - more than one departure path

- Runway Operating Configuration: (single, multiple dependent or multiple independent runways)

b. Tables 2-6 and 2-7 respectively are to be used to compute IFR capacity of a single or parallel runway configurations. Application of these tables is illustrated through use of examples contained in Section III of this Handbook.

The capacity of a runway used exclusively for low approaches is computed using Table 2-7 for "unrestricted airspace" and "independent runway" conditions at a Ratio = 4.0.

4. CARRIER PRACTICE LANDING CAPACITY PROCEDURES. The capacity of Carrier Practice Landing activities on a runway whether performed at an outlying field or on a runway set-aside for that purpose at a conventional station, has been established at a standard 80 approaches per hour. This value is based on:

- normal rectangular practice pattern
- four aircraft within pattern

Increasing number of aircraft in pattern will not materially increase capacity.

Therefore HTC = 80 arrivals per hour; 160 total movements by count.

5. DAILY CAPACITY ANALYSIS. This paragraph describes the procedures to determine total daily capacity of an air station. The procedure derives the total number of aircraft which can be accommodated within a specified operating period (such as a day or part of a day), for the runway configurations forecast to be available, and for the mix of aircraft and types of aircraft movements forecast to be operated during the period.

The procedure requires that the following data be developed for each daily capacity analysis:

- Choice of runway configurations which will be available during the period for operational use, considering forecast wind direction, wind velocity, ceiling and visibility.
- The number of hours of the day when each runway configuration will be used, considering daylight hours, weather forecasts and other operational factors bearing on choice and availability of runways.
- The hourly capacities for each runway operating configuration forecast to be used during the period of the analysis. The hourly runway capacity should be determined in accordance with Paragraphs 2 (VFR), 3 (IFR), or 4 (CPL) as appropriate for the forecast operating conditions.

a. For a single runway airport, or for the periods of time at any airport when a runway is used for both arrivals and departures, the runway capacity will be the mixed capacity of the runway, in aircraft per hour, multiplied by the number of hours the particular runway is usable. If during the day a change of operating condition is to be considered, such as a period of IFR operation, or a different runway is used, the new mixed capacity for this runway configuration multiplied by the hours it is usable, will give the partial day capacity for this condition. The total daily capacity will then be the sum of the capacities of all the single runway operating configurations usable.

b. For multiple runway operations when two runways are used simultaneously, one for takeoff and one for landing, the total hourly capacity is the sum of the separate capacities of the two runways. However, the total hourly capacity of such a two runway operating configuration may not be representative of the number of aircraft that can be accommodated over a longer term (daily or partial day). This will be true whenever the forecast mix of takeoff and landing operations does not match the relationship of the takeoff to landing capacity of the two runways. For example: two runways, one with HAC=40 and the other with HDC=60 will have a total hourly capacity of 100; however, an aircraft activity forecast of 200 movements with 50% landings will not be accommodated in two hours since only 40 landings per hour will take place. The effective capacity of the two runways is only 80 movements per hour, limited by HAC=40. In this case since the ratio* of arrivals to departures equals 1.00 (as indicated by "50% of landings"), the total capacity is twice the limiting (lowest value).

* $\text{Ratio} = \frac{\text{Arrivals}}{\text{Departures}}$

However, where ratios other than 1.00 are involved, it is necessary to compute hourly total capacity as follows:

$$\text{Hourly Total Capacity} = \frac{\text{HAC x (1 + Ratio)}}{\text{Ratio}}$$

"or"

HDC x (1 + Ratio),

whichever is less - application of this procedure is demonstrated through use of examples in Section III of this Handbook.

It is noted that in the calculation of Ratio, touch and go operations are considered as arrivals only. For example, given a traffic demand of 200 aircraft performing touch and go's, 300 "full-stop" arrivals and 250 departures, the

$$\text{Ratio} = \frac{200 + 300}{250} = \frac{500}{250} = 2.0$$

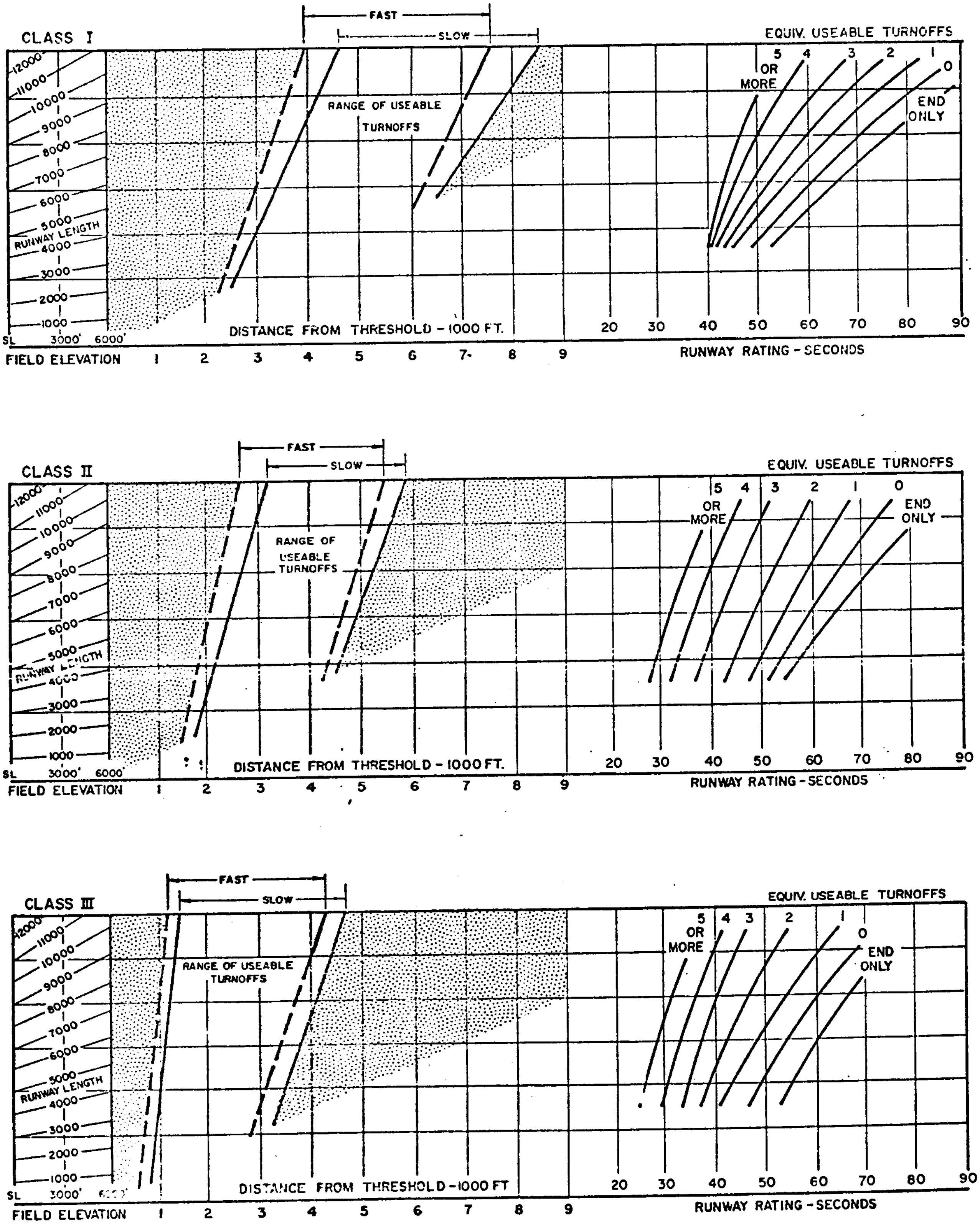


FIGURE 2-1

RUNWAY RATING

AVERAGE LANDING OCCUPANCY TIME-SECONDS

Table 2-1

HAC - HOURLY ARRIVAL CAPACITY - Movements Per Hour

Aircraft Class	Runway Rating					
	30	40	50	60	70	80
I	50	47	44	40	35	30
II	57	52	47	42	38	33
III	63	62	58	53	47	41

Use of Table: Enter with Runway Rating for each aircraft class as obtained in Step 2 on Tables 2-4 or 2-5 and read HAC below. Interpolate as required.

Table 2-2

EQUIVALENT MOVEMENT FACTORS
For Touch & Go or Landings in Formation

Landing Procedure	HAC - Movements per Hour							
	30	35	40	45	50	55	60	65
Formation of 2	.58	.59	.61	.62	.64	.65	.67	.68
Formation of 3	.45	.47	.49	.50	.52	.55	.56	.57
Formation of 4	.37	.40	.42	.44	.46	.48	.50	.52
Touch and Go	.17	.20	.23	.25	.27	.30	.33	.37

Use of Table: Enter HAC obtained above (Table 2-1) for each aircraft class and read Equivalent Movement Factors below. Interpolate as required.

Step No.		①		②	③	④	⑤	⑥	⑦
Procedure		From Field Survey or Forecast		Constants	① × ②	$③_S \div ③_G$	Constants	$④_S \times ⑤$	$⑥_G \times \frac{①_G}{③_G}$
Step Definition		Takeoff Demand		Equivalent Movement Factors	Takeoff Equivalent Movements	Class Distribution	Class HDC's	Weighted $(HDC)_E$	Weighted $(HDC)_A$
		Type Operation	No. of Aircraft						
Aircraft Class I		Single		1.00					
	FORMATION of	2		.60					
		3		.47					
		4		.40					
		Pairs		.50					
	Sub-Totals I		S		S	S	49	S	
Aircraft Class II		Single		1.00					
	FORMATION of	2		.63					
		3		.51					
		4		.45					
		Pairs		.50					
	Sub-Totals II		S		S	S	63	S	
Aircraft Class III		Single		1.00					
	FORMATION of	2		.69					
		3		.59					
		4		.54					
		Pairs		.50					
	Sub-Totals III		S		S	S	90	S	
ALL CLASSES	Grand-Totals		$①_G$		$③_G$	$④_G$		$⑥_G$	

Table 2–3

VFR HOURLY DEPARTURE CAPACITY (HDC) ANALYSIS WORK SHEET

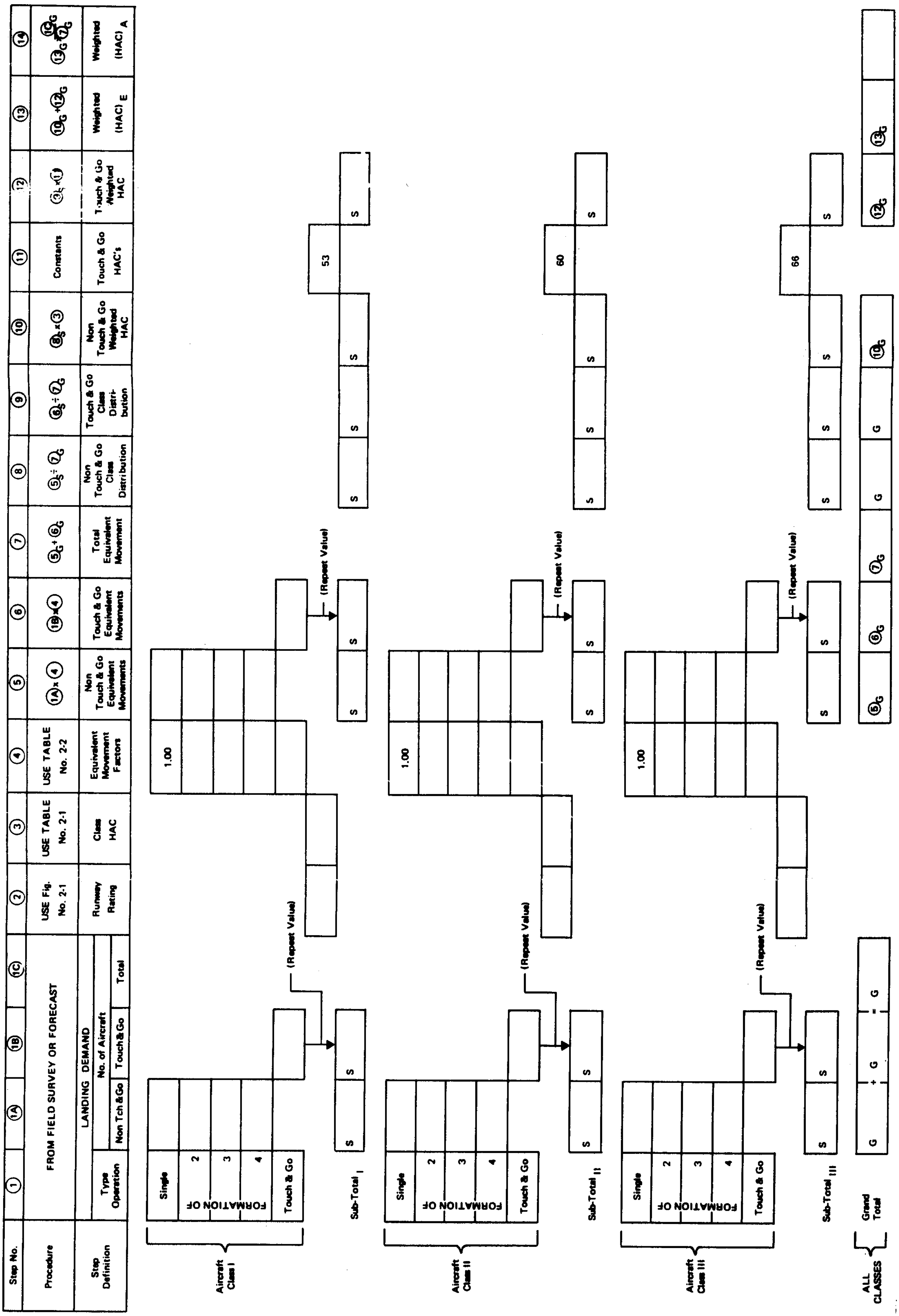


Table 2–4

VFR HOURLY ARRIVAL CAPACITY (HAC) ANALYSIS WORK SHEET

Step No.	1	1A	1B	1C	1D	2	3	4	5	6	7	8	9	10	11	12	13	14A	14B	14C	15	16
Procedure	FROM FIELD SURVEY OR FORECAST					USE Fig. No. 2-1	USE TABLE No. 2-1	USE TABLE No. 2-2	(1A)×(4)	(1B)×(4)	$5_S + 6_S$	CONSTANTS	(1D)×(8)	$1C_G + 1D_G$	$7_S + 9_S$	$7_G \div 11_G$	$11_S \div 11_G$	$2 \times \frac{5_S}{7_G}$	$\text{"20"} \times \frac{6_G}{7_G}$	$14A_G + 14B_G$	USE Fig. No. 2-2	$15_G \times \frac{10_G}{11_G}$
Step Definition	TYPE OPERATION	No. of LANDING AIRCRAFT: Non Touch & Go	No. of LANDING AIRCRAFT: Touch & Go	No. of LANDING AIRCRAFT: Total	No. of Takeoff Aircraft	Class Runway Rating	Class HAC's	Landing Equivalent Movement Factors	Non Touch & Go Equivalent Movements	Touch & Go Equivalent Movements	Total Landing Equivalent Movements	Takeoff Equivalent Movement Factors	Takeoff Equivalent Movements	Total Takeoffs And Landings	Total Take-off & Land. Equivalent Movements	Percent Landing	Class Distribution	Weighted Runway Rating: Non Touch & Go	Weighted Runway Rating: Touch & Go	Weighted Runway Rating: Total	$(HMC)_E$	$(HMC)_A$
Aircraft CLASS I: Single								1.00				1.00										
FORMATION OF 2												.60										
FORMATION OF 3												.47										
FORMATION OF 4												.41										
Touch & Go																						
Pairs												.50										
Sub-Total I		S	S (Repeat Value)		S				S	S (Repeat Value)	S		S		S		S	S				
Aircraft CLASS II: Single								1.00				1.00										
FORMATION OF 2												.63										
FORMATION OF 3												.51										
FORMATION OF 4												.46										
Touch & Go																						
Pairs												.50										
Sub-Total II		S	S (Repeat Value)		S				S	S (Repeat Value)	S		S		S		S	S				
Aircraft CLASS III: Single								1.00				1.00										
FORMATION OF 2												.69										
FORMATION OF 3												.59										
FORMATION OF 4												.54										
Touch & Go																						
Pairs												.50										
Sub-Total III		S	S (Repeat Value)		S				S	S (Repeat Value)	S		S		S		S	S				
ALL CLASSES: Grand Total		G	G	$1C_G$	$1D_G$				5_G	6_G	7_G		9_G		G		G	G				

* CROSS CHECK: Does $5_G + 6_G = 7_G$; Does $7_G + 9_G = 11_G$

Table 2–5
VFR HOURLY MIXED CAPACITY (HMC) ANALYSIS WORK SHEET

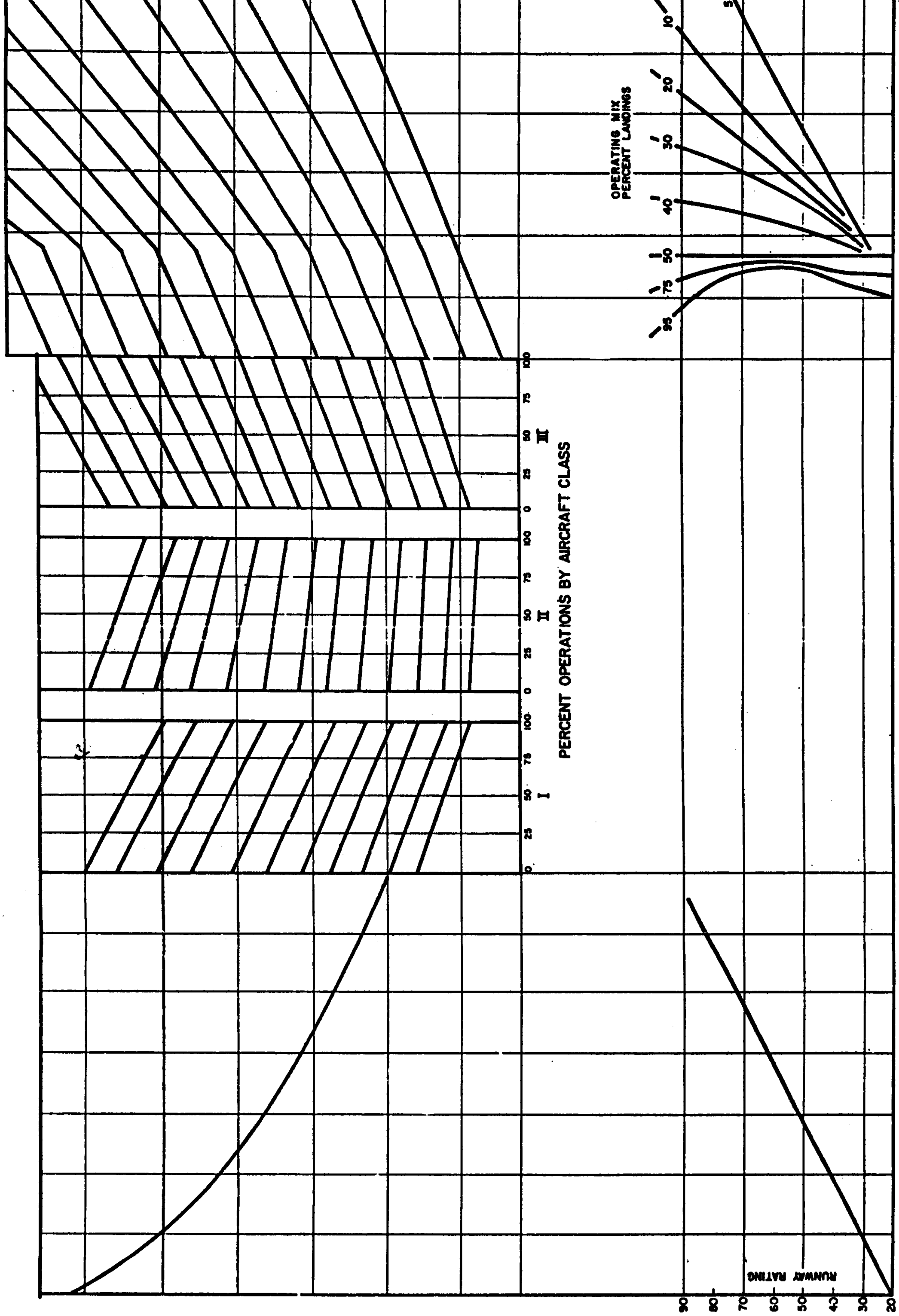


Figure 2-2
VFR RUNWAY CAPACITY FOR MIXED OPERATIONS

Table 2-6

IFR CAPACITY (SINGLE RUNWAY)

Type Navaid	Radar												Non-Radar
	PAR (1)						PAR (2) & Conventional						Conventional
Runway Rating	30		60		90		30		60		90		All Rating
Aircraft Class	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	All Classes
Ratio													
(UNRESTRICTED AIRSPACE)													
.2	46	46	43	43	41	41	46	46	43	43	41	41	28
.4	42	42	36	36	34	34	42	42	36	36	34	34	25
.6	42	42	37	37	32	32	42	42	37	37	32	32	21
.8	40	34	34	34	29	29	40	40	34	34	29	29	18
1.0	38	30	32	30	30	30	38	38	32	32	30	30	16
1.2	37	28	33	28	29	28	39	39	33	33	29	29	15
1.5	33	25	33	25	30	25	40	25	33	25	33	33	13
2.0	30	23	30	23	30	23	40	33	33	33	30	30	12
3.0	27	20	27	20	27	20	40	29	33	29	29	29	11
4.0	27	20	27	20	27	20	37	27	35	27	31	27	10
(RESTRICTED AIRSPACE)													
.2	30	30	24	24	24	24	30	30	24	24	24	24	28
.4	28	28	21	21	21	21	28	28	21	21	21	21	25
.6	24	24	21	21	21	21	24	24	21	21	21	21	21
.8	24	24	22	22	22	22	24	24	22	22	22	22	18
1.0	26	26	22	22	20	20	26	26	22	22	20	20	16
1.2	26	26	22	22	20	20	26	26	22	22	20	20	15
1.5	26	25	23	23	21	21	26	26	23	23	21	21	13
2.0	27	23	23	23	21	21	27	27	23	23	21	21	12
3.0	27	20	24	20	20	26	28	28	24	24	21	21	11
4.0	25	19	25	19	22	19	30	27	25	25	23	23	10

PAR (1) - PAR with single approach capability
PAR (2) - PAR with multiple approach capability
Conventional - Conventional navaid (VOR, TACAN, NDE)
I, II, III - Indicates applicable aircraft class
Unrestricted Airspace - More than one departure path capability
Restricted Airspace - Single departure path capability

Ratio = $\frac{\text{Arrival Demand}}{\text{Departure Demand}}$

Table 2-7

IFR CAPACITIES (PARALLEL RUNWAYS)

	Radar												Non-Radar	
Type Navaid	PAR (1)						PAR (2) & Conventional						Con.	
Runway Rating	All Ratings						All Ratings						All Ratings	
Aircraft Class	I		II		III		I		II		III		All Classes	
Ratio	(UNRESTRICTED AIRSPACE)													
	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.
.2	54	59	54	72	54	72	54	59	54	72	54	72	28	36
.4	45	69	45	70	45	53	45	69	45	84	45	77	25	28
.6	45	53	45	53	40	40	45	79	45	80	45	59	21	21
.8	45	45	45	45	34	34	45	68	45	67	45	50	18	18
1.0	40	40	40	40	30	30	46	60	46	60	44	44	16	16
1.2	37	37	37	37	27	28	46	55	46	55	40	40	15	15
1.5	33	33	33	33	25	25	45	50	45	50	37	37	13	13
2.0	30	30	30	30	23	23	45	45	45	45	33	33	12	12
3.0	27	27	27	27	20	20	40	40	40	40	29	29	11	11
4.0	25	25	25	25	19	19	38	38	38	38	27	28	10	10
	(RESTRICTED AIRSPACE)													
	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.
.2	30	36	30	36	30	36	30	36	30	36	30	36	28	36
.4	28	42	28	42	28	42	28	42	28	42	28	42	25	28
.6	27	48	27	48	27	40	27	48	27	48	27	48	21	21
.8	25	45	25	45	25	34	25	54	25	54	25	50	18	18
1.0	26	40	26	40	26	30	26	60	26	60	26	44	16	16
1.2	26	37	26	37	26	28	26	55	26	55	26	40	15	15
1.5	25	33	25	33	25	25	25	50	25	50	25	37	13	13
2.0	25	30	25	30	22	23	25	45	25	45	25	33	12	12
3.0	25	27	25	27	20	20	25	40	25	40	25	29	11	11
4.0	25	25	25	25	19	19	26	38	26	38	26	28	10	10

PAR (1) - PAR with single approach capability
PAR (2) - PAR with multiple approach capability
Con. - Conventional navaid (VOR, TACAN, NDE)
I, II, III - Indicates applicable aircraft class
Dep. - Release of departure dependent on assured landing on parallel runway (per ATC criteria)
Ind. - Release of departure not dependent on assured landing on parallel runway (per ATC criteria)

Ratio = $\frac{\text{Arrival Demand}}{\text{Departure Demand}}$

Section III. EXAMPLES

Using the procedures outlined in Section II, this section demonstrates the techniques involved by means of examples, covering the following basic areas:

- Runway Rating
- VFR Capacity
- IFR Capacity
- Daily Capacity
- Application of Figure 2-2

a. Runway Rating. To successfully calculate the runway rating for a given runway direction, adherence to 6 steps is necessary. These steps, listed below, apply to Figure 2-1 which is reproduced in this section for clarification.

(1) For each class, enter the runway rating figure with the field elevation.

(2) Proceed upward until the proper runway length line is intersected.

(3) Draw a line representing the runway, directly across the figure. On this "runway" plot the runway exits where they actually exist based on distance from threshold.

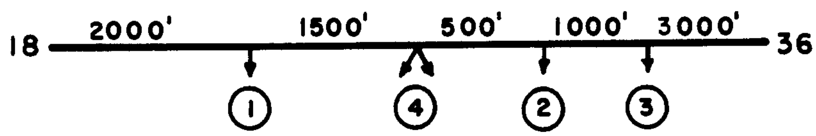
(4) Sum up the number of "slow" exits within the slow range.

(5) Sum up the number of "fast" exits within the fast range; multiply this number by two. If a fast exit falls in the "slow" range, but out of the fast range, count it as a "slow" exit.

(6) The sum of steps 4 and 5 are the equivalent usable exits. Extend the horizontal runway line over to the appropriate usable turnoff lines and read the runway rating on the axis below.

(Example 1)

R/W 18-36 is 8,000 feet long and is at sea level (sl). Calculate the runway rating in the R/W 18 direction for all three classes of aircraft. The plan view of Runway 18-36 looks like:



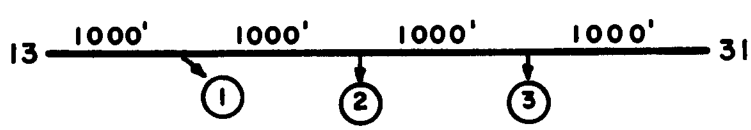
Exits ① ② and ③ are "slow."
Exit ④ is "fast."

Utilizing the aforementioned steps and Figure 2-1 (Example) on page C-33, the runway ratings are calculated to be:

Class I	48 sec.
Class II	38 sec.
Class III	39 sec.

(Example 2)

R/W 13-31 is 4,000 feet long and is 3,000 feet above sea level. The layout of exits as shown below:



Exits ② and ③ are "slow."
Exit ① is "fast."

Calculate the runway rating in the R/W 13 direction for Class III aircraft. The calculations are shown on Figure 2-1 (Example) on page C-34 with the rating calculated at 30 sec.

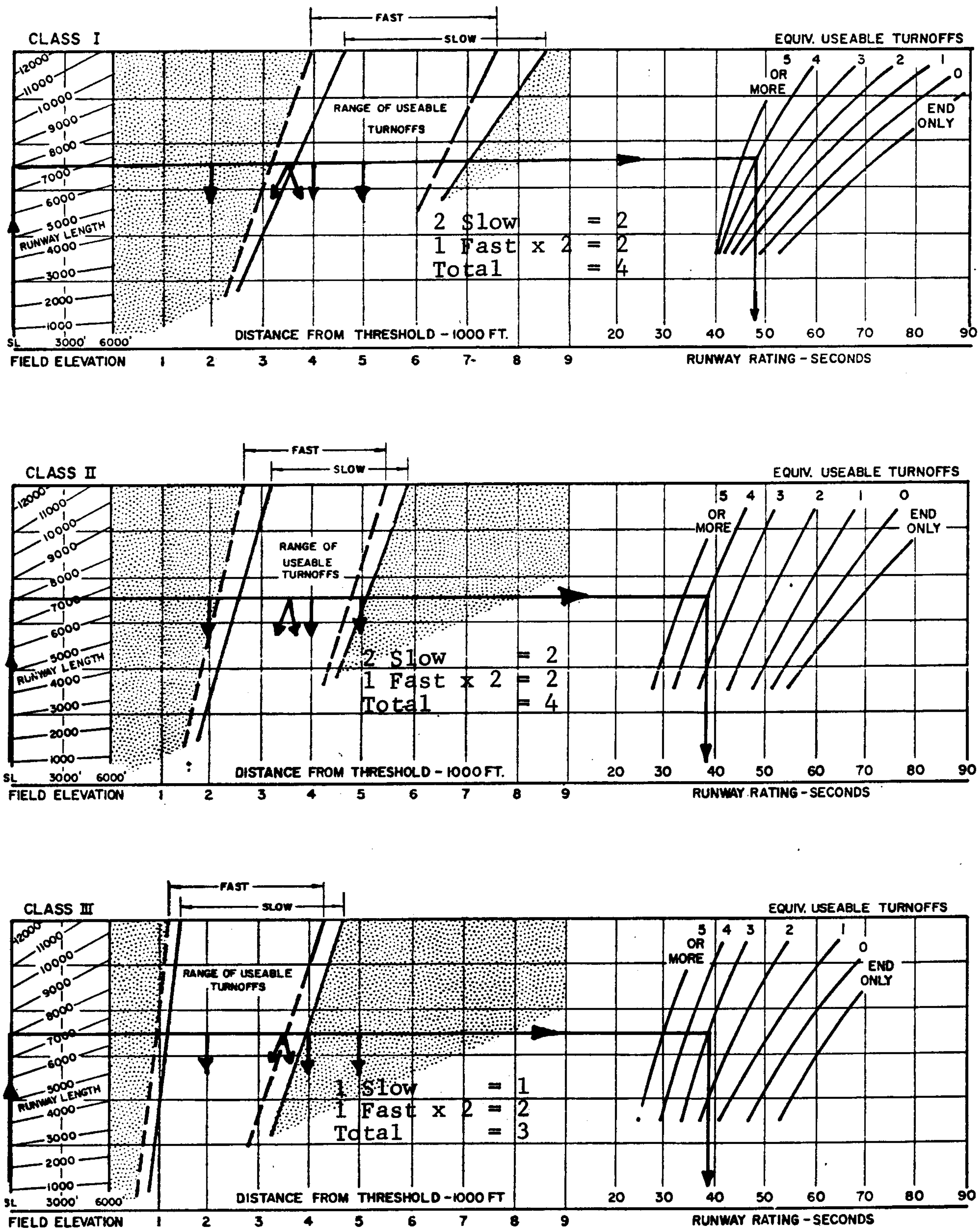


FIGURE 2-1 (Example)

RUNWAY RATING

AVERAGE LANDING OCCUPANCY TIME-SECONDS

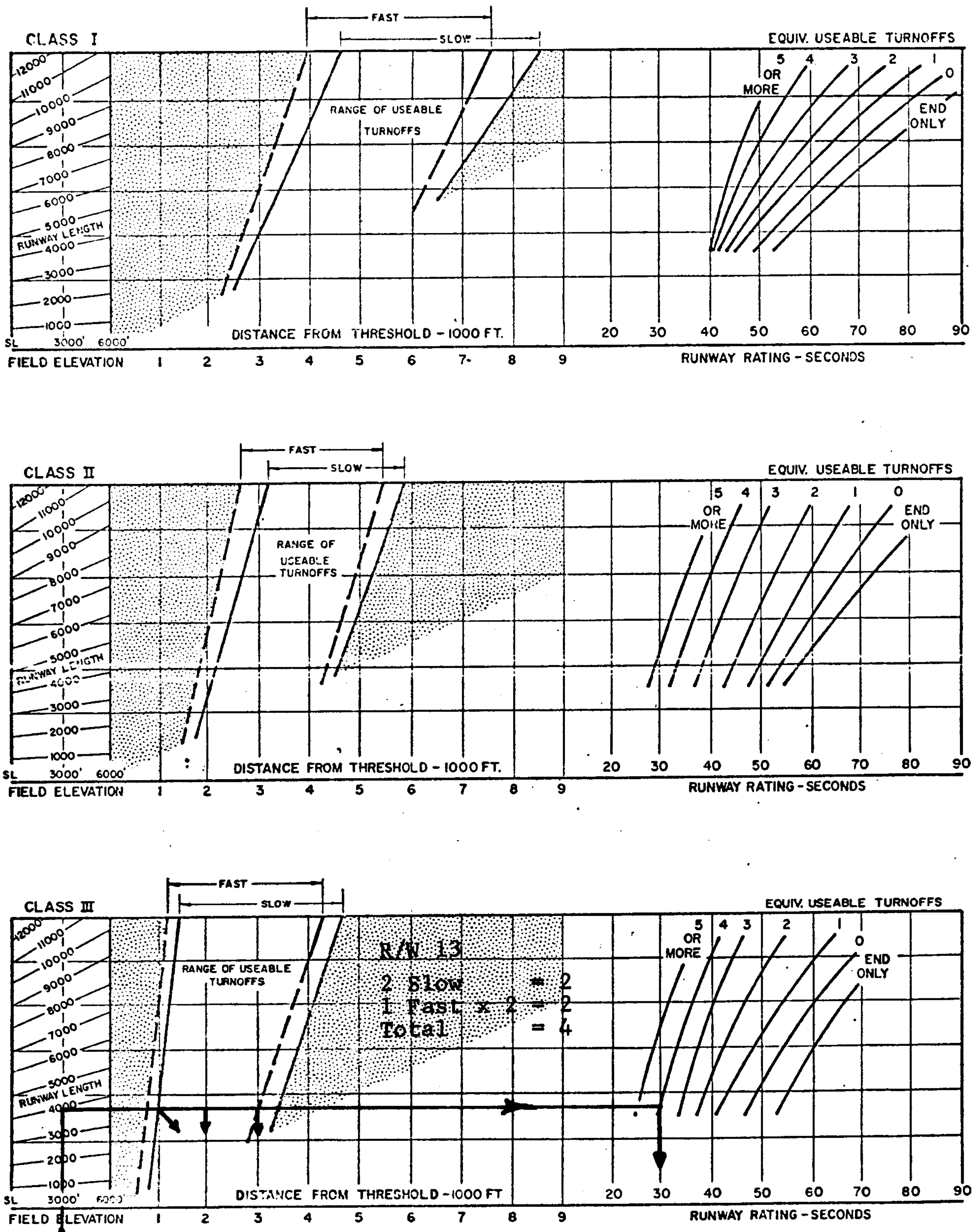


FIGURE 2-1 (Example)

RUNWAY RATING

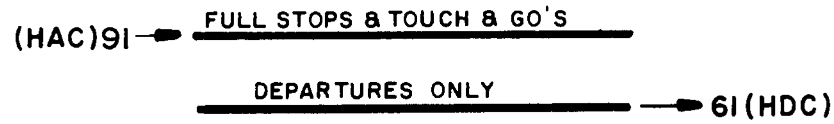
AVERAGE LANDING OCCUPANCY TIME-SECONDS

b. VFR Capacity. In these examples, the calculation of VFR runway capacities use Figure 2-2, Tables 2-1, 2-2, 2-3, 2-4, and 2-5. These figures and tables are reproduced for these examples on page numbers C-40 to C-44 (Example 1) and C-45 to C-49 (Example 2).

(Example 1)

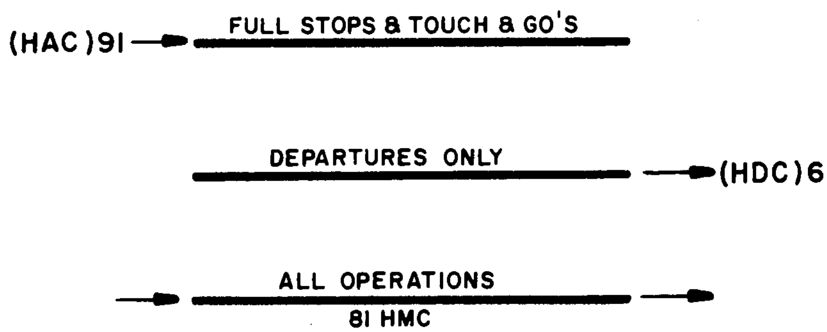
Mission	Jet fighter base.
Base Layout	Two 10,000' parallel runways, 1,500' centerline separation. 3,000' above sea level.
Manner of Operations	Arrivals on one runway; departures on the other.
Type of Aircraft	A6, A4, F4
Aircraft Classification	Class I
Operations Conducted	Formation arrivals and departures; Touch and Go's
Daily Activity (from survey)	300 single departures, 300 single arrivals, 100 aircraft in formation departures of 2, 100 aircraft in formation departures of 4, 100 aircraft in formation arrivals of 2, 100 aircraft in formation arrivals of 4, 600 Touch and Go's.
Exits	Two usable slows) = 4 equivalent One usable fast) turnoffs Runway Rating = 55 sec. (Assumed previous calculation)

Results



At a ratio of 2.2 (1100 arrivals divided by 500 departures per example "daily activity" input), the hourly total capacity equals 132 operations per hour; refer calculation procedure discussed on page numbers C-20 and C-21.

Question: What is the capacity if a third parallel is added 5,000' from the existing outboard runway? Mixed operations on new runway.



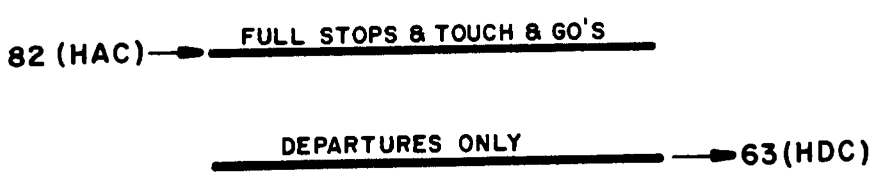
Total capacity = 132 (from above calculation) + 81 = 213 operations per hour.

(Example 2)

The air station undergoes a partial change in mission. Several squadrons of P-3's are moved in to serve as a coastal anti-submarine group. It is now necessary to recompute capacity with this new demand.

Mission	Jet fighter training, Coastal watch
Base Layout	Same as previous example.
Aircraft Classification	I and II
Manner of Operation	Same as previous example.
Operations Conducted	Touch and Go's; Formations
Daily Activity	Same as previous example except for a 200 movement increase in single arrivals and departures generated by the P-3's.
Exits	Runway rating = 55 (Class I) Runway rating = 43 (Class II) (assumed previous calculation)

Results:



At a ratio of 1.86 (1300 arrivals divided by 700 departures per example "daily activity" input), the hourly total capacity equals 126 operations per hour; refer calculation procedure discussed on page numbers C-20 and C-21.

Question: What is the capacity if the ratio of arrivals to departures equals 2.0?

$$\text{Hourly Total Capacity (HTC)} = \frac{\text{HAC x (1 + Ratio)}}{\text{Ratio}}$$

"or"

HDC x (1 + Ratio),

whichever is less.

$$\text{Therefore, HTC} = \frac{82 \text{ x } (1 + 2)}{2} = \frac{82 \text{ x } 3}{2} = 123$$

(Other formula results in higher value of 189.)

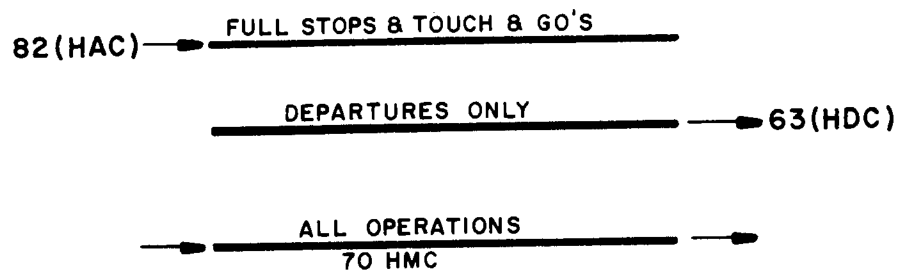
Question: What is the capacity if the ratio equals 0.8?

HTC = HDC x (1 + Ratio) =

63 x 1.8 = 113.4 (113)

(Other formula results in higher value of 184.5.)

Question: What is the capacity if a third parallel is added 5,000' from the existing outboard runway? Mixed operations are to be conducted on this runway.



Total Capacity = 126 (from above calculation based on Ratio = 1.86) + 70 = 196 operations per hour.

Step No.	①		②	③	④	⑤	⑥	⑦
Procedure	From Field Survey or Forecast		Constants	①×②	$③_S \div ③_G$	Constants	$④_S \times ⑤$	$⑥_G \times \frac{①_G}{③_G}$
Step Definition	Takeoff Demand: Type Operation	Takeoff Demand: No. of Aircraft	Equivalent Movement Factors	Takeoff Equivalent Movements	Class Distribution	Class HDC's	Weighted $(HDC)_E$	Weighted $(HDC)_A$
Aircraft Class I	Single	300	1.00	300				
	Formation of 2	100	.60	60				
	Formation of 3	–	.47	–				
	Formation of 4	100	.40	40				
	Pairs	–	.50	–				
	$Sub\text{-}Totals_I$	S 500		S 400	S 1.0	49	S 49	
Aircraft Class II	Single		1.00					
	Formation of 2		.63					
	Formation of 3		.51					
	Formation of 4		.45					
	Pairs		.50					
	$Sub\text{-}Totals_{II}$	S		S	S	63	S	
Aircraft Class III	Single		1.00					
	Formation of 2		.69					
	Formation of 3		.59					
	Formation of 4		.54					
	Pairs		.50					
	$Sub\text{-}Totals_{III}$	S		S	S	90	S	
ALL CLASSES	Grand-Totals	$①_G$ 500		$③_G$ 400	$④_G$ 1.0		$⑥_G$ 49	61

Table 2–3/EXAMPLE 1

VFR HOURLY DEPARTURE CAPACITY (HDC) ANALYSIS WORK SHEET

Step No.		1	1A	1B	1C	2	3	4	5	6	7	8	9	10	11	12	13	14
Procedure		FROM FIELD SURVEY OR FORECAST				USE Fig. No. 2-1	USE TABLE No. 2-1	USE TABLE No. 2-2	(1A) × (4)	(1B) × (4)	(5)G + (6)G	(5)S ÷ (7)G	(6)S ÷ (7)G	(8)S × (3)	Constants	(9)S × (11)	(10)G + (12)G	(13)G × (1C)G ÷ (7)G
Step Definition		LANDING DEMAND: Type Operation	No. of Aircraft: Non Tch & Go	No. of Aircraft: Touch & Go	Total	Runway Rating	Class HAC	Equivalent Movement Factors	Non Touch & Go Equivalent Movements	Touch & Go Equivalent Movements	Total Equivalent Movement	Non Touch & Go Class Distribution	Touch & Go Class Distribution	Non Touch & Go Weighted HAC	Touch & Go HAC's	Touch & Go Weighted HAC	Weighted (HAC) E	Weighted (HAC) A
Aircraft Class I		Single	300					1.00	300									
	Formation of	2	100					.61	61									
	Formation of	3	–					–	–									
	Formation of	4	100					.43	43									
		Touch & Go		600 (Repeat Value)		55	42	.24		144 (Repeat Value)					53			
Sub-Total I			S 500	S 600					S 404	S 144		S .74	S .26	S 31		S 14		
Aircraft Class II		Single						1.00										
	Formation of	2																
	Formation of	3																
	Formation of	4																
		Touch & Go		(Repeat Value)						(Repeat Value)					60			
Sub-Total II			S	S					S	S		S	S	S		S		
Aircraft Class III		Single						1.00										
	Formation of	2																
	Formation of	3																
	Formation of	4																
		Touch & Go		(Repeat Value)						(Repeat Value)					66			
Sub-Total III			S	S					S	S		S	S	S		S		
ALL CLASSES	Grand Total		G 500 +	G 600 =	G 1100				(5)G 404	(6)G 144	(7)G 548	G .74	G .26	(10)G 31		(12)G 14	(13)G 45	91

Table 2–4/EXAMPLE 1

VFR HOURLY ARRIVAL CAPACITY (HAC) ANALYSIS WORK SHEET

Table 2-1/Example 1

HAC - HOURLY ARRIVAL CAPACITY - Movements Per Hour

Aircraft Class	Runway Rating					
	30	40	50	60	70	80
I	50	47	(44)	(40)	35	30
II	57	52	47	42	38	33
III	63	62	58	53	47	41

Interpolate between 44 and 40; Use 42.

Table 2-2/Example 1

EQUIVALENT MOVEMENT FACTORS
For Touch & Go or Landings in Formation

Landing Procedure	HAC - Movements per Hour							
	30	35	(40)	(45)	50	55	60	65
Formation of 2	.58	.59	.61	.62	.64	.65	.67	.68
Formation of 3	.45	.47	.49	.50	.52	.55	.56	.57
Formation of 4	.37	.40	.42	.44	.46	.48	.50	.52
Touch and Go	.17	.20	.23	.25	.27	.30	.33	.37

For 42, interpolate and use .61
.49*
.43
.24

*This value not needed in example.

Step No.		1	1A	1B	1C	1D	2	3	4	5	6	7	8	9	10	11	12	13	14A	14B	14C	15	16
Procedure		FROM FIELD SURVEY OR FORECAST					USE Fig. No. 2-1	USE TABLE No. 2-1	USE TABLE No. 2-2	1A × 4	1B × 4	$5_S + 6_S$	CONSTANTS	1D × 8	$1C_G + 1D_G$	$7_S + 9_S$	$7_G \div 11_G$	$11_S \div 11_G$	$2 \times \frac{5_S}{7_G}$	$"20" \times \frac{6_G}{7_G}$	$14A_G + 14B_G$	USE Fig. No. 2-2	$15_G \times \frac{10_G}{11_G}$
Step Definition		TYPE OPERATION	No. of LANDING AIRCRAFT: Non Touch & Go	No. of LANDING AIRCRAFT: Touch & Go	No. of LANDING AIRCRAFT: Total	No. of Takeoff Aircraft	Class Runway Rating	Class HAC's	Landing Equivalent Movement Factors	Non Touch & Go Equivalent Movements	Touch & Go Equivalent Movements	Total Landing Equivalent Movements	Takeoff Equivalent Movement Factors	Takeoff Equivalent Movements	Total Takeoffs And Landings	Total Take-off & Land. Equivalent Movements	Percent Landing	Class Distribution	Weighted Runway Rating: Non Touch & Go	Weighted Runway Rating: Touch & Go	Weighted Runway Rating: Total	$(HMC)_E$	$(HMC)_A$
Aircraft CLASS I		Single	300			300			1.00	300			1.00	300									
	FORMATION OF	2	100			100			.61	61			.80	60									
		3	—			—			—	—			.47	—									
		4	100			100			.43	43			.41	41									
		Touch & Go		600			55	42	.24		144												
		Pairs				—							.50	—									
Sub-Total I			S 500	S 600 (Repeat Value)		S 500				S 404	S 144 (Repeat Value)	S 548		S 401		S 949		S 1.0	S 41				
Aircraft CLASS II		Single							1.00				1.00										
	FORMATION OF	2											.63										
		3											.51										
		4											.46										
		Touch & Go																					
		Pairs											.50										
Sub-Total II			S	S (Repeat Value)		S				S	S (Repeat Value)	S		S		S		S	S				
Aircraft CLASS III		Single							1.00				1.00										
	FORMATION OF	2											.69										
		3											.59										
		4											.54										
		Touch & Go																					
		Pairs											.50										
Sub-Total III			S	S (Repeat Value)		S				S	S (Repeat Value)	S		S		S		S	S				
ALL CLASSES		Grand Total	G 500	G 600	$1C_G$ 1100	$1D_G$ 500				5_G 404	6_G 144	7_G 548		9_G 401	1600	G 949	.58	G 1.0	G 41	5	46	48	81

* CROSS CHECK: Does $1A_G + 1B_G = 1C_G$; Does $7_G + 9_G = 11_G$

Table 2–5/EXAMPLE 1

VFR HOURLY MIXED CAPACITY (HMC) ANALYSIS WORK SHEET

1. Enter with Runway Rating = 46 from column 14c, Table 2-5 on page C-43
2. Parallel line to percent operations: Class I = 100% from column 13, Table 2-5.
3. Proceed vertically at Operating Mix Percent Landings = 57, from Column 12, Table 2-5.
4. Read $(HMC)_E$ = 48 at intersection of lines.

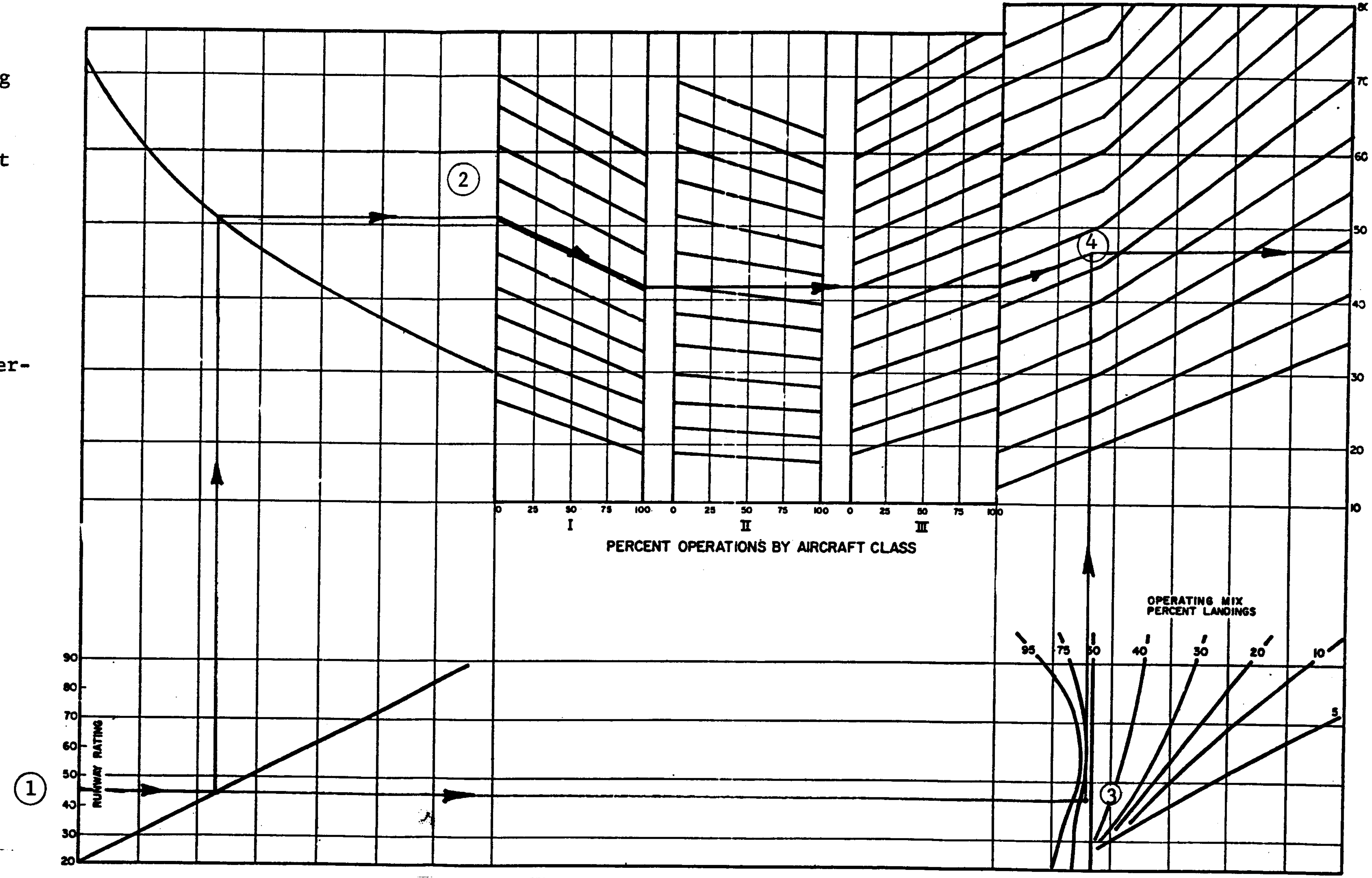


Figure 2-2/EXAMPLE 1
VFR RUNWAY CAPACITY FOR MIXED OPERATIONS

Step No.	①		②	③	④	⑤	⑥	⑦
Procedure	From Field Survey or Forecast		Constants	①×②	③S ÷ ③G	Constants	④S × ⑤	⑥G × ①G/③G
Step Definition	Takeoff Demand		Equivalent Movement Factors	Takeoff Equivalent Movements	Class Distribution	Class HDC's	Weighted (HDC)E	Weighted (HDC)A
	Type Operation	No. of Aircraft						
Aircraft Class I	Single	300	1.00	300				
	FORMATION of 2	100	.60	60				
	FORMATION of 3	—	.47	—				
	FORMATION of 4	100	.40	40				
	Pairs	—	.50	—				
Sub-Totals I		S 500		S 400	S .67	49	S 33	
Aircraft Class II	Single	200	1.00	200				
	FORMATION of 2		.63					
	FORMATION of 3		.51					
	FORMATION of 4		.45					
	Pairs		.50					
Sub-Totals II		S 200		S 200	S .33	63	S 21	
Aircraft Class III	Single		1.00					
	FORMATION of 2		.69					
	FORMATION of 3		.59					
	FORMATION of 4		.54					
	Pairs		.50					
Sub-Totals III		S		S	S	90	S	
ALL CLASSES	Grand-Totals	①G 700		③G 600	④G 1.0		⑥G 54	63

Table 2–3/EXAMPLE 2

VFR HOURLY DEPARTURE CAPACITY (HDC) ANALYSIS WORK SHEET

Step No.		①	①A	①B	①C	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭
Procedure		FROM FIELD SURVEY OR FORECAST				USE Fig. No. 2-1	USE TABLE No. 2-1	USE TABLE No. 2-2	①A × ④	①B × ④	⑤G + ⑥G	⑤S ÷ ⑦G	⑥S ÷ ⑦G	⑧S × ③	Constants	⑨S × ⑪	⑩G + ⑫G	⑬G ÷ ①C/⑦G
Step Definition		LANDING DEMAND: Type Operation	No. of Aircraft: Non Tch & Go	No. of Aircraft: Touch & Go	No. of Aircraft: Total	Runway Rating	Class HAC	Equivalent Movement Factors	Non Touch & Go Equivalent Movements	Touch & Go Equivalent Movements	Total Equivalent Movement	Non Touch & Go Class Distribution	Touch & Go Class Distribution	Non Touch & Go Weighted HAC	Touch & Go HAC's	Touch & Go Weighted HAC	Weighted $(HAC)_E$	Weighted $(HAC)_A$
Aircraft Class I		Single	300			55	42	1.00	300									
	FORMATION OF	2	100					.61	61									
		3	–					–	–									
		4	100					.43	43									
		Touch & Go		600				.24		144								
		$Sub\text{-}Total_I$	S 500	S 600					S 404	S 144		S .54	S .19	S .23	53	S 10		
Aircraft Class II		Single	200			43	51	1.00	200									
	FORMATION OF	2																
		3																
		4																
		Touch & Go		–						–								
		$Sub\text{-}Total_{II}$	S 200	S –					S 200	S –		S .27	S –	S 14	60	S –		
Aircraft Class III		Single						1.00										
	FORMATION OF	2																
		3																
		4																
		Touch & Go																
		$Sub\text{-}Total_{III}$	S	S					S	S		S	S	S	66	S		
ALL CLASSES		Grand Total	G 700 +	G 600 =	G 1300				⑤G 604	⑥G 144	⑦G 748	G .81	G .19	⑩G 37		⑫G 10	⑬G 47	82

(Repeat Value)

Table 2–4 / EXAMPLE 2

VFR HOURLY ARRIVAL CAPACITY (HAC) ANALYSIS WORK SHEET

Table 2-1/Example 2

HAC - HOURLY ARRIVAL CAPACITY - Movements Per Hour

Aircraft Class	Runway Rating 30	40	50	60	70	80
I	50	47	(44)	(40)	35	30
II	57	(52)	(47)	42	38	33
III	63	62	58	53	47	41

Class I: Interpolate between 44 & 40; Use 42.

Class II: Interpolate between 52 & 47; Use 51.

Table 2-2/Example 2

EQUIVALENT MOVEMENT FACTORS
For Touch & Go or Landings in Formation

Landing Procedure	HAC - Movements per Hour 30	35	(40)	(45)	50	55	60	65
Formation of 2	.58	.59	.61	.62	.64	.65	.67	.68
Formation of 3	.45	.47	.49	.50	.52	.55	.56	.57
Formation of 4	.37	.40	.42	.44	.46	.48	.50	.52
Touch and Go	.17	.20	.23	.25	.27	.30	.33	.37

Class I: Interpolate between 40 & 45; Use .61/.49*/.43/.24

Class II: Values not needed in this example.

*Value not needed in this example.

Step No.		①	①A	①B	①C	①D	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭A	⑭B	⑭C	⑮	⑯
Procedure		FROM FIELD SURVEY OR FORECAST					USE Fig. No. 2-1	USE TABLE No. 2-1	USE TABLE No. 2-2	①A×④	①B×④	$⑤_S+⑥_S$	CONSTANTS	①D×⑧	$①C_G+①D_G$	$⑦_S+⑨_S$	$⑦_G÷⑪_G$	$⑪_S÷⑪_G$	$2×\frac{⑤}{⑦_G}$	$"20"×\frac{⑥}{⑦_G}$	$⑭A_G+⑭B_G$	USE Fig. No. 2-2	$⑮_G×\frac{⑩_G}{⑪_G}$
Step Definition		TYPE OPERATION	No. of LANDING AIRCRAFT: Non Touch & Go	Touch & Go	Total	No. of Takeoff Aircraft	Class Runway Rating	Class HAC's	Landing Equivalent Movement Factors	Non Touch & Go Equivalent Movements	Touch & Go Equivalent Movements	Total Landing Equivalent Movements	Takeoff Equivalent Movement Factors	Takeoff Equivalent Movements	Total Takeoffs And Landings	Total Take-off & Land. Equivalent Movements	Percent Landing	Class Distribution	Weighted Runway Rating: Non Touch & Go	Touch & Go	Total	$(HMC)_E$	$(HMC)_A$
Aircraft CLASS I	Single		300			300			1.00	300			1.00	300									
Aircraft CLASS I	FORMATION OF 2		100			100			.61	61			.80	60									
Aircraft CLASS I	FORMATION OF 3		—			—			—	—			.47	—									
Aircraft CLASS I	FORMATION OF 4		100			100			.43	43			.41	41									
Aircraft CLASS I	Touch & Go			600			55	42	.24		144												
Aircraft CLASS I	Pairs					—							.50	—									
Sub-Total I			s 500	s 600		s 500				s 404	s 144	s 548		s 401		s 949		s .82	s 30				
Aircraft CLASS II	Single		200			200			1.00	200			1.00	200									
Aircraft CLASS II	FORMATION OF 2		—			—			—	—			.63	—									
Aircraft CLASS II	FORMATION OF 3		—			—			—	—			.51	—									
Aircraft CLASS II	FORMATION OF 4		—			—			—	—			.46	—									
Aircraft CLASS II	Touch & Go			—			43	51	—		—												
Aircraft CLASS II	Pairs					—							.50	—									
Sub-Total II			s 200	s —		s 200				s 200	s —	s 200		s 200		s 400		s .18	s 12				
Aircraft CLASS III	Single								1.00				1.00										
Aircraft CLASS III	FORMATION OF 2												.69										
Aircraft CLASS III	FORMATION OF 3												.58										
Aircraft CLASS III	FORMATION OF 4												.54										
Aircraft CLASS III	Touch & Go																						
Aircraft CLASS III	Pairs												.50										
Sub-Total III			s	s		s				s	s	s		s		s		s	s				
ALL CLASSES	Grand Total		G 700	G 600	①C G 1300	①D G 700				⑤G 604	⑥G 144	⑦G 748		⑨G 601	2,000	G 1349	.55	G 1.0	G 42	4	46	47	70

(Repeat Value)

* CROSS CHECK: Does $⑤_G+⑥_G=⑦_G$; Does $⑦_G+⑨_G=⑪_G$

Table 2–5/EXAMPLE 2

VFR HOURLY MIXED CAPACITY (HMC) ANALYSIS WORK SHEET

1. Enter with Runway Ratings = 46 from column 14C, Table 2-5 on page C-48
2. Parallel line to Percent Operations:
   Class I = 82
   Class II = 18
   from Column 13, Table 2-5.
3. Proceed vertically at Operating Mix Percent Landings = 55, from Column 12, Table 2-5.
4. Read $(HMC)_E$ = 47 at intersection of lines.

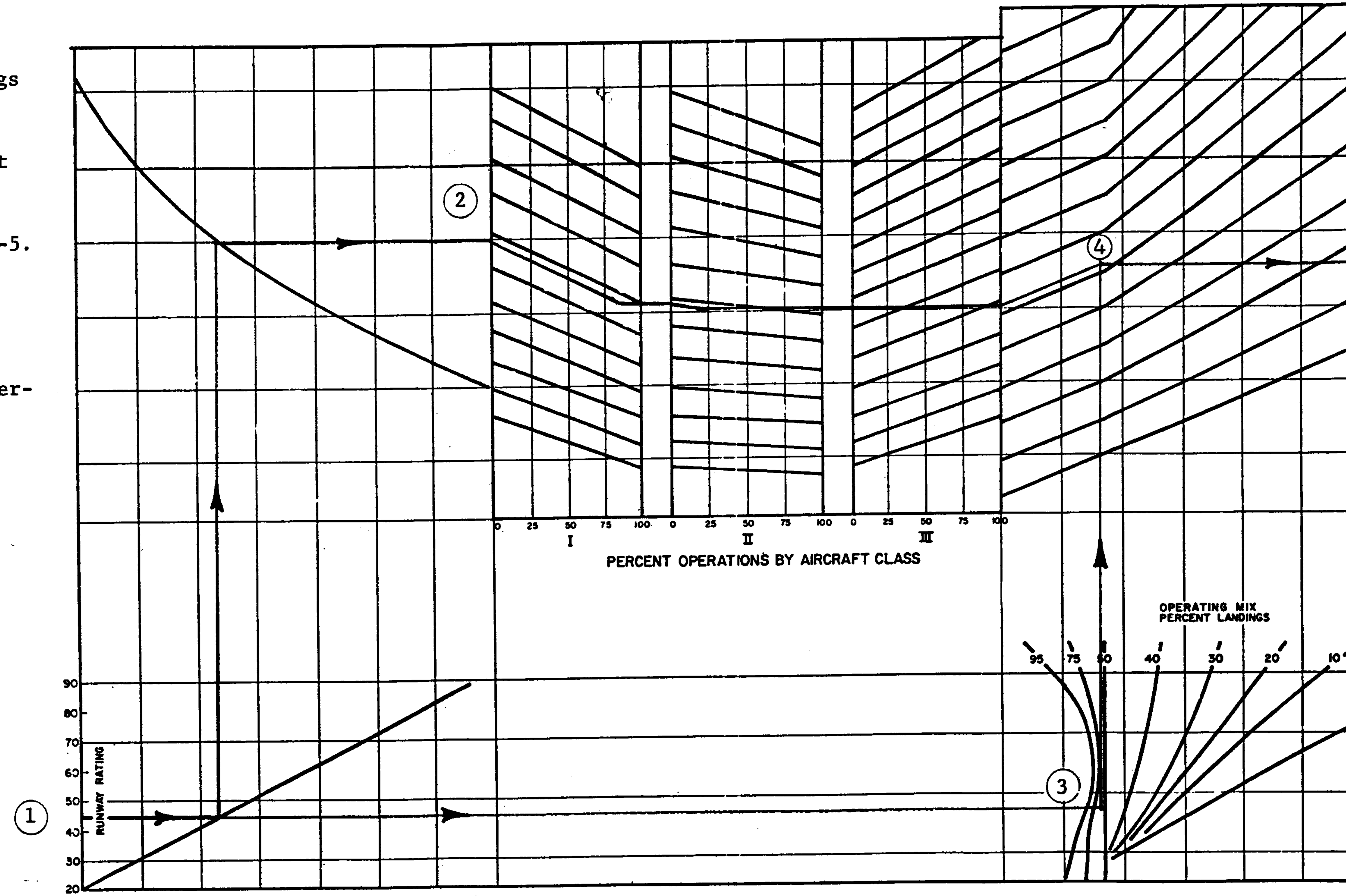


Figure 2-2/EXAMPLE 2
VFR RUNWAY CAPACITY FOR MIXED OPERATIONS

c. <u>IFR Capacity</u>. IFR runway capacities are computed using Tables 2-6 and 2-7. A series of examples follow indicating the use of these tables, which are reproduced here for convenience.

Examples.

(1) Compute the IFR capacity of:

Layout	Single Runway
Type Navaid	Conventional
Airspace	Unrestricted
Radar	Yes
Aircraft Class	III
Ratio (Arrivals/ Departures)	1.0
Runway Rating	60

Refer Table 2-6 (Example) on page C-53; Capacity = 32 operations/hour.

(2) Compute the IFR capacity of

Layout	Single Runway
Type Naviad	PAR (1)
Airspace	Unrestricted
Radar	Yes
Aircraft Class	II
Ratio (Arrivals/ Departures	1.2
Runway Rating	90

Refer Table 2-6 (Example) on page C-54; Capacity = 29 operations/hour.

(3) Compute the IFR capacity of:

Layout	Single Runway
Type Navaid	Conventional
Airspace	Restricted
Radar	No
Aircraft Class	III
Ratio (Arrivals/ Departures)	1.0
Runway Rating	75

Refer to Table 2-6 (Example) on page C-55; Capacity = 16 operations/hour.

(4) Compute the IFR capacity of:

Layout	Close Parallels - Dependent
Type Navaid	PAR (2)
Airspace	Unrestricted
Radar	Yes
Aircraft Class	50% I 50% III
Ratio (Arrivals/ Departures)	1.0
Runway Rating	75

Refer to Table 2-7 (Example) on page C-56;
Capacity = 46 operations/hour (Class I)
Capacity = 44 operations/hour (Class II)
Average = (0.5 x 46) + (0.5 x 44) = 45

(5) Compute the IFR capacity of:

Layout	Parallels - Dependent
Type Navaid	PAR (1)
Airspace	Restricted
Radar	Yes
Aircraft Class	I
Ratio (Arrivals/ Departures)	1.5
Runway Rating	60

Refer to Table 2-7 (Example) on page C-57;
Capacity = 25 operations/hour.

(6) Compute the IFR capacity of:

Layout	Single Runway
Type Navaid	PAR (1)
Airspace	Restricted
Radar	Yes
Aircraft Class	30% I; 50% II, 20% III
Ratio (Arrivals/ Departures)	1.0
Runway Rating	I @ 60; II @ 90; III @ 30

Refer to Table 2-6 (Example) on page C-58;
Capacity: Class I = 22; II = 20; III = 26

Weighted Capacity = Sum of each class capacity times percent class distribution

$$= (22 \times 0.30) + (20 \times 0.50) + (26 \times 0.20)$$
$$= 6.6 + 10 + 5.2$$
$$= 21.8 \text{ (Use 21)*}$$

* Always drop fractional values.

Table 2-6 (Example 1)

IFR CAPACITY (SINGLE RUNWAY)

Type Navaid	Radar												Non-Radar
	PAR (1)						PAR (2) & Conventional						Conventional
Runway Rating	30		60		90		30		60		90		All Rating
Aircraft Class	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	All Classes
Ratio													
(UNRESTRICTED AIRSPACE)													
.2	46	46	43	43	41	41	46	46	43	43	41	41	28
.4	42	42	36	36	34	34	42	42	36	36	34	34	25
.6	42	42	37	37	32	32	42	42	37	37	32	32	21
.8	40	34	34	34	29	29	40	40	34	34	29	29	18
1.0	38	30	32	30	30	30	38	38	32	32	30	30	16
1.2	37	28	33	28	29	28	39	39	33	33	29	29	15
1.5	33	25	33	25	30	25	40	25	33	25	33	33	13
2.0	30	23	30	23	30	23	40	33	33	33	30	30	12
3.0	27	20	27	20	27	20	40	29	33	29	29	29	11
4.0	27	20	27	20	27	20	37	27	35	27	31	27	10
(RESTRICTED AIRSPACE)													
.2	30	30	24	24	24	24	30	30	24	24	24	24	28
.4	28	28	21	21	21	21	28	28	21	21	21	21	25
.6	24	24	21	21	21	21	24	24	21	21	21	21	21
.8	24	24	22	22	22	22	24	24	22	22	22	22	18
1.0	26	26	22	22	20	20	26	26	22	22	20	20	16
1.2	26	26	22	22	20	20	26	26	22	22	20	20	15
1.5	26	25	23	23	21	21	26	26	23	23	21	21	13
2.0	27	23	23	23	21	21	27	27	23	23	21	21	12
3.0	27	20	24	20	20	26	28	28	24	24	21	21	11
4.0	25	19	25	19	22	19	30	27	25	25	23	23	10

PAR (1) - PAR with single approach capability
PAR (2) - PAR with multiple approach capability
Conventional - Conventional navaid (VOR, TACAN, NDE)
I, II, III - Indicates applicable aircraft class
Unrestricted Airspace - More than one departure path capability
Restricted Airspace - Single departure path capability

Ratio = $\frac{\text{Arrival Demand}}{\text{Departure Demand}}$

Table 2-6 (Example 2)

IFR CAPACITY (SINGLE RUNWAY)

	Radar												Non-Radar
Type Navaid	PAR (1)						PAR (2) & Conventional						Conventional
Runway Rating	30		60		90		30		60		90		All Rating
Aircraft Class	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	All Classes
Ratio													
(UNRESTRICTED AIRSPACE)													
.2	46	46	43	43	41	41	46	46	43	43	41	41	28
.4	42	42	36	36	34	34	42	42	36	36	34	34	25
.6	42	42	37	37	32	32	42	42	37	37	32	32	21
.8	40	34	34	34	29	29	40	40	34	34	29	29	18
1.0	38	30	32	30	30	30	38	38	32	32	30	30	16
1.2	37	28	33	28	29	28	39	39	33	33	29	29	15
1.5	33	25	33	25	30	25	40	25	33	25	33	33	13
2.0	30	23	30	23	30	23	40	33	33	33	30	30	12
3.0	27	20	27	20	27	20	40	29	33	29	29	29	11
4.0	27	20	27	20	27	20	37	27	35	27	31	27	10
(RESTRICTED AIRSPACE)													
.2	30	30	24	24	24	24	30	30	24	24	24	24	28
.4	28	28	21	21	21	21	28	28	21	21	21	21	25
.6	24	24	21	21	21	21	24	24	21	21	21	21	21
.8	24	24	22	22	22	22	24	24	22	22	22	22	18
1.0	26	26	22	22	20	20	26	26	22	22	20	20	16
1.2	26	26	22	22	20	20	26	26	22	22	20	20	15
1.5	26	25	23	23	21	21	26	26	23	23	21	21	13
2.0	27	23	23	23	21	21	27	27	23	23	21	21	12
3.0	27	20	24	20	20	26	28	28	24	24	21	21	11
4.0	25	19	25	19	22	19	30	27	25	25	23	23	10

PAR (1) - PAR with single approach capability
PAR (2) - PAR with multiple approach capability
Conventional - Conventional navaid (VOR, TACAN, NDE)
I, II, III - Indicates applicable aircraft class
Unrestricted Airspace - More than one departure path capability
Restricted Airspace - Single departure path capability

Ratio = $\frac{\text{Arrival Demand}}{\text{Departure Demand}}$

Table 2-6 (Example 3)

IFR CAPACITY (SINGLE RUNWAY)

Type Navaid	Radar												Non-Radar
	PAR (1)						PAR (2) & Conventional						Conventional
Runway Rating	30		60		90		30		60		90		All Rating
Aircraft Class	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	All Classes
Ratio													
(UNRESTRICTED AIRSPACE)													
.2	46	46	43	43	41	41	46	46	43	43	41	41	28
.4	42	42	36	36	34	34	42	42	36	36	34	34	25
.6	42	42	37	37	32	32	42	42	37	37	32	32	21
.8	40	34	34	34	29	29	40	40	34	34	29	29	18
1.0	38	30	32	30	30	30	38	38	32	32	30	30	16
1.2	37	28	33	28	29	28	39	39	33	33	29	29	15
1.5	33	25	33	25	30	25	40	25	33	25	33	33	13
2.0	30	23	30	23	30	23	40	33	33	33	30	30	12
3.0	27	20	27	20	27	20	40	29	33	29	29	29	11
4.0	27	20	27	20	27	20	37	27	35	27	31	27	10
(RESTRICTED AIRSPACE)													
.2	30	30	24	24	24	24	30	30	24	24	24	24	28
.4	28	28	21	21	21	21	28	28	21	21	21	21	25
.6	24	24	21	21	21	21	24	24	21	21	21	21	21
.8	24	24	22	22	22	22	24	24	22	22	22	22	18
1.0	26	26	22	22	20	20	26	26	22	22	20	20	16
1.2	26	26	22	22	20	20	26	26	22	22	20	20	15
1.5	26	25	23	23	21	21	26	26	23	23	21	21	13
2.0	27	23	23	23	21	21	27	27	23	23	21	21	12
3.0	27	20	24	20	20	26	28	28	24	24	21	21	11
4.0	25	19	25	19	22	19	30	27	25	25	23	23	10

PAR (1) - PAR with single approach capability
PAR (2) - PAR with multiple approach capability
Conventional - Conventional navaid (VOR, TACAN, NDE)
I, II, III - Indicates applicable aircraft class
Unrestricted Airspace - More than one departure path capability
Restricted Airspace - Single departure path capability

Ratio = $\frac{\text{Arrival Demand}}{\text{Departure Demand}}$

Table 2-7 (Example 4)

IFR CAPACITIES (PARALLEL RUNWAYS)

Type Navaid	Radar: PAR (1)						Radar: PAR (2) & Conventional						Non-Radar: Con.	
Runway Rating	All Ratings						All Ratings						All Ratings	
Aircraft Class	I		II		III		I		II		III		All Classes	
Ratio	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.
(UNRESTRICTED AIRSPACE)														
.2	54	59	54	72	54	72	54	59	54	72	54	72	28	36
.4	45	69	45	70	45	53	45	69	45	84	45	77	25	28
.6	45	53	45	53	40	40	45	79	45	80	45	59	21	21
.8	45	45	45	45	34	34	45	68	45	67	45	50	18	18
1.0	40	40	40	40	30	30	46	60	46	60	44	44	16	16
1.2	37	37	37	37	27	28	46	55	46	55	40	40	15	15
1.5	33	33	33	33	25	25	45	50	45	50	37	37	13	13
2.0	30	30	30	30	23	23	45	45	45	45	33	33	12	12
3.0	27	27	27	27	20	20	40	40	40	40	29	29	11	11
4.0	25	25	25	25	19	19	38	38	38	38	27	28	10	10
(RESTRICTED AIRSPACE)														
	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.
.2	30	36	30	36	30	36	30	36	30	36	30	36	28	36
.4	28	42	28	42	28	42	28	42	28	42	28	42	25	28
.6	27	48	27	48	27	40	27	48	27	48	27	48	21	21
.8	25	45	25	45	25	34	25	54	25	54	25	50	18	18
1.0	26	40	26	40	26	30	26	60	26	60	26	44	16	16
1.2	26	37	26	37	26	28	26	55	26	55	26	40	15	15
1.5	25	33	25	33	25	25	25	50	25	50	25	37	13	13
2.0	25	30	25	30	22	23	25	45	25	45	25	33	12	12
3.0	25	27	25	27	20	20	25	40	25	40	25	29	11	11
4.0	25	25	25	25	19	19	26	38	26	38	26	28	10	10

PAR (1) - PAR with single approach capability
PAR (2) - PAR with multiple approach capability
Con. - Conventional navaid (VOR, TACAN, NDE)
I, II, III - Indicates applicable aircraft class
Dep. - Release of departure dependent on assured landing on parallel runway (per ATC criteria)
Ind. - Release of departure not dependent on assured landing on parallel runway (per ATC criteria)

Ratio = $\frac{\text{Arrival Demand}}{\text{Departure Demand}}$

Table 2-7 (Example 5)

IFR CAPACITIES (PARALLEL RUNWAYS)

	Radar												Non-Radar	
Type Navaid	PAR (1)						PAR (2) & Conventional						Con.	
Runway Rating	All Ratings						All Ratings						All Ratings	
Aircraft Class	I		II		III		I		II		III		All Classes	
Ratio	(UNRESTRICTED AIRSPACE)													
	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.
.2	54	59	54	72	54	72	54	59	54	72	54	72	28	36
.4	45	69	45	70	45	53	45	69	45	84	45	77	25	28
.6	45	53	45	53	40	40	45	79	45	80	45	59	21	21
.8	45	45	45	45	34	34	45	68	45	67	45	50	18	18
1.0	40	40	40	40	30	30	46	60	46	60	44	44	16	16
1.2	37	37	37	37	27	28	46	55	46	55	40	40	15	15
1.5	33	33	33	33	25	25	45	50	45	50	37	37	13	13
2.0	30	30	30	30	23	23	45	45	45	45	33	33	12	12
3.0	27	27	27	27	20	20	40	40	40	40	29	29	11	11
4.0	25	25	25	25	19	19	38	38	38	38	27	28	10	10
	(RESTRICTED AIRSPACE)													
	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.	Dep.	Ind.
.2	30	36	30	36	30	36	30	36	30	36	30	36	28	36
.4	28	42	28	42	28	42	28	42	28	42	28	42	25	28
.6	27	48	27	48	27	40	27	48	27	48	27	48	21	21
.8	25	45	25	45	25	34	25	54	25	54	25	50	18	18
1.0	26	40	26	40	26	30	26	60	26	60	26	44	16	16
1.2	26	37	26	37	26	28	26	55	26	55	26	40	15	15
1.5	25	33	25	33	25	25	25	50	25	50	25	37	13	13
2.0	25	30	25	30	22	23	25	45	25	45	25	33	12	12
3.0	25	27	25	27	20	20	25	40	25	40	25	29	11	11
4.0	25	25	25	25	19	19	26	38	26	38	26	28	10	10

PAR (1) - PAR with single approach capability
PAR (2) - PAR with multiple approach capability
Con. - Conventional navaid (VOR, TACAN, NDE)
I, II, III - Indicates applicable aircraft class
Dep. - Release of departure dependent on assured landing on parallel runway (per ATC criteria)
Ind. - Release of departure not dependent on assured landing on parallel runway (per ATC criteria)

Ratio = Arrival Demand / Departure Demand

Table 2-6 (Example 6)

IFR CAPACITY (SINGLE RUNWAY)

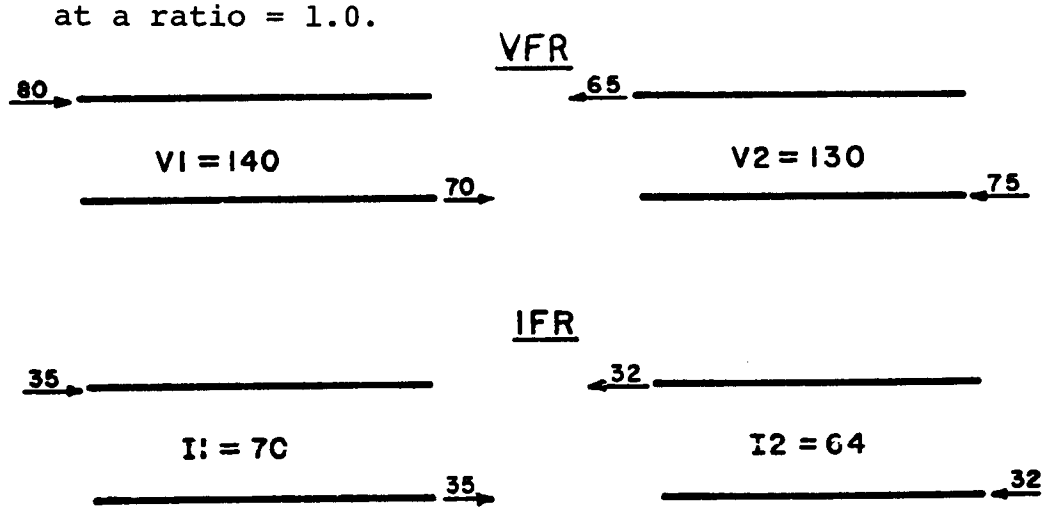
Type Navaid	Radar PAR (1)						Radar PAR (2) & Conventional						Non-Radar Conventional
Runway Rating	30		60		90		90		60		90		All Rating
Aircraft Class	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	I&II	III	All Classes
Ratio													
(UNRESTRICTED AIRSPACE)													
.2	46	46	43	43	41	41	46	46	43	43	41	41	28
.4	42	42	36	36	34	34	42	42	36	36	34	34	25
.6	42	42	37	37	32	32	42	42	37	37	32	32	21
.8	40	34	34	34	29	29	40	40	34	34	29	29	18
1.0	38	30	32	30	30	30	38	38	32	32	30	30	16
1.2	37	28	33	28	29	28	39	39	33	33	29	29	15
1.5	33	25	33	25	30	25	40	25	33	25	33	33	13
2.0	30	23	30	23	30	23	40	33	33	33	30	30	12
3.0	27	20	27	20	27	20	40	29	33	29	29	29	11
4.0	27	20	27	20	27	20	37	27	35	27	31	27	10
(RESTRICTED AIRSPACE)													
.2	30	30	24	24	24	24	30	30	24	24	24	24	28
.4	28	28	21	21	21	21	28	28	21	21	21	21	25
.6	24	24	21	21	21	21	24	24	21	21	21	21	21
.8	24	24	22	22	22	22	24	24	22	22	22	22	18
1.0	26	26	22	22	20	20	26	26	22	22	20	20	16
1.2	26	26	22	22	20	20	26	26	22	22	20	20	15
1.5	26	25	23	23	21	21	26	26	23	23	21	21	13
2.0	27	23	23	23	21	21	27	27	23	23	21	21	12
3.0	27	20	24	20	20	26	28	28	24	24	21	21	11
4.0	25	19	25	19	22	19	30	27	25	25	23	23	10

PAR (1) - PAR with single approach capability
PAR (2) - PAR with multiple approach capability
Conventional - Conventional navaid (VOR, TACAN, NDE)
I, II, III - Indicates applicable aircraft class
Unrestricted Airspace - More than one departure path capability
Restricted Airspace - Single departure path capability

Ratio = $\frac{\text{Arrival Demand}}{\text{Departure Demand}}$

d. <u>Daily Capacity</u>. Daily capacity is computed by applying the following steps:

(1) List all possible operating configurations; for this example assume touch and go traffic is negligible. In other words, the air station is assumed to operate at a ratio = 1.0.



(2) Estimate the % VFR and IFR weather during the average day. It may also be desirable to calculate the daily capacity on a basis of 100% VFR weather or 100% IFR weather. This example assumes the following:

85% VFR 15% IFR

(3) Estimate the % use of each operating priority; assumed as follows:

V 1	60%
V 2	25%
I 1	10%
I 2	5%

(4) Calculate a "weighted" average hourly capacity

$$\begin{array}{rcr} 140 \times .6 & = & 84.0 \\ 130 \times .25 & = & 32.5 \\ 70 \times .10 & = & 7.0 \\ 64 \times .05 & = & \underline{3.2} \\ & & 126.7 \quad (127) \end{array}$$

(5) It is unrealistic to assume that all available hours would be subject to peak hour demand. It can be assumed that the hours of peak demand and hours of slack demand could be identified (or stipulated) for any particular air station. This can be accomplished as follows:

- For each operating hour determine the expected demand level as a decimal percentage of 1.
- Sum these percentages to obtain the hours of utilization.

Assuming the following hourly utilization, the hourly utilization sum = 8.8.

Hour	1	2	3	4	5	6	7	8	9	10	11	12
% of Peak Demand	.3	.8	1	1	.8	.6	.9	1	1	.7	.4	.3

Note: Facility assumed open only 12 hours per day in this example.

.. Subjectively reduce "hours utilization" to account for periods of time that the runway facilities are not available for aircraft operations; as for example, emergencies, missed approaches, runway maintenance, other non-pilot utilization, etc.

.. Consider reduction of up to 15% for conventional operation and up to 50% for Carrier Practice Landing Operations - suggested per recommendation of NATRACOM as contained in Technical Report 583, Volume II of IV, prepared by Operations Research, Inc., under contract for the Department of Navy.

In the example, 8.8 hours would reduce to approximately 7.5 hours.

(6) Multiply the weighted hourly capacity times the total hours of utilization.

$$127 \times 7.5 = 952.5$$

Daily capacity = (953) operations/day

e. <u>Application of Figure 2-2</u>. The following additional examples demonstrate the particular use of Figure 2-2:

(1) Given: Runway Rating = 65
Percent Operations by Class: 100% I
Operating Mix Percent Landings: 30%

Determine $(HMC)_E$

Answer: 42 (Refer Figure 2-2/EXAMPLE on page C-63)

(2) Given: Runway Rating = 60
Percent Operations by Class: 100% II
Operating Mix Percent Landings: 30%

Determine $(HMC)_E$

Answer: 51 (Refer Figure 2-2/EXAMPLE on page C-64)

(3) Given: Runway Rating = 45
Percent Operations by Class: 100% III
Operating Mix Percent Landings: 45%

Determine $(HMC)_E$

Answer: 65 (Refer Figure 2-2/EXAMPLE on page C-65)

(4) Given: Runway Rating = 60
Percent Operations by Class: 50% I
50% III
Operating Mix Percent Landings: 15%

Determine $(HMC)_E$

Answer: 55 (Refer Figure 2-2/EXAMPLE on page C-66)

Given: Runway Rating = 65

Percent Operations:
Class I = 100%

Percent Landings = 30%

Answer: $(HMC)_E$ = 42

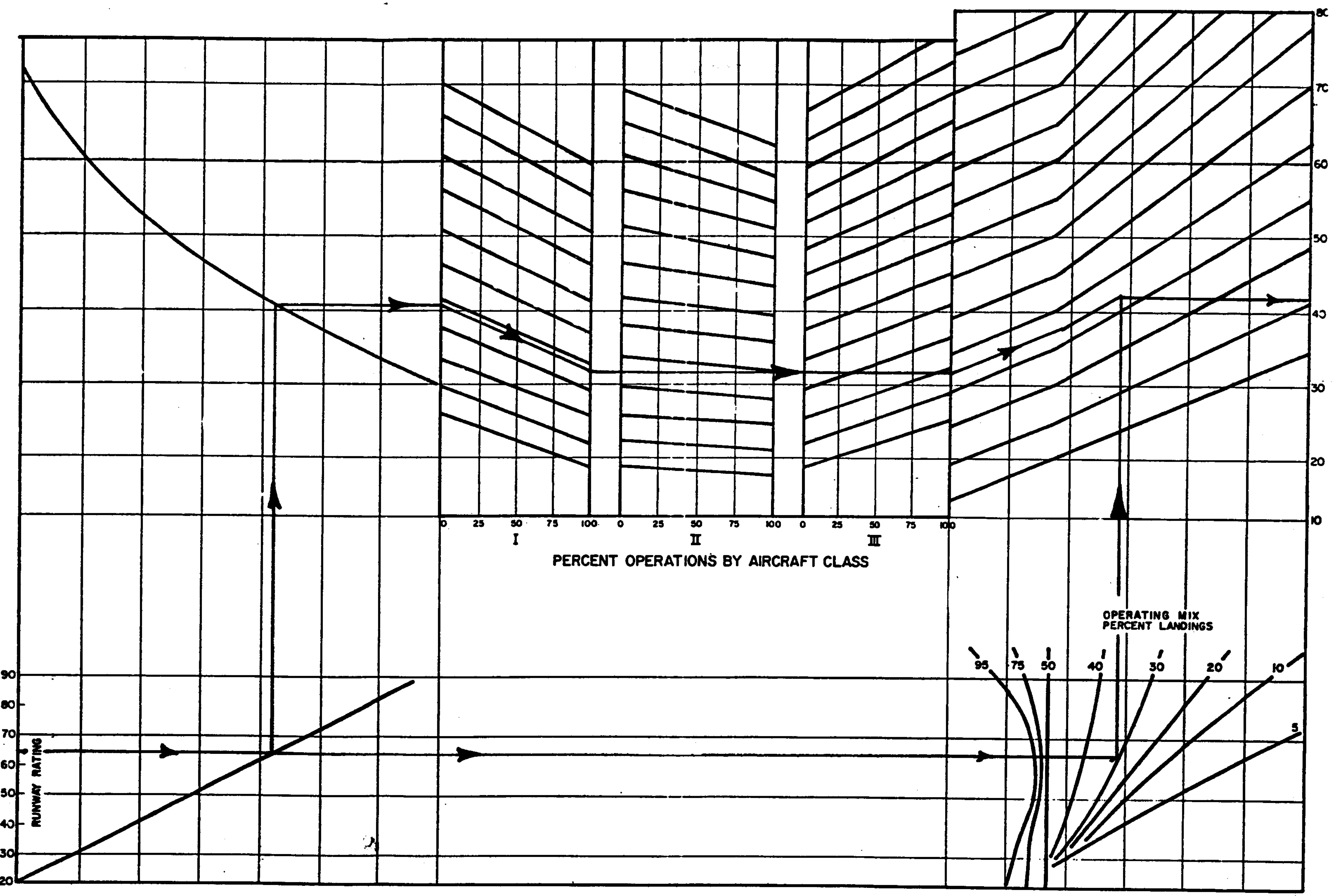


Figure 2-2/EXAMPLE
VFR RUNWAY CAPACITY FOR MIXED OPERATIONS

Given: Runway Rating = 60

Percent Operations:
Class II = 100%

Percent Landings = 30%

Answer: $(HMC)_E$ = 51

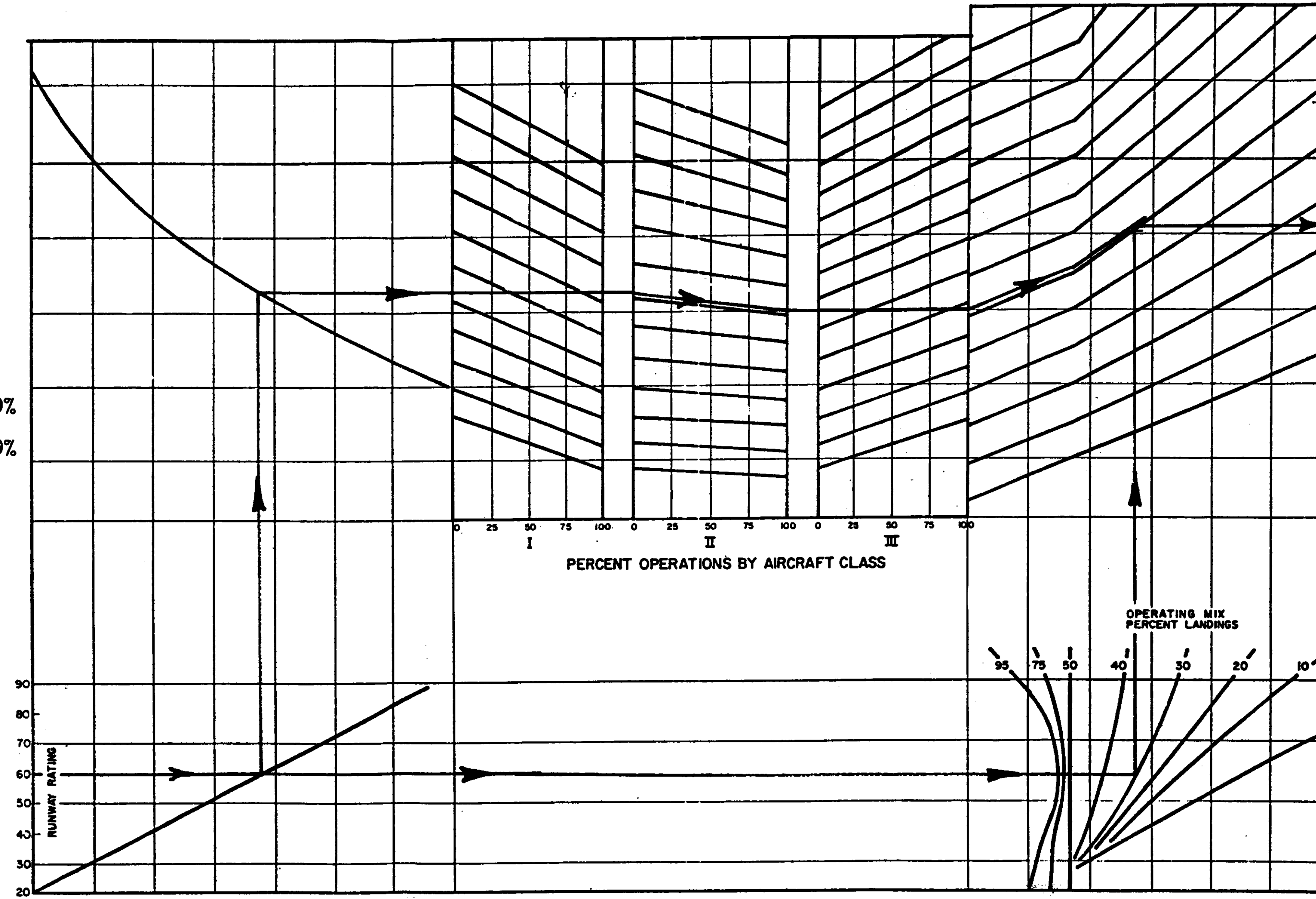


Figure 2-2/EXAMPLE
VFR RUNWAY CAPACITY FOR MIXED OPERATIONS

iven: Runway Rating = 45

Percent Operations:
Class III = 100%

Percent Landings = 45%

nswer: $(HMC)_E$ = 65

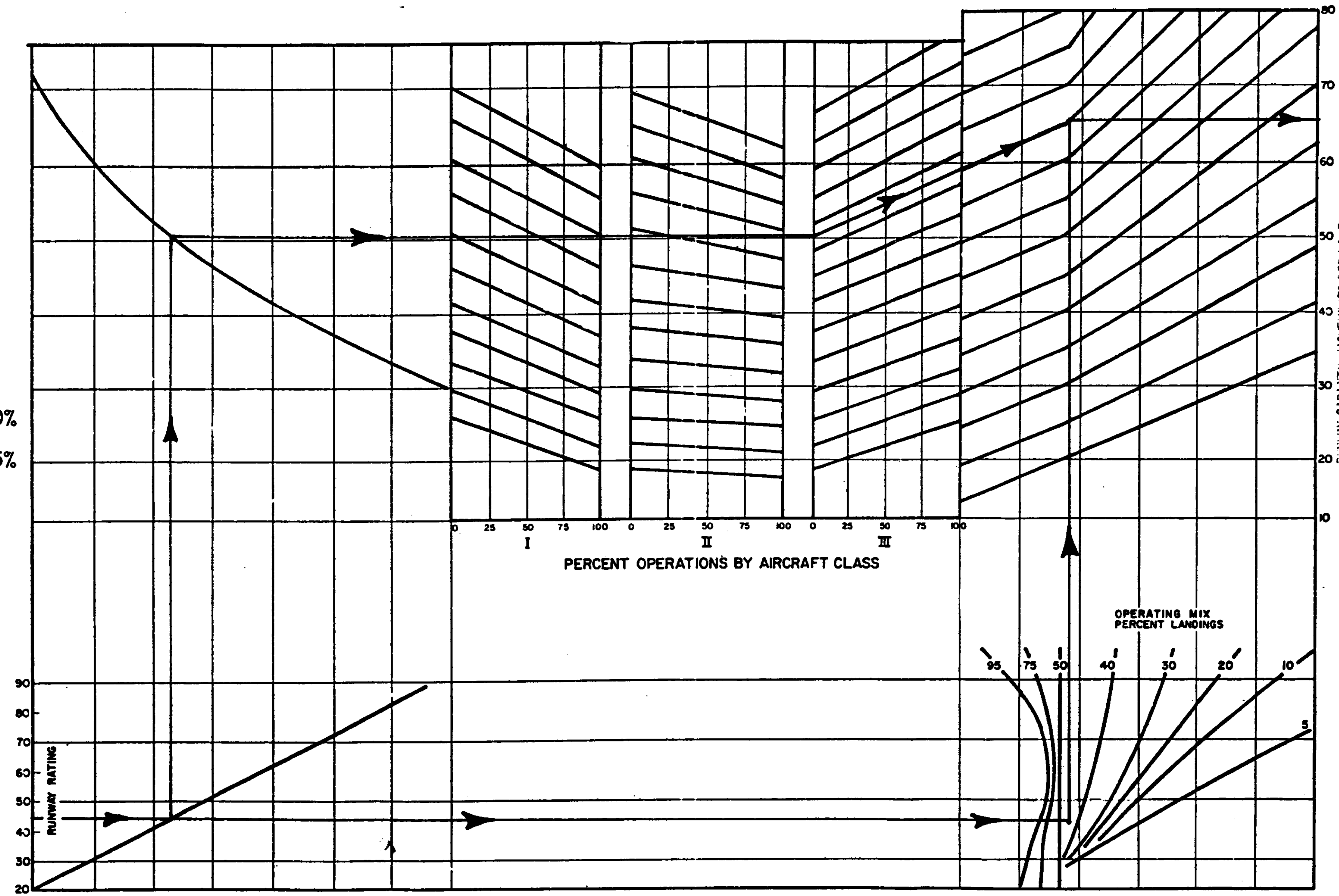


Figure 2-2/EXAMPLE
VFR RUNWAY CAPACITY FOR MIXED OPERATIONS

ven: Runway Rating = 60

Percent Operations:
Class I = 50%
Class III = 50%

Percent Landings = 15%

swer: $(HMC)_E$ = 55

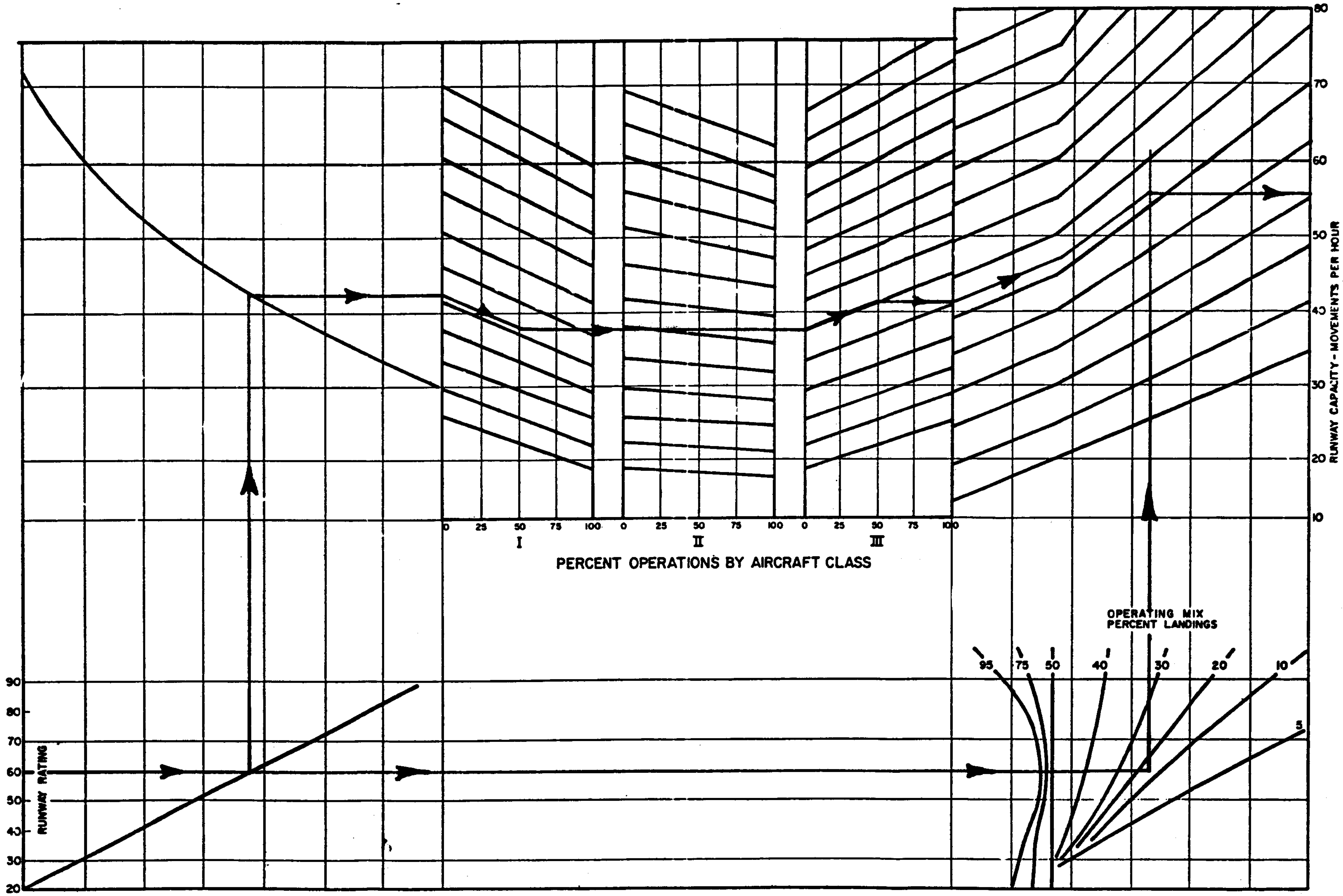


Figure 2-2/EXAMPLE
VFR RUNWAY CAPACITY FOR MIXED OPERATIONS

Section IV. WORK SHEETS

For use in the calculation of runway capacities, extra copies of the following figures and tables are provided:

Figure 2-1: Runway Rating

Figure 2-2: VFR Runway Capacity for Mixed Operations

Table 2-1: HAC - Hourly Arrival Capacity

Table 2-2: Equivalent Movement Factors

Table 2-3: VFR Hourly Departure Capacity (HDC) Analysis Work Sheet

Table 2-4: VFR Hourly Arrival Capacity (HAC) Analysis Work Sheet

Table 2-5: VFR Hourly Mixed Capacity (HMC) Analysis Work Sheet

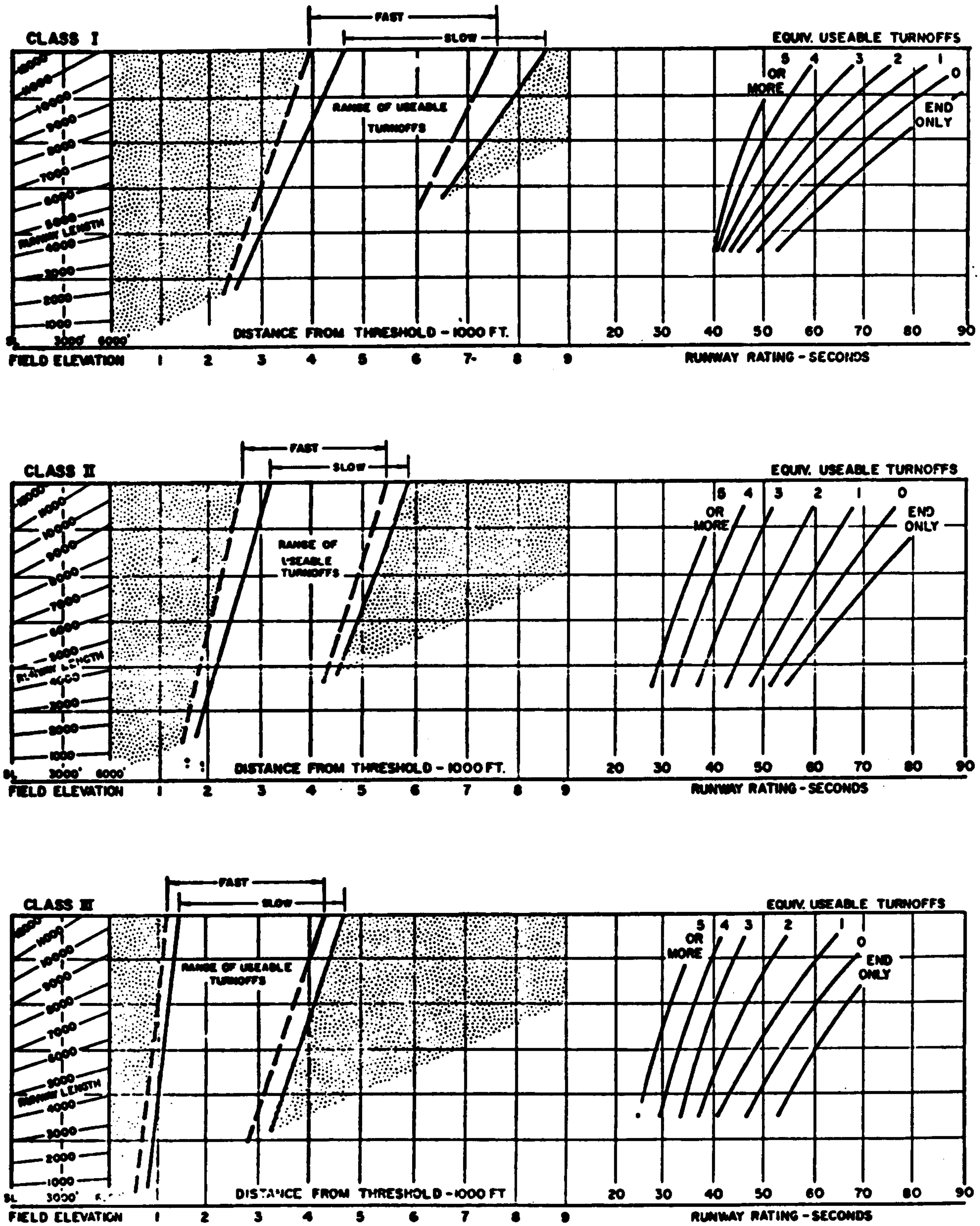


FIGURE 2-1

RUNWAY RATING

AVERAGE LANDING OCCUPANCY TIME-SECONDS

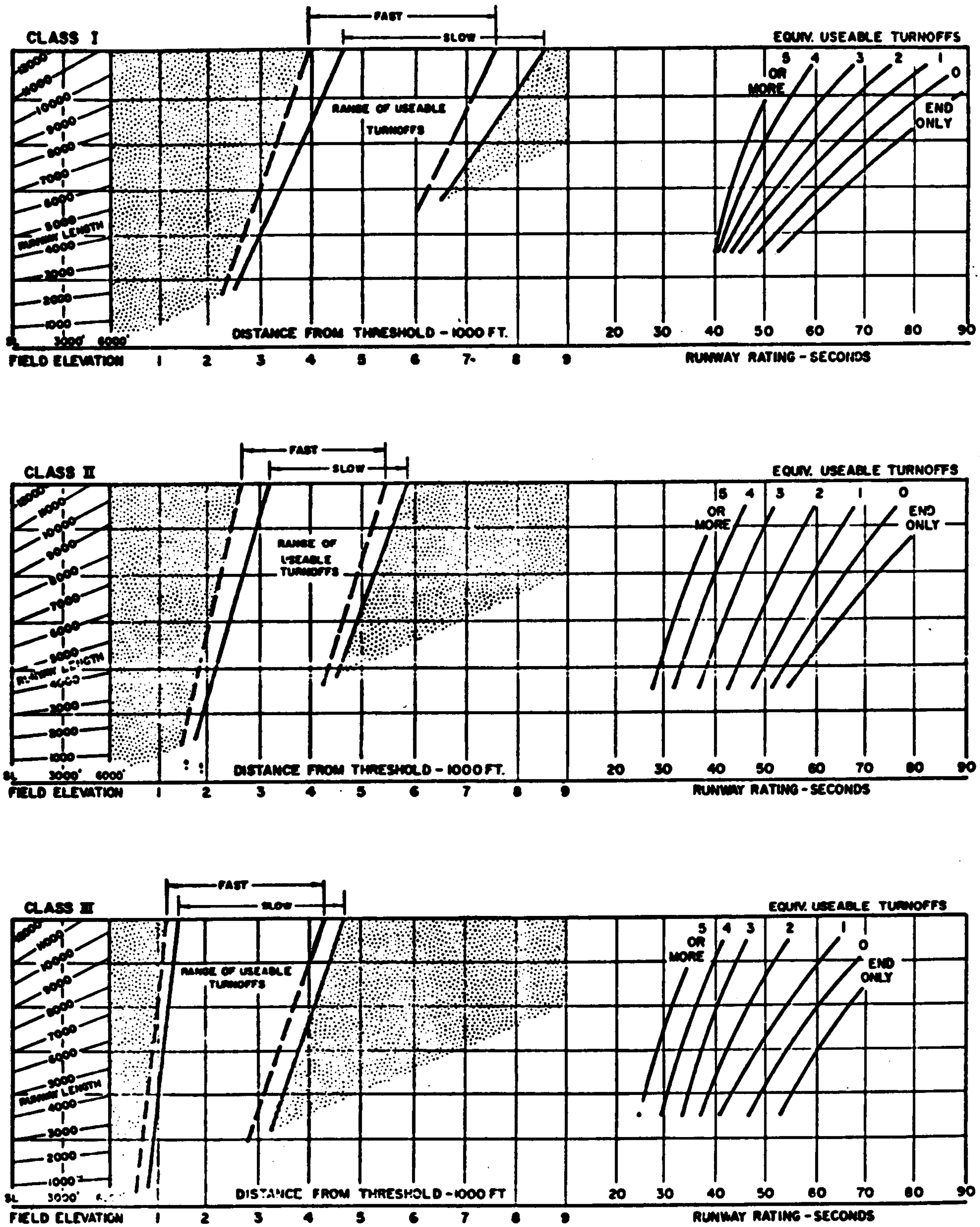


FIGURE 2-1

RUNWAY RATING

AVERAGE LANDING OCCUPANCY TIME-SECONDS

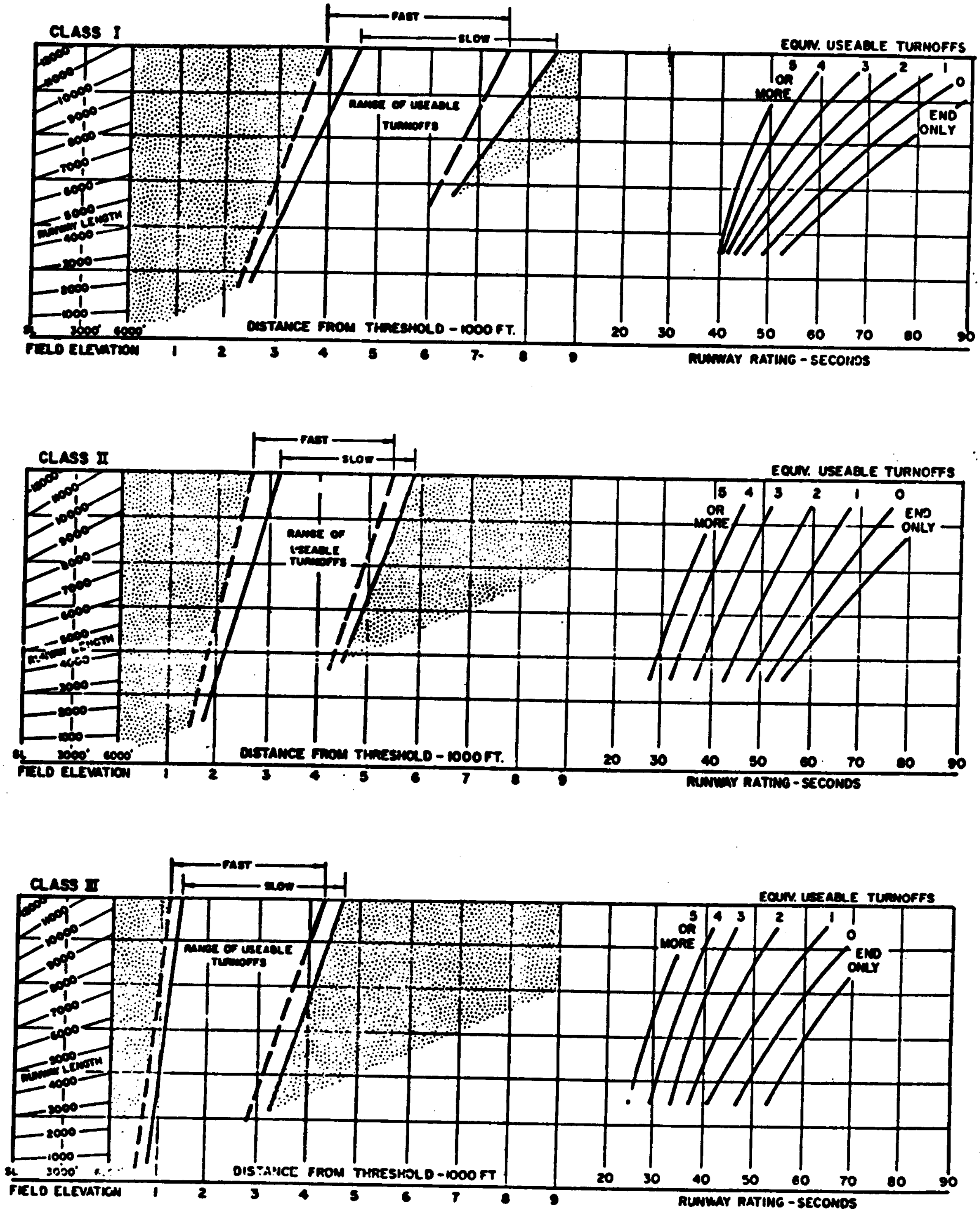


FIGURE 2-1

RUNWAY RATING

AVERAGE LANDING OCCUPANCY TIME-SECONDS

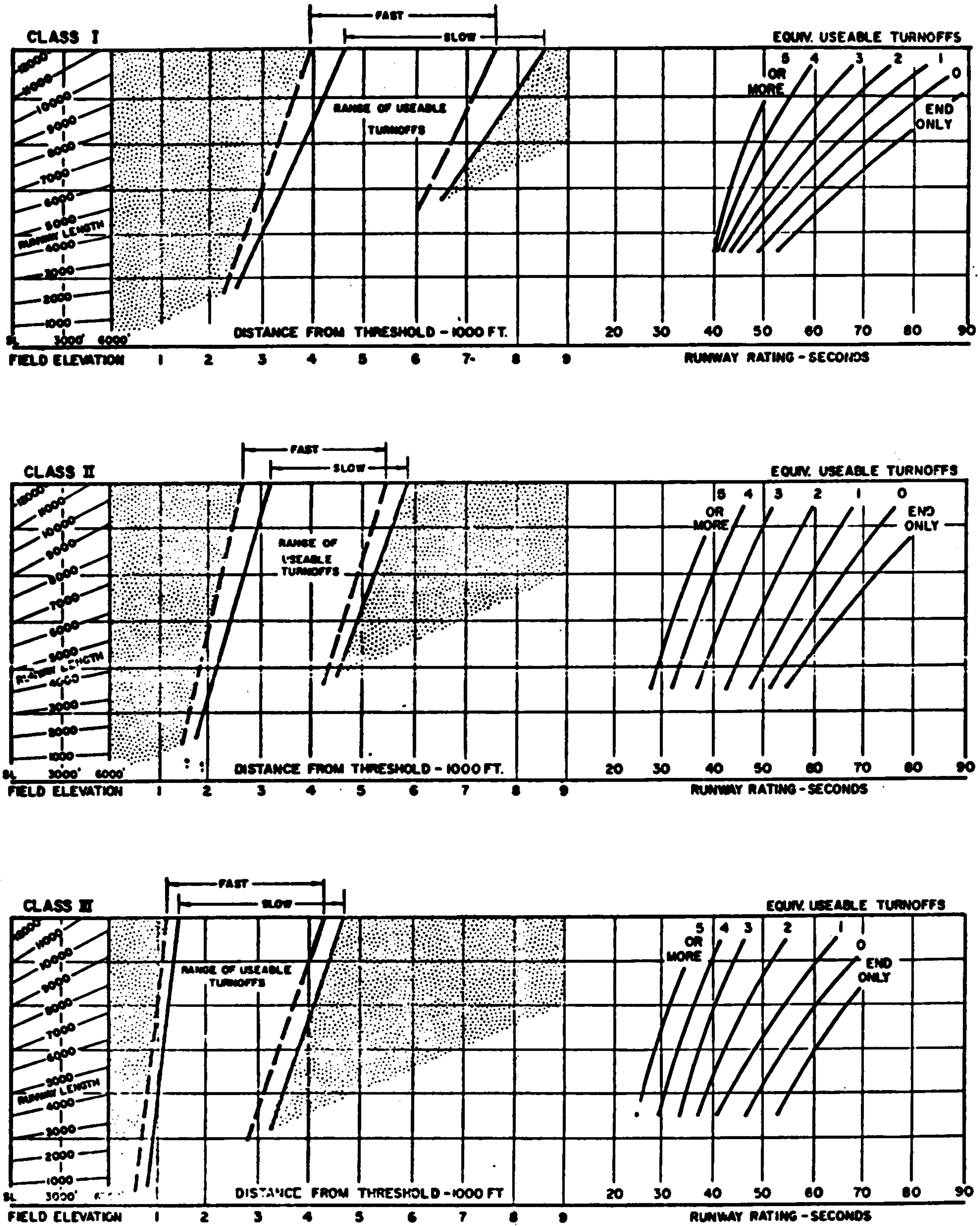


FIGURE 2-1

RUNWAY RATING

AVERAGE LANDING OCCUPANCY TIME-SECONDS

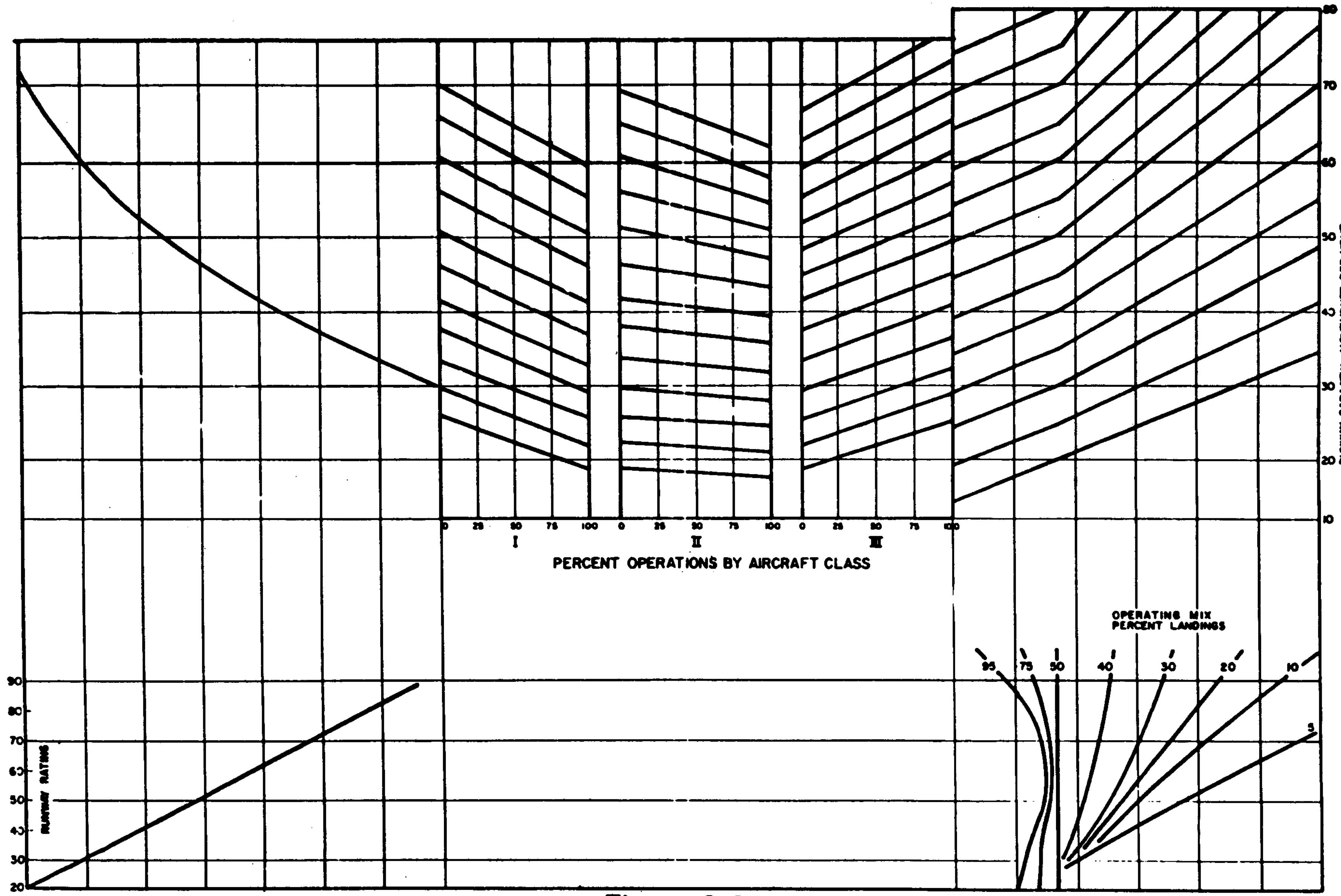


Figure 2-2
VFR RUNWAY CAPACITY FOR MIXED OPERATIONS

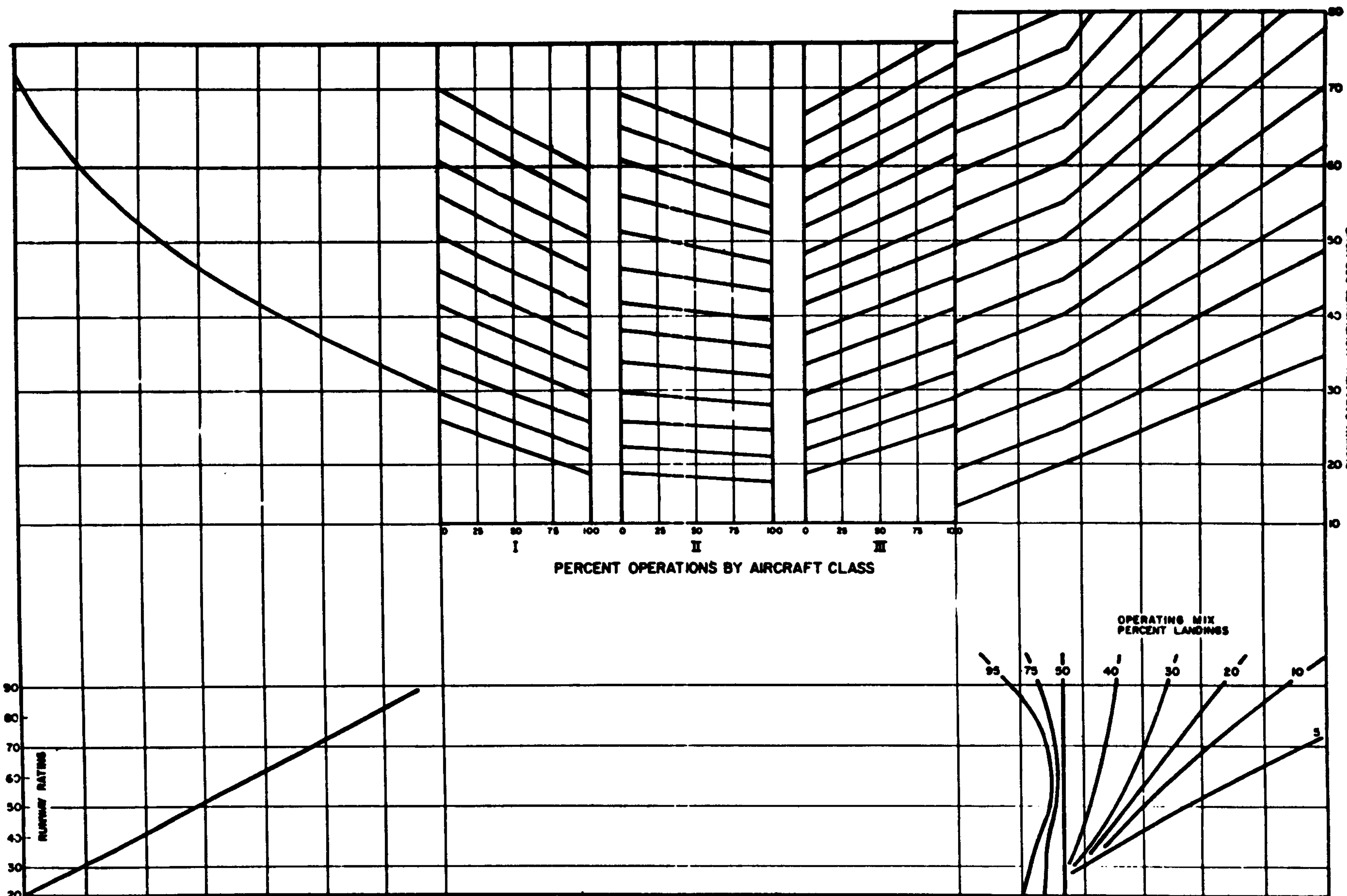


Figure 2-2
VFR RUNWAY CAPACITY FOR MIXED OPERATIONS

Table 2-1

HAC - HOURLY ARRIVAL CAPACITY - Movements Per Hour

Aircraft Class	Runway Rating					
	30	40	50	60	70	80
I	50	47	44	40	35	30
II	57	52	47	42	38	33
III	63	62	58	53	47	41

Use of Table: Enter with Runway Rating for each aircraft class as obtained in Step 2 on Tables 2-4 or 2-5 and read HAC below. Interpolate as required.

Table 2-2

EQUIVALENT MOVEMENT FACTORS
For Touch & Go or Landings in Formation

Landing Procedure	HAC - Movements per Hour							
	30	35	40	45	50	55	60	65
Formation of 2	.58	.59	.61	.62	.64	.65	.67	.68
Formation of 3	.45	.47	.49	.50	.52	.55	.56	.57
Formation of 4	.37	.40	.42	.44	.46	.48	.50	.52
Touch and Go	.17	.20	.23	.25	.27	.30	.33	.37

Use of Table: Enter HAC obtained above (Table 2-1) for each aircraft class and read Equivalent Movement Factors below. Interpolate as required.

Table 2-1

HAC - HOURLY ARRIVAL CAPACITY - Movements Per Hour

Aircraft Class	Runway Rating					
	30	40	50	60	70	80
I	50	47	44	40	35	30
II	57	52	47	42	38	33
III	63	62	58	53	47	41

Use of Table: Enter with Runway Rating for each aircraft class as obtained in Step 2 on Tables 2-4 or 2-5 and read HAC below. Interpolate as required.

Table 2-2

EQUIVALENT MOVEMENT FACTORS
For Touch & Go or Landings in Formation

Landing Procedure	HAC - Movements per Hour							
	30	35	40	45	50	55	60	65
Formation of 2	.58	.59	.61	.62	.64	.65	.67	.68
Formation of 3	.45	.47	.49	.50	.52	.55	.56	.57
Formation of 4	.37	.40	.42	.44	.46	.48	.50	.52
Touch and Go	.17	.20	.23	.25	.27	.30	.33	.37

Use of Table: Enter HAC obtained above (Table 2-1) for each aircraft class and read Equivalent Movement Factors below. Interpolate as required.

Table 2–3

VFR HOURLY DEPARTURE CAPACITY (HDC) ANALYSIS WORK SHEET

Step No.	①		②	③	④	⑤	⑥	⑦
Procedure	From Field Survey or Forecast		Constants	①×②	$③_S \div ③_G$	Constants	$④_S \times ⑤$	$⑥_G \times \frac{①_G}{③_G}$
Step Definition	Takeoff Demand: Type Operation	Takeoff Demand: No. of Aircraft	Equivalent Movement Factors	Takeoff Equivalent Movements	Class Distribution	Class HDC's	Weighted $(HDC)_E$	Weighted $(HDC)_A$
Aircraft Class I	Single		1.00					
	FORMATION of 2		.60					
	FORMATION of 3		.47					
	FORMATION of 4		.40					
	Pairs		.50					
						49		
Sub-Totals I		S		S	S		S	
Aircraft Class II	Single		1.00					
	FORMATION of 2		.63					
	FORMATION of 3		.51					
	FORMATION of 4		.45					
	Pairs		.60					
						63		
Sub-Totals II		S		S	S		S	
Aircraft Class III	Single		1.00					
	FORMATION of 2		.69					
	FORMATION of 3		.59					
	FORMATION of 4		.54					
	Pairs		.50					
						90		
Sub-Totals III		S		S	S		S	
ALL CLASSES — Grand-Totals		$①_G$		$③_G$	$④_G$		$⑥_G$	

Table 2–3

VFR HOURLY DEPARTURE CAPACITY (HDC) ANALYSIS WORK SHEET

Step No.	①		②	③	④	⑤	⑥	⑦
Procedure	From Field Survey or Forecast		Constants	①×②	③$_S$ ÷ ③$_G$	Constants	④$_S$ ×⑤	⑥$_G$ × ①$_G$/③$_G$
Step Definition	Takeoff Demand		Equivalent Movement Factors	Takeoff Equivalent Movements	Class Distribution	Class HDC's	Weighted (HDC)$_E$	Weighted (HDC)$_A$
	Type Operation	No. of Aircraft						
Aircraft Class I	Single		1.00					
	FORMATION of 2		.60					
	FORMATION of 3		.47					
	FORMATION of 4		.40					
	Pairs		.50					
Sub-Totals$_I$		S		S	S	49	S	
Aircraft Class II	Single		1.00					
	FORMATION of 2		.63					
	FORMATION of 3		.51					
	FORMATION of 4		.45					
	Pairs		.50					
Sub-Totals$_{II}$		S		S	S	63	S	
Aircraft Class III	Single		1.00					
	FORMATION of 2		.69					
	FORMATION of 3		.59					
	FORMATION of 4		.54					
	Pairs		.50					
Sub-Totals$_{III}$		S		S	S	90	S	
ALL CLASSES — Grand-Totals		①$_G$		③$_G$	④$_G$		⑥$_G$	

Table 2–4

VFR HOURLY ARRIVAL CAPACITY (HAC) ANALYSIS WORK SHEET

Step No.		1	1A	1B	1C	2	3	4	5	6	7	8	9	10	11	12	13	14
Procedure		FROM FIELD SURVEY OR FORECAST				USE Fig. No. 2-1	USE TABLE No. 2-1	USE TABLE No. 2-2	(1A)×(4)	(1B)×(4)	$5_G + 6_G$	$5_S ÷ 7_G$	$6_S ÷ 7_G$	$8_S × 3$	Constants	$9_S × 11$	$10_G + 12_G$	$13_G × 1C_G ÷ 7_G$
Step Definition		LANDING DEMAND				Runway Rating	Cla[illegible] H[illegible]	Equivalent Movement Factors	Non Touch & Go Equivalent Movements	Touch & Go Equivalent Movements	Total Equivalent Movement	Non Touch & Go Class Distribution	Touch & Go Class Distribution	Non Touch & Go Weighted HAC	Touch & Go HAC's	Touch & Go Weighted HAC	Weighted $(HAC)_E$	Weighted $(HAC)_A$
		Type Operation	No. of Aircraft: Non Tch & Go	Touch & Go	Total													
Aircraft Class I	Single							1.00										
	FORMATION OF 2																	
	FORMATION OF 3																	
	FORMATION OF 4																	
	Touch & Go																	
	(Repeat Value)																	
	Sub-Total I		S	S					S	S		S	S	S	53	S		
Aircraft Class II	Single							1.00										
	FORMATION OF 2																	
	FORMATION OF 3																	
	FORMATION OF 4																	
	Touch & Go																	
	(Repeat Value)																	
	Sub-Total II		S	S					S	S		S	S	S	60	S		
Aircraft Class III	Single							1.00										
	FORMATION OF 2																	
	FORMATION OF 3																	
	FORMATION OF 4																	
	Touch & Go																	
	(Repeat Value)																	
	Sub-Total III		S	S					S	S		S	S	S	66	S		
ALL CLASSES	Grand Total		G	G	G				5_G	6_G	7_G	G	G	10_G		12_G	13_G	

Table 2–4

VFR HOURLY ARRIVAL CAPACITY (HAC) ANALYSIS WORK SHEET

Step No.		①	①A	①B	①C	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭
Procedure		FROM FIELD SURVEY OR FORECAST				USE Fig. No. 2-1	USE TABLE No. 2-1	USE TABLE No. 2-2	①A × ④	①B × ④	$⑤_G + ⑥_G$	$⑤_S ÷ ⑦_G$	$⑥_S ÷ ⑦_G$	$⑧_S × ③$	Constants	$⑨_S × ⑪$	$⑩_G + ⑫_G$	$⑬_G × \frac{①C_G}{⑦_G}$
Step Definition		LANDING DEMAND: Type Operation	No. of Aircraft: Non Tch & Go	No. of Aircraft: Touch & Go	No. of Aircraft: Total	Runway Rating	Class HAC	Equivalent Movement Factors	Non Touch & Go Equivalent Movements	Touch & Go Equivalent Movements	Total Equivalent Movement	Non Touch & Go Class Distribution	Touch & Go Class Distribution	Non Touch & Go Weighted HAC	Touch & Go HAC's	Touch & Go Weighted HAC	Weighted $(HAC)_E$	Weighted $(HAC)_A$
Aircraft Class I		Single						1.00										
	FORMATION OF	2																
		3																
		4																
		Touch & Go																
	Sub-Total I		S	S (Repeat Value)					S	S (Repeat Value)		S	S	S	53	S		
Aircraft Class II		Single						1.00										
	FORMATION OF	2																
		3																
		4																
		Touch & Go																
	Sub-Total II		S	S (Repeat Value)					S	S (Repeat Value)		S	S	S	60	S		
Aircraft Class III		Single						1.00										
	FORMATION OF	2																
		3																
		4																
		Touch & Go																
	Sub-Total III		S	S (Repeat Value)					S	S (Repeat Value)		S	S	S	66	S		
ALL CLASSES	Grand Total		G	G	G				$⑤_G$	$⑥_G$	$⑦_G$	G	G	$⑩_G$		$⑫_G$	$⑬_G$	

Step No.		①	①A	①B	①C	①D	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭A	⑭B	⑭C	⑮	⑯
Procedure		FROM FIELD SURVEY OR FORECAST					USE Fig. No. 2-1	USE TABLE No. 2-1	USE TABLE No. 2-2	$(1A) \times (4)$	$(1B) \times (4)$	$(5)_S + (6)_S$	CONSTANTS	$(1D) \times (8)$	$(1C)_G + (1D)_G$	$(7)_S + (9)_S$	$(7)_G \div (11)_G$	$(11)_S \div (11)_G$	$2 \times \frac{(5)_S}{(7)_G}$	$\text{"20"} \times \frac{(6)_G}{(7)_G}$	$(14A)_G + (14B)_G$	USE Fig. No. 2-2	$(15)_G \times \frac{(10)_G}{(11)_G}$
Step Definition		TYPE OPERATION	No. of LANDING AIRCRAFT: Non Touch & Go	Touch & Go	Total	No. of Takeoff Aircraft	Class Runway Rating	Class HAC's	Landing Equivalent Movement Factors	Non Touch & Go Equivalent Movements	Touch & Go Equivalent Movements	Total Landing Equivalent Movements	Takeoff Equivalent Movement Factors	Takeoff Equivalent Movements	Total Takeoffs And Landings	Total Take-off & Land. Equivalent Movements	Percent Landing	Class Distri-bution	Weighted Runway Rating: Non Touch & Go	Touch & Go	Total	$(HMC)_E$	$(HMC)_A$
Aircraft CLASS I	Single								1.00				1.00										
	FORMATION OF 2												.80										
	FORMATION OF 3												.47										
	FORMATION OF 4												.41										
	Touch & Go																						
	Pairs										(Repeat Value)		.50										
Sub-Total I			S	S (Repeat Value)		S				S	S	S		S		S		S	S				
Aircraft CLASS II	Single								1.00				1.00										
	FORMATION OF 2												.63										
	FORMATION OF 3												.51										
	FORMATION OF 4												.46										
	Touch & Go			(Repeat Value)																			
	Pairs										(Repeat Value)		.50										
Sub-Total II			S	S		S				S	S	S		S		S		S	S				
Aircraft CLASS III	Single								1.00				1.00										
	FORMATION OF 2												.69										
	FORMATION OF 3												.59										
	FORMATION OF 4												.54										
	Touch & Go			(Repeat Value)																			
	Pairs										(Repeat Value)		.50										
Sub-Total III			S	S		S				S	S	S		S		S		S	S				
ALL CLASSES	Grand Total		G	G	$(1C)_G$	$(1D)_G$				$(5)_G$	$(6)_G$*	$(7)_G$		$(9)_G$		G		G	G				

* CROSS CHECK: Does $(5)_G + (6)_G = (7)_G$; Does $(7)_G + (9)_G = (11)_G$

Table 2–5

VFR HOURLY MIXED CAPACITY (HMC) ANALYSIS WORK SHEET

Step No.	①	①A	①B	①C	①D	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭A	⑭B	⑭C	⑮	⑯
Procedure	FROM FIELD SURVEY OR FORECAST					USE Fig. No. 2-1	USE TABLE No. 2-1	USE TABLE No. 2-2	①A×④	①B×④	$⑤_S+⑥_S$	CONSTANTS	①D×⑧	$①C_G+①D_G$	$⑦_S+⑨_S$	$⑦_G÷⑪_G$	$⑪_S÷⑪_G$	$2×\frac{⑤_S}{⑦_G}$	$"20"×\frac{⑥_G}{⑦_G}$	$⑭A_G+⑭B_G$	USE Fig. No. 2-2	$⑮_G×\frac{⑩_G}{⑪_G}$
Step Definition	TYPE OPERATION	No. of LANDING AIRCRAFT: Non Touch & Go	Touch & Go	Total	No. of Takeoff Aircraft	Class Runway Rating	Class HAC's	Landing Equivalent Movement Factors	Non Touch & Go Equivalent Movements	Touch & Go Equivalent Movements	Total Landing Equivalent Movements	Takeoff Equivalent Movement Factors	Takeoff Equivalent Movements	Total Takeoffs And Landings	Total Take-off & Land. Equivalent Movements	Percent Landing	Class Distribution	Weighted Runway Rating: Non Touch & Go	Touch & Go	Total	$(HMC)_E$	$(HMC)_A$
Aircraft CLASS I	Single							1.00				1.00										
	FORMATION OF 2											.80										
	FORMATION OF 3											.47										
	FORMATION OF 4											.41										
	Touch & Go																					
	Pairs		(Repeat Value)							(Repeat Value)		.50										
	Sub-Total I	S	S		S				S	S	S		S		S		S	S				
Aircraft CLASS II	Single							1.00				1.00										
	FORMATION OF 2											.63										
	FORMATION OF 3											.51										
	FORMATION OF 4											.46										
	Touch & Go				(Repeat Value)																	
	Pairs									(Repeat Value)		.50										
	Sub-Total II	S	S		S				S	S	S		S		S		S	S				
Aircraft CLASS III	Single							1.00				1.00										
	FORMATION OF 2											.69										
	FORMATION OF 3											.59										
	FORMATION OF 4											.54										
	Touch & Go				(Repeat Value)																	
	Pairs									(Repeat Value)		.50										
	Sub-Total III	S	S		S				S	S	S		S		S		S	S				
ALL CLASSES	Grand Total	G	G	$①C_G$	$①D_G$				$⑤_G$	$⑥_G$*	$⑦_G$		$⑨_G$		G		G	G				

* CROSS CHECK: Does $⑤_G + ⑥_G = ⑦_G$; Does $⑦_G + ⑨_G = ⑪_G$

Table 2–5

VFR HOURLY MIXED CAPACITY (HMC) ANALYSIS WORK SHEET

Supersession to FC 2-000-05N Appendix D (formerly NAVFAC P80.2 and UFC 2-000-05N)

Appendix D – Naval Mobile Construction Battalion Facilities (formerly P-80.2) was published on May 1, 1976 and is no longer an accurate description of the planning criteria required for facilities supporting a Naval Mobile Construction Battalion. Therefore, this supersession document has been created as a replacement and all category code and criteria information now reside in the FC 2-000-05N.

Naval Mobile Construction Battalion facilities utilize a number of expeditionary, operational, and base operations related category code numbers (CCNs) to define requirements. Some of these CCNs were added or updated in 2018 and 2019. Specific production or revision dates can be found on the revision pages included at the beginning of every FC sub section document (100-900 series). The following facilities are typically required to support a Naval Mobile Construction Battalion:

14309 Expeditionary Ops Support Facility

14311 Operational Vehicle Garage

14312 Operational Vehicle Laydown Area

12317 Overhead Cover, Miscellaneous

21451 Automotive Organizational Shop

21455 Vehicle Wash Platform

21710 Electronics/Communications Maintenance Shop

85210 Parking Area

This is the current list of NMCB related CCNs as of April 2019 and detailed descriptions of each are provided in the FC 2-000-05N. This list will be updated here and in the FC as mission dictates in the future.

FACILITY PLANNING FACTOR CRITERIA FOR NAVY & MARINE CORPS SHORE INSTALLATIONS

Appendix E
AIRFIELD SAFETY CLEARANCES

NAVFAC P-80.3
JANUARY 1982

APPROVED FOR PUBLIC RELEASE

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
200 STOVALL STREET
ALEXANDRIA, VIRGINIA 22332

DISTRIBUTION: (one copy each except as indicated)

SNDL List	21	Fleet Commanders-inChief
	23A	Naval Force Commanders (4 copies)
	24A	Naval Air Force COmmanders (4 copies)
	42A	Fleet Air Commands (2 copies)
	42B	Functional Wing COmmanders
	46A	Fleet Marine Force Commands (2 copies)
	46B	Aircraft Wing
	SOA	Unified Commands
	SOB	Specified Commands
SNDL List	Al	Immediate Office of the Secretary: SO - 2 only
	A/.A	Department Of the Navy Staff Offices
	A3	Chief of Navl Operations: (2 copiP.s OP-41, 44 and 51)
	A4A	Chi f of Naval Material
	Af:.	Headquarters U.S. Marine Corps (4 copies to LFF-1 and ASL-1)
	Bl	Secretary of Defense: DASO (I&H) only
	B2A	Joint Chiefs of staff: JCS-J4 only
	B3	Colleqe and University
	FAS	Air Facility LANT
	FAfi	Air Station LANT (2 copies each)
	FA7	Station LANT
	FB6	Air Facility PAC
	FB7	Air Station :RllC (2 copies each)
	FBlO	Station PAC
	FC4	Air Facility NAVEUR
	FC7	Station NAVEUR
	FKAlA	Air System Command Headquarters (10 copies AIR-410)
	FKA6Al	Air Developmenter Center
	FKNl	Facilities Engineering Command Division (60 copiP.s each)
	FKN2	Construction Battalion Center
	FKN3	Construction 0 in C
	FKNS	Rlblic Works Center (5 copies each)
	FKRlA	Air Station NAVAIRSYSCOM (2 copies each)
	FKRlB	Air Rew:irk Facility
	FKR3A	Air Enqineering Center
	FKR3C	Air Test Center
	FKR3E	Weapons Evaluation Facility
	FKR3H	Air Propulsion Center
	FKR4A	Missile Test Center
	FKR4B	Missile Range Facility
	FRl	Chief of Naval Reserve (5 copies)
	FR3	Air Station CNAVRES (2 copies each)
	FR4	Air Facility CNAVRES (2 copies each)
	FTl	Chief of Naval a3ucation and Training (5 copies)
	FT2	Chief of Naval Air Training (5 copies)

(contin1.1ed)

FTS	Chief of Naval Technical Training
FT6	Air Station CNET (2 copies each)
FT37	Scol ca: Officers (100 copies)
V3	Marine Corps Air Base Commanders (5 copies each)
V4	Marine Corps Air Facility (2 copies each)
VS	Marine Corps Air Station (2 copipes each)
Vl6	Marine Corps Base (2 copies each)

STOCKED: U.S. Naval Publications and Forms Center
SSOl Tabor Avenue
Philadelphia, PA 19120

TABLE OF CONTENTS

E-iii

SECTION I - GENERAL

A. RJR:EOSE. The purpose of this Appendix is to (1) provide facility planners with g'Jidance for identifying obstructions to air navigation and (2) establish airfield safety clearances for fixed winq aircraft and helicopter installations • The Appendix amplifies information provided in Federal Aviation Regulation Part 77, Objects Affecting Navigable Airspace and includes airfield clearance criteria specified in the Joint Service Manual NAVFAC P-971 (Airfield and Heliport Planning criteria) . Standards herein identify three types of airfield safety criteria:

(a) Height restrictions. Restrictfons in the f-:Jrm of specific height limits or imaginary surfaces through which objects shall not penetrate.

(b) Lateral Clearances. Standards as to how close objects may be sited to airfield pavements regardless of their height incl'Jding separations between airfield pavements.

(c) Clear Zones/Takeoff Safety Zones. The areas immediately adjacent to runway and helipad thresholds provide for unobstructed takeoffs and landings and serve as emergency overrun areas. Detailed q'Jidance is required to prevent obstructions in these areas•

The clearances and imaginary surfaces defined herein are to be used solely for siting facilities and determining obstructions as differentiated from standards to determine flight paths, qlide slopes, etc; actually flown by aircraft.

As a secondary purpose, the A?pendix identifies some other factors related to aircraft operations such as noise and accident potential which should be considered when sitinq facilities at air installations. The criteria in this Appendix conform to that established by the Department of Defense for the Air Installations Compatible Use Zone (AICUZ) Program.

The following manuals and instructions are pertinent to planning and siting facilities at Navy and Marine Corps air installations.

Federal Aviation Regulation, Part 77	Objects Affecting Navigable Airspace
DOD 4270.1-M	Department of Defense construction Criteria Manual
DOD INST 4165.57	Air Installation Compatible Use Zones
OPNAVINST 11010.36	Air Installations compatible Uses Zones (AICUZ) Program
NAVFACINST 11010.57B	Site Approval of Naval Shore Facilities
MCO P 11000.12A	Real Proberty Facilities Manual, Vol II, Facilities Planning and Programming
NAVFAC DM-21 (Series)	Airfield Pavements
NAVSEA OP-5, Vol I	Ammunition and Explosives Ashore

B. APPLICABILITY/WAIVERS. The criteria in this Appendix apply to Navy and Marine Corps air installations located in the United States, its territories, trusts, and possessions. Where a Navy or Marine Corps air installation is a tenant on a civil airport use these criteria to the extent practicable, otherwise FAA criteria apply. Where a Navy/Marine Corps air installation host a civilian airport, these criteria shall apply. Also apply these standards to the extent practicable at overseas locations where the Navy and Marine Corps have vested base rights. While the criteria in this Appendix are not intended for use in a theater-of-operations situation, they may be used as a guideline where prolonged use is anticipated and no other standard has been designated.

The criteria shall be us.ed for planning all new air installations and new airfield pavements at existing air installations. (Exception: Primary surfacewidth for Class B runways, See Section II, paragraph Cl.) Existing air installations have been developed using previous standards which may not conform to the criteria herein. Safety clearances at existing air installations need not be upgraded solely for the purpose of conforming to these criteria. However, at existingair installations where few structures have been sited/constructed in accordance with previous safety clearances, it may be feasible to apply the revised standards herein. The changes in standards primarily affect criteria for: (1) Class A designated runways (2) runways at basic training outlying fields used by T-34 aircraft and (3) helicopter landing facilities operating under Visual Flight Rules. Approval from Headquarters NAVFACENGCOM shall be obtained prior to revising-·safety clearances at existing airfield pavements to conform with new standards herein. NAVFACENGCOM will coordinate the approval with the Naval Air Systems Conunand and CNO/CMC as required.

Once safety clearances have been established for an air installation, there may be occasions where it is not feasible to meet the designated standards. In these cases a waiver must be obtained from the Naval Air Systems Conunand. The waiver and its relationship to the site approval process is defined in NAVFACINST 11010.57, Site Approval of Naval Shore Facilities.

C. EXEMPTIONS FROM WAIVER. Certain navigational and operational aids normally are sited in violation of airspace safety clearances in order to operate effectively. The following aids are within this group and reqvire no waiver from NAVAIR, provided they are sited in accordance with NAVFAC Definitive Designs (P-272) and/or the NAVFAC Design Manuals (DM Series):

a. Approach lighting systems
b. Visual Approach Slope Indicator (VASI) systems
c. Permanent Optical Lighting System (OLS), portable OLS and Fresnel lens equipment
d. Runways distance markers
e• Arresting Gear (A/G) systems including A/G signs
f. Taxiway guidance, holding and orientation signs
h. All beacons and obstructions lights
i. Arming and de-arming pad

D. DEFINITIONS.

Airfield Reference Point. The designated geographical location of an airfield. It is given in terms of the nearest second of latitude and longitude. The position of the reference point must be as near to the geometric center of the landing area as possible, taking future development of the airfield into account.

Established Airfield, Heliport or Helipad Elevation. The established elevation of the highest point of the usable landing area in terms of the nearest foot above mean sea level•

SECTION II – AIRFIELD CLEARANCES-FIXED WING AIRCRAFT

A. RUNWAY CLASSIFICATION. This Appendix uses the same runway classification system, Class A and B, established by the Office of the Secretary of Defense as a means of defining accident potential zones (APZs) for the Air Installations Compatible Use Zones (AICUZ) proqram. The r1Jnway classification must be known in order to determine the proper clear zone and air space criteria for a runway. The classification is dependent on the type of aircraft which operate from the runway:

TABLE A
RUNWAY CLASSIFICATIONS BY AIRCRAFT TYPE

Class A R1Jnways

C-1	C-47	OV-10	T-44
C-2	C-117	S-2	u-10
C-4	E-1	T-28	u-11
C-6	E-2	T-34	u-21
C-7	O-1	T-41	UV-18
c-12	0-2	T-42	
C-45	OV-1		

Class B Runways

A-3	c-10	F-4	P-2
A-4	C-14	F-5	P-3
A-5	C-15	F-8	S-3
A-6	C-118	F-14	SR-71
A-7	c-121	F-15	T-2
A-8	C-123	F-16	T-29
A-10	C-130	F-17	T-33
A-18	C-131	F-18	T-37
AV-8	C-135	F-100	T-38
B-1	C-137	F-101	T-39
B-52	C-140	F-104	TR-1
B-57	C-141	F-105	U-2
C-5	E-3	F-106	
C-9	E-4	F-111	

Class A runways are primarily used by small light aircraft as indicated in Table A and the runway should not have the potential for developmet for use by heavier aircraft or have a foreseeable requirement for such use. Ordinarily, Class A runways are less than 8000 feet long and less than 10 pe cent of the o erations involve class B type aircraft. Class B runways are a o er runways except sic training out y ng ields used by T-34 aircraft for which special criteria are specified.

: The classification of Navy and Marine Corps runways is determined as a part of the AICUZ program and is published in the AICUZ study for a particular installation. NAVPACENGCOM and NAVAIRSYSCOM concurrence and CMC/CNO approval is required prior to classifying any runway Class A or B. This approval is obtained via approval of the AICUZ study.

B. OBSTRUCTIONS TO AIRSPACE. The following paragraphs set standards for determining whether an object or structure is an obstruction to air navigation. It applies to existing and proposed objects including objects of natural growth or terrain. Facilities shall be sited so as no1r to be an obstruction to airspace.

An existing object (including a mobile object) is, and a future object would be, an obstruction to air navigation if it is higher than any of the following heights or surfaces.

- A height of- 500 feet above ground level at the site of the object.

A height that is 200 feet above ground level or above the established airfield elevation, whichever is higher, within 3 nautical miles of the established reference point of an airfield. This height increases in the proportion of 100 feet for each additional nautical mile of distance from the airfield up to a maximum of 500 feet.

Flight pers.

c. A height that results in raising an established or proposed Minimum Descent Altitude (MDA) within the initial approach segment, or the intermediate approach segment; or that which raises the Decision Height (DH) for Precision Approach Radar (PAR) or Instrument Landing system (ILS) glide slopes within the final approach segment; or that which affects a departure or missed approach climb gradient within the departure area or missed approach segment; or that which affects the MDA within the circling approach area.

Flight pers

d. A height within an enroute obstacle clearance area, including turn and termination areas, of a federal airway or approved off-airway route that would increase the minimum obstacle clearance altitude.

e. The surface of a takeoff and landing area of an airfield or any imaginary surface as defined in Section II, paragraph C (Section III, Paragraph C for helicopter facilities). However, no part of the takeoff or landing area itself is considered an obstruction.

The height restrictions in paragraphs (a), (b) and (e) can be evaluated by planning personnel. The restrictions imposed by paragraphs (c) and (d) should be evaluated by flight operations personnel, however the planner should be aware of their existence.

Traverse ways (roads, railroads, canals etc) must be considered in terms of height of the objects using them. This is done by establishing a minimum vertical clearance (the clearance represents the height of the object using the traverse way) which must be maintained bet'N'een the traverse way and the imaginary surfaces. The clearances are given in Table B and must be maintained except when:

a. Use of the traverse way is controlled. Control in this sense is exercised by Air Traffic Control (ATC) facility or through an agreement between the responsible ATC facility and another agency with the capability to exercise control.

b. Use of an existing traverse way is physically limited to lesser heights. For example, overpasses along a public highway have a clearance of 13 feet thereby restricting use of the highway to vehicles of 13 feet in height or less. Thirteen feet could then be used as the minimum vertical clearance requirement•

TABLE B

Highway, Railroad and Waterway Clearances

Item Description	Traverse Way	Clearance
Minimum vertical clearance between established imaginary surfaces and traverse ways	Interstate highway that is part National System of Military and Interstate Highways	17 ft
	Other public highways not covered above	15 ft
	Private or military road	10 ft minimum, or height of highest mobile object that normally would traverse them, whichever is greater
	Railroads	23 ft
	Waterway or other traverse way not previously covered	A distance equal to the height of the highest mobile object that normally would traverse them

C. IMAGINARY SURFACES. The following imaginary surfaces are defined for fixed wing aircraft facilities and are shown on the figures at the end of Section II.

1. Primary Surface. A/'surface .on iiAe !Jround--or--wattr centered lengthwise on the runway and extending 200 feet beyond each end of the runway. The width of the primary surface is:

(a) 1000 feet - Class A runways
- Basic Training Outlying Fields (OLFs) used by T-34 aircraft

(b) 1500 feet - Class B runways constructed prior to June 1981

(c) 2000 feet - Class B runways constructed at new air installations where no runway existed prior to June 1981

NAVAIRSYSCOM, in coordination with NAVFACENGCOM, will determined on an individual basis whether a 1"500 or 2000 foot wide primary surface shall be applied for new Class B runways constructed at air installations having existing runways with a 1500 foot wide primary surface.

2. Clear Zone Surface. See section II, paragrah D for Clear Zone standards.

3. Approach Departure Clearance Surface. An inclined or combination inclined and horizontal plane, symmetrical about the runway centerline extended. The inclined plane flares outward and upward from the primary surface, beginning with the same width as the primary surface and starting with the centerline elevation at the runway end. The slope and dimensions of the surface vary by runway class:

a. Class A runway. The slope of the surface is 40 to 1 until it reaches an elevation of 500 feet above the established airfield elevation. It then continues horizontally at this elevation to a point 50,000 feet from the point of beginning. The outer width is 16,000 feet.

b. Class B runway. The slope of the surface is 50 to 1 until it reaches an elevation of 500 feet above the established airfield elevation. It then continues horizontally at this elevation to a point 50,000 from the point of beginning. The outer width is 16,000 feet.

c. OLF Basic Training Outlying Field (for T-34 aircraft). The slope of the surface is 20:1 and the surface continues until it rises 400 feet in elevation. The surface flares outward at an angle of 50 43'.

4. <u>Inner Horizontal Surface.</u> An oval shaped plane at a height of 150 feet above the established airfield elevation. For Class A and B runways it is constructed by scribing an arc with a radius of 7,500 feet about the centerline at each end of each runway and interconnecting these arcs with tangents. The radius is reduced to 3,200 feet at Basic Training outlying Fields (for T-34 aircraft).

5. Conical Surface. An inclined plane that extends from the periphery of the inner horizontal surface outward and upward at a 20 to 1 slope. For Class A and B runways it extends for horizontal distance of 7,000 feet and to a height of 500 feet above the established a'irfield elevation. For Basic Training OLF (T-34 aircraft) runways, it extends for a horizontal distance of 5,000 feet and to a height of 400 feet above the established airfield elevation.

6. Outer Horizontal Surface. For Class A and B runways, a plane located 500 feet above the established airfield elevation, extending outward from the outer periphery of the conical surface for horizontal distance of 30,000 feet. This surface is not applied at Basic Training Outlying fields (T-34 aircraft).

7. <u>Transitional Surface</u>.

a. Class A and B runways. Inclined planes which connect the primary surface and the approach -,departure clearance surface to the inner horizontal surface, conical surface, outer horizontal surface or other transitional surfapes. The slope is 7 to 1 outward and upward from the primary and approach-departure clearance surfaces at right angles to the runway centerline and runway centerline extended. To determine the elevation for the beginning of the transitional surface at any point along the lateral boundary of the primary surface, draw a line from the point, perpendicular to the runway centerline or the runway centerline extended. The elevation of the runwa e or centerline extended at t at intersection s the elevation for t,tle b9 !ling--()£- the--7to 1 sloee.

14 Clear

b. Basic Training OLF (T-34 aircraft). Same definition as for the Class A and B runway except the slope is 2:1.

O. CLEAR ZONES. The areas adjacent to the runway thresholds require special restrictions to provide· aircraft overrun areas and unrestricted visibility of airfield lighting. To accomplish this, clear zones are specified for each class of runway and further, the clear zone is subdivided into 'rypes I, II and III to define the degree of restrictive use. The standards herein are in conformance with clear zone sizes specified in the AICUZ program•

Type Runway	Clear zone	Clear Zone Width	Remarks
Class A		1000 FT	NOTE 1.
Class B	Length 3000	Same as approach departure-clearance surface	NOTE 2.
Basic Training OLF (T-34)	3000 Ft	1000 Ft	NOTE 3.

NOTE 1. The class A runway and clear zone are new to Navy and Marine Corps planning standards. Previously, all air installations except OLF's for basic training propeller aircraft received a clear zone equivalent to what is now specified for Class B runways. The criteria for Class A runway clear zones should only be applied after CID/CMC has approved the classification of a particular runway as Class A.

NOTE 2. The DOD AICUZ program allows for a rectangular clear zone with a 3000 foot width for new construction, however, Navy accident data indicates the fan shaped clear zone is adequate for Navy installations. Clear zones with 3000 foot width shall not be planned unless coordinated with Headquarters, NAVFACENGCOM.

NOTE 3. The width of clear zone for basic training OLF's used by propeller aircraft was previously defined by the width of the approach-departure clearance surface. The criteria have been revised to conform with AICUZ guidelines.

The restrictions on land use within a clear zone vary. Therefore, the clear zone has been divided into three areas, Type I, II and III, for which specific restrictions are specified.

a. Clear Zone (Type-I) - This zone is inunediately adjacent to the end of the runway. It should be cleared, graded and free of above ground objects (except airfield lighting) and is to receive special ground treatment or pavement in the area designated as the runway overrun. This type clear zone is required at both ends of all runways.

b. Clear Zone (Type - II) - This zone is used only for class B runways and is an extension of the Type I clear zone except that the width is reduced. The Type II clear zone shall be graded and cleared of all above ground objects except airfield lighting•

c. Clear Zone {Type III). This zone is laterally adjacent to the type II clear zone for Class B runways and is used in lieu of the type II clear zone at Class A runways and basic trainlng OLFs used by T-34 aircraft. Objects in this zone shall not penetrate the approach departure clearance surface. Trees, shrubs, bu§hes, or any other na _l,IJ;J, g_rgwt:h _ _. hall, be ped 10 et below the appach aepa-rtre clearance surface or to a lesser . !!_i9!1_--- if neces'sary . to... inun.-:Y. slofl ! X_?!._ a:i.;-I!<r-::n91 1Rmf:..-· Bull.dings for human habitation 'shalY not be sited in the e III Clear Zone yen ▪. ey would }}Q_t, _pJnS..-!;----t;h_ aeEroach dep!1rture clearance .. su'rface-'"' 'T'he '-land in this type clear zone is best utilfzed for agricull:ure or permanent open space exclusive of agricultural uses which would attract birds or water-fowl. Land uses which would include. human activity for extended periods or group activities should be avoided. Tr.aJ[erse ways (ds, railroads, canals, etc.,) are permitted provided they woUid not penetrate airfield imaginary surfaces after the - I.9Jit'"(){ the traverse way has been increased by the distanc.E!:; _SJ>E!c_!.!- in Section II, par _9raph _" ..:

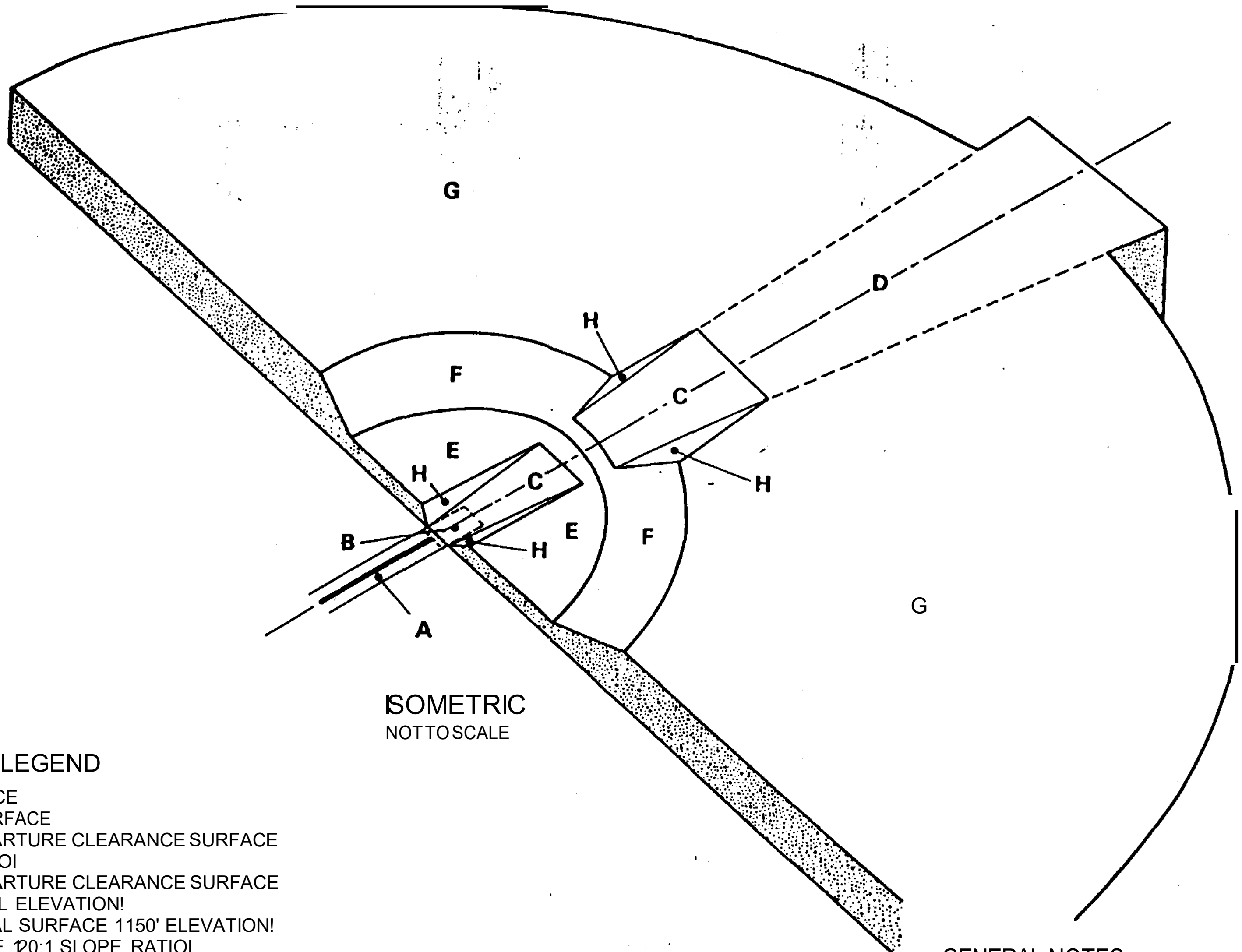
E. LATERAL CLEARANCES. In order to insure the safe operation of aircraft on the ground there are later.al clearances established for most airfield pavements. For example, no structures shall be sited within 100 feet of the edge of a f--bœa- wlnq.:;. Jrqr- --P rkin9 apron· i!ncC· - ;ret.iines:2f a runwa"? -- ahd" parallel ta_j,way shall be a minimum of 500 feet.-ARa..rt. The lateral clearances are listed in P-80 under the category code for the pavement to which they apply.

F. OTHER CONSIDERATIONS.

1. Air Installations Compatible Use Zones (AICUZ) Program. The criteria herein related to clear zones conforms to Navy AICUZ guidelines established by OPNAVINST 11010.36, Air Installation Compatiable Use Zones (AICUZ) Program. The AICUZ concept embodies a method of defining, quantifying and mapping aircraft noise, potential aircraft accident areas and existing or -potential incompatible land uses, both on and off an air installation. The criteria herein is concerned with avoiding obstructions to air navigation and therefore does not address the aircraft accident potential zones, noise descriptions or compatible land use guidelines identified in the AICUZ program. OPNAVINST 11010.36 should be used as a basis for applying AICUZ guidelines.

2. Airfield Exolosives Prohibited Areas. The Naval Sea Systems Command has established criteria with respect to handling and storing ammunition and explosives which are published in NAVSEA OP-5, Volume 1, Ammunition and Explosives Ashore. This publication addresses areas near runways and under flight paths where ammunition and explosives are prohibited and NAVSEA OP-5 should be used for ordnance safety criteria.

G. DRAWINGS. The following Figures are provided to illustrate the imaginary surfaces, typical airfield layouts and clear zones•



ISOMETRIC
NOT TO SCALE

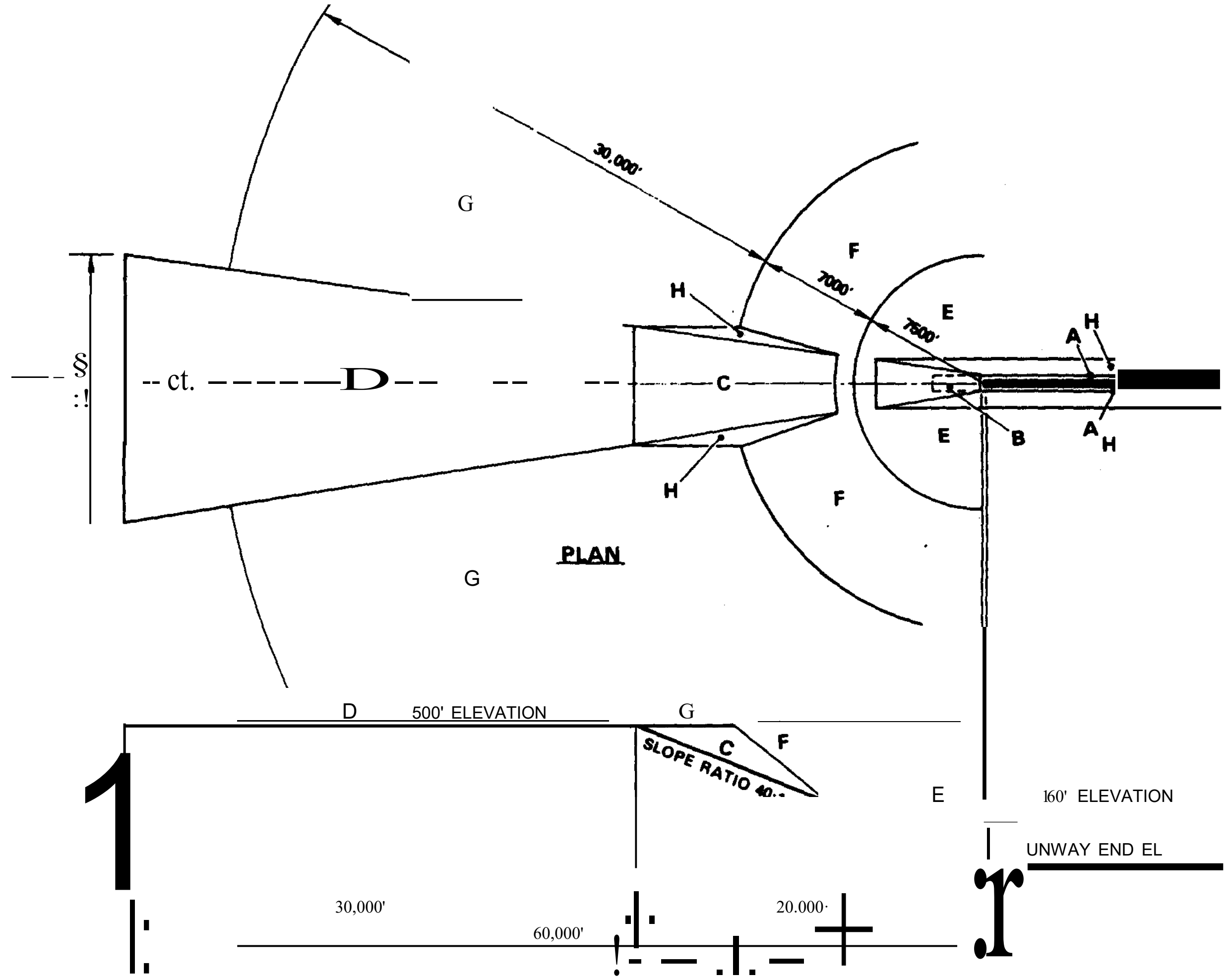
LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE
C APPROACH-DEPARTURE CLEARANCE SURFACE (40:1 SLOPE RATIO)
D APPROACH-DEPARTURE CLEARANCE SURFACE (500' HORIZONTAL ELEVATION)
E INNER HORIZONTAL SURFACE (150' ELEVATION)
F CONICAL SURFACE (20:1 SLOPE RATIO)
G OUTER HORIZONTAL SURFACE (500' ELEVATION)
H TRANSITIONAL SURFACE (7:1 SLOPE RATIO)

GENERAL NOTES

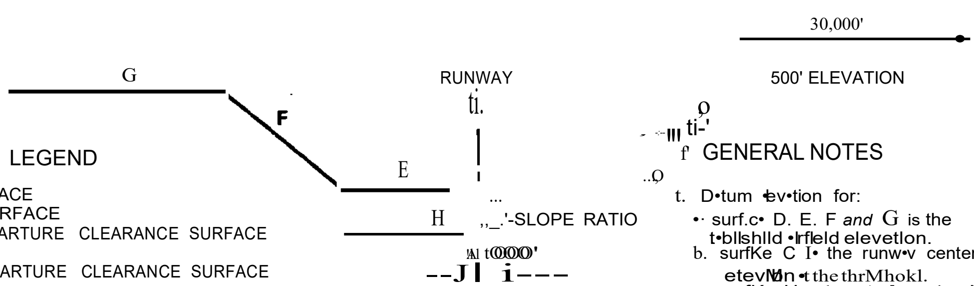
1. See Figure II-2 for Sections

FIGURE II-1
CLASS A RUNWAY - AIRSPACE (ISOMETRIC)



LONGITUDINAL SECTION

NOT TO SCALE



TRANSVERSE SECTION

NOT TO SCALE

LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE
C APPROACH-DEPARTURE CLEARANCE SURFACE (SLOPE)
D APPROACH-DEPARTURE CLEARANCE SURFACE (HORIZONTAL)
E INNER HORIZONTAL SURFACE
F CONICAL SURFACE
G OUTER HORIZONTAL SURFACE
H TRANSITIONAL SURFACE

GENERAL NOTES

1. Datum elevation for:
   a. surface D, E, F and G is the established airfield elevation.
   b. surface C is the runway centerline elevation at the threshold.
   c. surface H varies at each point along the runway centerline.
2. The orientation shown on the plan are for the case of level runway.

FIGURE II-2

CLASS A RUNWAY-AIRSPACE (PLAN & SECTIONS)

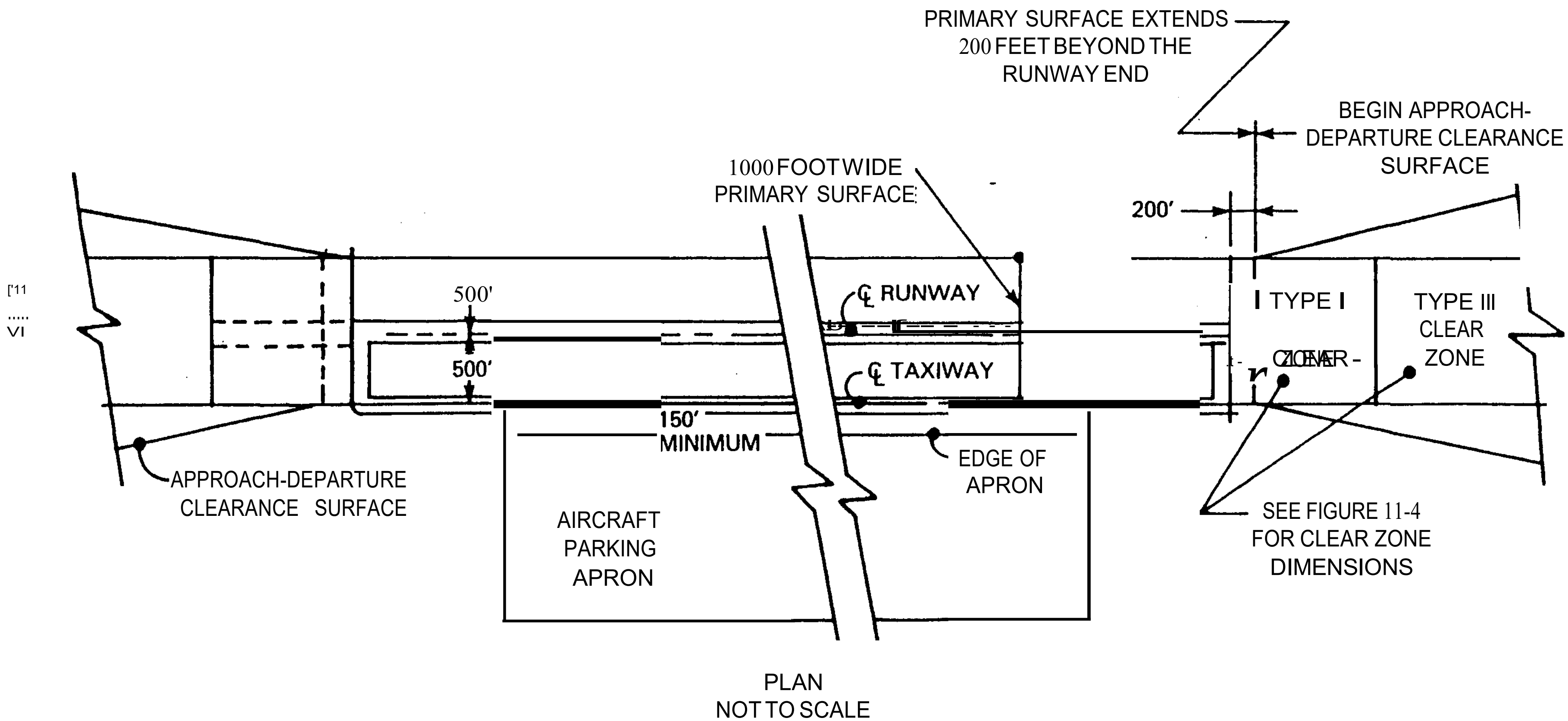
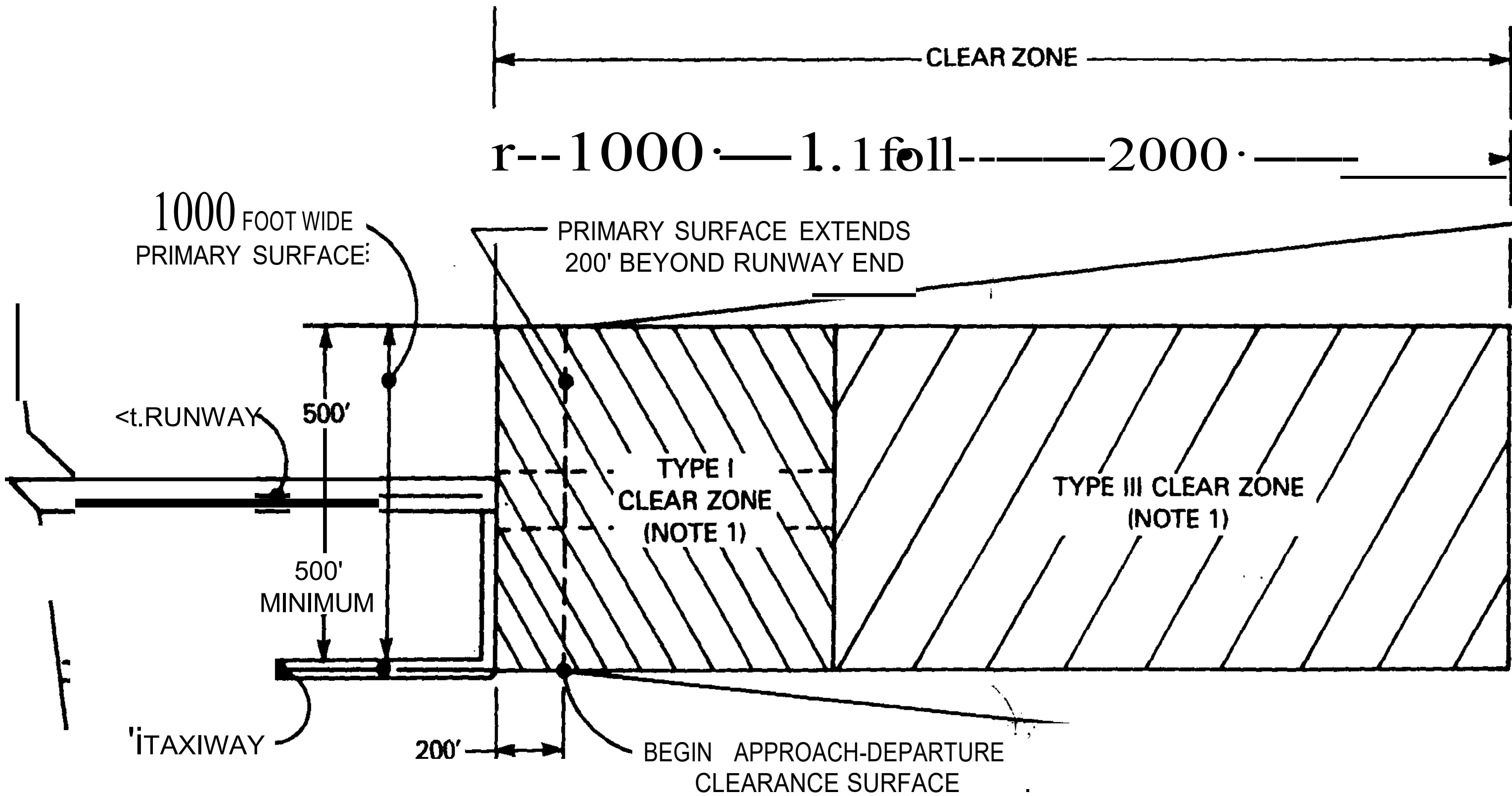


FIGURE II-3.
CLASS A RUNWAY (TYPICAL LAYOUT)



NOTES

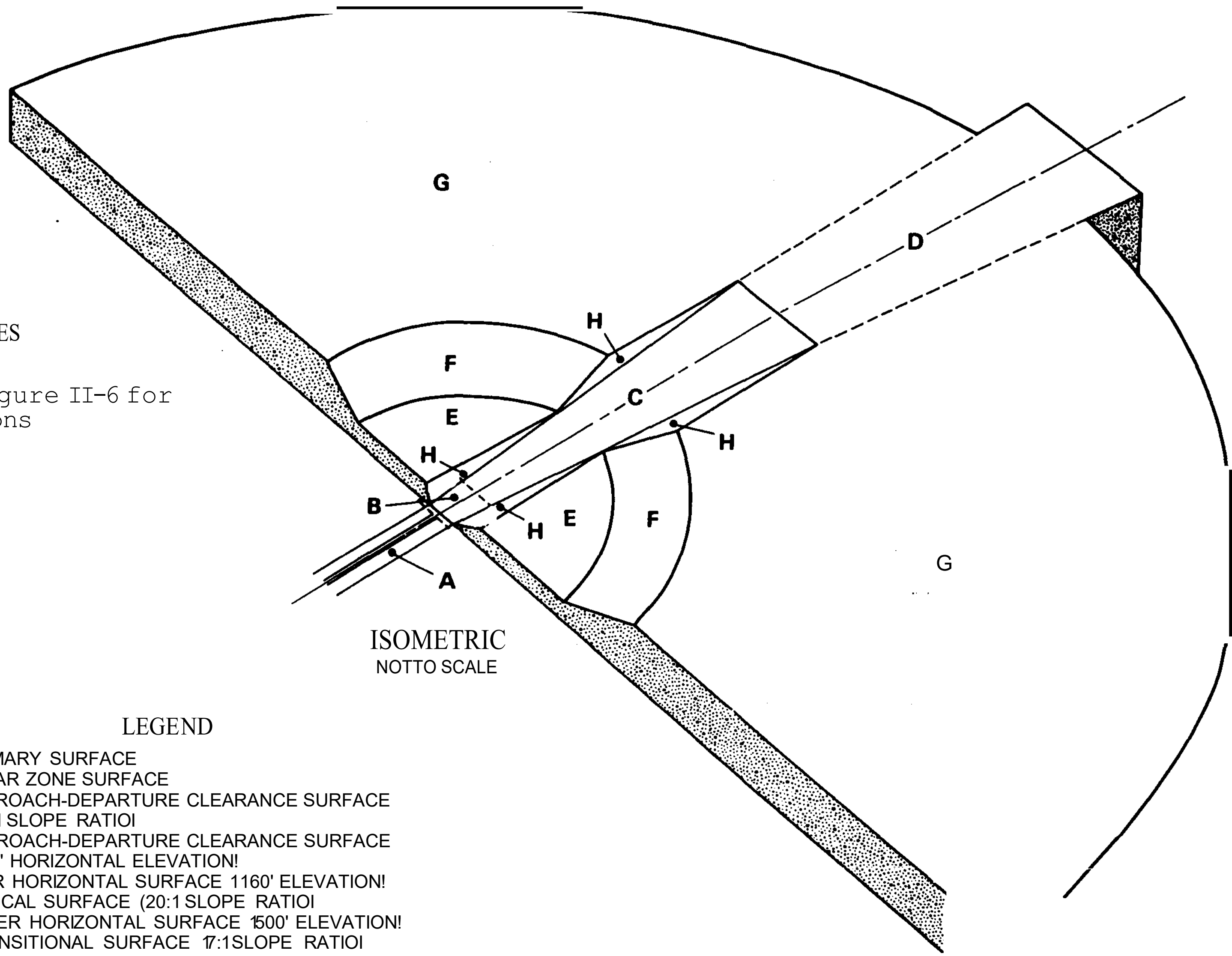
(1) See Section II, paragraph D for land use restrictions in the Type I and III clear zones.

FIGURE II-4

CLASS A RUNWAY - CLEAR ZONE

GENERAL NOTES

1. See Figure II-6 for Sections



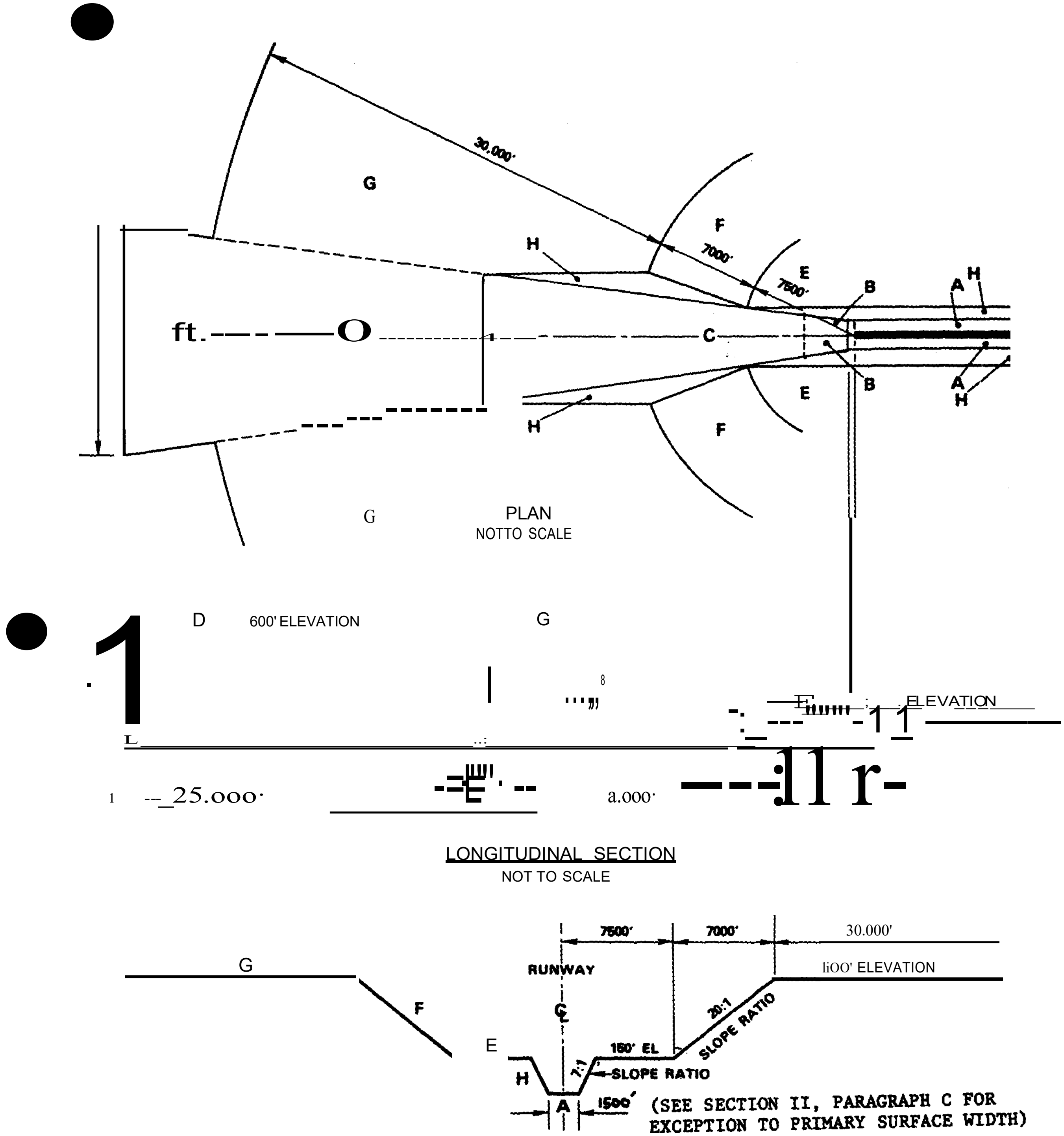
ISOMETRIC
NOTTO SCALE

LEGEND

A PRIMARY SURFACE
B CLEAR ZONE SURFACE
C APPROACH-DEPARTURE CLEARANCE SURFACE 160:1 SLOPE RATIOI
D APPROACH-DEPARTURE CLEARANCE SURFACE 1500' HORIZONTAL ELEVATION!
E NNER HORIZONTAL SURFACE 1160' ELEVATION!
F CONICAL SURFACE (20:1 SLOPE RATIOI
G OUTER HORIZONTAL SURFACE 1500' ELEVATION!
H TRANSITIONAL SURFACE 17:1 SLOPE RATIOI

FIGURE II-5

CLASS B RUNWAY - AIRSPACE (ISOMETRIC)



LEGEND

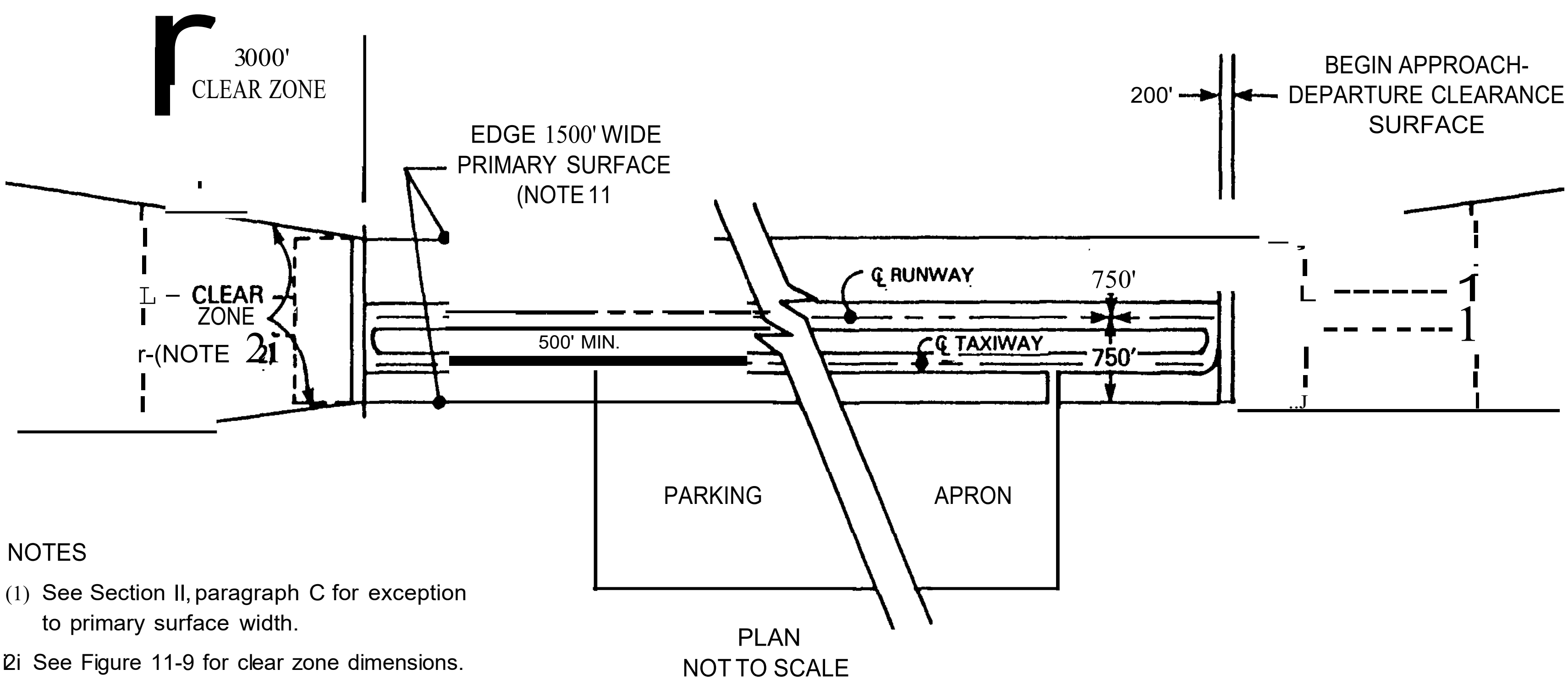
A PRIMARY SURFACE
8 CLEAR ZONE SURFACE
C APPROACH-DEPARTURE CLEARANCE SURFACE BLOPEI
D APPROACH-DI!PARTURI! CLEARANCE SURFACE HORIZONTALI
E NNER HORIZONTAL SURFACE
F CONICAL SURFACE
G OUTER HORIZONTAL SURFACE
H TRANSITIONAL SURFACE

GENERAL NOTES

1. Datum el-lon for:
   a. 9UrfMe D. E, F and G le the ntablI8hed llirfleld ....
   b. eurface C i. the runw.y -..tine elev8lion llt the thnllhotd.
   c. turfKw H veriea at eeoh point •'°"9 the runway ____....
2. Th• lntanactlon• thown on the plM era for th• can of a level ru1tW9Y.

UGURE II-6

CLASS B RUNWAY-AIRSPACE PLAN & SECTIONS)



NOTES

(1) See Section II, paragraph C for exception to primary surface width.

(2) See Figure 11-9 for clear zone dimensions.

FIGURE II-7

CLASS B RUNWAY- TYPICAL LAYOUT - SINGLE RUNWAY

GENERAL NOTES

- THE LAYOUT SHOWN IS SCHEMATIC IN THAT IT ASSUMES THAT THE ENDS OF THE PARALLEL RUNWAYS ARE AT THE SAME ELEVATION. WHERE THE RUNWAY ENDS ARE AT DIFFERENT ELEVATIONS (OR IF THE RUNWAYS ARE STAGGERED), APPLY THE AIRSPACE CRITERIA TO EACH RUNWAY SEPARATELY AND THEN SUPERIMPOSE THE IMAGINARY SURFACES FOR EACH RUNWAY. WHERE SURFACES OVERLAP, THE LOWER ONE GOVERNS.
- THE DATUM ELEVATION IS THE ESTABLISHED AIRFIELD ELEVATION.

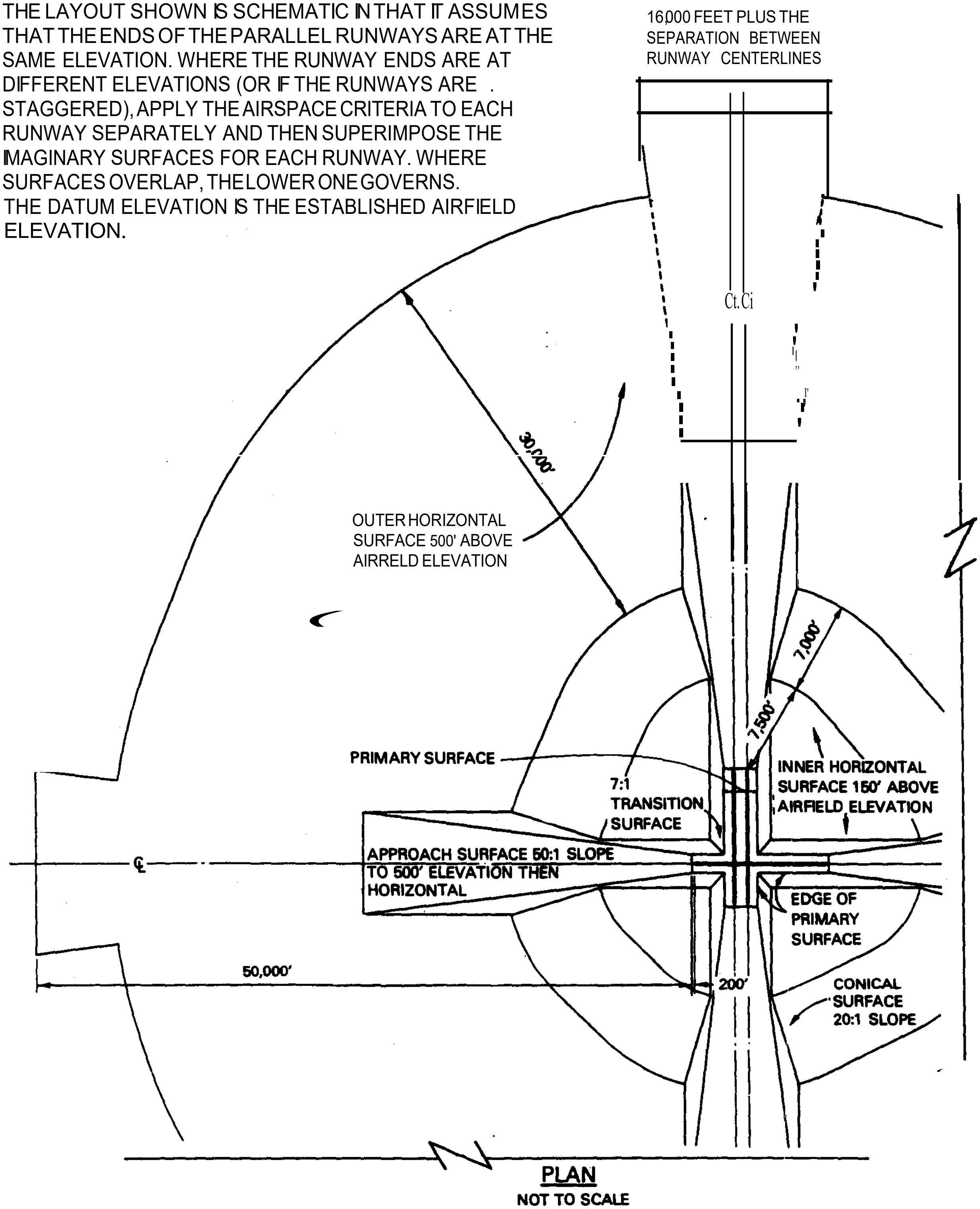
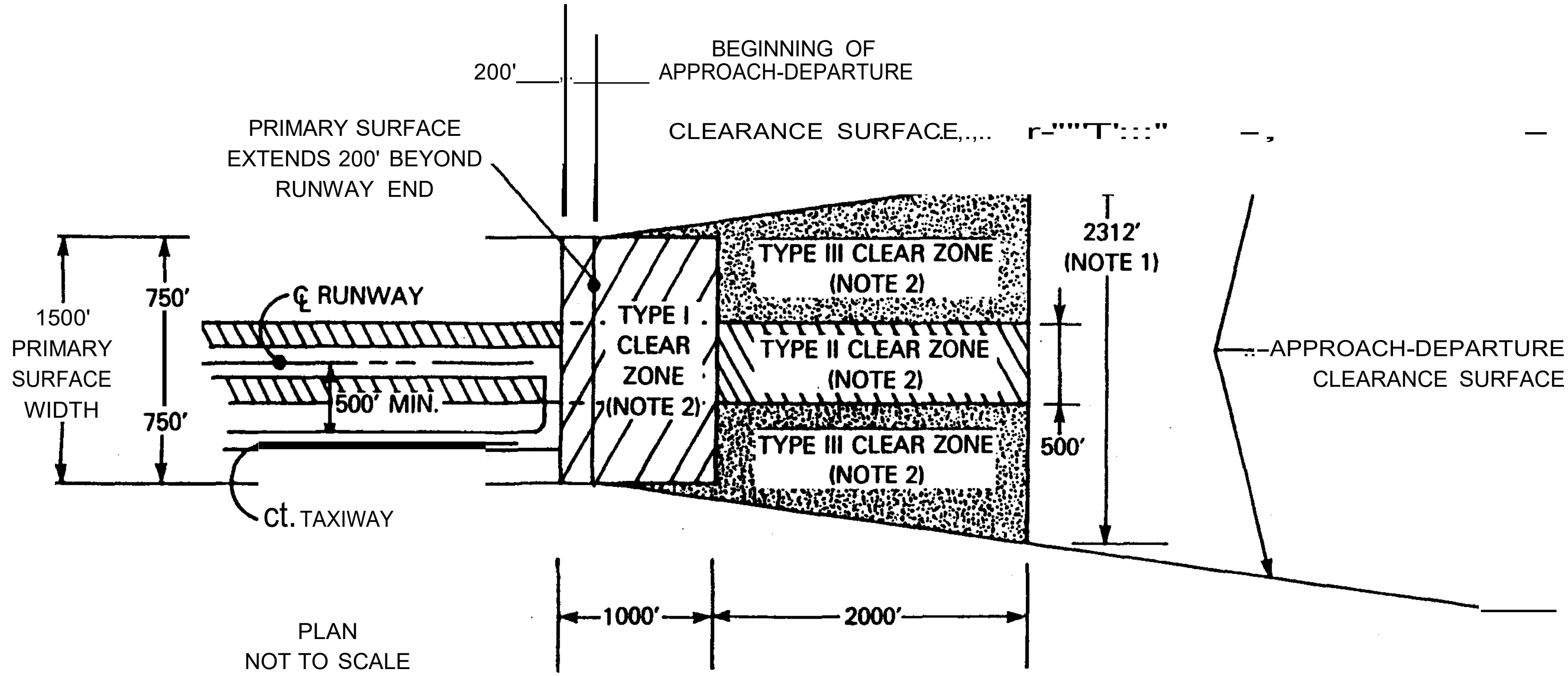


FIGURE II-8
CLASS B RUNWAY - TYPICAL LAYOUT - PARALLEL & CROSSWIND RUNWAYS

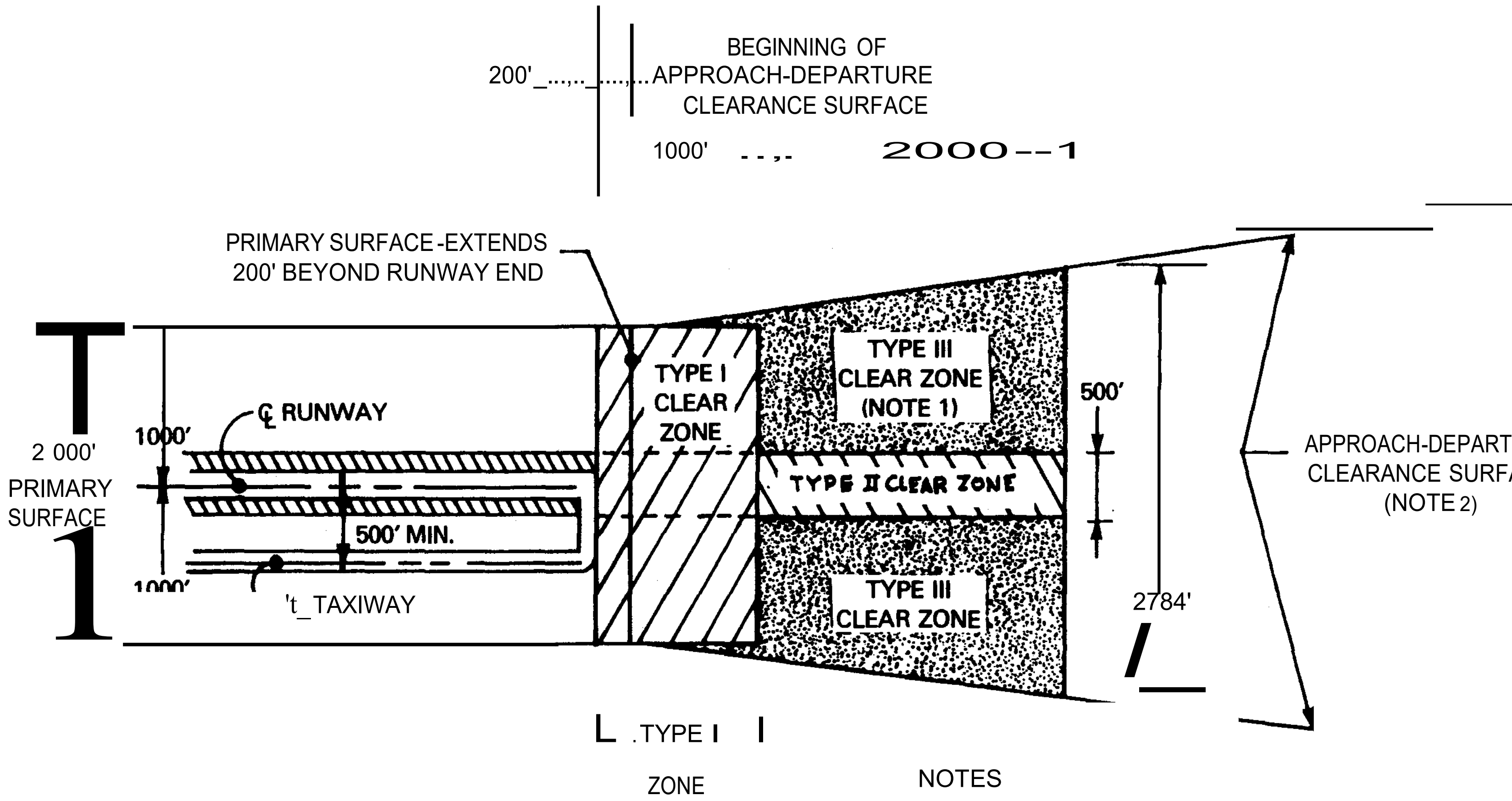


NOTES

(1) This dimension is based on criteria herein whic revises outer width of approach-departure clearance surface to 16,000 feet. At runways where the outer width has been established at 15,500 feet (based on previous criteria of 7°-58'-11" flare angle for approach-departure clearance surface), this dimension is 2284 feet.

(2) See Section II, paragraph D for land use restrictions in Types I, II, and III clear zones.

FIGURE II-9
CLASS B RUNWAY - CLEAR ZONE
(1500 WIDE PRIMARY SURFACE)



NOTES

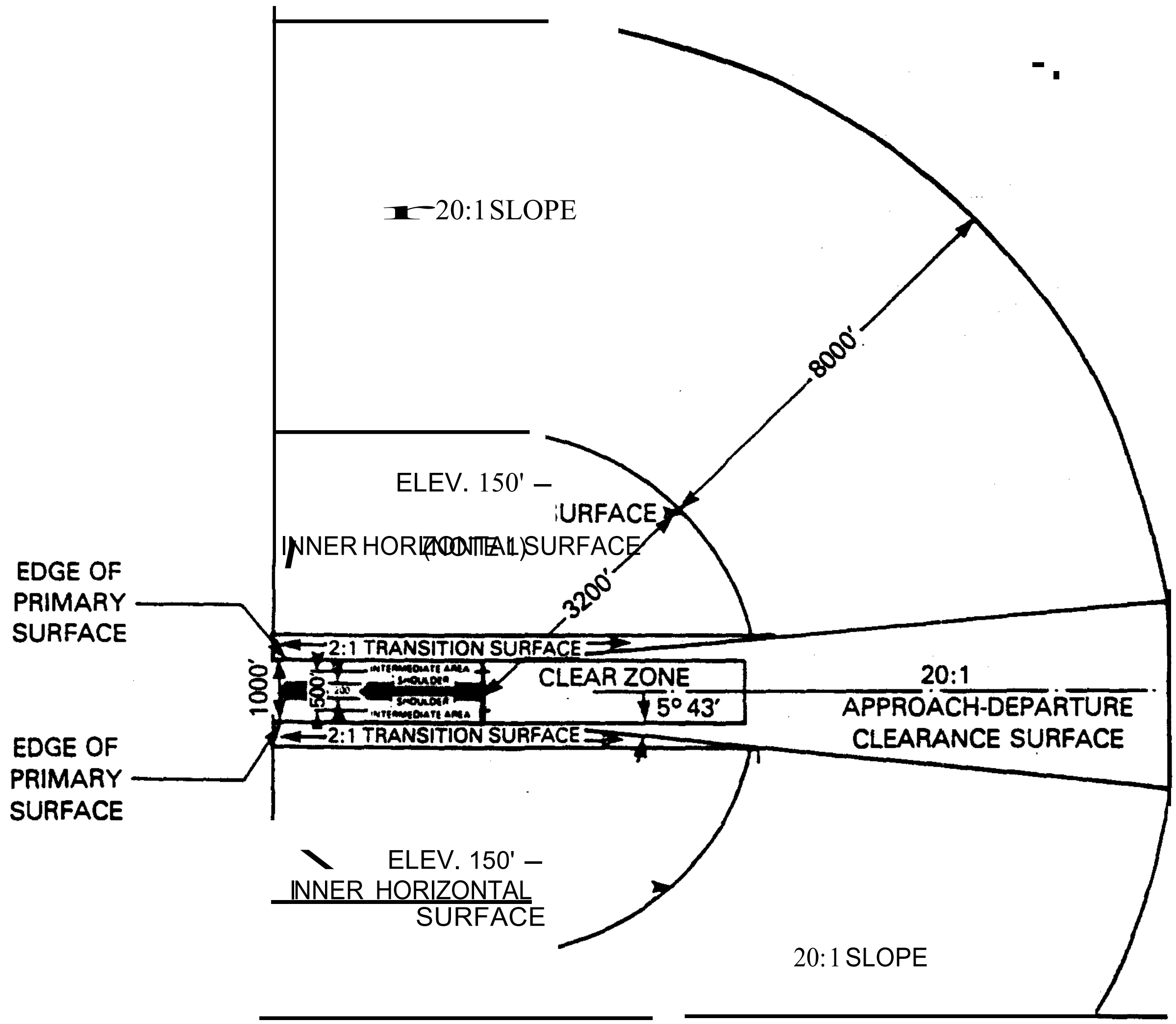
(1) See Section II, paragraph D for land use restrictions for Types I, II, and III clear zones and for possible variance from the dimensions shown.

(2) The approach-departure clearance surface begins 200 feet from the runway end with a width of 2000 feet and flares outward to a width of 16,000 feet at a point 50,000 feet (measured horizontally) from its beginning.

FIGURE II-10

CLASS B BUNWAY - CLEAR ZONE

(2000 FOOT WIDE PRIMARY SURFACE)



NOTES

(1) Inner horizontal surface elevation is 150 feet above the established airfield elevation.

PLAN
NOT TO SCALE

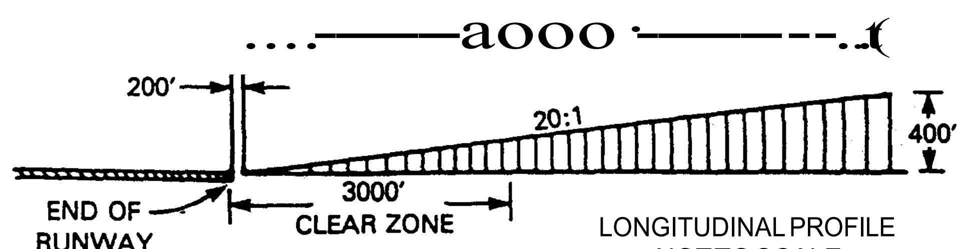
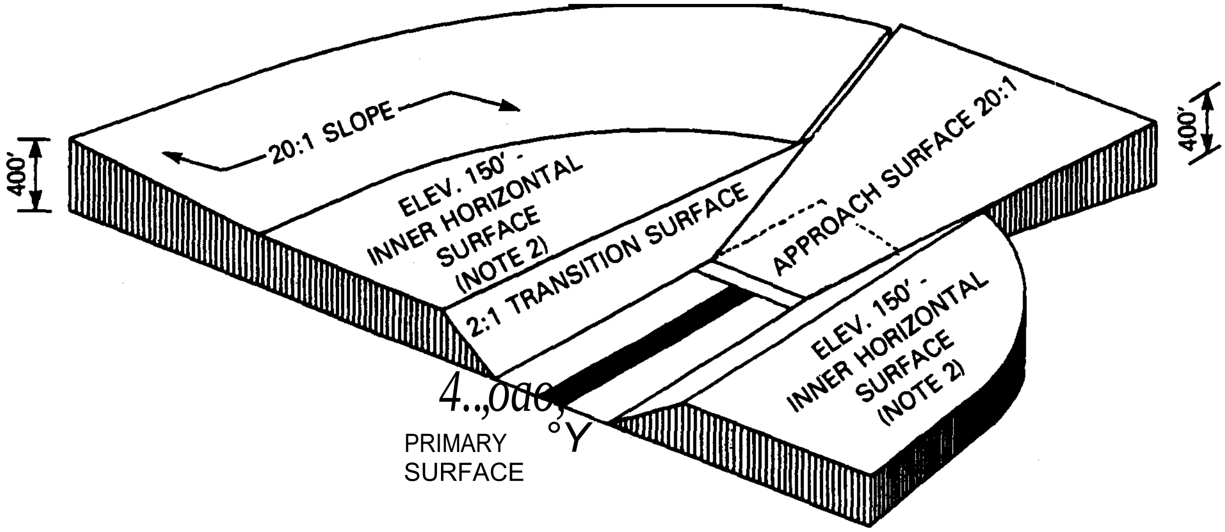
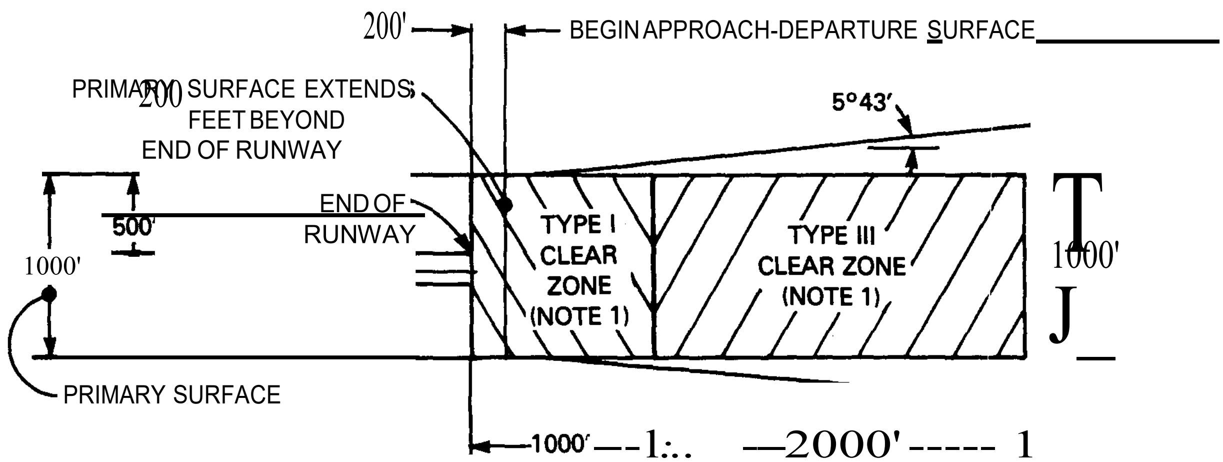


FIGURE II-11

AIRSPACE-BASIC TRAINING OUTLYING FIELD
(T-34 AIRCRAFT)



ISOMETRIC
AIRSPACE/IMAGINARY SURFACES
NOT TO SCALE



NOTES

(1) See Section II, paragraph D for land use restrictions in Types I and III clear zones.

(2) Inner horizontal surface elevation is 150 feet above the established airfield elevation.

CLEAR ZONE DETAIL
NOT TO SCALE

FIGURE II-12

BASIC TRAINING OUTLYING FIELD (T-34 AIRCRAFT) AIRSPACE ISOMETRIC AND CLEAR ZONE DETAIL

SECTION III - AIRFIELD CLEARANCES - HELICOPTERS

A. TYPES OF FACILITIES. The major helicopter landing facilities consist of helipads and helicopter runways. The airspace clearances for helicopter facilities differ for Instrument Fight Rules (IFR) and Visual Flight Rules (VFR), therefore, the type of flight operations (IFR or VFR) must be identified before the obstruction standards may be applied.

B. OBSTRUCTIONS TO AIRSPACE. The standards for determining, obstruction to air navigation for helicopter facilities are the same as specified for fixed wing aircraft in Section II, paragraph B, except that different imaginary surfaces are defined for helicopter facilities.

C. IMAGINARY SURFACES. The following imaginary surfaces are defined for helicopter facilities and are shown on the figures at the end of Section III:

1. Primary Surface. A horizontal plane symetrically centered on the helicopter runway or helipad at the established elevation of the landing surface. The area beneath the primary surface (referred to as the primary surface area) shall be free of obstructions. The dimensions of the primary surface are:

Type Facility	Length of Primary Surface	Width of Primary Surface
VFR Helipad	150 FT	150 FT
VFR Runway	Runway length plus 75 feet at each end	300 FT
IFR Helipad	1550 FT	750 FT
IFR Runway (Single GPI) (Note 1)	1550 FT	750 FT
IFR Runway (Double GPI) (Note 1)	2450 FT	750 FT

Note 1. The GPI (Ground point intercept) is the point on the centerline of the landing surface where the straight line extension of the glide slope intersects the approach surface baseline. For planning purposes, the GPI can be considered to be the helicopter touchdown point. The primary surface xtends beyond the runway a distance of 775 feet from the GPI. The lengths shown are based on a single GPI at the middle of a 450 foot runway and a 1000 foot runway with two GPIs, each 50 feet in from the runway end.

2. Horizontal Surface (IFR only). A circular or oval level plane, located 150 feet above the established runway or helipad elevation, defined by scribing an arc with a 4,600 radius from the GPI. For multiple

GPI's, connect the arcs with tangents.

3. Transitional Surface. Planes that connect the primary sur·face and the approach-departure clearance surface and horizontal surface. &ach surface is outward and upward from the edge of the primary surface or approach-departure clearance surface at a specified slope measured perpendicular to the runway centerline or helipad longitudinal centerline.

a. VFR Facilities. The slope ratio is 2:1 and for runways it rises to 150 feet above the established elevation of the landing surface. For helipads, the surface rises at a 2:1 slope until it reaches a horizontal distance of 250 feet from the centerline of the pad, it then rises vertically to an elevation of 150 feet above the established elevation of the landing surface.

b. IFR Facilities. The slope ratio is 4:1 and rises to the horizontal surface. At the intersection of the horizontal surface and the approach departure surface, it continues adjacent to the approach-departure clearance surface for the entire length, at which point an elevation of 375 feet above the approach-departure clearance surface is reached.

4. Approach-Departure Clearance Surface. An inclined plane which flares outward and upward above the runway or helipad lc>ngitudinal centerline extended. It starts at the end of the primary surface with the same width as the primary surface at the established elevation of the landing surface. '!be area under this surface is referred to as the approach - departure zone•

Type Facility	Width at Start	Width at End	Length	Slope
VFR Helipad	150 FT	500 FT	1,200 FT	8:1 (Note 1)
VFR Runway	300 FT	600 FT	1,200 FT	8:1 (Note 1)
IFR Helipad and Runway	750 FT	8,000 FT	24,225 FT	25:1

Note 1. When VFR helicopter facilities are located such that they do not fall under the horizontal surface of a fixed wing runway or FR helicopter landing area, the approach departure surface shall be continued on an 8:1 slope until the minimum in route altitude is reached. The width for the extension of the surface shall be 500 feet for helipads and 600 feet for runways.

D. TAKE OFF SAFETY ZONE. A take off safety zone is required under the first 400 feet of VFR approach departure clearance surfaces. and has the same width as the approach-departure clearance surface. i;iafety zone shall be free of obstructions, rough graded .amt turfed where pract.foa6le:--- Takii off Efafety ·zonesare-ot-req\lire-d ··al-·· IFR faciiltiesoue to-eb-;;;;tensive primary surface provided for these facilities. An 800 foot long take-off safety zone is provided at Marine Corps Helicopter

Training Outlying fields, see Figure III-6•

E. LATERAL CLEARANCES. In order to insure the safe operation of helicopters on the ground,, there are lateral clearances established for many airfield pavements. For example, no structures shall be siteli• within 100 feet of the edge of a fixed wing aircraft parking apron.. The lateral clearances are listed in NAVFAC P-80 under the category code for the pavement to which they apply.

F. OTHER CONSIDERATIONS.

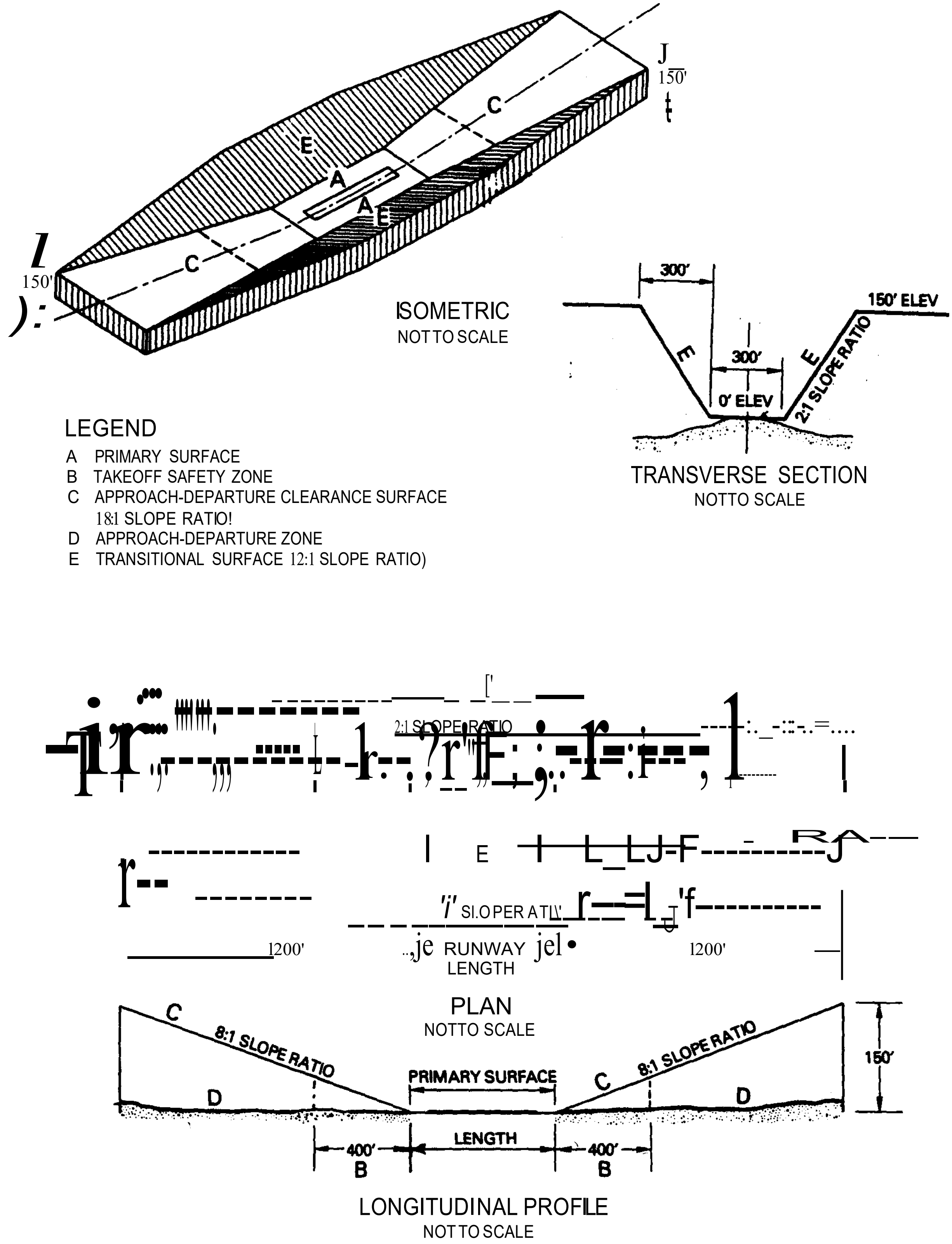
1. Air Installations Compatiable Use Zones (AICUZ) Program. The AICUZ concept embodies a method of defining, quantifying and mapping aircraft noise, potential aircraft accident areas and existing or potential incompatible land uses, both on and off an air installation. AICUZ guidelines are specified in OFNAVINST 11010.36 and apply to helicopter as well as fixed wing aircraft installations.

2. Airfield Explosives Prohibited Areas. The Naval Sea Systems Conunand has established criteria with respect handling and storing ammunition and explosives which are published in NAVSEA OP-5, Volume 1, Ammunition and Ex:plosives Ashore. This publication addresses areas near runways and helipads and .under flight paths where ammunition and explosives are prohibited and should be used for ordnance safety criteria.

G. DRAWINGS. The following figures are provided to illustrate the imaginary surfaces, typical helicopter facility layout and take off safety zones•

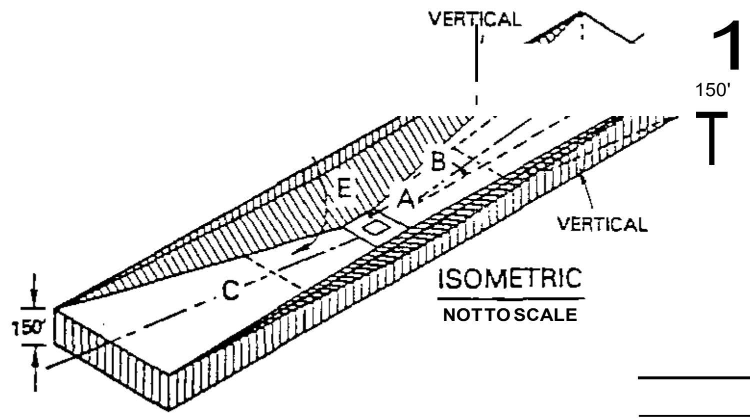
	Figure	Title
	III-1	VFR HELICOPI'ER.RUNWAY-AIRSPACE
	III-2	VFR BELIPAD-AIRSPACE
	III-3	IFR BELIPAD/RONWAY-AIRSPACE (ISOMETRIC)
	III-4	IFR HELIPAO/RUNWAY-AIRSPACE (PIAN & SECTION)
	III-5	IFR HELIPAD/RONWAY-HUMARY SURFACE
	III-6	MARINE COR:ES HELICOPI'ER OUTLYING FIELD (VFR)
?i:>te (1)	III-7	BELICOP!'ER LANDING LANES-TYPICAL LAYOUT

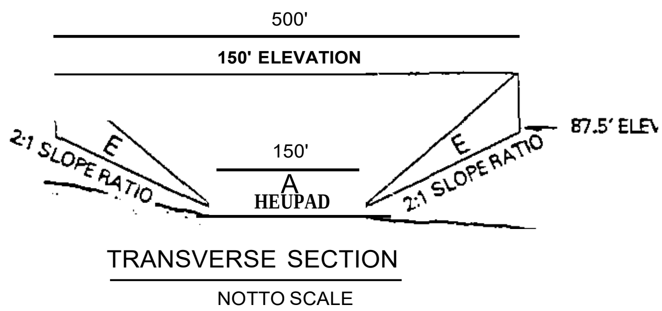
Note (1): Figure III-7 is included to show the spacing between multiple VFR touchdown points on a single runway and the separation between parallel VFR runways. The heliport configuration shown is for a typical Army staging field and should not be used for planning Navy/Marine Corps installations without the prior approval of the Naval Air Systems Conunand



150'
C
E
A
A
E
C
150'
ISOMETRIC
NOT TO SCALE
LEGEND
A PRIMARY SURFACE
B TAKEOFF SAFETY ZONE
C APPROACH-DEPARTURE CLEARANCE SURFACE
18:1 SLOPE RATIO!
D APPROACH-DEPARTURE ZONE
E TRANSITIONAL SURFACE 12:1 SLOPE RATIO)
300'
150' ELEV
E
300'
E
2:1 SLOPE RATIO
0' ELEV
TRANSVERSE SECTION
NOT TO SCALE
2:1 SLOPE RATIO
E
1200'
RUNWAY
LENGTH
1200'
PLAN
NOT TO SCALE
C
8:1 SLOPE RATIO
PRIMARY SURFACE
C
8:1 SLOPE RATIO
150'
D
D
400'
B
LENGTH
400'
B
LONGITUDINAL PROFILE
NOT TO SCALE

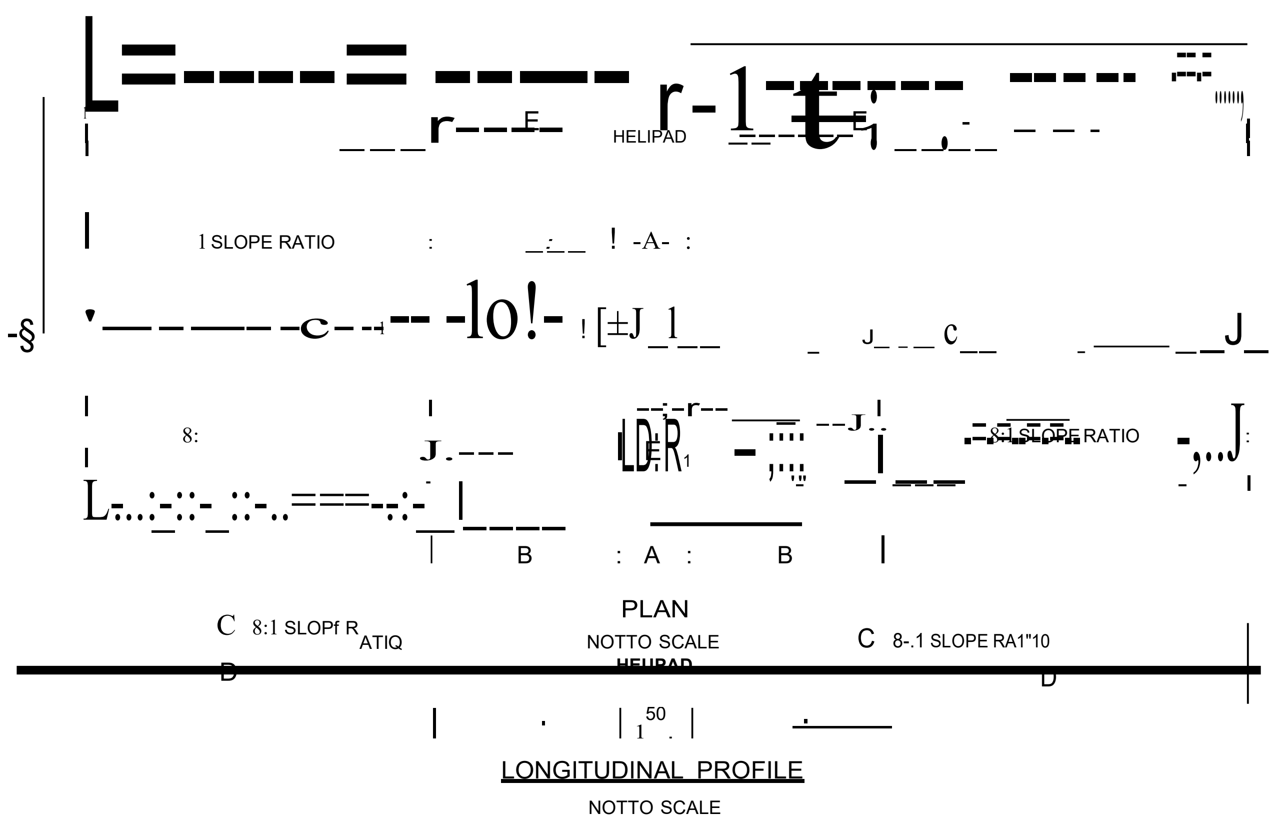
FIGURE III-1





LEGEND

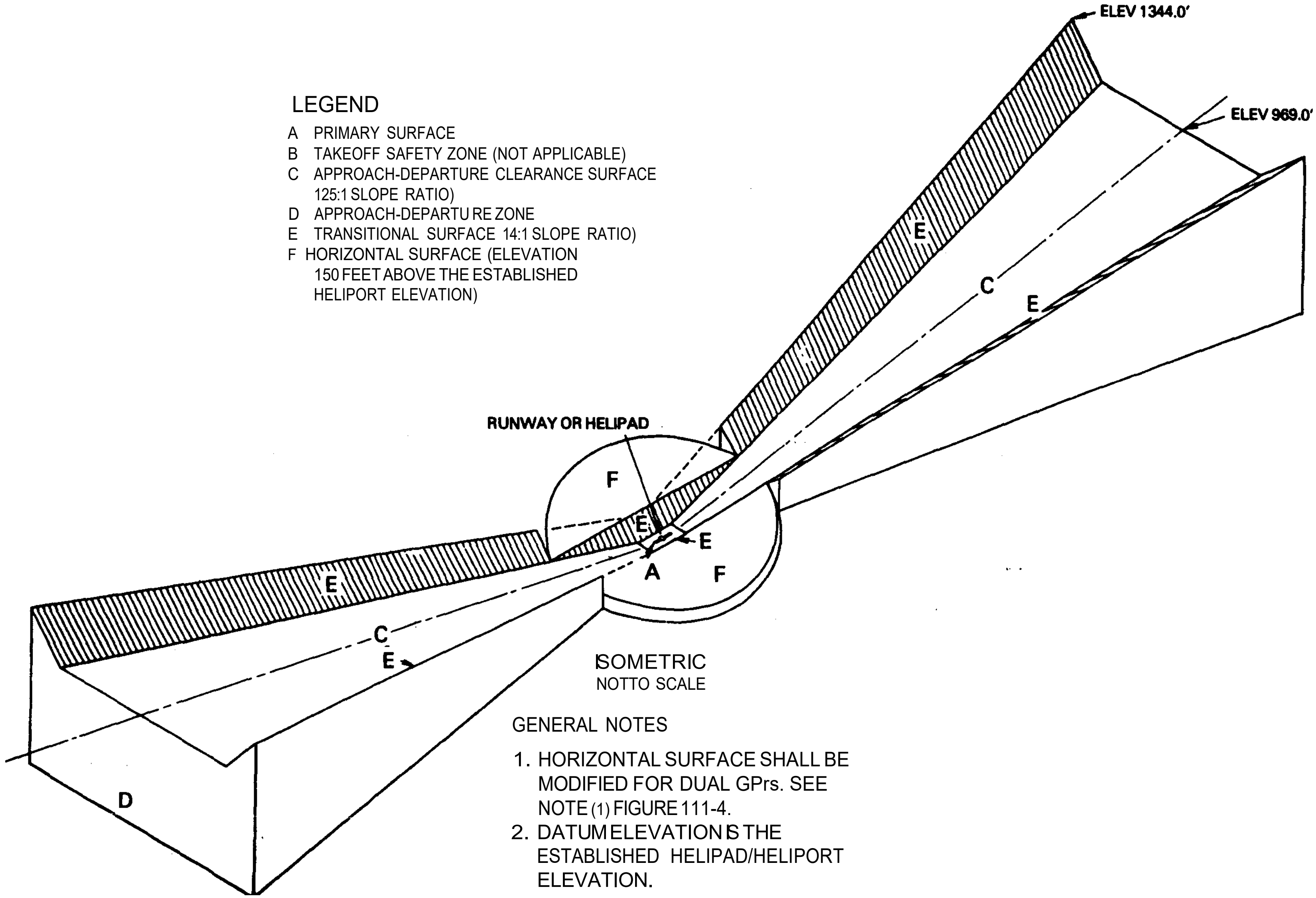
A PRIMARY SURFACE
B TAKEOFF SAFETY ZONE
C APPROACH--DEPARTURE CLEARANCE
SURFACE 18:1 SLOPE RATIOI
0 APPROACH-OEPARTURE ZONE
E TRANSITIONAL SURFACE
12:1 SLOPE RATIO)



E-28

FIGURE III-2

VFR HELIPAD - AIRSPACE



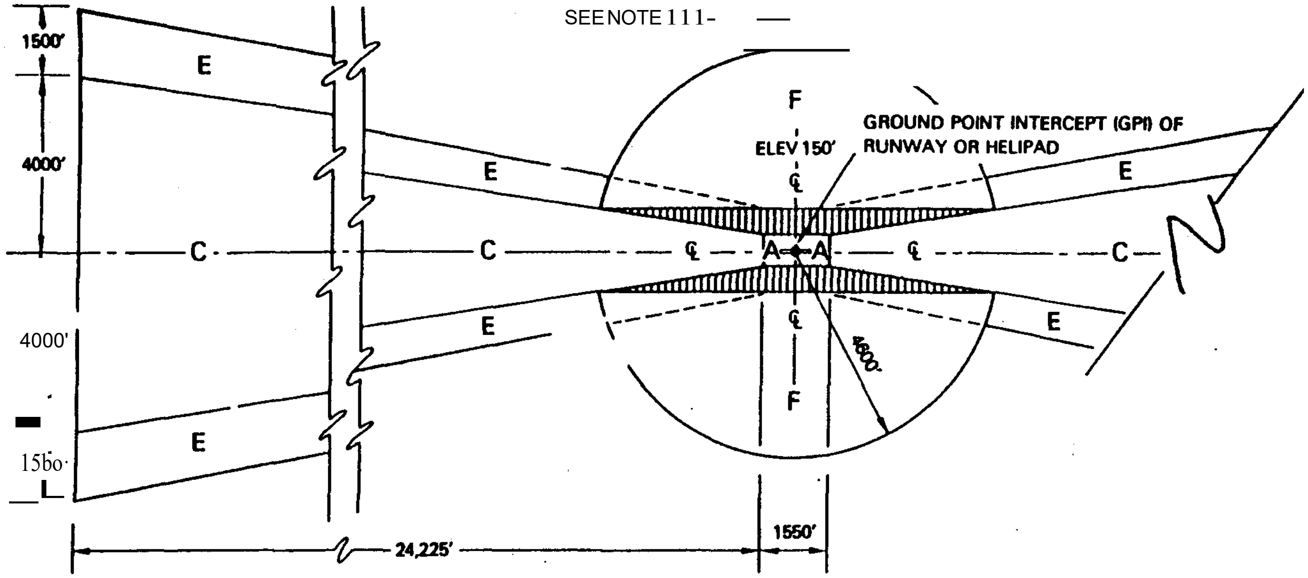
LEGEND

A PRIMARY SURFACE
B TAKEOFF SAFETY ZONE (NOT APPLICABLE)
C APPROACH-DEPARTURE CLEARANCE SURFACE 125:1 SLOPE RATIO)
D APPROACH-DEPARTU RE ZONE
E TRANSITIONAL SURFACE 14:1 SLOPE RATIO)
F HORIZONTAL SURFACE (ELEVATION 150 FEET ABOVE THE ESTABLISHED HELIPORT ELEVATION)

GENERAL NOTES

1. HORIZONTAL SURFACE SHALL BE MODIFIED FOR DUAL GPrs. SEE NOTE (1) FIGURE 111-4.
2. DATUM ELEVATION IS THE ESTABLISHED HELIPAD/HELIPORT ELEVATION.

FIGURE III-3
IFR HELIPAD/RUNWAY AIRSPACE (ISOMETRIC)



PLAN

NOf'i'O'ScALE

LEGEND

A PRIMARY SURFACE

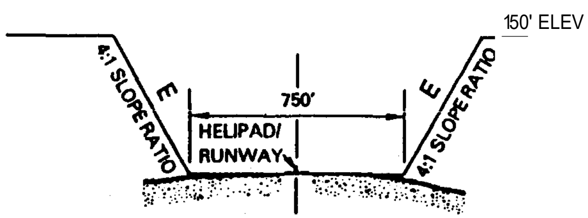
B TAKEOFF SAFETY ZONE NOT APPLICABLE!

C APPROACH-DEPARTURE CLEARANCE 125:1 SLOPE RATIO!

D APPROACH-DEPARTURE ZONE

E TRANSITIONAL SURFACE 14:1 SLOPE RATIO!

F HORIZONTAL SURFACE 1150' ELEVATION!



TRANSVERSE SECTION

NOT TO SCALE

NOTE 111 CIRCULAR HORIZONTAL SURFACE APPLIES TO SINGLE GPI. FOR RUNWAY WITH TWO GPI's, SWING 4600 FOOT RADIUS ARCS ABOUT EACH GPI AND CONNECT WITH TANGENTS

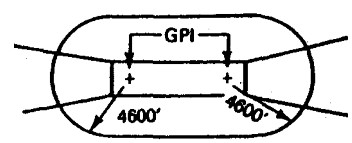
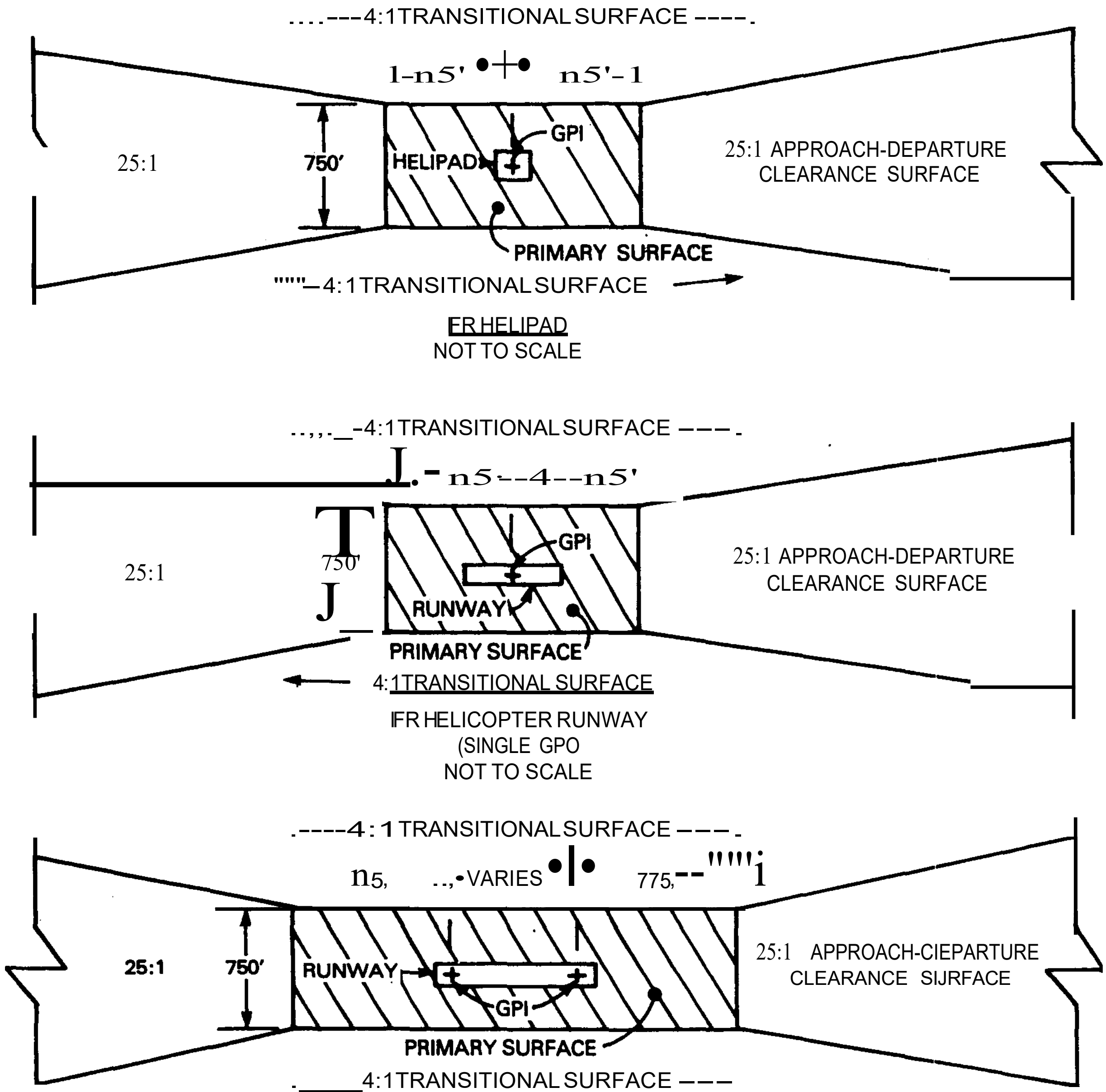


FIGURE III-4

IFR HELIPAD/RUNWAY-AIRSPACE PLAN & SECTION

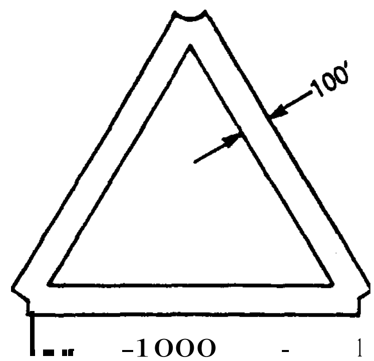


IFR HELICOPTER RUNWAY
(DUAL GPI'S)
NOT TO SCALE

GENERAL NOTE
— GPI is the ground point intercept. See Section III, paragraph C for definition.

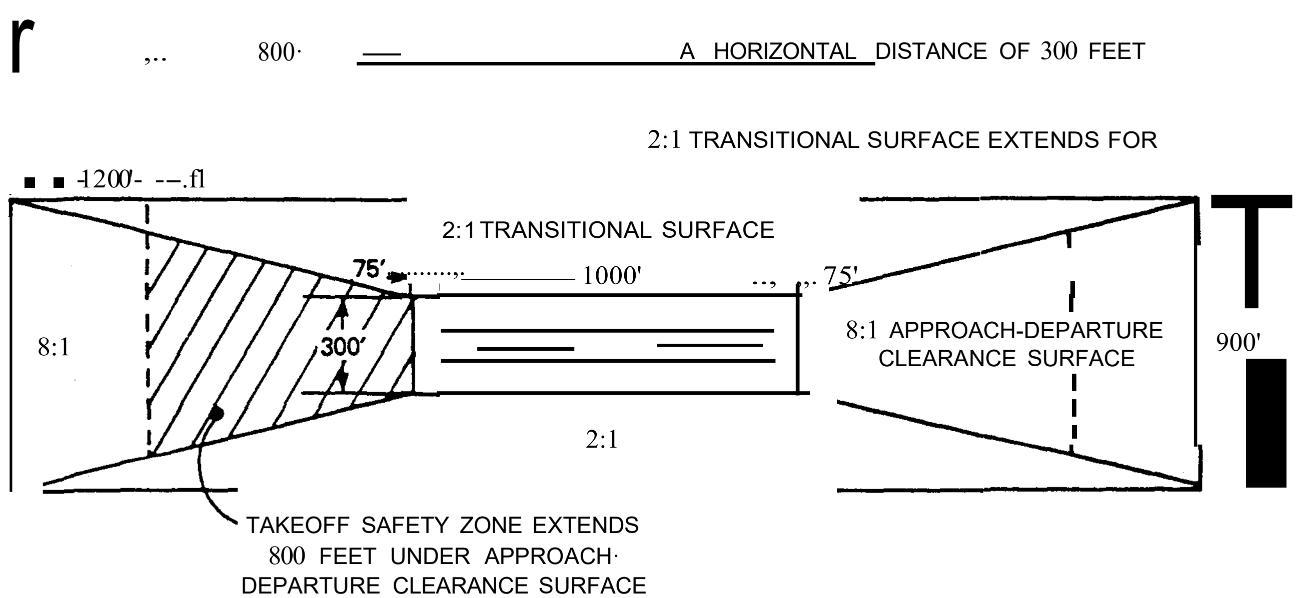
FIGURE III-5

IFR HELIPAD/RUNWAY-PRIMARY SURFACE



1. THREE 1000 FOOT LONG RUNWAYS ARRANGED IN EQUILATERAL TRIANGLE
2. AIRSPACE SHOWN BELOW SHOULD BE APPLIED TO EACH RUNWAY

PLAN – SCHEMATIC NOT TO SCALE

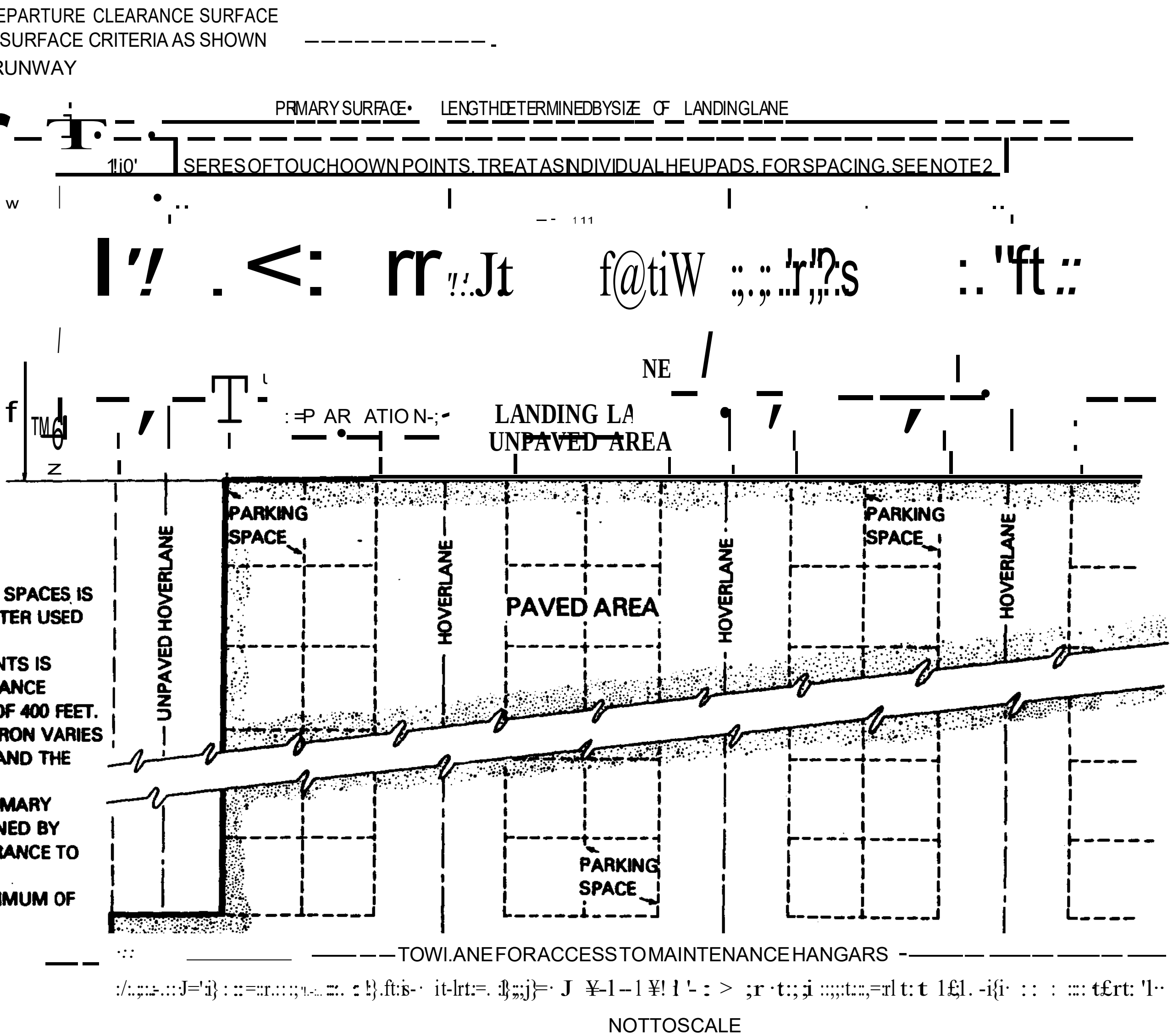


TYPICAL AIRSPACE/IMAGINARY SURFACES
PLAN – NOT TO SCALE

FIGURE III-6

MARINE CORPS HELICOPTER OUTLYING FIELD

(VFR)



NOTES

1. WIDTH OF HOVERLANES AND PARKING SPACES IS DETERMINED BY THE TYPE OF HELICOPTER USED AND THE CLEARANCES REQUIRED.
2. INTERVAL BETWEEN TOUCHDOWN POINTS IS DETERMINED BY THE CENTERLINE DISTANCE BETWEEN HOVERLANES OR MINIMUM OF 400 FEET.
3. SIZE AND LAYOUT OF THE PARKING APRON VARIES WITH THE TYPE OF HELICOPTER USED AND THE MISSION REQUIREMENTS.
4. MINIMUM DISTANCE BETWEEN THE PRIMARY SURFACE AND THE APRON IS DETERMINED BY THE 2:1 TRANSITIONAL SURFACE CLEARANCE TO PARKED AIRCRAFT.
5. MULTIPLE LANES TO BE SPACED A MINIMUM OF 200 FEET CENTERLINE TO CENTERLINE.

LEGEND

PAVING

FIGURE III-7

HELICOPTER LANDING LANES - TYPICAL LAYOUT

SECTION IV - LAND REQUIREMENTS

Land acquisition guidance for Navy and Marine corps air installations is given in OPNAVINST 11010.36, Air Installations compatible Land Use zones (AICOZ) Program. The AICOZ land acquisition policies address the area beyond runways under flight paths. No policy is provided for the primary surface and laterally adjacent areas, which fall under the transitional surfaces. Land requirements in these areas are usually dictated by the requirement to site supporting facilities such as aprons, hangars, station buildings, etc. However as a minimum, the area within the primary surface and laterally out from the primary surface until the transitional surface is 50 feet above the ground should be controlled by fee purchase or restrictive easement. Fee purchase is preferred for the primary surface area.

* U.S.GOYERHMo:NT PRINTING OFFIC£: 1112 -J67-422/60I

FACILITIES CRITERIA (FC)

FACILITY PLANNING FOR NAVY AND MARINE CORPS SHORE INSTALLATIONS

APPENDIX F

AUSTERE FACILITIES (NAVY)

FACILITIES CRITERIA PROGRAM

FACILITIES CRITERIA NAVY AND MARINE CORPS

AUSTERE FACILITIES (NAVY) PLANNING CRITERIA

Record of Changes

Change No.	Date	Location
1	05/01/2013	Revised **“FOREWORD”** by removing images of draft CNIC Instruction and providing hyperlink to CNIC document site; updated language in Introduction to focus on Planning functions; updated 61050-2 allowance for office GSF; updated 72127-3 and Table 72127-2 for space allowances in centralized bathrooms.
2	02/16/2017	CCN 721-27: Revised Title of CCN, revised CNIC N93 as POC to verify scope, replaced term “Lodging” with “Unaccompanied Housing” in correspond with N-code responsibilities within the CNIC organization.
3	01/10/19	Corrected Table 72235-A to correct typo error showing 151-200 capacity to 151-250 capacity.
4	06/12/2022	CNIC reference information is deleted under “**Description of Changes.”** CNIC broken link is removed under “**FOREWORD.”**
5	03/02/2023	Change UFC 2-000-05N to FC 2-000-05N document due to the fact that this planning criteria is not unified among the other DoD services.
6	03/17/2023	Change URLs to access the following: 1. Under 610-50, UFC 4-610-01 2. Under 721-27, FC 4-722-10N 3. Under 722-35, FC 4-722-01N 4. Under 740-49, FC 4-740-02N

Description of Changes:

The following significant changes were made in this UFC revision:

- Criteria updates and coordination align with references in UFC 4-610-01, FC 4-721-10N, FC 4-722-01N, and FC 4-740-02N.

FOREWORD

This publication, "*Appendix F - Austere Facilities (Navy)"* is a supplement to FC 2-000-05N *"Facility Planning for Navy and Marine Corps Shore Installations"*, and provides facility planning criteria for use in computing quantitative austere facility requirements at specifically designated Navy installations.

TABLE OF CONTENTS

INTRODUCTION

PURPOSE

The purpose of this appendix is to provide planning guidance for developing Basic Facility Requirements (BFRs) for the following category code numbers (CCNs):

- CCN 610-50 Austere Administrative Facility
- CCN 721-27 Austere Unaccompanied Housing
- CCN 722-35 Austere Dining Facility
- CCN 740-49 Austere Indoor Fitness Center

DEFINITION AND SCOPE

An austere facility is defined as a structure which has been planned, designed and constructed with minimal footprint area, infrastructure, and finishes, while incorporating the applicable building codes and facility criteria to assure adherence to all health, life safety, force protection, sustainability and accessibility standards and regulations necessary to fulfill the required mission.

Austere construction is intended for facilities in locations determined by CNIC and approved by OPNAV to be eligible for austere facilities construction. The austere standards are intended to be applied flexibly and in varying degrees to all facilities at locations designated as austere. The flexibility should be allowed to ensure the criteria are appropriate for individual austere locations.

Austere facilities should be built with the least total ownership costs (TOC) possible, including purchase, maintenance and use of consistently available alternative local goods.

APPLICABILITY

This Appendix should be used for proper space planning of all facilities that are designated as austere during project programming by CNIC and OPNAV.

610 50 AUSTERE ADMINISTRATIVE FACILITY (SF)

For austere administrative facilities design criteria, refer to UFC 4-610-01 Appendix C, located here: https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-4-610-01

61050-1 DEFINITION.

Austere administrative facilities accommodate the executive and staff functions at designated austere naval installations. The functions performed in an administrative office are primarily logistical and personnel management. These facilities are intended to provide the minimum footprint area and finish supporting administrative functions while providing minimal up front and total ownership costs in comparison to non-austere facilities.

Austere administrative buildings will be no more than two stories tall and do not include elevators. These facilities will utilize open office space layouts with provisions for a single private office and conference room.

Building size, shape, and area-to-perimeter ratio have a direct impact on the cost and efficiency of the facility, and all of these aspects should be considered during the planning phase. A simple shape with efficient structural layout and a high area-to-perimeter ratio yields the most economical facility.

61050-2 BASIC PLANNING FACTORS. The basic factors required to size austere administrative facilities are:

- The number of occupants, which drives the open office space requirement
- The special purpose rooms or spaces required

Note that all austere administrative space requirements below are provided in terms of Gross Square Feet (GSF).

61050-2.1 Open Office Space. The basic planning factor for open office space within an austere administrative facility is 80 GSF per building occupant. This figure includes all circulation spaces, hallways, bathrooms, mechanical rooms, electrical rooms and stairwells. Workstations/cubicles in austere administrative facilities shall be 6 x 8 ft (1.8 x 2.4 m). Requirements for special purpose rooms (shown below) are additive to the open office space requirement.

61050-2.2 Special Purpose Rooms. Any rooms/spaces not included as part of the open office space above, are to be considered as special purpose rooms/spaces. Examples of authorized spaces are listed below. Other types of special purpose rooms such as a SCIF, training room, or dedicated storage room must be individually justified based on mission requirements.

- Private office – 135 GSF

- Weather Vestibule - 64 GSF per vestibule
- Telecommunications/server room – 100 GSF per floor
- Administrative support space - includes space for photocopy machine space and work area, printers, files, facsimile machine space and work area, scanners, non-secured office supply storage, shredders, and safes.
    - File Area. An allowance of 7 GSF will be made per letter file cabinet, and 8 GSF per legal file cabinet.
    - Office Equipment. This category of space includes printers, copiers, shredders, fax machines, digital senders, and other similar equipment. The size is largely dependent on the number and types of machines used. Plotters should be considered in addition to the average square foot number used.
    - Safes. The space required will be dependent on the size and number of safes required.
- Conference Areas. Conference requirements must be carefully tailored to an organization's mission and experience, and then adjusted to take into consideration the availability of building conference facilities that can be shared. Based upon the number of building occupants, the following allowances should be made:

No. of Persons	Floor Area in GSF
8	160
Up to 14	280
Up to 24	480

61050-3 ACCESS AND PARKING. Access and parking is not authorized for Privately Owned Vehicles (POVs). Fire truck access and fire lanes are authorized. Service vehicle access is authorized for pickups, deliveries, maintenance, etc as needed. Minimal parking for official vehicles, particularly alternative modes of transportation such as electric vehicles is authorized where applicable. Access drives for pickup and drop off areas for shuttle buses, etc. are authorized. Total parking areas for residents, visitors, staff, and service personnel should be extremely minimal and limited to mission support.

721 27 AUSTERE UNACCOMPANIED HOUSING (PN)

For austere unaccompanied housing design criteria, refer to FC 4-721-10N Appendix E, located here: https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/fc-4-721-10n.

72127-1 GENERAL Austere Unaccompanied Housing provides berthing facilities at enduring Naval installations that exclusively support missions in designated austere locations and are staffed with personnel on rotational deployments

Initial/preliminary requirements are determined by following the steps in section 72127-3 "Space Allowance". Preliminary site selection is also performed during the initial planning phase.

Once the initial scope is determined, the findings are forwarded to CNIC (N93), for review. A subsequent independent assessment will be performed to determine the final project scope. This assessment will validate the site selection, determine the final number of rooms and minimal support areas necessary to meet the requirements of austere quarters, and identify any companion projects necessary to provide a complete and usable facility.

The space planning methodology included in this category code will accommodate the projected enduring and surge base population based on official loading and deployment projections relative to the unique nature of staffing with rotational personnel that will yield 90% average projected occupancy for the proposed facility/complex (see details under 72127-3 Space Allowance).

72127-2 DEFINITION. Austere unaccompanied personnel housing facilities will only be located at designated Naval installations. The current austere facility guidance provides for standardized room modules with centralized shower/toilet facilities for active duty personnel and reservists. The guidance in Section 72127-3 provides standardized room modules, with variable occupancy determined by the rank structure of the personnel occupying each module and the surge status of the installation.

Table 72127-1 provides a listing and description of all potential functional program areas for these facilities.

Table 72127-2 tabulates space requirements based on the installation population being served by the facility.

Table 72127-1 Austere Quarters Functional Program Areas

Functional Program Area	Description
Resident Services (required)	
Entrance vestibule	Entry airlock
Resident corridors/circulation	Access to guest rooms, toilets, showers and support areas.
Resident module [1]	Standard multi-occupant room with sleeping area, desks and clothes storage.
Centralized toilets & showers	Space provided in central, convenient location on each floor for resident access to toilets and showers.
Facility Floor Support (required)	
Janitorial areas	Janitor closet on each floor or wing.
Housekeeping areas	Housekeeping support and supplies on each floor or wing.
Utility rooms	Mechanical, electrical, communications and sprinkler rooms located for efficient utility distribution.
Optional Support Areas (supporting justification necessary)	
Laundry, linens	Spaces equipped with industrial-grade laundry equipment. Justified only for installations which do not provide a centralized laundry service.
Laundry, resident use	Spaces equipped for self-service resident laundry requirements. Justified only for installations which do not provide a centralized laundry service.
Linen storage, clean	Storage area for distribution of clean linens.
Linen storage, soiled	Storage area for soiled linens, adjacent to receiving area or laundry spaces.
Receiving	Service entrance for equipment and service supplies.
Reception	Reception desk for check-in and check-out. Justified only for installations which do not have a centralized billeting assignment office.
Storage, cleaning fluid	Separate storage for chemicals used for cleaning, etc.
Storage, general supply	Storage and warehousing of facility supplies.

[1] The final number of rooms will be determined through individual assessment by CNIC/N9.

72127-3 SPACE ALLOWANCE. Berthing modules under CCN 72127 are intended for variable occupancy depending on the rank of the occupants. Each standard module has 288 net square feet (NSF) of living/sleeping area. The maximum steady-state (non-surge) occupancy per module is four persons, resulting in a minimum 72 NSF per person.

For planning purposes, the steady-state module occupancy standards are:

4 persons per module ----- (72 NSF per person)------------------- E1 through E6
2 persons per module ----- (144 NSF per person)------------------- E7 through E8
2 persons per module ---WO1 through WO4
2 persons per module -- O1 through O4
2 persons per module ---Civilian equivalent
1 person per module ------- (288 NSF per person)-----------------------------------E9
1 person per module -- WO5
1 person per module -- O5 and above
1 person per module --Civilian equivalent

Refer to the space allowances shown in Table 72127-2 to obtain a comprehensive facility size. For initial planning purposes, allow for all required austere spaces shown in Table 72127-1. Omit the optional support areas shown in the table, unless justified by the lack of centralized services located elsewhere on the installation (include justification in the project documentation) .

Initial project scope is determined by actual loading capacity requirement (i.e., the number of personnel needing housing for a given steady-state period). Austere berthing facilities should be planned for a 90% occupancy rate. The modules will accommodate the use of bunks to allow for doubled maximum occupancy during periods of temporary population surge.

The facility shall incorporate space on each floor for interior, centralized toilets and showers sufficient for the planned steady-state population. The initial project scope shall provide for one water closet with lavatory per 10 persons allowing 30 NSF per wc/lavatory, and one shower per 8 persons allowing 20 NSF per shower.

No space allowances shall be provided for common gathering areas or kitchen spaces. Elevators are not authorized. Provide a concrete pad and removable railing section for each floor above the pad for use of a portable lift for the movement of furniture to upper floors.

72127-4 ACCESS AND PARKING. Access and parking is not authorized for Privately Owned Vehicles (POVs). Fire truck access and fire lanes are authorized. Service vehicle access is authorized for pickups, deliveries, maintenance, etc as needed. Minimal parking for official vehicles, particularly alternative modes of transportation such as electric vehicles is authorized where applicable. Access drives for pickup and drop off areas for shuttle buses, etc. are authorized. Total parking areas for residents, visitors, staff, and service personnel should be extremely minimal and limited to mission support.

Table 72127-2. Space Allowances for Austere Quarters

Functional Program Area	Base Area		Space Standard (planning factor)	Description	Sample (see notes)		
	ft^2	m^2			Req't	NSF	NSM
Entrance Vestibule	100	9.3	Per facility	Standard size	Req'd	100	9.3
Standard Resident Module	288	26.8	Standard 4-person berthing module		Req'd	51,840	4,816.1
Central Gang Toilet/ Shower	50	4.6	Water Closet and Lavatory = 30 NSF @ 1 per 10 PN Shower and drying area = 20 NSF @ 1 per 8 PN	Based on information in UFC 3-420-01 and UFC 4-740-03	Req'd	3960	367.9
Janitor Areas	25	2.3	Per Facility floor wing	Includes mop sink, janitor supplies and equipment	Req'd	75	7.0
House-keeping Areas	50	4.6	Per Facility floor wing	Accommodates housekeeping supplies and storage	Req'd	150	13.9
Utility Rooms	16	1.5	Per 25 modules	Comm. rooms only; other utility rooms are included in net-to-gross multiplier	Req'd	128	11.9
Laundry, Linen	450	41.8	Optional facility space at 450 SF for up to 25 modules + 4 SF per ea additional module	Only authorized when no centralized laundry service is available at the installation.	Opt.	0	0.0
Laundry, Resident	110	10.2	110 NSF per 10 modules	Two to four washers and two to four dryers per every 10 room modules	Opt.	0	0.0
Linen Storage, Clean	150	13.9	25 NSF per 16 modules	Shelving	Opt.	0	0.0
Linen Storage, Soiled	100	9.3	100 NSF +15 NSF per 10 modules	Includes carts and sorting space	Opt.	0	0.0
Receiving	150	13.9	150 NSF	Service entrance to receive goods and equipment	Opt.	0	0.0
Reception Desk	64	5.9	64 NSF	Desk area to assign rooms and issue linens. Allowed if central billeting not used on installation.	Opt.	0	0.0
Storage, General Supply	600	55.7	600 NSF	Includes segregated space for cleaning fluid storage	Opt.	0	0.0
					Sample Subtotal	**56,253**	**5,226.1**
					Net-to-Gross Factor @ 30%	16,876	1,567.8
					Sample Total	**73,129**	**6,793.9**

Notes:
1. Sample is for a 180 module, three floor facility.
2. The "Req't" column indicates whether or not space is authorized for designated austere facilities.

722 35 AUSTERE DINING FACILITY (SF)

For Austere Dining Facilities design criteria, refer to FC 4-722-01N Appendix C, located here: https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/fc-4-722-01n.

72235-1 GENERAL. Austere dining facilities shall provide for cafeteria style feeding of short order and regular meals much like traditional facilities, but with reduced footprint and finish requirements.

72235-2 DEFINITION. Austere dining facilities provide core dining, food preparation, and support areas for locations determined austere by CNIC. These facilities are intended to provide the minimum footprint area and finishes to support galley functions while providing minimal up front and total ownership costs in comparison to non-austere locations.

72235-3 SPACE ALLOWANCE. Projects are subject to review by Naval Supply Systems Command and subsequently by DOD Food Planning Board. Austere dining facility requirements are generated in two basic steps: (1) Determination of the installation dining loading, and (2) Determination of space allowances using Table 72235-A.

Step 1 – Determination of Installation Dining Loading

72235-4 The number of personnel to be served during a meal period shall be determined by multiplying the maximum military, authorized civilian, and authorized contractor installation population by the austere utilization factor of 90%. Personnel on separate rations shall not be included in the serving requirements when planning new dining facilities, or retaining and modernizing permanent facilities. Include the average on-board count of crews of ships entitled to rations-in-kind while shipboard dining facilities are out of service in the projected occupancy figure.

Step 2 – Determination of Space Allowances

72235-5 FUNCTIONAL COMPONENTS. The authorized floor areas are based on the number of personnel to be served as determined by Step 1. The facility size shall conform to Table 72235-A. The following assumptions have been made in the planning methodology contained herein:

- For austere facility dining, seating is based on 12 SF (1.1 SM) per seat.
- Three meals per day are served, seven days per week as a minimum.
- Bussing method is self-buss to remote dish room.
- The service capacity of a properly equipped and manned regular meal serving line will sustain a service rate of eight personnel per minute. A properly equipped and manned short-order to-order serving line will sustain a service rate of five personnel per minute.

- Seating capacity is traditionally determined by dividing the total number of patrons to be served by the turnover rate. Turnover rates can vary according to the size of facility and seating capacities. Table 72235-A lists the turnover rates upon which each facility size has been based. For situations that require variations in the turnover rate, the space allowances must be adjusted accordingly. See UFC 4-722-01 for more information on turnover rates and minimum seating capacity.
- The local command determines the meal period.
- For planning purposes the total service time should not be less than 72 minutes or more than 142 minutes.

72235-6 STORAGE. Storage area requirements shall be calculated as 20% of the facility subtotal (see Table 72235-A) and shall include areas for the storage of dry foods, refrigerated and frozen foods, consumables, and other non-food goods. Storage areas may be integral to the dining facility or may be stand-alone facilities in appropriate environments, but are included in the dining facility square footage and do not warrant a separate property record card. Storage allowance may be increased based on remote locations with longer delivery cycles, but must be justified by the user and approved by CNIC/N9.

72235-7 NET TO GROSS FACTOR. The net-to-gross multiplier accounts for mechanical and other utility space, wall thicknesses and structural columns, and common areas throughout the building. For planning purposes, apply a net-to-gross factor of 1.25 to the facility subtotal (see Table 72235-A).

72235-8 SPACE ALLOWANCE TABLE. The area allowances shown in Table 72235-A on the following pages are provided for various dining facility sizes based on population to be served (see 72235-4). Total size of a facility shall be based on the number of personnel served as shown at the top of each of the following tables. NOTE: The facility total allowances shown include provisions for a flight kitchen. If this space is not applicable, deduct the appropriate allowance from the facility total.

TABLE 72235-A
SPACE CRITERIA FOR AUSTERE DINING FACILITIES

		Facility Size Classifications							
		1-80 Personnel Served		81-150 Personnel Served		151-250 Personnel Served		251-400 Personnel Served	
		62 Min. Seats		108 Min. Seats		116 Min. Seats		172 Min. Seats	
		1.3 Max Turnover		1.4 Max Turnover		2.2 Max Turnover		2.3 Max Turnover	
	Functional Components	NSF	SM	NSF	SM	NSF	SM	NSF	SM
PUBLIC AREAS	Dining and Circulation	750	69.7	1305	121.2	1500	139.4	2400	223.0
	Public Toilets	180	16.7	200	18.6	220	20.4	250	23.2
	Queue	130	12.1	250	23.2	325	30.2	500	46.5
	Sign-in Station	40	3.7	40	3.7	40	3.7	60	5.6
	Subtotal	**1100**	**102.2**	**1795**	**166.8**	**2085**	**193.7**	**3210**	**298.2**
SERVING AREAS	Regular Food Line	250	23.2	320	29.7	0	0.0	0	0.0
	Fast Food Line	0	0.0	0	0.0	0	0.0	0	0.0
	Combination Food Line	0	0.0	0	0.0	420	39.0	620	57.6
	Beverage Line	200	18.6	250	23.2	350	32.5	500	46.5
	Dish Washing	180	16.7	250	23.2	320	29.7	380	35.3
	Subtotal	**630**	**58.5**	**820**	**76.2**	**1090**	**101.3**	**1500**	**139.4**
PREP AREAS	Kitchen	520	48.3	640	59.5	655	60.9	880	81.8
	Utensil Wash	0	0	0	0	175	16.3	220	20.4
	Subtotal	**520**	**48.3**	**640**	**59.5**	**830**	**77.1**	**1100**	**102.2**
SUPPORT AREAS	Offices	106	9.8	106	9.8	212	19.7	212	19.7
	Staff Toilets	260	24.2	260	24.2	260	24.2	260	24.2
	Staff Lockers	0	0	0	0	120	11.1	160	14.9
	Janitor's Closet	25	2.3	25	2.3	25	2.3	50	4.6
	Can Wash	40	3.7	40	3.7	40	3.7	40	3.7
	Loading Dock	400	37.2	400	37.2	400	37.2	460	42.7
	Subtotal	**831**	**77.2**	**831**	**77.2**	**1057**	**98.2**	**1182**	**109.8**
	FACILITY SUBTOTAL	**3,081.0**	**286.2**	**4,086.0**	**379.6**	**5,062.0**	**470.3**	**6,992.0**	**649.6**
	Storage: 20% of facility subtotal	616	57.2	817	75.9	1,012	94.1	1,398	129.9
	Net-to-Gross: 25% of facility subtotal	770	71.6	1,022	94.9	1,266	117.6	1,748	162.4
	Flight Kitchen	100	9.3	100	9.3	100	9.3	100	9.3
	FACILITY TOTAL	**4,567**	**424.3**	**6,025**	**559.7**	**7,440**	**691.2**	**10,238**	**951.2**

TABLE 72235-A (cont)
SPACE CRITERIA FOR AUSTERE DINING FACILITIES

Functional Components		Facility Size Classifications							
		401-650 Personnel Served		651-1000 Personnel Served		1001-1500 Personnel Served		1501-2200 Personnel Served	
		288 Min. Seats		345 Min. Seats		460 Min. Seats		575 Min. Seats	
		2.3 Max Turnover		2.9 Max Turnover		3.3 Max Turnover		3.9 Max Turnover	
		NSF	SM	NSF	SM	NSF	SM	NSF	SM
PUBLIC AREAS	Dining Area and Circulation	3760	349.3	5060	470.1	6055	562.5	8800	817.5
	Public Toilets	300	27.9	320	29.7	340	31.6	370	34.4
	Queue	750	69.7	1000	92.9	1100	102.2	1650	153.3
	Sign-in Station	80	7.4	100	9.3	120	11.1	120	11.1
	Subtotal	**4890**	**454.3**	**6480**	**602.0**	**7615**	**707.5**	**10940**	**1016.4**
SERVING AREAS	Regular Food Line	600	55.7	650	60.4	1050	97.5	1300	120.8
	Fast Food Line	600	55.7	650	60.4	650	60.4	650	60.4
	Combination Food Line	0	0.0	0	0.0	0	0.0	0	0.0
	Beverage Line	650	60.4	700	65.0	810	75.3	1056	98.1
	Dish Washing	180	16.7	250	23.2	320	29.7	380	35.3
	Subtotal	**2030**	**188.6**	**2250**	**209.0**	**2830**	**262.9**	**3386**	**314.6**
PREP AREAS	Kitchen	1040	96.6	1350	125.4	1555	144.5	2160	200.7
	Utensil Wash	330	30.7	400	37.2	500	46.5	600	55.7
	Subtotal	**1370**	**127.3**	**1750**	**162.6**	**2055**	**190.9**	**2760**	**256.4**
SUPPORT AREAS	Office	318	29.5	318	29.5	318	29.5	318	29.5
	Staff Toilets	360	33.4	430	39.9	450	41.8	500	46.5
	Staff Lockers	260	24.2	380	35.3	380	35.3	480	44.6
	Janitor's Closet	50	4.6	75	7.0	75	7.0	100	9.3
	Can Wash	40	3.7	60	5.6	60	5.6	60	5.6
	Loading Dock	600	55.7	600	55.7	800	74.3	800	74.3
	Subtotal	**1628**	**151.2**	**1863**	**173.1**	**2083**	**193.5**	**2258**	**209.8**
FACILITY SUBTOTAL		**9,918.0**	**921.4**	**12,343.0**	**1,146.7**	**14,583.0**	**1,354.8**	**19,344.0**	**1,797.1**
Storage: 20% of facility subtotal		1,984	184.3	2,469	229.3	2,917	271.0	3,869	359.4
Net-to-Gross: 25% of facility subtotal		2,480	230.4	3,086	286.7	3,646	338.7	4,836	449.3
Flight Kitchen		125	11.6	125	11.6	150	13.9	150	13.9
FACILITY TOTAL		**14,506**	**1,347.7**	**18,022**	**1,674.3**	**21,295**	**1,978.4**	**28,199**	**2,619.8**

Notes:

(1) Not all locations will require a flight kitchen. A flight kitchen is a staging area where food products are assembled and packaged for delivery to aircraft. Remove the allowable area form the total requirement where flight kitchens are not needed

(2) Dining area seating and circulation is based on 12 NSF per person.

(3) Office area is based on accommodating office staff at 106 SF per person. Use of individual offices in lieu of a single office will be determined during the design phase.

(4) For planning purposes, including recordation in iNFADS, loading docks must be counted at full size, or 100%. For cost purposes, loading docks can be counted at 50% of the allowable area.

(5) For a breakdown of the staff lockers, refer to UFC 4-722-01 Dining Facilities, Appendix C, Section B-8.2. Lockers for staff personnel up to 150 PN should be integrated into the gross area of the building.

72235-9 OVERSIZED FACILITIES. Dining facilities that require more space than the maximum shown in Table 72235-A shall be sized as follows: Divide the projected increased demand/loading capacity by 2,200 (maximum personnel) shown in the table. This will yield a multiplier greater than "1". Apply this multiplier to the allowances shown for the specific areas within the various functional components (Public, Serving, Prep, and Support Areas) for 2,200 personnel. Calculate the subtotals for the functional components and use the process provided for calculating storage adjustments and computing net-to-gross area as shown in Table 72235-A.

The following is provided as an example:

A new dining facility is required to accommodate 3,500 personnel (PN). Divide the 3,500 PN capacity requirement by the Table 72235-A maximum allowance of 2,200 PN; the result is a factor of 1.59. Using the maximum allowances for the functional components of the 2,200 PN facility, calculate as follows:

Public Areas:	13,140 NSF x 1.59 =	20,892.6 NSF
Serving Areas:	4,288 NSF x 1.59 =	6,817.9 NSF
Preparation Areas:	4,335 NSF x 1.59 =	6,892.7 NSF
Support Areas:	2,440 NSF x 1.59 =	3,879.6 NSF
Facility Subtotal:	=	38,482.8 NSF
Storage Req't (20% of Facility Subtotal):	=	7,696.6 GSF
Net to Gross Allowance (25% of Fac. Sub.):	=	9,620.7 GSF
Facility Total Requirement:	=	55,800.1 GSF

(Note: If a flight kitchen is required, it is added to the final facility GSF requirement; see Table 72235-A)

72235-10 ACCESS AND PARKING. Access and parking is not authorized for Privately Owned Vehicles (POVs). Fire truck access and fire lanes are authorized. Service vehicle access is authorized for pickups, deliveries, maintenance, etc as needed. Minimal parking for official vehicles, particularly alternative modes of transportation such as electric vehicles is authorized where applicable. Access drives for pickup and drop off areas for shuttle buses, etc. are authorized. Total parking areas for residents, visitors, staff, and service personnel should be extremely minimal and limited to mission support.

740 49 AUSTERE INDOOR PHYSICAL FITNESS CENTER (GYM) (SF)

For Austere Fitness Centers design criteria, refer to UFC 4-740-02 Appendix F located here: https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-4-740-02

This is the link to the Whole Building Design Guide (WBDG) Federal Facilities Criteria web page that hosts both the UFC 4-740-02 and the associated Fitness Space Program Spreadsheet (for non-Austere facilities). For Austere Dining Facilities, use space planning criteria located within this document.

The Department of the Navy Fitness Standards and Metrics which influence requirements for physical fitness facilities are available at this CNIC website: http://www.navyfitness.org/fitness/.

74049-1 GENERAL. Refer to the introduction to 740-series category codes (in the "700 Series - Housing and Community Facilities" section of this UFC) for general instructions regarding planning procedures and allowances for community facilities.

74049-2 DEFINITION. Austere physical fitness facilities provide facilities and support services to meet the individual physical fitness, coordination, skills development, recreational and training needs of military personnel stationed in designated austere operating environments. These facilities may also serve authorized civilians. Activities that are typically accommodated in these facilities include: athletic gear issue, calisthenics, cardiovascular training, physical fitness training, and weight-training.

74049-3 RELATED FACILITIES. Consideration should be given to collocation of the facility with other existing or planned recreational facilities in order to (1) take advantage of potential savings in space requirements and operating costs, and (2) provide users with the increased convenience of clustered facilities. These facilities would include:

- 740 53 Indoor Swimming Pool
- 750 10 Outdoor Playing Courts
- 750 20 Playing Fields
- 750 30 Outdoor Swimming Pool.

74049-4 INSTALLATION POPULATION. The primary functional components of an Indoor Fitness Facility - Basketball Court, Aerobics/Exercise Area, Cardiovascular Training Area, Weight Training Area, and Indoor Playing Court - are sized based on installation population. Installation population ranges are as follows:

XSMALL = Population 0-500
SMALL = Population 501-3,000
MEDIUM = Population 3,001-7,000

LARGE = Population 7,001-14,000
XLARGE = Population 14,001-30,000

74049-4.1 Installation population is defined as Active Duty enlisted and officers, average on board transients, reservists and authorized civilians. Population numbers should be consistent with projected base loading data.

For facility planning purposes at installations with deployable forces, the active duty demand population is included all of the non-deployable population, plus two-thirds of the deployable population, to reflect time away on deployment. However, calculation of the deployable population may be adjusted based on the actual deployment experience at individual installations.

74049-5 SPACE ALLOWANCES. Space allowances for Austere Indoor Physical Fitness facilities are determined using Tables 74049-1 through 74049-5 on the following pages. The space allowance required for each component to meet the demand is obtained from the calculations of the installation population served by the facility. The total allowance for a facility is the sum total of the net space allowances for each functional component, adjusted using the net-to-gross factors reflected in the tables.

Notes for Space Allowance Tables 74049-1 through 74049-5:

(1) Indoor Basketball Courts are discouraged in austere environments, and must be justified to, and authorized by, CNIC N944 prior to project scoping.

(2) Fitness area includes warm-up/cool-down area, free weights, circuit/weight training machines, and cardiovascular equipment (bicycle, stepper, rower). Space for one Instructor Station should be included in each separate Weight Training Area.

(3) Staff support spaces consist of:

- (a) Control Counter and minimal administrative area.
- (b) Gear Issue and Laundry Room for check-out of athletic gear and recreation equipment for leisure use.
- (c) If gymnasium is authorized, include a Gymnasium Equipment Storage Room for equipment and supplies, such as roll-away baskets goals, volleyball standards, gymnasium floor coverings, roll-away bleachers, etc.

(4) Space allowances in the tables are minimum allowances.

Table 74049-1
Space Allowance for Extra-Small Facility

AUSTERE INDOOR FITNESS CENTER					
Size = Base Population 1-500 = EXTRA SMALL					
	Functional Components	Qty	Allowance Per Qty (NSF)	NSF	SM
PUBLIC SPACES	Entry Lobby (qty = module)	1	100	100	9.3
	Control Counter (qty = module)	1	125	125	11.6
	Equip Issue Storage (qty = module)	2	175	350	32.5
	Subtotal			**575**	**53.4**
FITNESS SPACES	Unit PT/Group Exercise Partionable Room(s) (qty = # of persons)	0	50	0	0.0
	Unit PT/Group Exercise Storage (10% of Unit PT/Group Exercise Room(s)		0.1	0	0.0
	Stretching Space	3	50	150	13.9
	Cardiovascular Equipment	20	50	1000	92.9
	Selectorized (machine) Weights	10	50	500	46.5
	Free/Plate Weights	15	65	975	90.6
	Fitness Assessment	1	125	125	11.6
	Gymnasium	**** See Notes ****			
	Subtotal			**2750**	**255.5**
ADMIN SPACES	Support Staff Workstations (qty = workstations)	0	64	0	0.0
	Copy/file/work/break Room (qty = workroom module)	1	80	80	7.4
	Subtotal			**80**	**7.4**
LOCKER ROOMS	Men's (60% of pop.) (qty = slots; see notes)	29	12	348	32.3
	Women's (40% of pop.) (qty = slots; see notes)	19	12	228	21.2
	Subtotal			**576**	**53.5**
SUPPORT	Laundry Room (1/2 machine combo laundry room)	1	180	180	16.7
	Laundry Storage Room	1	131	131	12.2
	Loading Dock	1	90	90	8.4
	Subtotal			**401**	**37.3**
	FACILITY SUBTOTAL			**4,382.0**	**407.1**
	Net-to-Gross: 20% of facility subtotal			876	81.4
	FACILITY TOTAL			**5,258**	**488.5**

Notes:
1) Gymnasiums (basketball/volleyball courts) are optional and MUST be approved in writing by CNIC/N9. Approval letters must be attached to the Basic Facilities Requirement (BFR) document. Where approved, add: 8892 NSF (gym) + 700 NSF (storage) * 1.2 = **11,510 GSF/1069.4 SM.**
2) Locker distribution shown above is planned as a 60% male and 40% female split. This ratio can be changed based on mission needs but the final ratio needs to be represented on the appropriate BFR document(s).
3) For locker distribution, provide two slots (spaces) for every three lockers (66%). This includes one full-sized and two half-sized lockers for every three required.
4) Men's locker room includes space for 2 showers and 1 watercloset/lavatory modules.
5) Women's locker room includes space for 1 showers and 1 watercloset/lavatory modules.
6) The net to gross factor is based on a single story facility. In cases where the facility requires multiple floors, change the net to gross factor to 28%, or 1.28.

Table 74049-2
Space Allowance for Small Facility

AUSTERE INDOOR FITNESS CENTER					
Size = Base Population 501-3000 = SMALL					
	Functional Components	**Qty**	**Allowance Per Qty (NSF)**	**NSF**	**SM**
PUBLIC SPACES	Entry Lobby (qty = module)	2	100	200	18.6
	Control Counter (qty = module)	1	125	125	11.6
	Equip Issue Storage (qty = module)	2	175	350	32.5
	Subtotal			**675**	**62.7**
FITNESS SPACES	Unit PT/Group Exercise Partionable Room(s) (qty = # of persons)	25	50	1250	116.1
	Unit PT/Group Exercise Storage (10% of Unit PT/Group Exercise Room(s)		0.1	125	11.6
	Stretching Space	3	50	150	13.9
	Cardiovascular Equipment	35	50	1750	162.6
	Selectorized (machine) Weights	18	50	900	83.6
	Free/Plate Weights	15	65	975	90.6
	Fitness Assessment	1	125	125	11.6
	Gymnasium	**** See Notes ****			
	Subtotal			**5275**	**490.1**
ADMIN SPACES	Support Staff Workstations (qty = workstations)	1	64	64	5.9
	Copy/file/work/break Room (qty = workroom module)	1	80	80	7.4
	Subtotal			**144**	**13.4**
LOCKER ROOMS	Men's (60% of pop.) (qty = slots; see notes)	51	13	663	61.6
	Women's (40% of pop.) (qty = slots; see notes)	34	13	442	41.1
	Subtotal			**1105**	**102.7**
SUPPORT	Laundry Room (1/2 machine combo laundry room)	1	180	180	16.7
	Laundry Storage Room	1	189	189	17.6
	Loading Dock	1	90	90	8.4
	Subtotal			**459**	**42.6**
	FACILITY SUBTOTAL			**7,658.0**	**711.5**
	Net-to-Gross: 20% of facility subtotal			1,532	142.3
	FACILITY TOTAL			**9,190**	**853.7**

Notes:
1) Gymnasiums (basketball/volleyball courts) are optional and MUST be approved in writing by CNIC/N9. Approval letters must be attached to the Basic Facilities Requirement (BFR) document. Where approved, add: 8892 NSF (gym) + 700 NSF (storage) * 1.2 = **11,510 GSF/1069.4 SM.**
2) Locker distribution shown above is planned as a 60% male and 40% female split. This ratio can be changed based on mission needs but the final ratio needs to be represented on the appropriate BFR document(s).
3) For locker distribution, provide two slots (spaces) for every three lockers (66%). This includes one full-sized and two half-sized lockers for every three required.
4) Men's locker room includes space for 4 showers and 3 watercloset/lavatory modules.
5) Women's locker room includes space for 2 showers and 3 watercloset/lavatory modules.
6) The net to gross factor is based on a single story facility. In cases where the facility requires multiple floors, change the net to gross factor to 28%, or 1.28.

Table 74049-3
Space Allowance for Medium Facility

AUSTERE INDOOR FITNESS CENTER					
Size = Base Population 3001-7000 = MEDIUM					
	Functional Components	**Qty**	**Allowance Per Qty (NSF)**	**NSF**	**SM**
PUBLIC SPACES	Entry Lobby (qty = module)	3	100	300	27.9
	Control Counter (qty = module)	2	125	250	23.2
	Equip Issue Storage (qty = module)	2	175	350	32.5
	Subtotal			**900**	**83.6**
FITNESS SPACES	Unit PT/Group Exercise Partionable Room(s) (qty = # of persons)	25	50	1250	116.1
	Unit PT/Group Exercise Storage (10% of Unit PT/Group Exercise Room(s)		0.1	125	11.6
	Stretching Space	6	50	300	27.9
	Cardiovascular Equipment	64	50	3200	297.3
	Selectorized (machine) Weights	18	50	900	83.6
	Free/Plate Weights	30	65	1950	181.2
	Fitness Assessment	1	125	125	11.6
	Gymnasium	**** See Notes ****			
	Subtotal			**7850**	**729.3**
ADMIN SPACES	Support Staff Workstations (qty = workstations)	2	64	128	11.9
	Copy/file/work/break Room (qty = workroom module)	2	80	160	14.9
	Subtotal			**288**	**26.8**
LOCKER ROOMS	Men's (60% of pop.) (qty = slots; see notes)	75	13	975	90.6
	Women's (40% of pop.) (qty = slots; see notes)	50	13	650	60.4
	Subtotal			**1625**	**151.0**
SUPPORT	Laundry Room (2/4 machine combo laundry room)	1	230	230	21.4
	Laundry Storage Room	1	318	318	29.5
	Loading Dock	1	90	90	8.4
	Subtotal			**638**	**59.3**
	FACILITY SUBTOTAL			**11,301.0**	**1,049.9**
	Net-to-Gross: 20% of facility subtotal			2,260	210.0
	FACILITY TOTAL			**13,561**	**1,259.9**

Notes:
1) Gymnasiums (basketball/volleyball courts) are optional and MUST be approved in writing by CNIC/N9. Approval letters must be attached to the Basic Facilities Requirement (BFR) document. Where approved, add: 8892 NSF (gym) + 700 NSF (storage) * 1.2 = **11,510 GSF/1069.4 SM.**
2) Locker distribution shown above is planned as a 60% male and 40% female split. This ratio can be changed based on mission needs but the final ratio needs to be represented on the appropriate BFR document(s).
3) For locker distribution, provide two slots (spaces) for every three lockers (66%). This includes one full-sized and two half-sized lockers for every three required.
4) Men's locker room includes space for 5 showers and 4 watercloset/lavatory modules.
5) Women's locker room includes space for 3 showers and 4 watercloset/lavatory modules.
6) The net to gross factor is based on a single story facility. In cases where the facility requires multiple floors, change the net to gross factor to 28%, or 1.28.

Table 74049-4
Space Allowance for Large Facility

AUSTERE INDOOR FITNESS CENTER					
Size = Base Population 7,001-14,000 = LARGE					
	Functional Components	**Qty**	**Allowance Per Qty (NSF)**	**NSF**	**SM**
PUBLIC SPACES	Entry Lobby (qty = module)	4	100	400	37.2
	Control Counter (qty = module)	3	125	375	34.8
	Equip Issue Storage (qty = module)	3	175	525	48.8
	Subtotal			**1300**	**120.8**
FITNESS SPACES	Unit PT/Group Exercise Partionable Room(s) (qty = # of persons)	50	50	2500	232.3
	Unit PT/Group Exercise Storage (10% of Unit PT/Group Exercise Room(s)		0.1	250	23.2
	Stretching Space	8	50	400	37.2
	Cardiovascular Equipment	80	50	4000	371.6
	Selectorized (machine) Weights	36	50	1800	167.2
	Free/Plate Weights	30	65	1950	181.2
	Fitness Assessment	1	125	125	11.6
	Gymnasium	**** See Notes ****			
	Subtotal			**11025**	**1024.3**
ADMIN SPACES	Support Staff Workstations (qty = workstations)	3	64	192	17.8
	Copy/file/work/break Room (qty = workroom module)	2	80	160	14.9
	Subtotal			**352**	**32.7**
LOCKER ROOMS	Men's (60% of pop.) (qty = slots; see notes)	106	13	1378	128.0
	Women's (40% of pop.) (qty = slots; see notes)	70	13	910	84.5
	Subtotal			**2288**	**212.6**
SUPPORT	Laundry Room (3/6 machine combo laundry room)	1	315	315	29.3
	Laundry Storage Room	1	579	579	53.8
	Loading Dock	1	90	90	8.4
	Subtotal			**984**	**91.4**
	FACILITY SUBTOTAL			**15,949.0**	**1,481.7**
	Net-to-Gross: 20% of facility subtotal			3,190	296.3
	FACILITY TOTAL			**19,139**	**1,778.1**

Notes:
1) Gymnasiums (basketball/volleyball courts) are optional and MUST be approved in writing by CNIC/N9. Approval letters must be attached to the Basic Facilities Requirement (BFR) document. Where approved, add: 8892 NSF (gym) + 700 NSF (storage) * 1.2 = **11,510 GSF/1069.4 SM.**
2) Locker distribution shown above is planned as a 60% male and 40% female split. This ratio can be changed based on mission needs but the final ratio needs to be represented on the appropriate BFR document(s).
3) For locker distribution, provide two slots (spaces) for every three lockers (66%). This includes one full-sized and two half-sized lockers for every three required.
4) Men's locker room includes space for 7 showers and 5 watercloset/lavatory modules.
5) Women's locker room includes space for 5 showers and 5 watercloset/lavatory modules.
6) The net to gross factor is based on a single story facility. In cases where the facility requires multiple floors, change the net to gross factor to 28%, or 1.28.

Table 74049-5
Space Allowance for Extra-Large Facility

AUSTERE INDOOR FITNESS CENTER					
Size = Base Population 14,001-30,000 = EXTRA LARGE					
	Functional Components	Qty	Allowance Per Qty (NSF)	NSF	SM
PUBLIC SPACES	Entry Lobby (qty = module)	5	100	500	46.5
	Control Counter (qty = module)	4	125	500	46.5
	Equip Issue Storage (qty = module)	3	175	525	48.8
	Subtotal			1525	141.7
FITNESS SPACES	Unit PT/Group Exercise Partionable Room(s) (qty = # of persons)	50	50	2500	232.3
	Unit PT/Group Exercise Storage (10% of Unit PT/Group Exercise Room(s)		0.1	250	23.2
	Stretching Space	12	50	600	55.7
	Cardiovascular Equipment	125	50	6250	580.6
	Selectorized (machine) Weights	36	50	1800	167.2
	Free/Plate Weights	45	65	2925	271.7
	Fitness Assessment	1	125	125	11.6
	Gymnasium	**** See Notes ****			
	Subtotal			14450	1342.5
ADMIN SPACES	Support Staff Workstations (qty = workstations)	4	64	256	23.8
	Copy/file/work/break Room (qty = workroom module)	2	80	160	14.9
	Subtotal			416	38.6
LOCKER ROOMS	Men's (60% of pop.) (qty = slots; see notes)	136	13	1768	164.3
	Women's (40% of pop.) (qty = slots; see notes)	91	13	1183	109.9
	Subtotal			2951	274.2
SUPPORT	Laundry Room (4/8 machine combo laundry room)	1	385	385	35.8
	Laundry Storage Room	1	579	579	53.8
	Loading Dock	1	90	90	8.4
	Subtotal			1054	97.9
	FACILITY SUBTOTAL			20,396.0	1,894.9
	Net-to-Gross: 20% of facility subtotal			4,079	379.0
	FACILITY TOTAL			24,475	2,273.8

Notes:
1) Gymnasiums (basketball/volleyball courts) are optional and MUST be approved in writing by CNIC/N9. Approval letters must be attached to the Basic Facilities Requirement (BFR) document. Where approved, add: 8892 NSF (gym) + 700 NSF (storage) * 1.2 = **11,510 GSF/1069.4 SM.**
2) Locker distribution shown above is planned as a 60% male and 40% female split. This ratio can be changed based on mission needs but the final ratio needs to be represented on the appropriate BFR document(s).
3) For locker distribution, provide two slots (spaces) for every three lockers (66%). This includes one full-sized and two half-sized lockers for every three required.
4) Men's locker room includes space for 9 showers and 7 watercloset/lavatory modules.
5) Women's locker room includes space for 6 showers and 7 watercloset/lavatory modules.
6) The net to gross factor is based on a single story facility. In cases where the facility requires multiple floors, change the net to gross factor to 28%, or 1.28.

74049-6 ACCESS AND PARKING. Access and parking is not authorized for Privately Owned Vehicles (POVs). Fire truck access and fire lanes are authorized. Service vehicle access is authorized for pickups, deliveries, maintenance, etc as needed. Minimal parking for official vehicles, particularly alternative modes of transportation such as electric vehicles is authorized where applicable. Access drives for pickup and drop off areas for shuttle buses, etc. are authorized. Total parking areas for residents, visitors, staff, and service personnel should be extremely minimal and limited to mission support.

UFC 2-100-01
30 September 2020
Change 2, 19 March 2025

UNIFIED FACILITIES CRITERIA (UFC)

INSTALLATION MASTER PLANNING

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

INSTALLATION MASTER PLANNING

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

Record of Changes (changes are indicated by **\1** ... **/1/**)

Change No.	**Date**	**Location**
1	13 Jan 22	3-10.2.7
2	19 Mar 25	Removed ICRP Section (3-10.2) and replaced with reference to law; made related terminology changes throughout.

This UFC supersedes UFC 2-100-01, *Installation Master Planning*, dated 25 October 2019.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

CHRISTINE T. ALTENDORF, PhD, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Command

NANCY J. BALKUS, P.E., SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW
Deputy Assistant Secretary of Defense (Construction)
Office of the Assistant Secretary of Defense (Sustainment)

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 2-100-1, *Installation Master Planning*

Superseding: UFC 2-100-1, *Installation Master Planning*, dated 25 October 2019, with Change 1.

Description: 10 USC 2864 requires all major military installations to have a Master Plan. This specific document is issued under the authority of DoDI 4165.70, Real Property Management, which implements the requirement for installation Master Plans.

Reasons for Document:

- Updates master planning processes and products, including energy and **\2\ /2/** resilience and requirements for transportation and military installation resilience components as required by 10 USC 2864.
- Updates master planning processes and products to incorporate **\2** requirements of **/2/** FY20 National Defense Authorization Act
- Administrative revisions to comply with UFC 1-300-01, *Criteria Format Standard*.

Summary of Changes:

FY20 NDAA Changes:

- FY20 NDAA Section 2801(a): 3-4.b, 3-10.2, 4-2.1 (Requirement to have a Military Installation Resilience Component **\2** [MIRC] **/2/** to the Master Plan).
- FY20 NDAA Section 2804(c) (i): 2-2.16, 2-5.1.1, 2-6, 2-8, 2-9, 2-9.1, 2-9.3, 3-5.6.1, 3-6.1.6, 3-5.5, 3-5.6.1, 3-5.7, 3-6.1.1, 3-6.1.3.c, 3-6.1.6, 3-6.4, 3-7, Appendix B (Verbiage changes to specifically identify **\2** resilience **/2/** and weather considerations in planning processes).
- FY20 NDAA section 2804(c)(ii): 3-5.6.2.a, 3-5.6.2.2 (Specifies certain agencies for **\2\ /2/** information).
- FY20 NDAA section 2804(c)(iv): 2-2.17.1, 3-10.2 **\2** Follow Service-specific guidance, as appropriate. **/2/**

Summary of Other Changes:

- Specific updates to institute **\2** DoD Regional Sea Level **/2/** (DRSL) database **\2\ /2/**: 2-2.17.1.2 (new paragraph), 3-5.6.1.
- Include use of the DoD **\2** Extreme Conditions **/2/** Assessment Tool: 2-2.17.1.1.

- Updates to incorporate explosive safety quantity-distance arcs: 2-2.1, 2-3.2, 2-9, 3-5.6.1, 3-5.7.1, D-3.
- Updates to reflect changes in UFC 4-010-01, DoD Minimum Antiterrorism Standards for Buildings; adds reference to 4-020-01, DoD Security Engineering Facilities Planning Manual: 2-5.2
- Updates to the descriptions of aesthetics and Network Plan to provide greater fidelity on the requirement: 2-8.1.
- Clarification to Illustrative Plan description: 2-9.1.
- Clarifications to Plan-Based Programming: 2-11.
- Removed requirement for a land pattern matrix: 3-4.1.
- Clarifications to the Installation Street and Transit Plan for consistency with 10 USC 2864: 3-6.4.3.
- Clarifications to Program Development: 3-8.2.
- Added description of Functional Annexes to the requirements of the Master Plan to accommodate additional components of the Master Plan as required by 10 USC 2864: 3-4.2, 4-2.1.
- Add requirement for Installation Energy Plan per OSD Memo and 10 USC 2864: 3-10.1, 4-2.1, Appendix E.
- Added description of optional Functional Annexes: 3-10.
- Clarified the applicability of Appendix B and removed references to use LEED-ND criteria.
- Updated training courses in Appendix C.
- **\1** Added requirement to identify coordination efforts maintaining or enhancing military installation resilience or resilience of the community infrastructure: 3 10.2.7. **/1/**
- **\2** Removed ICRP Section (3-10.2) and replaced with reference to law; made related terminology changes throughout. **/2/**

Impact:

- Additional costs to complete the Installation Energy Plan (IEP) and **\2** MIRC **/2/** will be needed.
- Improved installation efficiency, safety, resilience, and mission **\2** sustainment **/2/**.
- Enhanced integration of comprehensive planning and project programming activities.

Unification Issues: There are no unification issues.

TABLE OF CONTENTS

FIGURES

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

DoD is one of the world's largest builders, owners, and operators of infrastructure and is responsible for managing millions of acres of land and billions of dollars' worth of facilities and infrastructure worldwide. Effective long-term development and management of these resources requires thoughtful and thorough master planning. Master planning is a continuous analytical process that involves evaluating factors affecting the present and future physical development and operation of an installation. This evaluation forms the basis for determining development objectives and planning proposals to solve current problems and meet future needs. Each step of the process builds upon the preceding step, providing a logical framework for the planning effort. For military installations, planning is accomplished primarily at the installation level through a comprehensive and collaborative planning process resulting in a Master Plan. This process provides a means for resilient and energy-efficient installation development that supports mission requirements.

1-2 PURPOSE AND SCOPE.

10 USC 2864 requires all major military installations have a Master Plan. DoDI 4165.70, *Real Property Management*, establishes the requirement for installation Master Plans. This UFC prescribes DoD minimum requirements for master planning processes and products in accordance with DoDI 4165.70. The process includes the use of a Master Plan and its components as a tool to provide ongoing planning for installations in support of the mission. DoD planners utilize this UFC, the DoDI, and applicable agency instructions to prepare Master Plans and other planning documents. Affiliated design and programming professionals will refer to the Master Plan as they prepare site-specific design proposals. By incorporating today's needs and mission requirements into a compelling vision with clear goals and measurable objectives, installation planners can prepare a Master Plan that **\2** supports future mission and installation requirements **/2/**. This UFC outlines a complete process for master planning (and ultimately the development of a Master Plan) through the preparation of linked plans (Functional Annexes) that can be implemented entirely or incrementally based on each installation's needs and resources. A successful Master Plan:

- Provides timely and correct planning information and real property support for installation missions and supports informed decision-making.
- Promotes cooperative and interactive intra- and inter-Service and inter-governmental relationships.
- Incorporates infrastructure, assurance, and anti-terrorism considerations.
- Incorporates resilience analysis to ensure mission sustainment over the intended lifespan of the infrastructure and assets.

- Incorporates environmental planning to identify environmental impacts and protect and enhance natural, cultural, and environmental resources while supporting mission requirements.
- Supports and encourages **\2** resilient **/2/** and energy-efficient development.
- Provides scope for all programs involving real property acquisition, design, and construction; real property management and operation; real property facility utilization and accounting; real property sustainment (maintenance and repair); and disposal of land and facilities.
- Maintains an accurate audit trail of master planning and real property decisions.
- Ensures efficient and compatible land use (identifying and respecting natural and man-made constraints) and maximizes facility utilization.
- Provides input to the privatization of family housing, utilities, and services.
- Sustains ranges and training areas to meet training and testing missions on a consistent and long-term basis.
- Identifies resource requirements directly and indirectly associated with real property sustainment and development.
- Protects an installation's long-term viability by providing capability for growth, expansion of requirements, and flexible facility and land-use decisions that can accommodate changes to missions and/or users.
- Encourages policies and interaction with the local community to avoid encroachment and maximizes opportunities for joint use while preserving mission capability and growth potential.
- Supports federal energy mandates.
- Creates connected and visually pleasing environments by coordinating development, removing clutter, enforcing consistent architectural themes, creating appropriate pedestrian and vehicle circulation patterns, and focusing attention on installation appearance, which can enhance quality of life and contribute to the overall mission.
- Informs and is informed by related plans at each installation, including energy plans, utility capacity plans, range complex Master Plans (RCMP), anti-terrorism (AT) plans, integrated cultural and natural resource management plans,**\2** resilience **/2/** plans, and transportation plans.
- Supports**\2** risk reduction **/2/** of environmental hazards and encroachment as well as effective integration of air installation compatible use zone (AICUZ) and range air installation compatible use zone (RAICUZ) constraints and mission synergy.

1-3 APPLICABILITY.

\2 This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, with no exceptions. **/2/**

1-4 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, *DoD Building Code*. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and **\2** resilient building **/2/** requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-5 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, *Cybersecurity of Facility-Related Controls*, and as required by individual Service implementation policy.

1-6 GLOSSARY.

Appendix E contains acronyms, abbreviations, and terms.

1-7 REFERENCES.

Appendix F contains a list of references used in this UFC. The publication date of the code or standard is not included in this UFC. Unless otherwise specified, the most recent edition of the referenced publication applies.

This Page Intentionally Left Blank

CHAPTER 2 MASTER PLANNING STRATEGIES AND GENERAL REQUIREMENTS

2-1 INTRODUCTION.

One of the primary purposes of the planning process is to apply comprehensive planning strategies through facility and infrastructure development, including planning, programming, engineering and design, construction, reuse, real estate actions, public-private ventures, operations and maintenance, and disposal. The following ten strategies support the DoD-wide overarching installation planning philosophy, which is to develop a **\2** resilient **/2/** platform to support the effective execution of assigned military missions as efficiently as possible.

- **\2** Resilience **/2/** planning
- Natural, historic and cultural resource management
- Healthy community planning
- Defensible planning
- Capacity planning
- Area development planning
- Network planning
- Form-based planning
- Facility standardization
- Plan-based programming

2-2 \2\ RESILIENCE /2/ PLANNING.

\2 Resilience **/2/** planning leads to lasting development—meeting present mission requirements without compromising the ability of future generations to meet their needs. The goal of such development is to make the most effective use of limited resources, reduce fossil fuel use and increase the use of alternative fuels, and create more compact, and resilient communities while meeting security and safety requirements. Incorporate the following key principles of **\2\ r**esilience **/2/** planning into Master Plans, Area Development Plans (ADP), and other planning products.

2-2.1 Compact Development.

Conserve land as a resource to be utilized to the maximum extent possible. This can be achieved through compact development patterns that support an appropriate mix of uses, encourage walking and other alternative modes of transportation, accommodate appropriate residential and commercial densities, and incorporate a more integrated grid network of streets and sidewalks. Land use patterns and transportation systems may have to be reconfigured to create opportunities for future development. Compact development patterns include multi-story buildings, increased residential densities, mixed-uses, and minimal spacing between buildings while maintaining consideration of

AT requirements as well as other constraints (e.g., airfield clearances or explosive safety quantity-distance arcs).

2-2.2 Infill Development.

To conserve limited land resources, to the maximum extent possible, focus plan development within the installation core (existing cantonment area) and on previously developed land. Place buildings or designated open spaces in gaps between existing developed areas and buildings while taking care to ensure preservation or addition of greenspace. Infill development results in greater density at the core of the installation and supports integrated land use and transportation networks to include transit-oriented development. Removing/replacing aging low-density development with higher density development may also be appropriate. Take into account the potential impacts of all proposed actions on historic properties when considering infill within an historic district.

2-2.3 Transit-Oriented Development.

Transit-oriented development focuses compact, mixed-use development around transit corridors. Locate public transit stops along these corridors (for buses, streetcars, light rail) at approximately half-mile intervals. Development intensity and density should be greatest along these corridors and around the transit stops. On military bases, such development typically takes the form of three- to five-story buildings for administrative, commercial, and residential uses. Transit-oriented development has many advantages, including lowering traffic congestion and vehicular accidents, reducing parking requirements, and lowering CO_2 emissions. Transit-oriented developments also promote healthy communities by focusing on pedestrian use and encouraging more walking and cycling. With appropriate building typologies (e.g., rowhouses, apartments, multi-level office buildings) and with sufficient transit intervals, vehicle miles traveled can decrease by up to 50%. Seek out ways to connect mass transit systems on the installation to outside transit systems.

2-2.4 Horizontal Mixed Uses.

To make compact development feasible:

- Create synergies.
- Reduce land use and construction costs.
- Integrate compatible uses into horizontal mixed-use development.t
- Segregate incompatible uses (e.g., industrial areas should be separate from housing).

Uses typically found on military installations, community support (retail, recreation, schools, lodging), housing, medical, administrative, and classroom training uses are generally compatible. Consider integrating these uses into horizontal mixed-use districts to enable walking or biking from one use to another. Ideally, uses within walkable areas are within a 10-minute walking radius (roughly 2,500 feet [760 meters]). Where appropriate, create a campus or town center-like atmosphere since these places are tested examples of horizontal mixed-use districts. Use compact mixed-use zones to support combined heat and power district systems, which can increase the efficiency of primary energy use in a district. Use mixed-use districts to appropriately balance out energy use. In areas where living and working are within one district, the system can operate at increased efficiencies since energy-use peaks are offset.

2-2.5 Vertical Mixed Uses.

Vertical mixed-use is compatible uses located within the same building, enabling maximize land use and infrastructure efficiencies. Synchronizing future requirements is required to achieve vertical mixed-use development. Ground floor education and training centers with unaccompanied housing on upper floors is an example of vertical mixed-use construction using appropriated funds. Collaboration with agencies such as the Army Air Force Exchange Service (AAFES), the Defense Commissary Agency (DeCA), and privatized housing partners enables the creation of mixed-use buildings and neighborhoods using non-governmental funds. Use collaborative efforts to combine non-appropriated and appropriated funds in one facility using conjunctive funding. Identify and program costs associated with each funding category separately. An example of conjunctively funded vertical mixed-use is military family housing (appropriated funds) located above a commissary (non-appropriated funds).

2-2.6 Connected Transportation Networks.

Connect uses within each district, as well as the districts themselves, by roads, sidewalks, and bikeways. Size transportation networks to support mission requirements through properly programming projects. A connected network of streets is based on a modified grid pattern that affords multiple route options for vehicles, bicyclists, and pedestrians. The grid network uses appropriately scaled roads to define smaller block sizes that can accommodate a mix of compatible uses. Multi-way boulevards, parkways, main streets, residential streets, and alleys are examples of street types appropriate for integration into grids and for use on military installations. When streets are built with integrated bikeways and continuous sidewalks buffered from the street by planting strips, users have more safe transportation options. When establishing the transportation network, incorporate concepts that maximize safety for all users. A connected transportation network of streets with sidewalks, pedestrian pathways, and bicycle trails reduces the distance between origins and destinations and increases transportation alternatives. Short blocks and an absence of cul-de-sacs characterize a connected street network. Sidewalk easements improve connectivity in extremely long blocks and sidewalks should incorporate best practices for fitness such as mile markers. Installation gates are part of the transportation network. Coordinate the transportation plan with local/state/regional government agencies to ensure the installation’s transportation network is linked with surrounding transportation access and systems.

2-2.7 \2\ Resilient /2/ Landscape Elements.

Ensure plans incorporate appropriate use of street trees, shrubs, and ground cover. These landscape elements can control soil erosion, reduce the heat island effect, absorb stormwater, improve air quality, provide comfortable places for recreation, and support AT measures. In addition, trees improve the environment and provide shade, aesthetics, and security protection on an installation. Space street trees 25 feet to 30 feet (7.6 meters to 9 meters) on center on roadways to improve pedestrian safety by slowing vehicle traffic; provide shade for paving, vehicles, and pedestrians; and shade buildings, which can reduce energy consumption. To the greatest extent possible, use native plant materials that are suitable for the particular **\2** plant hardiness zone (consistent with USDA's Plant Hardiness Zone Map) **/2/** and soil conditions to limit maintenance requirements and conserve water resources. Refer to UFC 3-201-02, *Landscape Architecture*, for additional information.

2-2.8 Low-Impact Development and Stormwater Management.

The use of on-site natural features to control stormwater runoff quantity and quality in lieu of traditional "end-of-the-pipe" solutions is a land planning and engineering design approach termed Low Impact Development (LID). LID is required by the Energy Independence and Security Act of 2007, § 438, and DoD policy. UFC 3-210-10, *Low Impact Development,* defines the design requirements associated with compliance. This approach implements engineered small-scale hydrologic controls to replicate the pre-development hydrologic condition of watersheds through infiltrating, filtering, storing, evaporating, and detaining runoff close to its source. These controls include not only open space and natural features but also manmade features such as building roofs, streets, and parking surfaces. Other examples include bioswales, car parks, and on-street parking, which use substantially less paving per car than off-street parking. LID applies equally to new construction and redevelopment and is best accomplished at the installation level.

2-2.8.1 LID and Area Development Planning.

Include LID practices and strategies in the development of the Vision Plan, Area Development Plans (ADPs), planning design standards, and other planning studies. When developing plans defined in this UFC, minimize impervious surfaces and ensure there is adequate space available on-site to offset the increase in impervious areas associated with siting new facilities and structures. Reduce the amount of impervious surface areas by implementing the following best management practices (BMP):

- Pervious pavements
- On-street parking
- Compact alignment, including in-fill, mixed-use, and multi-story solutions
- Minimized street widths that maintain adequate fire protection access
- Structured parking

2-2.8.2 LID and Integrated Management Practices.

Adding additional site area will allow the use of low-cost integrated management practices (IMP) such as bioretention and bioswales. A general rule of thumb for planning purposes is to allow an additional 10% of site area for increases in impervious areas. A more detailed estimate can be obtained if soil conditions are known or by evaluating existing IMP features from adjacent sites. Anti-terrorism and force protection (AT/FP) setbacks may be used to provide bioretention features given the unobstructed space and concealment requirements of UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*, are met. In addition, provide a minimum of 20 feet (6.1 meters) of separation from the structure/building foundation to the face of the bioretention feature. Use surface parking areas with integrated bioswales to minimize perimeter bioretention facilities.

2-2.8.3 LID and Project Programing.

If site constraints prevent the use of low-cost features, identify additional LID costs during project development and on DD Form 1391, *FY_ Military Construction Project Data*. High-cost IMP features include rainwater harvesting**, \2** vegetated **/2/** roofs, underground storage, or other structural IMP. Refer to UFC 3-260-01, *Airfield and Heliport Planning and Design*, paragraph 2-5.5, “Storm Water Management Facilities,” and paragraph 2-3.3, “Safety,” and UFC-3-201-01, *Civil Engineering*, paragraph 3-6.2, “Airfields,” for restrictions to certain LID measures for certain installation areas, in particular airfields, to control bird air strike hazards (BASH).

2-2.9 Multi-Story Construction.

One-story buildings inefficiently use valuable land. Plan for and specify multi-story buildings when possible. Land efficiency improves with multi-story construction and can be justified, even with progressive collapse requirements, when balanced against the cost of land and utilities required to serve multiple buildings. As appropriate, combine multiple users into multi-story buildings. If planning multi-story construction within or adjacent to an historic district or historic properties, contact the installation Cultural Resources Manager early in the planning process. This minimizes project delays or changes resulting from the presence of historic properties. Consider multi-story buildings as a flood **\2** risk reduction **/2/** strategy.

2-2.10 Building Orientation and Configuration.

Plan sites to provide flexibility for building orientation and configuration. This strategy optimizes building performance, conserves energy, and enhances indoor environmental quality such as thermal comfort and day-lighting. Minimize existing and planned obstructions from landscaping, structures, topography, and adjacent developments to preserve solar access and natural ventilation. Buildings of any configuration with footprint elements of approximately 50 feet (15 meters) or less (wings, central courtyards) can allow natural light deep into the building, which, when combined with energy-efficient glazing, reduces energy consumption. Narrow buildings with operable windows allow natural ventilation to effectively flow through the interiors, which can reduce energy costs associated with air conditioning. Use narrow buildings to define outdoor spaces and for infill development. When laying out building footprints on Illustrative Plans, strive to use building footprints no wider than 50 feet (15 meters). Use buildings wider than 50 feet (15 meters) to optimize energy performance, especially in colder **\2** regions **/2/**. Special-purpose buildings like hangars, large-format retail, and warehouses need not comply with this strategy.

2-2.11 Energy Conservation.

Include energy conservation as part of the planning goals. Employ energy demand reduction and the development of installation-wide and building-level **\2** resilience **/2/** supplies as strategies to attain the energy conservation goals. **\2** Resilience **/2/** planning also includes consideration of **\2** alternative energy **/2/** production, energy security improvements, and energy efficiency enhancements. Leverage opportunities to produce **\2** alternative **/2/** energy through the use of solar, geothermal, biomass, and other production sources. Reducing dependence on energy from outside sources increases energy security. Installations are responsible for fulfilling the goals associated with EO 13834, *Efficient Federal Operations*, which sets various federal energy and environmental management goals, including reduction of energy intensity, increasing the use of energy sources, including **\2** alternative energy types **/2/**, and designing and operating **\2** **r**esilient **/2/** buildings.

2-2.11.1 Building Automation.

Consider installation-wide building automation systems as part of the master planning process. The proper use of this tool is a cost-efficient way for an installation to manage and reduce energy consumption. Coordinate with the appropriate personnel to implement **\2** resilient **/2/** energy strategies, as appropriate.

2-2.11.2 District and Nodal Energy.

Nodal energy plants, which produce hot water, chilled water, and/or steam for nearby facilities, are generally more efficient than large central plants or individual building-level systems. Nodal plants combine the benefits of economies of scale and load leveling, and avoid system duplication. Nodal plants support medium- to large-scale **\2** alternative **/2/** energy systems and can make **\2** alternative energy types **/2/** more cost effective. Large central energy plants are generally less cost-effective due to line losses and operations and maintenance costs. Individual building-scale energy systems are often less cost-effective due to limitations of system size, efficiency, and optimization of system type. Infill development and increased density reduces runs and makes nodal energy more efficient. Follow UFC 3-410-01, *Heating, Ventilating, and Air Conditioning Systems*, when considering district or nodal energy generation and distribution.

2-2.12 Water Conservation.

Incorporate strategies to reduce water consumption at the planning level. Strategies include the use of greywater, designing low-maintenance landscaping features, and using synthetic turf when applicable (e.g., youth and adult sports fields.) Planners should be engaged throughout the design process to ensure water conservation measures are applied whenever feasible.

2-2.13 Waste Management.

Incorporate strategies to reduce waste at the planning level. Adaptive reuse (as opposed to demolition) can reduce construction waste.

2-2.14 Facility Utilization and Building Reuse.

Support and use outputs of the installation facility utilization processes. Effective facility utilization maximizes the capacity of an installation's infrastructure and minimizes the installation's real property operations costs. Use existing facilities, to the extent possible, to meet installation requirements. This principle includes fully utilizing existing facilities and reuse, repurposing, or removal of existing assets. This also supports **\2** energy savings **/2/** objectives as installations should not heat, cool, or maintain excess facilities. Ensure facility utilization is in compliance with the Vision Plan and Regulating Plan.

2-2.15 Lifecycle Planning.

Consider the full lifecycle cost of planning decisions with a focus on return on investment. Lifecycle cost analysis (LCCA) instructions are in UFC 1-200-02, *High Performance and Sustainable Building Requirements*. Include the opportunity cost of land as a focus.

2-2.16 Flood Protection.

Identify flood hazard areas during the planning process. EO 11988, *Floodplain Management*, and UFC 3-201-01 require the construction of buildings above the 100-year floodplain elevation. Changes in 2009 to the International Building Code (IBC) require the use of ASCE 24, *Flood Resistant Design and Construction*, when designing buildings in a flood hazard area. Facilities sited within a flood hazard area require extensive and costly foundations and ground floor framing systems. Master plans must identify flood hazard areas as a constraint. Avoid siting facilities in a flood hazard area if other practical alternatives are available. For facilities that must be sited in a flood hazard area with no practical alternative, identify additional costs on DD Form 1391 and ensure compliance with **\2** risk reduction **/2/** and reporting requirements as identified in UFC 3-201-01. For CONUS installations, contact the installation public works/civil engineer organization or the FEMA Map Service Center to obtain flood hazard areas. For OCONUS installations, contact the installation public works/civil engineer organization and/or obtain host nation resources for accurate flood hazard area information. When flood maps are not available, perform additional studies to delineate flood hazard areas and the 100-year flood plain elevation.

2-2.17 Planning for \2\ Extreme Weather Resilience /2/.

Identify and assess risks to the installation from the effects of extreme weather and develop plans to address and **\2** reduce **/2/** those risks. Weather is the day-to-day environmental conditions at a particular locale measured in terms of temperature, atmospheric pressure, wind, and moisture. Weather phenomena are short-term occurrences, including snowfall or rain events, storm surge, thunderstorms, tornados, cold fronts, or heat waves. **\2** Extreme weather means recurrent flooding, drought, desertification, wildfires, thawing permafrost, sea level fluctuation, changes in mean high tides, or any other weather-related event, or anticipated change in environmental conditions, that present (or are projected to present) a recurring annual threat to the security of the United States or of allies and partners of the United States. **/2/** Each DoD location is affected differently by local weather and geography. Assess the risks related to extreme weather events applicable to a specific location as part of **\2** an extreme **/2/** weather and **\2\ r**esilience **/2/** analysis to develop appropriate recommendations and plans for the installation.

2-2.17.1 Scenario Planning.

a. Scenario planning is an accepted method for planning when future conditions are uncertain. Scenarios do not have an associated likelihood of occurrence. Rather than addressing a single plausible future condition, installation planners work with several **\2** scenarios **/2/** to bracket the range of potential future conditions for their installation. Using and evaluating the potential effects from multiple plausible future conditions enables the understanding of whether the installation is (or could be) resilient to different future **\2** extreme weather **/2/** conditions. Master plans identify opportunities for future development, usually within the next 20 years; scenario planning acknowledges completed facility and infrastructure projects last longer than the plan timeframe. To support decision-making such as future facility siting, scenarios should cover the design life of a new asset, which is typically 50 or more years.

b. Develop a list of the scenarios for evaluation, impacts at the installation level, and a list of preparedness and resilience measures that will be implemented alone or as a group. **\2** Use Service-specific guidance to conduct scenario planning, as appropriate. **/2/**

c. Be aware of (and document) the uncertainties relating to **\2** projected natural resource changes **/2/**, current knowledge, and planning assumptions used during the planning process. Evaluate a range of scenarios informed by the data sources as described in paragraph 3-5.6. **\2** Provide **/2/** information on the potential risks **\2** and help formulate potential solutions **/2/**.

d. **\2** Extreme **/2/** weather considerations in planning should include, as applicable to the installation: storm surge flooding, non-storm surge (riverine or surface) flooding, hurricanes/typhoons, high winds, tornados, drought, wildland fires/wildfires, permafrost, desertification, volcanic, seismic, tsunamis, subsidence, **\2** extreme water level (EWL) **/2/**, precipitation change, annual average temperature increases, and extreme heat/cold. Not all phenomena are applicable to all installations. Document those phenomena applicable to an installation in the constraints mapping process and **\2** Military Installation Resilience Component (MIRC) **/2/**. The following two resources are available to aid in the scenario planning process and other tools, models, or databases may be used, if available.

2-2.17.1.1 DoD \2\ Extreme Conditions Assessment Tool (DECAT) /2/.

DoD **\2** developed, at Congressional direction, a method to assess **/2/** the exposure to extreme weather **\2\ /2/** for selected U.S. and foreign locations for each Department. The Extreme **\2** Conditions **/2/** Assessment Tool is a geospatial indicator-based **\2\ /2/** web **\2\ /2/** tool **\2** that **/2/** includes indicators (current and future) for many **\2\ /2/** factors, including coastal total water levels, coastal erosion, riverine flooding, drought, desertification, wildfires, thawing permafrost, and historic extreme weather events.

The tool is Common Access Card (CAC) -enabled and available at the following web sites:

- CONUS, Alaska, Hawaii: **\2** https://dodresilience.cwbi.mil/ords/f?p=118:1 **/2/**
- Rest of the World (ROW): **\2** https://dodresilience.cwbi.mil/ords/f?p=119:1 **/2/**

2-2.17.1.2 /2/ DoD Regional Sea Level (DRSL) Database.

For coastal or tidally influenced installations, use **\2\ /2/** the DoD Regional Sea Level (DRSL) database **\2** housed within DECAT **/2/** to ensure DoD uses a consistent, authoritative data set for DoD sites. Scenarios are not predictions **\2\ /2/** but plausible future conditions. The DRSL database is CAC-enabled **\2\ /2/.**

The DRSL database **\2** encompasses regional sea level fluctuations and EWL scenarios for three time horizons for DoD sites worldwide. **/2/** The DRSL database may be used for determining floodplains and flood design elevations. For installations, sites, or data not included in the DRSL database (primarily OCONUS), consult your Service-specific guidance. Incorporate at least one projection from each timeframe—2035, 2065, and 2100—into constraints mapping (paragraph 3-5.6).

2-3 NATURAL, HISTORIC AND CULTURAL RESOURCE MANAGEMENT.

Consider natural, historic, and cultural resources in the planning process. Natural resources include threatened and endangered species, wetlands, habitat areas, forests, undisturbed land, and important viewsheds. Historic and cultural resources include historic buildings, structures, objects, districts, landscapes, and archaeological sites, as well as sites sacred to Native American tribes. Coordinate planning decisions with installation cultural and natural resource managers early in the planning process to avoid project delays and additional funding needs from the inadvertent discovery of historic, cultural, and natural resources within proposed project areas. Consider and prioritize actions required by environmental laws, requirements, and policies to drive actions throughout the planning process.

2-3.1 Land Preservation.

Land is a valuable natural resource to DoD for installation **\2** mission requirements **/2/** and future viability. It is critical for training, sustaining, and deploying our forces. Employ policies and plans that preserve land to the maximum extent possible. On many installations, land is a training resource and preservation of training capabilities is a national priority. All installations should include land preservation as a primary consideration in installation master planning since they may have training missions now or in the future.

2-3.2 Mission Compatibility.

Another important function of land preservation is to provide and maintain a buffer between the civilian community and key functions of a military installation, including ranges, impact areas, airfields, heliports, and maneuver areas. Ensure on-base mission-required buffers, such as airfield clearances and explosive safety quantity-distance arcs, are maintained. Military land requirements are constantly changing and it is becoming increasingly difficult to acquire new land to meet expanding requirements. Whether the goal is to preserve valuable range and training land, land for future installation development, or to conserve irreplaceable environmental habitat or cultural resources, land preservation will be a key objective of the Master Plan.

2-3.3 Management of Historic and Cultural Resources.

DoD is required to take into account the potential effects of its actions on historic properties eligible for or listed in the National Register of Historic Places and areas considered sacred sites by federally recognized Native American tribes. When historic properties have the potential to be affected, comply with the requirements of the National Historic Preservation Act (NHPA) (16 USC 470). In accordance with § 106 of the NHPA, codified in 36 CFR Part 800, federal agencies will take into account the potential effects of their proposed actions on historic properties and avoid, minimize, **\2** or **/2/** reduce **\2\ /2/** any adverse effects to historic properties in consultation with the state historic preservation office, Native American tribes, and other relevant consulting parties. Effects to historic properties can be direct (e.g., demolition) or indirect (e.g., adverse impacts to the setting or viewshed of a historic district). Involve the installation's Cultural Resource Manager early in the planning process to avoid delays. Refer to UFC 1-200-02, Appendix D, "Projects Impacting a Historic Building or District," for strategies for improving performance of historic properties.

2-4 HEALTHY COMMUNITY PLANNING.

Regular physical activity is critically important for the health and well-being of people of all ages and reduces the negative impact from many chronic diseases. Physical fitness is key to military readiness. Incorporate health considerations and opportunities for physical activity based on advice from representatives of the installation's medical staff. Include installation health representatives and Morale, Welfare, and Recreation (MWR) representatives in visioning sessions and planning charrettes.

2-4.1 Planning for Walking, Running, and Biking.

Effective planning creates conditions that encourage physical activity, connect land uses and facilities, and provide safe, protected pathways for physical fitness training for Service members and their families. High connectivity, mixed land uses, and well-designed pedestrian and bicycle infrastructure decrease auto dependence and increase levels of walking, running, and cycling. Pedestrians and cyclists require contiguous and safe pathways that connect origins and destinations. Include key destinations such as the main gate, fitness center, food locations, and accommodations for walkers, runners, formation runners, bicyclists, and motor vehicle users on plans.

2-4.2 Community Gardens.

Healthy communities not only provide for physical activity through walking and biking but also provide opportunities to grow healthier food choices. In accordance with installation policy, incorporate locations for community gardens and local food production.

2-5 DEFENSIBLE PLANNING.

Military installations must be safe and secure to operate effectively and efficiently. Two key programs impact planning: the DoD Mission Assurance (MA) program as it relates to Defense Critical Infrastructure (DCI) and AT. Integrate the strategies of defensible planning with the goal of achieving a resilient installation to multi-spectrum types of natural and/or man-made threats.

2-5.1 Defense Critical Infrastructure (DCI).

The DoD Mission Assurance (MA) program guides protection of DCI, which is a capability-focused risk management program that seeks to manage risk to installation assets and infrastructure (see DoDD 3020.40, *Mission Assurance (MA)*, and DoDI 3020.45, *Mission Assurance (MA) Construct*. The DoD uses MA as a process to protect or ensure the continued function and resilience of capabilities and assets that directly relate to mission execution. MA enables mission success and supports commanders in both deliberate and adaptive planning as well as strategic risk management. DCI contributes to mission assurance and complements other DoD programs, such as strategic mobilization, industrial preparedness, supply chain risk management, AT, physical security, and continuity of operations. It addresses assets on the installation and in surrounding communities critical to mission accomplishment and overall **\2** resilience **/2/** of the installation.

2-5.1.1 DCI and the Master Plan.

Incorporate a DCI analysis in the Master Plan to minimize risk to the installation's strategic infrastructure and networked assets that support the critical missions necessary to provide combat capabilities. Critical infrastructure may include both on-post assets and off-post assets such as buildings, bridges, dams, facilities, and utility and transportation systems essential to planning, mobilizing, deploying, executing, and sustaining U.S. military operations. Assets become critical as dependencies upon them to support missions become critical (i.e., without the assets the mission will fail). As identified in the DCI analysis, develop contingencies in the Master Plan to **\2** reduce **/2/** or remediate risks, including existing or future projected risk resulting from extreme weather events, **\2\ /2/** sea level **\2** fluctuations, EWL **/2/**, wildfires, flooding, and other changes in environmental condition. Identification of elements of defense critical infrastructure may lead to classification issues. Coordinate with installation operational elements to identify any restrictions and find alternate means to identify such elements. Avoid incorporating anything into Master Plans that would lead them to be classified.

2-5.1.2 Stationing Actions.

As part of a stationing action, consider DCI requirements to ensure a single point of failure is not created that could adversely impact mission success. As an all-hazards based program, DCI ensures the capability to detect and assess information, provide timely warning, execute planned actions to **\2** reduce risks **/2/** or prevent disruptions to critical assets, and, if necessary, recover full mission capability.

2-5.2 Antiterrorism (AT) and Master Planning.

Coordinate with the installation antiterrorism officer (ATO) early in the planning process to ensure AT requirements are incorporated into Master Plans while pursuing other planning goals (such as compact development and **\2** resilient **/2/** design) that may be spatially interrelated. Determining the facility design basis threat (DBT) is the first step in planning antiterrorism requirements. Consider site-specific threats, the value of assets within the building, mission-related issues, and constraints that might dictate measures beyond the minimum requirements. Use UFC 4-020-01, *DoD Security Engineering Facilities Planning Manual*, to establish project AT and security requirements and determine if the minimum standards are adequate or if additional **\2** risk reduction **/2/** measures are required. The geographic combatant command (GCC) may provide additional prescriptive AT requirements or raise the DBT related to a specific asset, installation, or region. Installation commanding officers, regional commanders, or geographic combatant commanders may raise the DBT for a project, installation, or geographic region. Inhabited buildings within the installation boundary are generally low risk and will not warrant a defined threat or level of protection. In this instance, only the minimum standards in UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*, apply. For the majority of facilities, the Master Plan need only incorporate the

19 minimum antiterrorism construction standards within UFC 4-010-01, regardless of the asset value and without an established threat.

2-5.2.1 Antiterrorism Officer (ATO).

The ATO is responsible for working with the installation planner and other base security personnel in evaluating the local threat environment, the installation's access control screening capabilities, and determining the risk to the asset within the building. This analysis, using the procedures within UFC 4-020-01, will yield a building DBT and **\2** risk reduction **/2/** measures that provide a measurable level of protection for the asset(s). The DBT may drive consolidation of parking areas, parking garages, and pedestrian-only areas as well as the consolidation or dispersal of critical assets.

2-5.2.2 Site Security Considerations.

Consider the following three key physical security principles of natural surveillance, territorial reinforcement, and physical access control, which are elements of defensible space/crime prevention through environmental design. Additional strategies to enhance site security and provide AT **\2** risk reduction **/2/** include clustering facilities into compounds or pods providing a higher density core with parking and vehicle circulation on the perimeter. Place low-occupancy facilities within standoff space for other high-occupancy buildings. Provide a pedestrian-friendly space with AT **\2\ /2/** benefits. For more information, refer to the master planning considerations chapter in UFC 4-020-01.

2-5.2.2.1 Natural Surveillance.

To enhance physical security, site buildings to allow for natural surveillance of the built environment. Designate entry placements and window locations to give occupants opportunities to observe the built environment. Site buildings within view of other occupied facilities. Give careful consideration before minimizing windows in building designs. Doing so reduces the opportunity for natural surveillance or "eyes on the street," thereby reducing building protection and making the buildings more susceptible to crime, vandalism, and terrorism. Special-purpose buildings like hangars, large-format retail buildings, athletic and recreation facilities, and warehouses need not comply with this strategy.

2-5.2.2.2 Territorial Reinforcement.

Another physical security strategy is territorial reinforcement. Use physical design to shape defensible areas with clear property lines, landscape elements that define public and private spaces, and buildings sited to frame identifiable realms. Cluster facilities that are functionally compatible to reduce the perimeter, limit access points, and provide compact security areas. Arrange buildings in proximity to one another to create defensible spaces that can be protected more efficiently than scattered buildings.

2-5.2.2.3 Natural Access Control.

Natural access control can enhance physical security. Design streets, sidewalks, and building entries to mark public routes as distinct from private routes. Design landscaping, fencing, and building orientation to naturally and unobtrusively control unauthorized access.

2-6 CAPACITY PLANNING.

Capacity planning is a process to determine an installation's maximum development capacity based on conformance to the planning vision, goals, and objectives. While known requirements need to be sited in the Master Plan, room needs to be reserved for unknown future requirements. The difference between the existing condition and the future build-out is the capacity. Planning precedes project programming, is proactive, and does not just account for current known requirements. Show capacity on Illustrative Plans through the use of "notional buildings" or areas designated for "potential future growth." Account for changes in developable areas over time. Identify currently constrained sites as future developable areas contingent upon resolving factors such as restoring a contaminated site or demolishing out-of-service buildings. Future developable areas may also be limited because of factors such as **\2** EWL **/2/** or increases in wetland **\2** areas **/2/**.

2-6.1 Capacity Planning and Parking.

Capacity planning addresses organizational and non-organizational parking needs through a combination of parking strategies, including on-street parking, off-street parking, and structured parking. Strive to minimize parking to the maximum extent possible through land-use practices that support shared-use parking, transit, and alternative modes of transportation. Parking for the commissary and exchange is typically placed with direct access to the main entrances of these facilities. For safety reasons, limit on-street parking to only parallel parking. Provide roadway markings to identify parallel parking stalls. Avoid perpendicular and angled parking on roadways. Perpendicular and angled parking is generally unsafe and increases the hazard of starting, stopping, and turning in moving traffic. Avoid on-street parking on roads designed to move high traffic volumes at moderate or high speeds. On lower speed roadways, such as main streets or residential streets, on-street parking is acceptable because it calms traffic and thus reduces vehicle speeds. On-street parallel parking on local access lanes parallel to arterials is also an acceptable solution for multiway boulevards.

2-6.2 Growth Boundary.

Establish a growth boundary around an installation's cantonment area(s) to focus development toward the core and preserve the periphery for ecological functions, range and training, or other appropriate uses. With the exception of range and training and related functions, all projected future development will occur within the growth boundary. This boundary identifies opportunities to accommodate future missions in both contiguous and non-contiguous development areas and should also be identified on every ADP-level plan as appropriate. Review the growth boundary every five years; determination of the installation's capacity for growth occurs within the area defined by the growth boundary.

2-7 AREA DEVELOPMENT PLANNING.

As part of the master planning process, divide installations into identifiable and connected districts based on geographical features, land use patterns, building types, and/or transportation networks. Prepare an ADP for each district. This leads to developing the Master Plan in logical planning increments. The number of ADP districts will vary based on the size and geographic features of the installation.

2-7.1 District Area Focus.

By focusing planning at the district level, ADPs can be updated as mission requirements or command priorities change without redoing the entire Master Plan. Planning at the district level allows the ADPs to be incorporated in the installation's Master Plan updates. Complete Illustrative Plans and Regulating Plans for each ADP.

2-7.2 Incremental Development.

As resources allow, target specific districts for new ADPs and update the Master Plan accordingly. This ensures the Master Plan is a living document relevant to current requirements and future needs. The incremental approach to updating the Master Plan recognizes the resource limitations and district development priorities common across all installations.

2-8 NETWORK PLANNING.

While significant planning is at the ADP level, ADPs are linked through network planning. Networks consider linkages and systems that span ADP district boundaries. These include installation-wide utility systems, transportation networks, and parks and open space networks. Network Plans consider holistic approaches to energy-efficient development and installation-level resilience measures. Network planning also includes coordination and integration of planning with privatized housing or privatized utility partners.

2-8.1 Aesthetics and Network Planning.

2-8.1.1 When creating Network Plans, aesthetics should be a key consideration. The appearance of an area can be improved by reducing the visual clutter of utility wires. Placing utility wires underground allows communities to highlight their unique beauty without poles and wires in the way. Without overhead utilities, communities can more readily undertake improvement projects such as sidewalk widening and tree planting without having to snake around poles or trim vegetation to make way for power lines.

2-8.1.2 Burying lines eliminates extreme weather hazards, fire hazards, accidents, and safety risks from power outages due to downed lines. Placing utility lines underground reduces possible health risks from electromagnetic radiation and improves road safety by removing or reducing the chance of motorists striking poles.

2-8.1.3 Underground cables are insulated, electrically shielded, and out of the way. Underground transmission allows for no electrocution hazard for people or wildlife, no collision or entanglement hazards for aircraft, no risk of line exposure from traffic collisions, and no fire risk to people, wildlife, nature, or homes from arcing power lines during windy conditions.

2-8.1.4 Using this development strategy minimizes the visual impact of utilities on an installation. As a result, more green space can create biophilic interactions and boost overall morale. Coordinate with the installation maintenance department for successful implementation of this strategy.

2-8.2 Coordination of Plan Efforts.

Various components of underground utilities are often constructed independently without coordination, which results in severe second-order effects including repeated road resurfacing and landscaping. Communications infrastructure is the component most often considered as an afterthought. Additionally, there are network planning considerations where redundancies in both electrical and communications linkage are critical. Develop integrated plans for the components of the various infrastructure networks to prevent such deleterious effects and address these mission and coordination opportunities when developing Network Plans.

2-9 FORM-BASED PLANNING.

Form-based planning guides programming, design, and construction by identifying the form for installation development through the specification of building types, building floor elevations, number of stories or maximum height, set-backs, circulation patterns, orientation, landscaping, and land use. Form-based planning translates that form into a set of specific planning directives based on the specified allowances. The directives use products typically developed by planners, including Illustrative Plans, Capacity Plans, and street, building, and landscape standards to flexibly guide development. This approach supports mission needs, program requirements, environmental constraints and opportunities, and other development factors, including identifying parcels with significant constraints to future development (e.g., flood hazard areas, cultural resources, explosive safety quantity-distances arcs, airfield and heliport clearances). Form-based planning gives installation commanders the ability to exercise more control in the installation development process by creating planning practices based on a **\2** resilient **/2/** form that supports the installation’s planning vision. This approach provides direction for both short- and long-term development. Form-based planning promotes horizontal and vertical mixed-uses, compact and walkable development patterns, and emphasizes spatial principles that support **\2\ /2/** resilient development.

Form-based planning uses the components described in paragraphs 2-9.1 through 2-9.5.

2-9.1 Illustrative Plan.

This plan illustrates potential development that supports the overarching planning vision. At a minimum, the Illustrative Plan must show relevant project sites for known projects, notional building footprints for unspecified long-term development, as well as proposed transportation networks, street trees, open spaces, and parks. The detail shown in this plan can vary depending on the scale of the district. In all cases, the Illustrative Plan should reflect the documented installation vision, include parameters as explained in the Regulating Plan, and represent the preferred alternative.

2-9.2 Regulating Plan.

The Regulating Plan identifies the most important elements of the Illustrative Plan such as build-to lines, required entry and/or parking locations, minimum and maximum building heights, building ground elevations, setbacks for constraints, and acceptable uses. Regulating Plans are enhanced land-use plans that define allowable uses as well as building form requirements. The Regulating Plan replaces the traditional land-use plan by addressing land uses and building form together. In addition, the Regulating Plan provides specific guidance to shape development in accordance with the planning vision.

2-9.3 Building Envelope Standards (BES).

The BES regulate acceptable massing, height, fenestration, exterior envelopes, and uses. The BES also addresses requirements for minimum building floor elevations, where appropriate.

2-9.4 Street Envelope Standards (SES).

The SES describe and graphically present allowable street types and circulation elements in plan and section.

2-9.5 Landscape Standards.

The Landscape Standards show, at a minimum, appropriate type and placement of major landscape elements (street trees). These standards may also include other natural landscape features (trees, shrubs, ground cover) and manmade hardscape features (street furniture, signage, lighting). Landscape Standards must meet the requirements outlined in UFC 3-201-01.

2-9.6 Implications for Designers/Developers.

The key standards are tied to parcels identified on the Regulating Plan. When development is proposed for a particular parcel, the standards are given to the designer/developer to ensure proposed projects conform to the overall installation planning vision.

2-10 FACILITY STANDARDIZATION.

Service-developed standard area requirements and spatial relationships recognize the need for consistency in building types repeated across installations. These area requirements and spatial relationships can be maintained within a variety of building designs that are consistent with the installation's Regulating Plan and Installation Planning Standards. When appropriate, standardized area requirements and spatial relationships will be included in the development of Illustrative and Regulating Plans. Site standard designs consistent with the Master Plan. If standard designs are not used, pursue waivers as appropriate.

2-11 PLAN-BASED PROGRAMMING.

Program requirements include all facility needs required to enable mission support. Validate facility requirements and projects against the Master Plan and the planning strategies before they are programmed. Installation planning and programming staff need to capture facility requirements and propose solutions to meet those requirements from the options available: better utilization of existing facilities; renovation or modernization of existing facilities; leased facilities; and new construction. Most requirements come from established Service-specific criteria and by industry or commercial standards. Requirements can be developed to ensure compliance with the Regulating Plan and form-based code and requirements identified in associated plans or Functional Annexes. Funding source requirements include all fund sources: major construction, minor construction, operations and maintenance, NAF, the exchange, DeCA, private entities.

Document program requirements on DD Form 1391 in accordance with DoD 7000.14-R, *Department of Defense Financial Management Regulation*, Volume 2B, Chapter 6, and Service-specific processes and procedures. Ensure programming documentation includes holistic programming requirements, including mission facility requirement/facility sizing authorization, and any planning site requirements (parking per the form-based code, on-street parking and curb and gutter, LID practices, **\2** energy/water/resilience **/2/** practices) as identified in the plan.

CHAPTER 3 MASTER PLANNING PROCESS AND PRODUCTS

3-1 INTRODUCTION.

The installation Master Plan documents a comprehensive planning process using a standard set of products. The planning process is as important as the Master Plan documents themselves. An effective master planning process continually collects the constantly changing information affecting the installation and its mission, and communicates them and the installation's Master Plan to affected stakeholders.

3-2 PLANNING PHASES.

While not entirely linear, the planning process consists of the four primary phases described in the following subsections. The master planning process and the Master Plan result from the application of these phases.

3-2.1 Identification.

This phase prepares the foundation for detailed planning through identification of a planning vision, specific goals that support the vision, and measurable planning objectives supporting one or more goals. The product that results from this phase is the Vision Plan.

3-2.2 Evaluation.

In the evaluation phase, development alternatives are prepared and evaluated for all scales of planning, from individual districts to the overall installation.

3-2.3 Implementation.

In the implementation phase, prepare a preferred alternative to implement the vision and prepare detailed documents to guide installation development and implementation of the plan. The products that document this phase are the Installation Development Plan (IDP) and the Installation Planning Standards. Prepare the Installation Development Program and the Plan Summary at the end of this phase.

3-2.4 Monitoring and Amending.

Change is inevitable because of resource constraints, mission changes, or changes in environmental, social, or political conditions. Revise and update the Master Plan to reflect changes to maintain its relevance as a useful planning and management tool. At a minimum, review Master Plans annually and update as mission requirements dictate. Each Service identifies the appropriate level and type of review.

3-3 STAKEHOLDER INVOLVEMENT.

During the development of the Master Plan, talk with stakeholders to fully understand the scope of their vision and mission requirements. Stakeholders include anyone using or maintaining a facility within the scope of a planning boundary, installation leadership, members of the civil engineering/planning/public works staff, environmental, natural and cultural resources staff, installation AT personnel, military police, fire department staff, mission operators, tenants, privatized housing and lodging partners, private utility partners. Stakeholders also include members of higher-level headquarters and echelons with oversight over the installation. The importance of stakeholder involvement cannot be overemphasized—it is essential to walk the sites in each ADP district and talk with users and stakeholders. In addition to internal DoD stakeholders, external stakeholders are also important sources of information and input. These include local municipalities, state governments, transportation agencies, other federal agencies, and federally recognized tribes. Involve relevant stakeholders in all stages of the process.

3-3.1 Retail Stakeholder Involvement.

Retail stakeholders on installations provide invaluable community support to the installation community. Engage retail stakeholders in all phases of the planning process. Their facilities are multi-faceted and require special planning attention. In planning for these facilities, retail stakeholders include the following planning considerations: the business case analysis, convenience for the customer, and parking/traffic/circulation and site layout.

3-3.2 Business Case.

Military retailers need to generate earnings to support the customer and support MWR programs for the Services. If the demographics or location cannot justify the business need, the risk is often too great to invest the capital. When retail or commercial development is desired, engage the military retailer early in the planning process to ensure the business case is met.

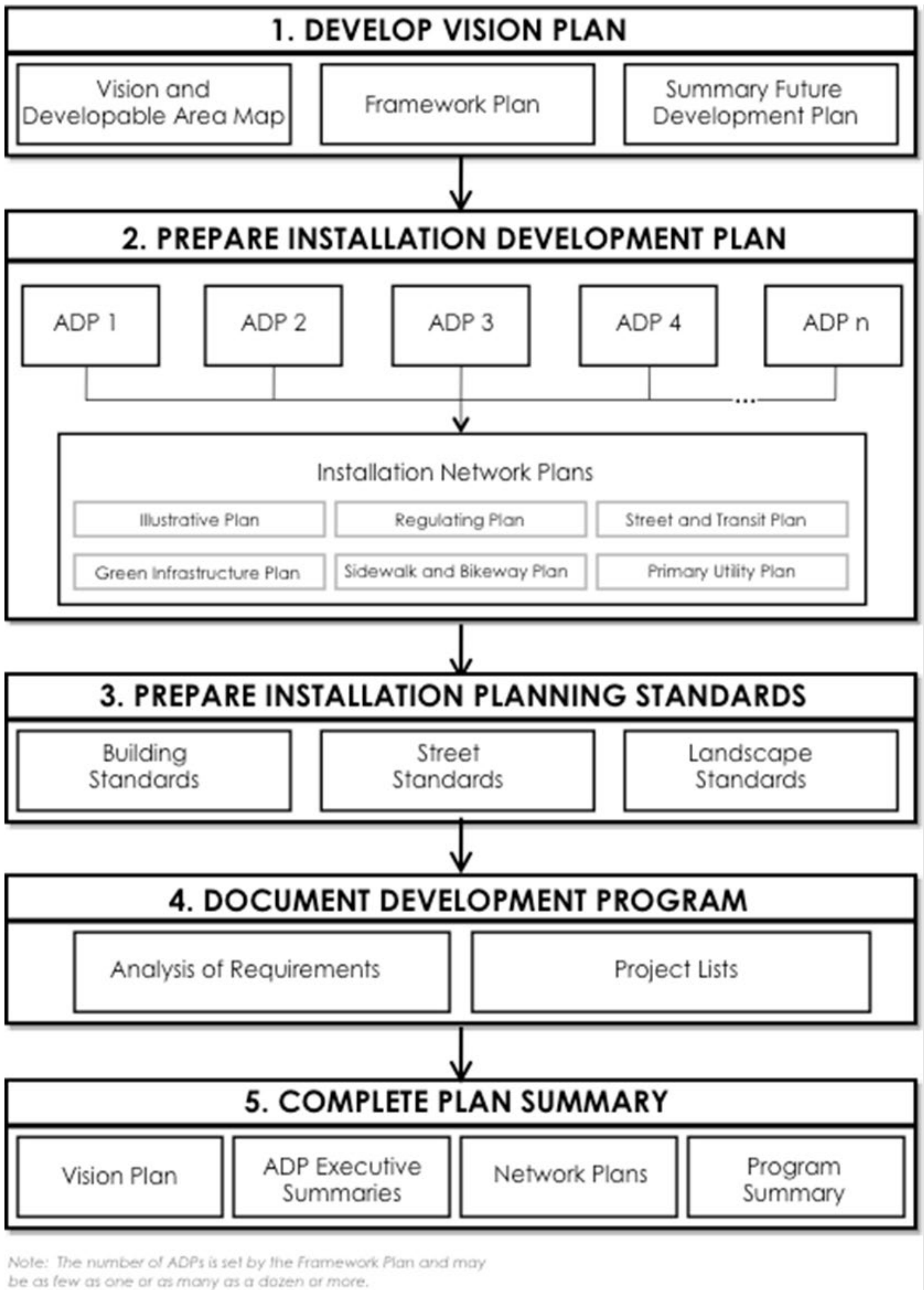
3-3.3 Convenience.

Military retailers focus on customer convenience. Co-locate the exchange and commissary when possible. Locate parking for convenience and accessibility for customers. Consider many customers will drive from off-installation locations. Locate fast food and convenience stores along the outbound lane of traffic leading toward an exit gate or in high-traffic areas for convenient customer access.

3-3.4 Parking/Traffic Circulation and Site Layout.

Convenient, accessible, and safe parking is a primary focus for retail operations. Ensure layouts support safe pedestrian access. The delivery areas should be separate from the building entrance. For functionality and safety, locate customer parking and refueling operations with direct access to the building entry. Locate receiving in the rear of the building. Screen large parking areas from streets and the pedestrian realm with linear buildings and appropriate landscaping. Vehicular access to all sides of the building is necessary for convenience and life safety.

Figure 3-1 Planning Process and Product Graphic



3-4 PRODUCTS.

The Master Plan includes the following products. See Figure 3-1.

3-4.1 Vision Plan.

The Vision Plan includes a statement of the planning vision, planning goals, and planning objectives, any installation-wide constraints and opportunities map(s), a developable area map, a Framework Plan for the entire installation, and a summary future development plan.

3-4.2 Installation Development Plan (IDP).

The IDP includes ADPs (including detailed constraints and opportunities maps, Regulating Plans, Illustrative Plans, Implementation Plans, capacity analysis, and supporting sketches and renderings) and applicable Network Plans.

3-4.3 Installation Planning Standards.

Installation Planning Standards include the BES, the Landscape Standards, and the SES.

3-4.4 Installation Development Program.

The Installation Development Program is the overall strategy for using and investing in real property. It includes a list of current known projects needed to support installation missions.

3-4.5 Plan Summary.

The Plan Summary is an executive summary of each the above planning products. Create the Plan Summary in a severable format to facilitate sharing with local communities and the public.

3-4.6 Functional Annexes to the Master Plan.

The Functional Annexes include stand-alone planning products that support the master planning process, including, but not limited to, Installation Energy Plans (IEP), **\2** MIRCs **/2/**, Area Development Execution Plans (ADEP), Complex Plans, and Project Development Plans (PDP).

3-5 VISION PLAN.

A vision for planning differs from an overall installation mission by defining ideal development principles for maximizing the installation’s long-term capabilities. The installation mission statement cites the specific responsibilities the installation must support. It is near-term and meets the current military needs for our nation. Installation missions can change as our nation’s military requirements change.

3-5.1 Installation Mission.

In order to begin a holistic planning process and build an effective vision statement for planning, it is imperative to understand the installation's missions. Identify principal mission objectives and activity types, such as support, training, administration, and production. Identify installation units, organizations, and their relationships to installation missions. Determine planning end-strengths. Identify and quantify the supported population, including assigned billeting units, tenant activities, community support organizations, and supported populations (e.g., active-duty military, civilians, military dependents and retirees, government-authorized space for contractors). Address functional relationships among activities and facilities and identify issues and opportunities for operating and developing the installation.

3-5.2 Planning Vision and Goals.

Establishing a vision statement for planning is the first step in the planning process. Engage senior installation leadership and ask for their input into the overall vision and goals for the installation planning process. Be prepared to help the installation leadership understand how to develop a vision to ensure priorities for future installation-wide development are met.

3-5.3 Vision Statement.

The vision statement is a clear and concise description of a desired end state and captures the essence of the entire planning effort. A strong vision creates a mental picture of what the installation will look like. Collaborate with stakeholders and decision-makers to create the vision statement. Engage stakeholders in a series of workshops and community surveys, and conduct a visioning charrette that includes mission operators, military members, family members, civilian staff, and installation leadership to create the vision statement. Include stakeholders from non-military, community, and other local and state agencies in the visioning process. Examples of strong vision statements include:

- "In support of the mission, Service members, and families, we will create a **\2** resilient **/2/** community of walkable neighborhoods with identifiable town centers connected by great streets."
- "This installation will be a **\2** resilient **/2/** research and development community that fosters mission excellence through energy-efficient buildings organized into a walkable campus."

3-5.4 Planning Goals.

The goals of the Master Plan flow from the vision and focus on long-term redevelopment and construction projects necessary to fulfill mission requirements and reshape the installation. Ideally, the key development goals are embedded within the vision statement. The key development goals are underlined in the vision statements in paragraph 3-5.3.

3-5.5 Planning Objectives.

Planning objectives support the vision and goals and incorporate inputs from the planning process and the planning strategies described in Chapter 2. The objectives define how to achieve the goals in the vision. Each objective is specific and measurable, enabling plan implementation monitoring. In the sample vision statement, the goal of a **\2** resilient **/2/** community can include planning objectives consisting of compact, mixed-use, multi-story development. Consider the installation mission and analysis of on- and off-post conditions in selection of specific objectives. Incorporate the ten DoD planning strategies discussed in Chapter 2 into the planning objectives. Select other objectives based on installation design themes, developmental opportunities and constraints, potential encroachment situations, weather-related **\2** resilience **/2/** challenges, and consideration of community planning agencies, groups, businesses, and affected individuals' views and plans.

3-5.6 Constraints and Opportunities Maps.

Collection and analysis of two major types of data, on-installation data and off-installation data, enables a full understanding of the existing landscape and holistically incorporate mission requirements into the Master Plan. Collect this data using a variety of methods, including electronic collection and stakeholder input. Compile and consolidate data to create a narrative and a set of maps indicating the overall site constraints and developable areas (opportunities) as described in the following paragraphs. This analysis helps form the basis for planning decisions.

3-5.6.1 On-Installation Data Collection.

On-installation data collection incorporates analysis of existing natural and man-made conditions, including land use, circulation, and utilities. Identify restrictions on land use due to mission requirements, such as airfield clearances and explosive safety quantity-distance arcs, as well as any environmental contamination (chemical, munitions, asbestos) such as remediation sites or unexploded ordnance areas. Include potential changes in the natural environment due to **\2** extreme **/2/** weather in the evaluation. Identify areas affected by a 1% annual chance flood event and other current and projected flood hazard areas, to include 1% annual chance flood events and potential permanently inundated areas. For coastal or tidally influenced areas, evaluate and document multiple **\2** EWL scenarios **/2/** using the DRSL database (see paragraph 2-2.17.1.2) to support decision-making. Incorporate **\2** EWL **/2/** projections reflecting the installation's mission and risk tolerance in base flood elevations (BFE) in coastal or tidally influenced areas. Evaluate the natural environment with a particular focus on those elements that may create significant limitations on the operation or construction of buildings, roadways, utility systems, runways, training ranges, airfields, heliports, and other facilities. Data collected also includes analysis of the human environment, including the location of all historic districts, historic properties, and known archaeological sites. Current and forecasted demographics, military community services, outdoor recreation/physical conditioning areas, training ranges, maneuver areas, existing facilities and their uses, traffic patterns and intensity, and utility systems use and capacities must all be incorporated.

3-5.6.1.1 Mission Data.

Mission requirements largely determine land and facility support requirements. Utilize data on current and proposed mission requirements to establish limitations and conditions that directly affect the installation's ability to execute mission support. Consult the real property database of record and/or the realty specialist concerning real property inventory data and the gross and net square footage of facilities. Analyze existing land uses and land use restrictions and collect and analyze installation-specific and headquarters-driven plans, planning guidance, and facility allowances.

3-5.6.1.2 Demographic Data.

Develop an understanding of the installation’s demographics and identify appropriate principles to meet the needs of each major demographic group. Demographics to consider include personnel working on the installation, personnel living on the installation, personnel living off the installation, and retirees.

3-5.6.1.3 Data Layers.

The analysis includes an in-depth look at development constraints and opportunities across the installation and within districts when planning at the district level. Data is not effective unless a regional perspective is portrayed. Because some of the information is likely to be sensitive, installation security personnel should review the document for suitability for public release. Use GIS, GeoMapping, or other similar systems. When preparing a Master Plan, incorporate and integrate with local GIS systems. Develop all deliverables in compatible formats to ensure ease of use. Typical layers referenced are in Appendix D. Follow Service-specific guidance for geospatial data requirements (AFI 32-10112, *Installation Geospatial Information and Services (IGI&S)*, USACE ECB 2018-7, *Advanced Modeling Requirements on USACE Projects - Category: Directive and Policy*, or OPNAVINST 11000, *Facilities and Land Management Ashore*, Ser N/420U045).

3-5.6.2 Off-Installation Data Collection.

Contact local, state, and federal agencies for off-installation data, reports, and plans that may be helpful to the planning process. It is vital to understand regional and vicinity conditions that affect the installation. Leverage these data request interactions to interview local and regional stakeholders for their thoughts on the installation planning process and priorities. In some cases, opportunities to share costs on infrastructure or link to local development initiatives may be available. Review existing regional and vicinity maps, analyze regional transportation systems (roads, railroads, commuter mass transit systems, airports), and collect data on socioeconomic conditions, demographic patterns, **\2** extreme weather **/2/**, and community land use and planning. This effort includes assessments of community services, land leases/easements, encroachment issues, and federal support services. Sources of data include, but are not limited to:

- Federal agencies, including the Census Bureau, National Academy of Sciences, US Geological Survey, US Global Change Research Office (or any similar successor entities), National Weather Service, Environmental Policy Agency, Department of Transportation, including the Federal Aviation Administration.
- State and county departments, including Highways and Transportation, Natural Resources and Conservation, Fish and Wildlife, Planning and Community Affairs, Housing, Public Health, Environmental Policy, State Historic Preservation Officers/Offices.
- Local government offices, including City Hall, Public Works, Public Health, Parks and Recreation, school districts, fire and police departments.
- Other local agencies, including utility and power companies, Chamber of Commerce, regional planning agencies.
- Installation staff activities working directly with the local governments, agencies, and departments.

3-5.6.2.1 Off-Installation Personnel.

Make every effort to understand the needs of various populations that live off the installation but rely on the installation for services. Retirees, reservists, spouses, and civilian and military staff who work, shop, recreate, and train on the installation may live outside the fence line. These populations may outnumber those who live on the installation and have distinctly different needs with respect to accessibility and transportation.

3-5.6.2.2 Environmental Conditions.

Where changing external conditions impact planning decisions, seek to understand, monitor, and adapt to these changes. Such conditions include, but are not limited to, changes in land use and population density near installations; changes in climatic conditions such as temperature, rainfall patterns, storm frequency and intensity, and water levels; and changes in infrastructure assets and configurations beyond and linking to the installation. Use projections from reliable and authorized sources to anticipate changing environmental conditions during the design life of existing or planned new facilities and infrastructure. Include sources such as the following:

- Census Bureau (for population projections)
- The National Academy of Sciences (for land use change projections)
- The U.S. Geological Survey (for land use change projections)

3-5.7 Developable Area Map.

3-5.7.1 Planning accounts for known requirements and provides a framework for future undefined requirements. Effective plans identify areas for future requirements on a developable area map. The developable area map highlights and calculates those areas that, given the identified vision, constraints, and opportunities, are open for development and areas for future development to support growth. This plan shows the general overall development capacity of an installation. Developable area maps designate where the type of development may be limited or require special consideration due to specific constraints, such as AT, airfield clearances, explosive safety quantity-distance arcs, or **\2** extreme **/2/** weather-related impacts. See Figure 3-2.

3-5.7.2 The Framework Plan is part of the planning visioning process. The Framework Plan is a map of the entire installation showing the ADP districts, key transportation and land use concepts, and other significant features that influence development patterns. The plan can also graphically represent priority ADP districts. To establish ADP boundaries, planners should use geographic features, key transportation systems, open space networks, existing land-use patterns, and boundaries of any identified historic districts or other architectural style. An ADP district may incorporate one or more identified historic districts. See Figure 3-3.

3-5.8 Summary Future Development Plan.

This plan locates known projects on an installation map using a numbered key tied to a project list. The intent is not to show building footprints or other planning details, but simply to identify locations targeted for known requirements and deconflict project site selections. See Figure 3-4.

Figure 3-2 Developable Area Map Graphic

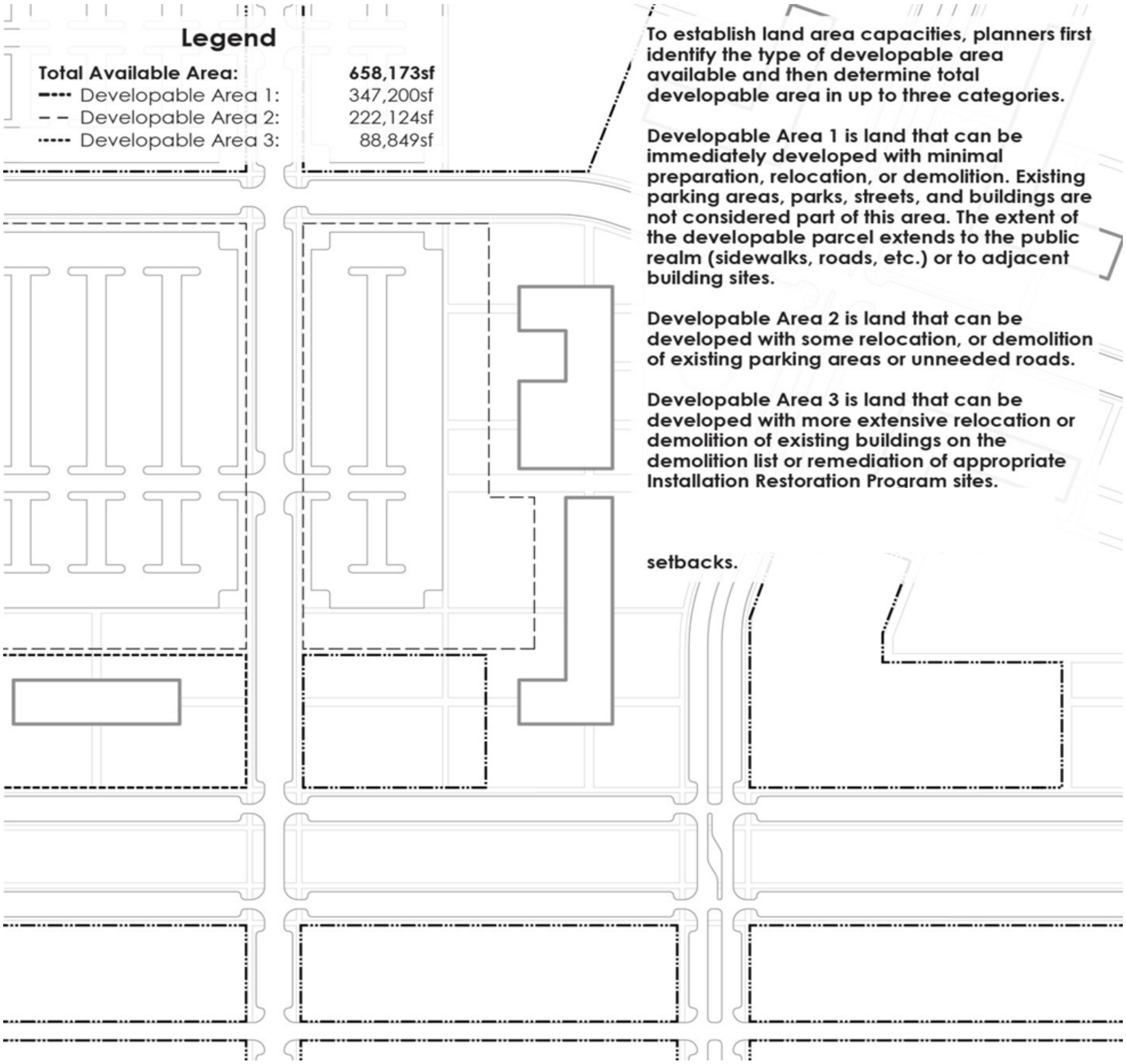


Figure 3-3 Framework Plan Graphic

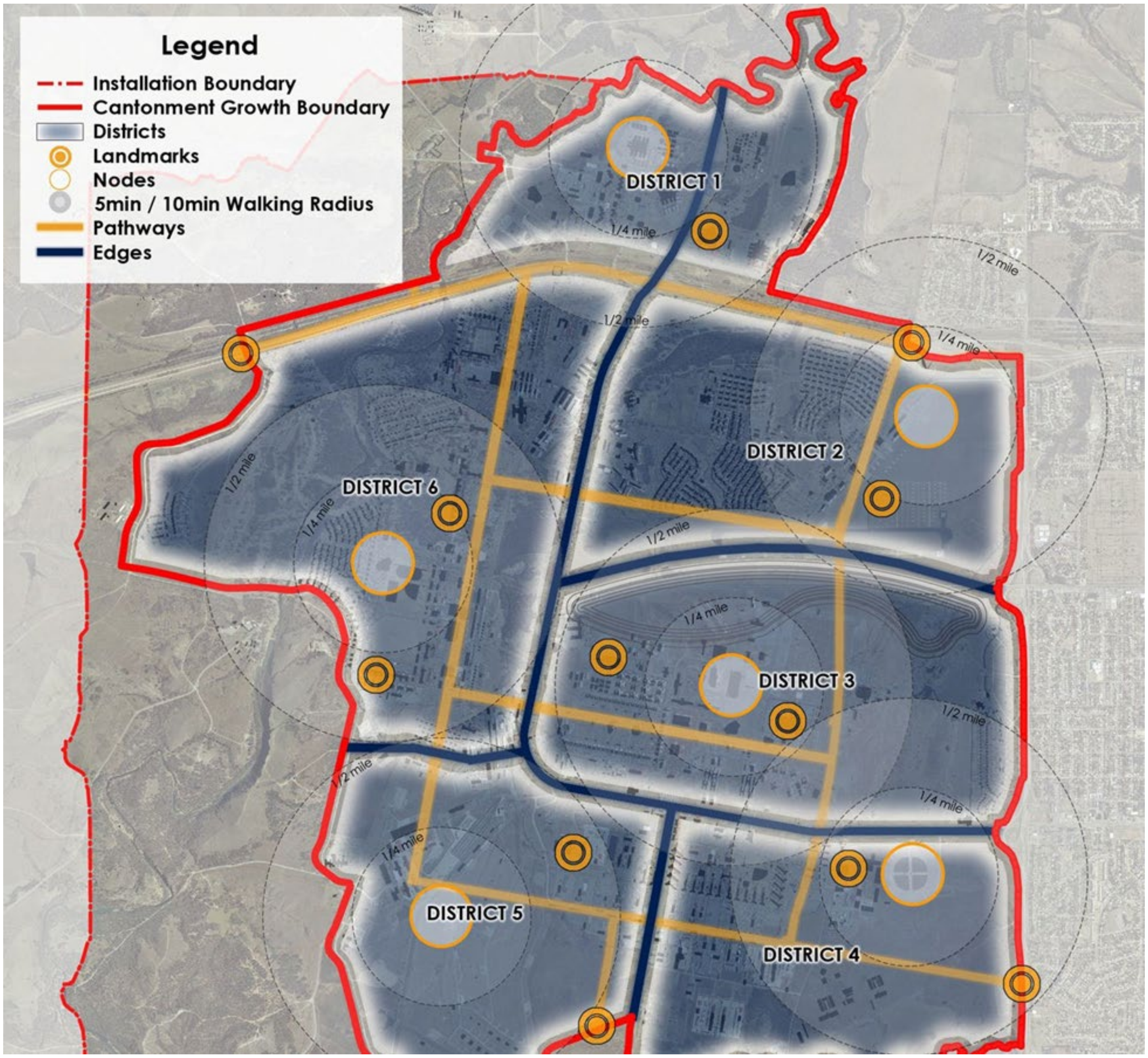
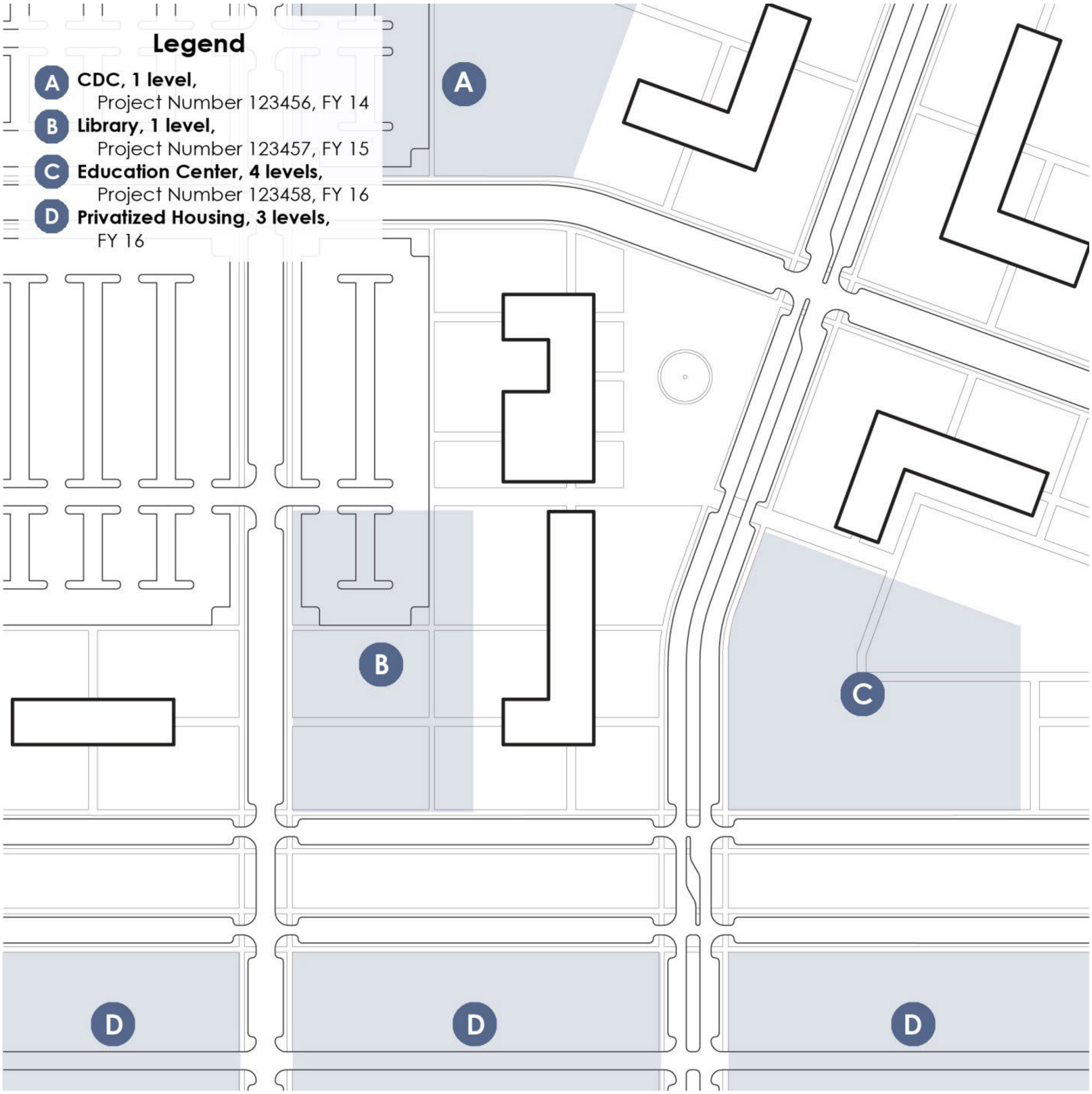


Figure 3-4 Summary Future Development Plan Graphic



3-6 INSTALLATION DEVELOPMENT PLAN (IDP).

The IDP includes ADPs and applicable Network Plans.

3-6.1 Area Development Plan (ADP).

The bulk of the installation planning effort occurs at the scale of an ADP, which is a detailed plan for a district that includes detailed constraints and opportunities maps, Illustrative Plans, Regulating Plans, Implementation Plans, and capacity analysis. Include other supporting plans, maps, and graphics that illustrate the planning/development intent as needed. ADPs describe constraints and opportunities, system studies, existing facility assessments, program requirements, and alternatives analysis. Master plans must address a level of development appropriate for each installation and are applicable for small- and large-scale development efforts, such as renovation or new construction, respectively. Project programming and funding processes achieve the Master Plan vision. ADPs are ideally suited for the task of identifying, coordinating, and synchronizing competing requirements, and as such, they are useful at installations focused on sustainment, restoration, and modernization (SRM) funding and installations focused on military construction (MILCON) funding. In order to support the Master Plan requirements, scope ADPs to address the methodology set forth in this UFC and meet the specific product requirements. Other related planning documents cited in this UFC are dependent on the information in the ADPs to build a comprehensive planning picture, including the Network Plans and Functional Annexes.

3-6.1.1 ADP Analysis.

Before beginning the ADP process, perform a thorough analysis of the existing conditions, identify existing program requirements, and a review of the installation's planning vision, goals, and objectives. Assess the constraints and opportunities map to identify existing and potential impacts to developable areas. Review the installation's planning standards and Functional Annexes, including the IEPs and **\2** MIRCs **/2/**, to identify impacts on future development and development guidelines.

3-6.1.2 ADP Design.

After the analysis, develop conceptual alternatives, evaluate those alternatives against measurable criteria, and then select and design in detail a preferred alternative. Develop an ADP for each district on the installation as determined in the Framework Plan.

3-6.1.3 Developing Alternatives.

Developing alternatives is a critical component of the master planning process. The National Environmental Policy Act (NEPA) requires considering various alternatives to minimize adverse impacts on the environment. Creating multiple options allows planners, stakeholders, and installation leadership to ensure the ADP best fulfills the development vision. In developing alternatives, planners review functional and spatial relationship concepts as well as the reality of existing facility locations and the existing off-post and on-post environment. Develop alternatives depicting the long-range development of the ADP district, including arrangement of functional areas, circulation, and utility systems. In documenting this phase of the ADP process, describe and show the alternatives and discuss the results of the alternative evaluation. When preparing alternatives, keep the following in mind:

- Address new mission requirements, improvements to, replacement, or relocation of existing mission support facilities, and implementation of the Installation Planning Standards.
- Each alternative may be based on a theme or point of emphasis to allow comparisons and tradeoffs.
- Consider the constraints associated with future flood hazards and other factors, and evaluate the ability of the installation to adapt to existing or future hazards, including from **\2** extreme **/2/** weather, **\2** sea level fluctuations, EWL **/2/**, wildfires, flooding, and other effects over the time horizons identified during scenario planning.
- Define and evaluate alternatives to satisfy deficiencies, eliminate excess, and preserve room for future growth.
- Include determining the maximum capacity of an installation, or even critical sub-areas of an installation, whether or not there is currently an identified need.
- If appropriate, present the alternatives to the Installation Planning Board for discussion and decision before the recommended solution becomes part of the ADP.

3-6.1.4 Evaluating Alternatives.

This analysis supports the NEPA process by considering several alternatives and evaluating potential environmental impacts of each alternative. The process for evaluating alternatives should be presented to the Installation Planning Board to demonstrate how the preferred course of action was selected.

3-6.1.5 Designing the Preferred Alternative.

After evaluating the ADP alternatives, fully develop a preferred alternative that best meets the planning vision, goals, and objectives for the district. The preferred alternative is a graphical and narrative description of the fully developed plan for the district that emerges from the alternatives analysis phase and consists of the Regulating Plan, Illustrative Plan, and Implementation Plans.

3-6.1.6 Regulating Plan.

The Regulating Plan provides specific information on permitted development for each building parcel within a district and functions as an enhanced land-use plan. This plan designates the locations where different uses or building form standards apply. Instead of solely defining land uses, this method defines building form (e.g., height and frontage) while allowing for a range of possible uses. See Figure 3-5.

3-6.1.6.1 Regulating Plan Designations.

The Regulating Plan establishes development regulations for specific parcels on the installation. Use existing and planned roads, permanent fence lines and borders, and natural features like riparian corridors to establish parcel lines. Each ADP district will be composed of parcels defined by parcel lines. Parcels may correspond to entire blocks. Blocks may also be subdivided to create smaller parcels in response to site-specific design requirements. The parcels, whether they are entire blocks or portions of a block, have the same accompanying regulations governing building form, placement, and use across the parcel. Refer to the criteria established for that parcel to guide the design process when a building is proposed for a specific parcel.

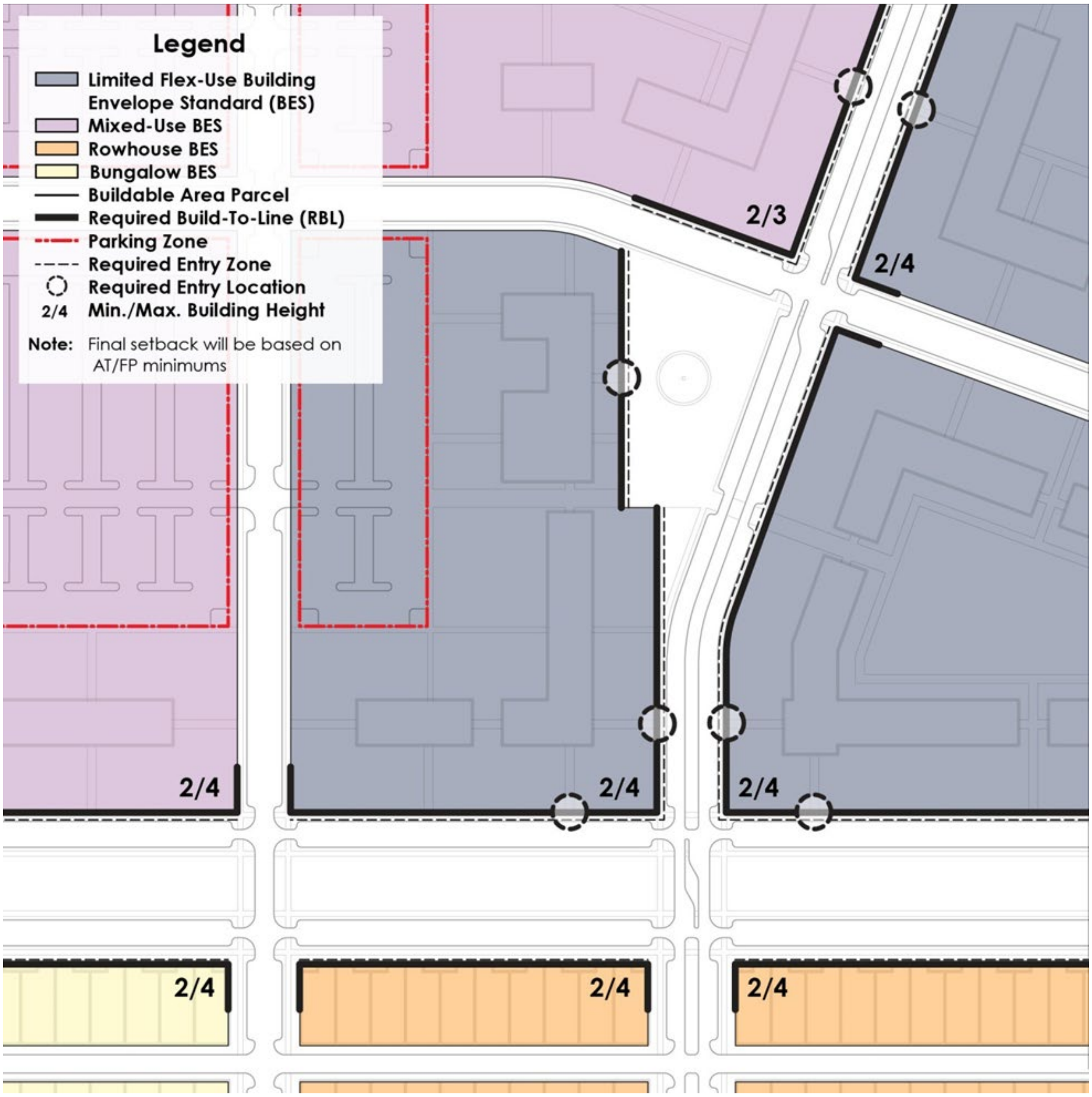
3-6.1.6.2 Regulating Plan Components.

Only the most important aspects of the Master Plan are regulated. These include build-to lines, minimum and maximum building heights, key entry locations, appropriate uses, parking and roadway configurations, and any conditions for development based on the constraints analysis. The Regulating Plan identifies the designated BFE within flood hazard areas, accounting for coastal and riverine flooding risks, as applicable.

3-6.1.6.3 Regulating Plan Functions.

The Regulating Plan ensures facilities, parks, parking, and other uses are sited in alignment with the overall master planning vision over time. The Regulating Plan specifies allowable building types on individual parcels in a district, assigns development standards to specific physical locations, shows how each parcel relates to public spaces and the surrounding neighborhood, and references the more detailed building, street, and landscape standards contained in the Installation Planning Standards.

Figure 3-5 Regulating Plan Graphic



3-6.1.7 Illustrative Plan.

The Illustrative Plan graphically illustrates development within a district that conforms to the Regulating Plan. The Illustrative Plan shows only one possible outcome allowed by the Regulating Plan; it is a sample diagram and does not imply any policy requirements but graphically shows how to portray planning principles. Figure 3-6 illustrates a sample Illustrative Plan graphic. The Illustrative Plan is a valuable tool for developing the Capacity Plan and Regulating Plan and communicates future development potential. It can be confusing to installation stakeholders as it only represents one possible outcome, rather than all the possibilities allowed by the Regulating Plan.

3-6.1.7.1 Illustrative Plan Requirements.

The Illustrative Plan shows project site selections for known projects, notional building footprints for unspecified long-term development to facilitate capacity analysis, as well as existing and proposed roads, sidewalks, bicycle networks, street trees, open spaces, and parks. The various facility requirements will be translated into building “footprints,” utilizing appropriate siting considerations. Identify short-term stopgaps and recommended long-term solutions to satisfy mission, land-use, and real property requirements.

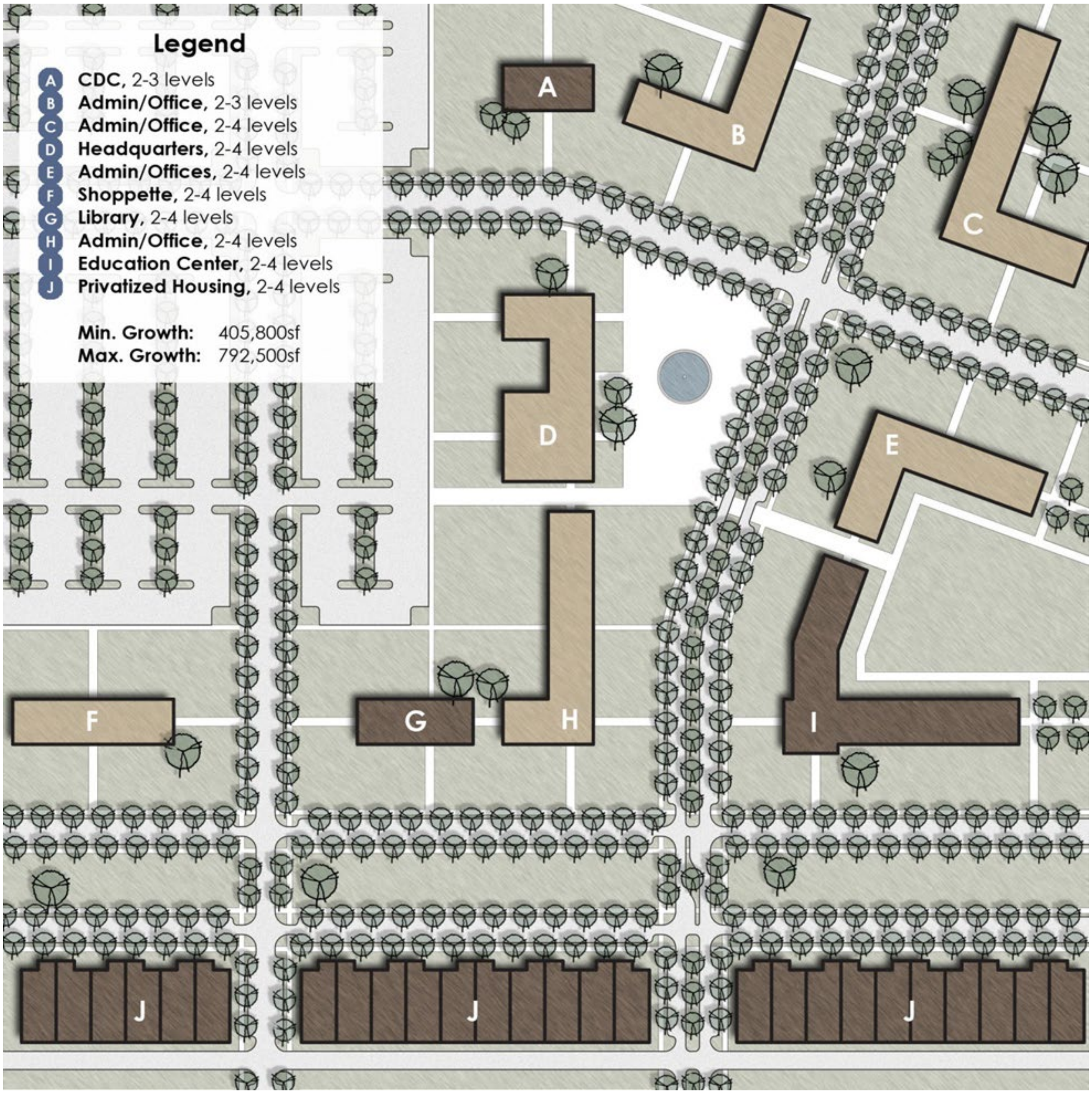
3-6.1.7.2 Relationship Between Regulating Plan and Illustrative Plan.

The Regulating Plan guides the development of the area and is created iteratively with the Illustrative Plan. The Regulating Plan allows for more flexibility than an Illustrative Plan and serves as an underlay to the Illustrative Plan.

3-6.1.7.3 Capacity Analysis.

Effective plans identify future requirements and provide room for notional facilities and specific facilities that have not been programmed. Capacity analysis also accounts for the carrying capacity of the land and developable area on an installation. A capacity analysis should be calculated and shown on Illustrative Plans as “notional buildings designated for potential future growth.” Calculate additional square footage of future facilities to indicate the potential capacity of an area.

Figure 3-6 Illustrative Plan Graphic



3-6.2 Implementation Plans.

Implementation plans depict sequencing of key relocation, demolition, and construction actions required to move the installation from its current state to the final state shown on the Illustrative Plan.

3-6.3 Environmental Documentation.

Revise environmental documentation as necessary to include an analysis of the anticipated environmental impacts of plan implementation, identification of appropriate **\2** risk reduction **/2/** measures, and documentation of the results. Follow all Service-specific environmental regulations and requirements.

3-6.4 Network Plans.

After completion of the ADPs for the priority districts on the installation, combine relevant information into appropriate Network Plans. Network Plans show future development for the installation as a whole, consist of the Installation Illustrative Plan, Regulating Plan, Street and Transit Plan, Sidewalk and Bikeway Plan, Green Infrastructure Plan, and Primary Utility Plan. Network Plans are also an appropriate place to identify **\2** cost-saving **/2/** net-zero planning strategies and forecasts for energy, waste, and water, as well as **\2** resilience **/2/** impacts.

3-6.4.1 Installation Illustrative Plan.

This plan combines all of the ADP Illustrative Plans onto one graphic plan. This is a simple plan to create once the Illustrative Plan for each ADP has been completed. Indicate where ADPs have not been accomplished on the Installation Illustrative Plan. The primary purpose of the Installation Illustrative Plan is to graphically illustrate all major future development.

3-6.4.2 Installation Regulating Plan.

This plan combines all of the ADP Regulating Plans onto one graphic plan. This is a simple plan to create once the Regulating Plan for each ADP has been completed. Indicate where ADPs have not been accomplished on the Installation Regulating Plan.

3-6.4.3 Installation Street and Transit Plan.

This Network Plan identifies and maps all current and proposed streets across the installation and forms the preferred end state for the installation street network. This plan should also identify how the street network is connected to the network outside the installation and how street networks outside the installation affect the installation network. Installation street types will be keyed to the Installation Planning Standards. Additionally, this plan identifies current or proposed transit routes and transit stops. Develop and update the transit plan in consultation with the metropolitan planning organization designated for the metropolitan planning area in which the military installation is located, if one exists. Include considerations of ways to diversify and connect transit systems (if one exists).

3-6.4.4 Installation Sidewalk and Bikeway Plan.

This Network Plan identifies and maps all current and proposed sidewalks and bikeways across the installation and forms the preferred end state for the installation sidewalk and bikeway networks. The sidewalk and bikeway types will be keyed to the Installation Planning Standards.

3-6.4.5 Installation Green Infrastructure Plan.

This Network Plan identifies and maps all major parks and open space elements and will include, at a minimum, current and proposed parks, open spaces, riparian corridors, wetlands, and significant bodies of water.

3-6.4.6 Installation Primary Utility Plan.

This Network Plan identifies all current and proposed primary utility lines across the installation and forms the preferred end state for the installation primary utility network. Primary utilities include, but are not limited to, lines for water, wastewater, storm sewer, electricity, natural gas, steam, telephone, and cable systems. Show all granted easements and rights of way for utilities, as well as central and alternative (e.g., solar) energy sites. Development of an Installation Primary Utility Plan must be closely coordinated with the owner(s) of privatized utility system(s), as appropriate.

3-7 INSTALLATION PLANNING STANDARDS.

Installation Planning Standards provide a clear set of guidelines to ensure the installation’s vision and planning objectives for development are achieved, even if drastic changes to missions or programs occur. These standards are developed to 1) meet **\2** extreme **/2/** weather and **\2** military installation **/2/** resilience, and energy efficiency requirements; 2) promote visual order and architectural consistency; 3) enhance the natural and man-made environments through consistent architectural themes and standards; and 4) improve the functional aspects of the installation. At a minimum, include BES, SES, and landscape standards.

3-7.1 Building Envelope Standards (BES).

The intent of BES is to shape and detail public space that is safe, comfortable, and functional through placement and envelope controls for each building type. The standards aim for the minimum level of control necessary to meet the planning goals and include BES, site-planning standards, and building-related force protection standards. Relate the BES to existing environments where appropriate and feasible. Typical elements defined in each BES are massing, height, placement (e.g., required build-to lines and percentage of building that must be built to the required build-to lines), allowable parking locations, materials, and use. Also included is a general description of the building type. Each BES is coded to the Regulating Plan. Installations will develop a BES for each applicable building type on the installation, including the following:

- Mission building types (flightline facilities, hangars, and simulator facilities)
- Industrial building types (warehouses, maintenance facilities, research labs, and production facilities)
- Administrative building types (headquarters facilities and general offices)
- Medical building types (medical centers, hospitals, and clinics)
- Mixed-use building types (mixed-use building types incorporate commercial uses on the ground floor and any other type of approved uses above)
- Flex-use building types (flex-use building types incorporate any approved type of use on any floor)
- Commercial community support building types (large-format retail stores, religious buildings, schools, lodges, restaurants, bowling centers, recreation facilities, clubs, and stand-alone retail)
- Residential building types (single-family homes, row houses, townhomes, apartments, and unaccompanied personnel housing)

3-7.2 Street Envelope Standards (SES).

These standards illustrate typical configurations for all street types on an installation through SES. Each SES addresses vehicular traffic-lane widths, curb radii, sidewalk and tree planting area dimensions, and on-street parking configurations. An SES is required for every type of street specified on the installation. After a street type (or section of a street, as an entire street need not follow the same standard throughout its length) is selected, the characteristics desired for that street section will be documented in plan and section. The street types are coded to the Regulating Plan developed for each ADP and for the installation.

3-7.3 Landscape Standards.

Landscape standards show the appropriate type and placement of landscape elements, which may include natural landscape features (trees, ground cover), man-made hardscape features (street furniture, signage, lighting), and landscape-related force protection standards. Landscape standards identify the installation's landscape theme(s), addressing both design intent and allowable plant materials and site furnishing elements. At a minimum, these standards will address street tree placement and type. Ensure compliance with UFC 3-201-02, *Landscape Architecture*.

3-8 INSTALLATION DEVELOPMENT PROGRAM.

The Installation Development Program is the overall strategy for using and investing in real property to support installation missions and DoD objectives. It describes permanent comprehensive/holistic solutions, as well as short-term actions necessary to correct deficiencies and meet current and future mission needs through a method that ensures infrastructure reliability and contributes to **\2** resilient **/2/** development.

3-8.1 Program Elements.

The Installation Development Program will be completed at the installation level and reflected in component parts in each ADP. It will include the following elements:

3-8.1.1 Narrative.

Begin with an executive summary describing the key facility areas requiring the most attention in the near future, including a listing of required facilities and existing surplus or deficits. The program narrative provides a description of key development issues and strategies used to overcome these issues. The program narrative includes all interim steps required to achieve the desired end state.

3-8.1.2 Project Listing.

Include a list of major projects planned for the installation and identify all funding sources and project types: MILCON, major renovation or recapitalization projects (O&M), military family housing (MFH), non-appropriated funds (NAF), Army and Air Force Exchange Service (AAFES), Navy Exchange (NEX), Marine Corps Community Services (MCCS), Defense Commissary Agency (DeCA), MWR, resilience, and energy projects, real estate actions, public-private initiatives, and privatized housing, lodging, or utilities initiatives. Include projects identified in the Functional Annexes in this list and identified as supporting those efforts. Include demolition projects in the listing. Include information such as title, project number, fiscal year, and estimated program amount. The listing should address all programmed projects as well as other known projected requirements that may not yet be programmed. If no fiscal year or program amount is known at the time, note that the project requires programming.

3-8.2 Program Development.

Program development is the process of developing the Implementation Plan for ADPs and allocating resources (funding) to each of the projects. Planners will consult with programmers to identify the program requirements. A portion of programmed requirements on military installations will focus on recapitalization, sustainment, and restoration of existing infrastructure. Program development will be based in part on Service-specific facility evaluation systems and condition assessments.

3-9 PLAN SUMMARY.

Once the above planning processes and products are completed, prepare a Plan Summary that includes the Vision Plan, executive summaries of the ADPs, appropriate Network Plans, and a summary of the Installation Development Program. Prepare the Plan Summary to allow sharing with community partners.

3-10 FUNCTIONAL ANNEXES.

Functional Annexes support the master planning process by providing inputs to planning framework and the Vision Plan, especially with goals and objectives for long-term development and constraints to be considered at all stages of installation planning. Functional Annexes identify gaps in facilities and infrastructure which are addressed in the master planning process. Functional annexes include, but are not limited to, IEPs, **\2** MIRCs **/2/**, ADEPs, Complex Plans, and PDPs. Planners should include the associated updates to the Master Plan core documents for these planning efforts, including constraints and opportunities maps, ADPs, and Installation Development Programs. The IEP and **\2** MIRC **/2/** are required under this UFC to meet the requirements of 10 USC 2864. Follow Service-specific guidance on additional Functional Annexes.

3-10.1 Installation Energy Plan (IEP).

\2 The requirements for **/2/** preparing the energy resilience portion of the IEP **\2** are **/2/** contained in DoDI 4170.11, *Installation Energy Management.* This instruction is supplemented by the guidance provided in the OASD (EI&E) Memorandum, "**\2** Installation Energy Plans – Energy Resilience and Cybersecurity Update and Expansion of the Requirement to All DoD Installations **/2/**," effective **\2** May 2018 **/2/**. Follow the guidance in these two documents when developing IEPs. **\2\ /2/**

3-10.2 \2\ Military Installation Resilience Component (MIRC) /2/.

\2 The requirements for MIRCs are described in 10 USC 2964(a), 10 USC 2864(c), and FY25 NDAA Section 2847 on water resilience, coastal erosion resilience, and stormwater management. **/2/**

3-10.3 Area Development Execution Plans (ADEP).

Use ADEPs to synchronize project requirements identified in the programming phase. Use Service-specific tools and methods or processes identified during the planning phase as part of the plan-based programming approach. Develop ADEPs at the district level but each Service or installation may develop ADEP plans by parcel or grid. The outcome is a technical plan depicting all projects and a database for integration into the installation’s five-year work plan.

3-10.4 Complex Plan.

A Complex Plan, also referred to as a campus plan or nodal plan, bridges the scale between district-wide ADPs and building-specific site plans. These plans are useful when a tenant or user has a need for a grouping of facilities within a district built from the district’s Regulating Plan and Planning Standards to synchronize the identified requirements with the district’s planning goals. A Complex Plan includes specific building footprints scaled to the program for known projects, existing buildings, buildings under construction, buildings slated for demolition, and existing and proposed horizontal infrastructure, including streets, sidewalks, parking areas, and open spaces.

3-10.5 Project Development Plan (PDP).

The PDP (also known as Customer Concept Documents [CCD] or Planning Charrette Report [PCR]) documents the concept for a proposed new building or renovation project. Designers prepare a PDP following completion of an ADP or Campus Plan to connect the PDP to the planning direction for the district or campus. This allows architecture and planning to work together in support of the installation's planning vision. A PDP results in products planners can relay to designers to complete the design process.

A PDP includes:

- Room-by-room program development
- Construction budget
- Energy model tied to the district's **\2** IEP **/2/** if one is in place
- Weather **\2** resilience **/2/** analysis
- Site plan tied to the district's Regulating Plan and Planning Standards
- Conceptual floor plans, elevations, building sections and major system narratives to inform the development of follow-on programming documentation which may include DD 1391s or site approval forms
- Rendering(s) to illustrate the quality of the proposed project

Designers can develop PDPs for MILCON, SRM, and other applicable project types with input from a focused group of stakeholders using a participatory planning process in preparation for completion of the programming documentation (i.e., DD Form 1391). The intent is to bridge planning to programming and the design process.

3-11 SITE APPROVAL PROCESS.

Site all facility acquisition or construction projects in accordance with an approved Master Plan. An approved Master Plan siting means the project meets all guidelines and objectives set forth in the Regulating Plan and Installation Planning Standards. All projects must have approved site selections prior to the start of design. Attain site approval during the project programming process for SRM projects and during development of the DD Form 1391 for MILCON projects. All projects must remain in compliance with the Master Plan through the design process. Projects proposed by affiliated agencies, including, but not limited to, privatized housing contractors, MCCS, NEX, AAFES, DeCA, Defense Health Agency, and Department of Defense Education Activity (DoDEA) must also have the sites approved. Refer to Service-specific guidance for the detailed site approval process.

3-12 PROJECT REQUIREMENTS AND THE REGULATING PLAN.

Requirements for construction projects must be succinct, clear, and in conformance with the Master Plan. The Regulating Plan provides the required regulatory guidance to ensure the installation's vision for development is met. Apply the Regulating Plan to all forms of acquisition used to implement the Master Plan. Include the Regulating Plan and supporting BES, Landscape Standards, and SES in the solicitation for proposed construction projects and subsequent contract documents for design and development of a project. Include single-line drawings (floor plans, elevations) if they are developed as part of an ADP to illustrate a way to meet the intent of the Regulating Plan. Evaluate project designs on how well they conform to the Regulating Plan and supporting standards.

3-13 INSTALLATION PLANNING BOARD (IPB) MASTER PLAN ENDORSEMENT AND APPROVAL PROCESS.

The IPB (Facilities Board for the Air Force) will approve the installation's Master Plan and it will be endorsed by the appropriate approval authority designated by each Service. The Master Plan is the result of an iterative process and can be approved in parts or as a whole, depending upon completion timelines. Approve the Vision Plan, IDP, Program, and Installation Planning Standards as they are completed. Specific approval procedures are developed by each Service.

3-13.1 Installation Planning Board (IPB).

Each Service determines the responsible authority to establish and convene an IPB. The IPB will assist the installation leadership to manage, develop, and, in some cases, realign, clean up, and close the installation, supported sites, or area facilities and real estate. Every installation will have an IPB. See Appendix A for recommended roles, responsibilities, membership, and operations of an IPB.

3-13.2 Endorsement.

An appropriate authority determined by each Service will endorse the installation's overall Master Plan. This endorsement can take the form of a separate letter or a letter integral to the document. Update the endorsement with each change of command. A new commander, however, does not drive the need for an updated Master Plan; do not update Master Plans solely due to a change of command. The intent of the collaborative, integrated planning process described in this UFC is to produce **\2** an Installation **/2/** Master Plan that can be updated as mission needs (not command changes) dictate.

3-13.3 Headquarters Approval.

Installations must submit their master planning products to the appropriate headquarters agency for approval in accordance with Service-specific policy and regulations.

This Page Intentionally Left Blank

CHAPTER 4 KEY PERFORMANCE INDICATORS

4-1 GENERAL.

This UFC establishes key performance Indicators or metrics used to track compliance with the requirements herein. Each Service will establish procedures to track these indicators for every installation. In addition, in recognition of the complexities of planning at today's military installations and the need for continuous training, this UFC recommends each Service establish minimum training requirements for planners and installation leadership.

4-2 MASTER PLAN COMPLIANCE.

Master Plan compliance will be evaluated using three tiers. Tier 1 is required compliance with minimum products. Tier 2 is required compliance with the planning strategies. Tier 3 is optional conformance to a suggested set of planning principles tied to the installation vision. Evaluate installation Master Plans against the following key performance indicators.

4-2.1 Tier 1: Product Compliance.

Each Service will ensure installations have the appropriate planning products that document their planning process. At a minimum, every installation will have a Master Plan that includes:

- Vision Plan and its elements
- IDP, including ADPs, and its elements
- Installation Planning Standards (BES, Landscape Standards, and SES)
- Installation Development Program and its elements
- Plan Summary
- IEP and **\2** MIRC ***/2/*** as a Functional Annex

An appropriate higher level of authority will evaluate planning products. Per DoDI 4165.70, Master Plans will cover at least a ten-year period and be reviewed and updated at least every five years. Services will report the number of Master Plans with all products complete and current on an annual basis during the Program Objective Memorandum briefings to OSD.

4-2.2 Tier 2: Strategy Compliance.

All Master Plans will incorporate the appropriate planning strategies identified in Chapter 2 of this UFC. An appropriate higher level of authority will evaluate integration of the strategies into installation Master Plans.

4-2.3 Tier 3: Principle Compliance.

Compliance with the planning principles in Appendix B is optional. Planners should, however, incorporate the relevant principles into their Master Plans to support the installation's planning vision. Conformance can be measured using a variety of quantitative methods. For examples, refer to Appendix B.

4-3 TRAINING REQUIREMENTS.

Training on installation master planning is an essential function and will be supported by each Service. This includes training for DoD master planners, installation commanders and contractors. The DoD Master Planning Institute, hosted by USACE, is an appropriate source for planning training. See Appendix C for more information.

4-4 CERTIFICATION.

For master planners working in and with DoD, successfully passing and maintaining certification through the American Institute of Certified Planners (AICP) is encouraged.

APPENDIX A BEST PRACTICES

A-1 JOINT BASE LEWIS-MCCHORD REAL PROPERTY MASTER PLAN.

Starting in August 2007, planners at Joint Base Lewis-McChord began developing a new real property Master Plan that incorporates many of the strategies and requirements of this UFC. The result is an award-winning plan that has successfully guided development at the installation. The American Planning Association's Federal Planning Division honored the Historic Downtown Area Development Plan in 2008 and the entire Real Property Master Plan as "Outstanding Federal Planning Project (Honorable Mention)" in 2010.

A-1.1 Planning Strategies.

The focus of the effort is on **\2** resilience **/2/** planning using the following principles: compact, infill, and transit-oriented development; horizontal and vertical mixed-uses; multi-story and narrow buildings; and connected transportation networks. The plan also incorporates other strategies in this UFC, including natural and cultural resource preservation, healthy community planning, defensible planning, and capacity planning. The plan was created using area development planning tied together with network planning and implemented through the use of form-based planning—a first for DoD. With the plan in place, installation staff are now able to implement plan-based programming.

A-1.2 Planning Process.

A-1.2.1 The process described in this UFC was applied at Joint Base Lewis-McChord.

A-1.2.2 Installation planners and stakeholders first met in a series of public workshops to create the Vision Plan. **\2\ /2/**

A-1.2.3 The Vision Plan included a Framework Plan and an overall constraints and opportunities map. The Framework Plan subdivided the installation into planning districts and identified key planning concepts to guide the district planning effort.

A-1.2.4 Upon completion of the Vision Plan, the team began work on the IDP by focusing first on completing Regulating Plans, Illustrative Plans, Implementation Plans, and supporting sketches and renderings for each district's ADP. When the ADPs were completed, the planning team created overall Network Plans that include an overall Regulating Plan (Figure A-1), Illustrative Plan, Transportation Plan (Figure A-2), Pedestrian and Bikeway Plan (Figure A-3), and Open Space Plan (Figure A-4).

Figure A-1 Regulating Plan

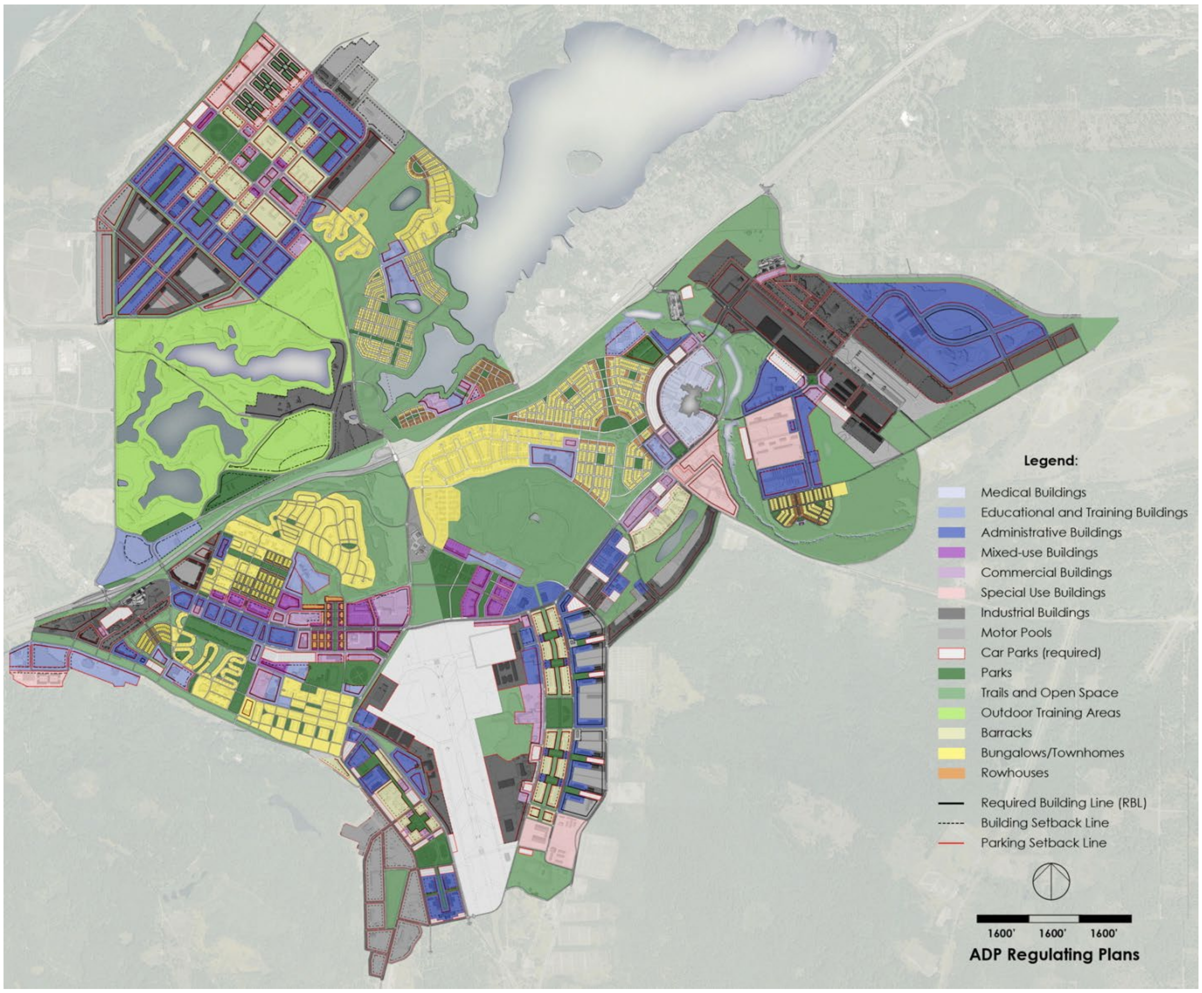


Figure A-2 Transportation Plan

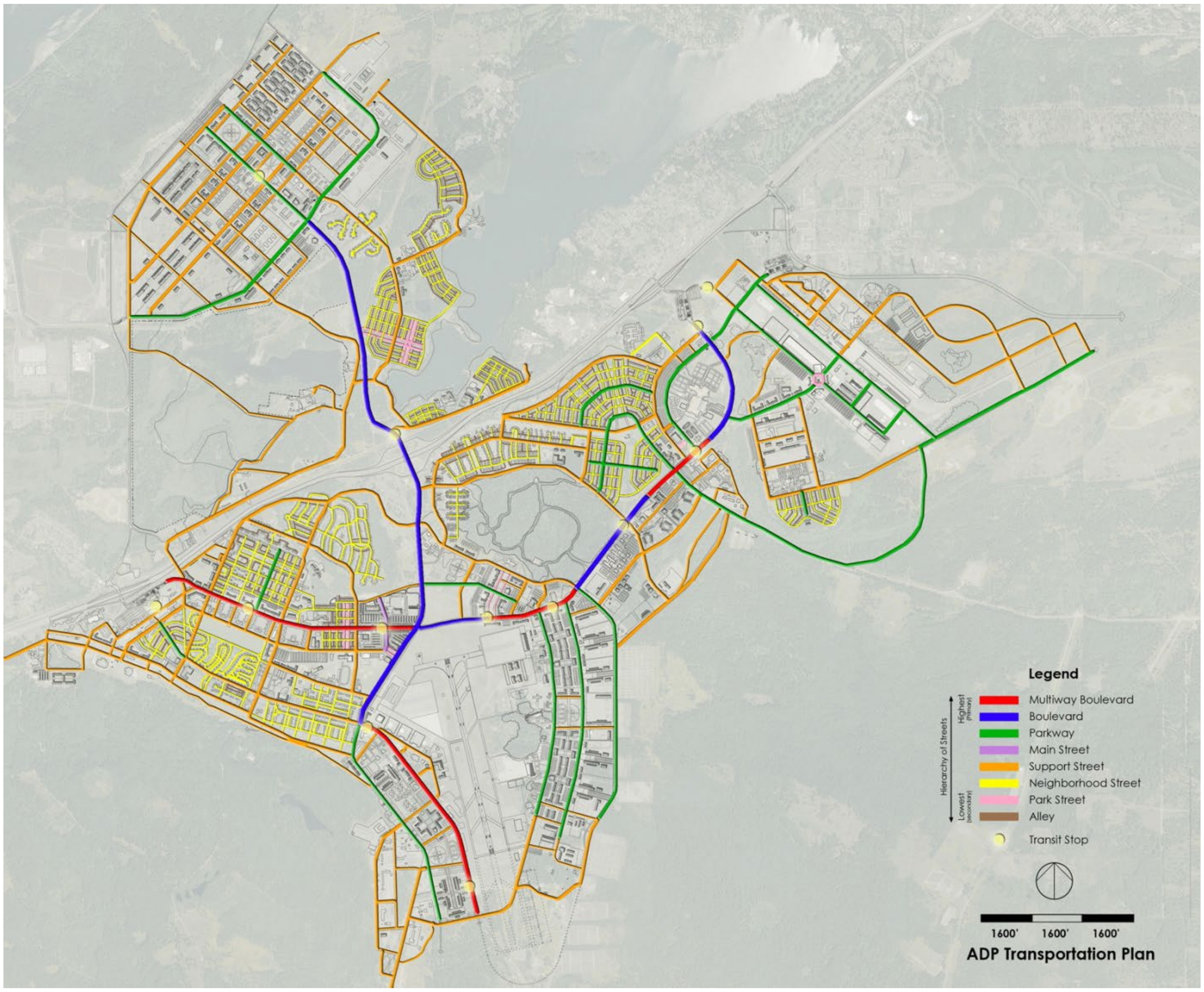


Figure A-3 Pedestrian and Bikeway Plan

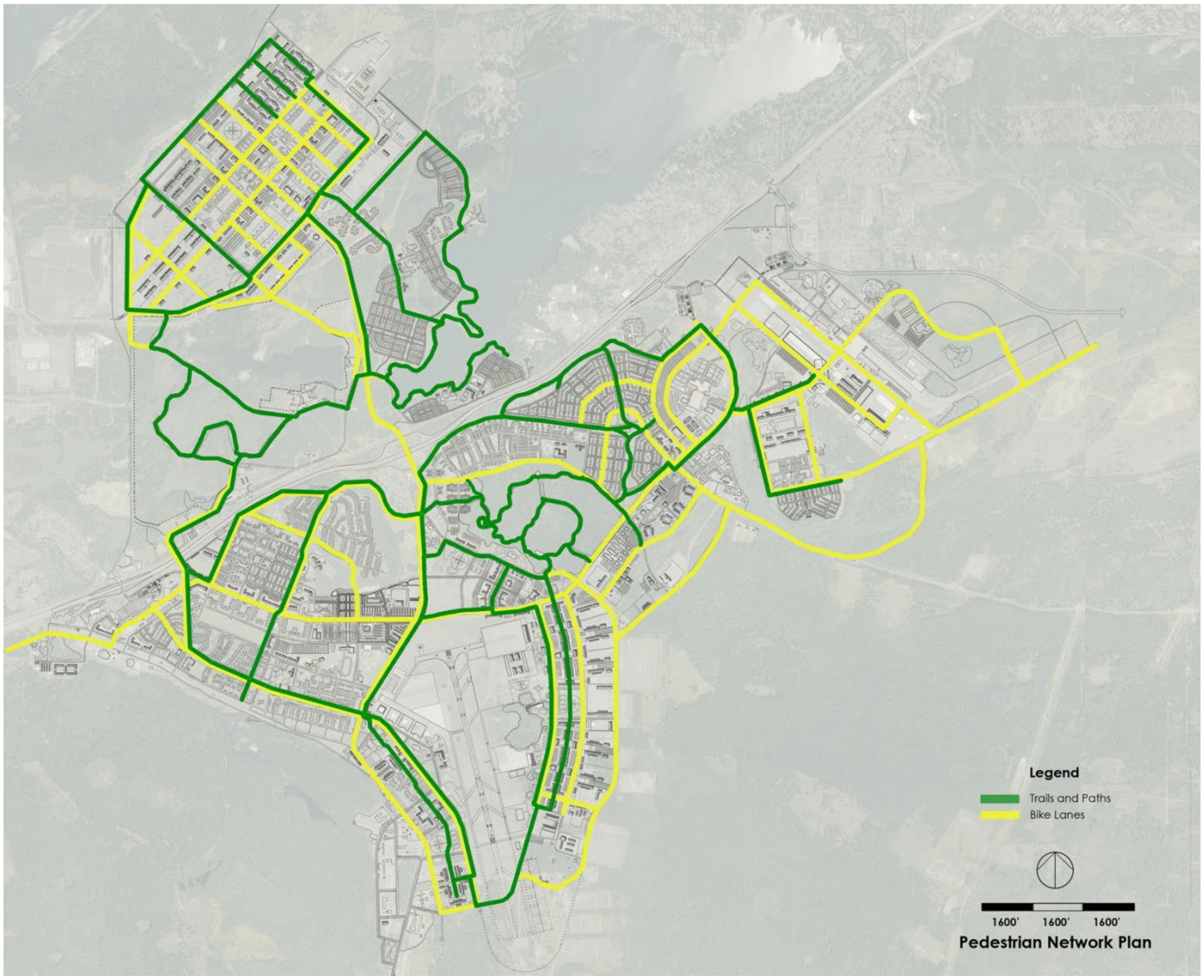
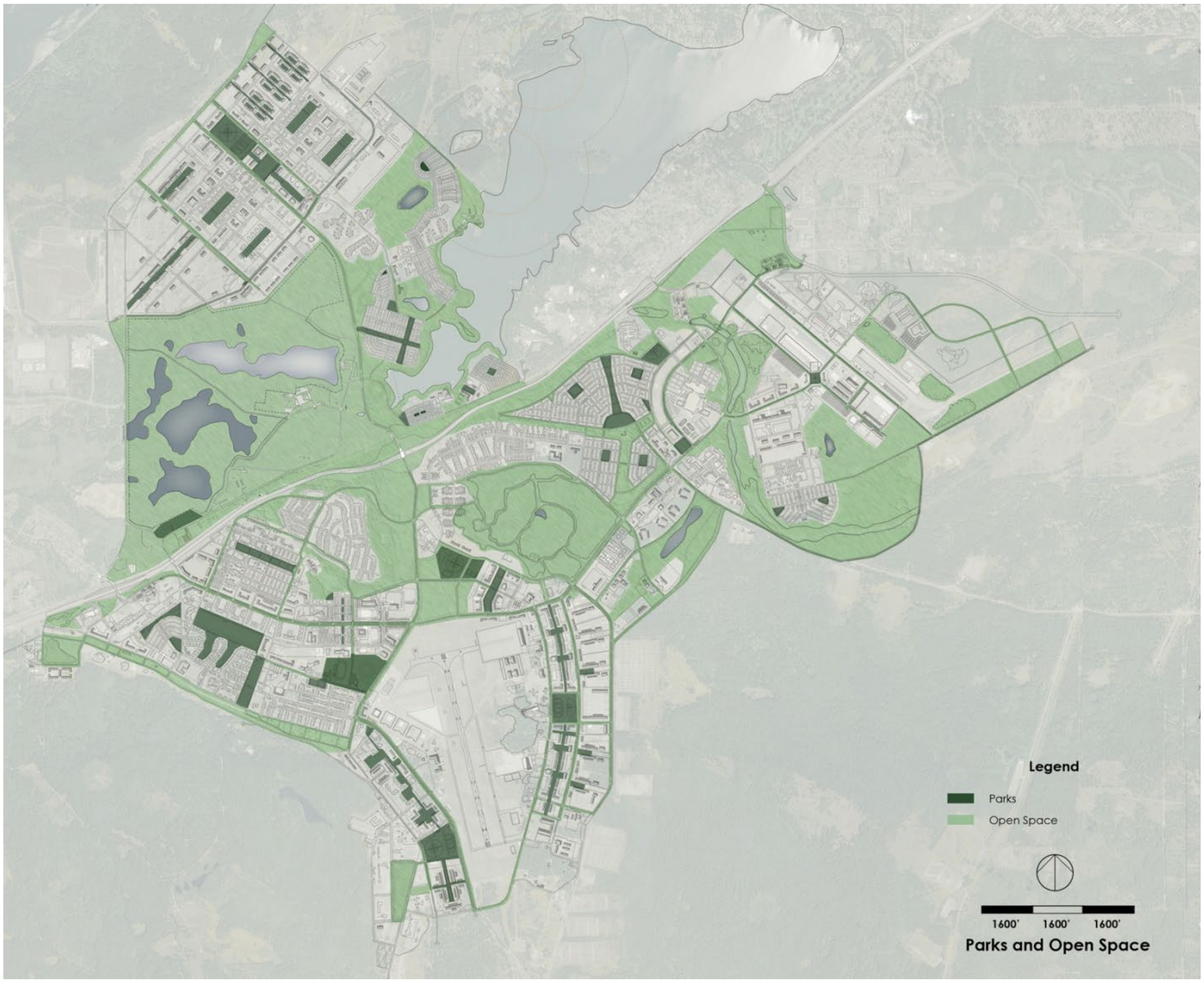


Figure A-4 Open Space Plan



A-1.2.5 As part of the area development planning process, the planning team developed Installation Planning Standards for streets, buildings, and landscapes. Additionally, within each ADP, the team documented the Installation Development Program. A Plan Summary, referred to by the Army as the Real Property Master Plan Digest, documented the entire effort.

A-1.3 Plan Implementation.

A-1.3.1 The plan integrated into the installation's planning process. Upon completion, the garrison commander and the senior mission commander endorsed the plan. Perhaps most importantly, the Regulating Plan is used in the site approval process, and when proposed projects do not conform to the regulations, they are sent back to the project proponents for revision or reconsideration. Additionally, relevant elements of the plan are used to guide decisions of the IPB and **\2** other installation boards and committees.**/2/**

Figure A-5 Street Transformation

A-1.3.2 The images in Figure A-5 are from a street transformation at Joint Base Lewis-McChord and demonstrate how planning can be used to synchronize infrastructure and facility investments.

A-1.4 Key Performance Indicators.

Installation planning staff created a**\2\ /2/** system to identify how well the installation is performing with regards to the Master Plan. Based on the planning vision, they identified **\2\ /2/** planning goals, **\2** for example, **/2/** mission capabilities, **\2\ /2/** walkable neighborhoods, identifiable town centers, and great streets. **\2** Each goal was **/2/** operationalized through **\2\ /2/** design principles. Each principle **\2** was assigned **/2/** a rating **\2\ /2/** used to score conformance at any stage in the development cycle, from the current condition to complete build-out. The metric **\2** was **/2/** based on a point system similar to the LEED Reference Guide for Neighborhood Development (LEED-ND) **\2** where **/2/** planning staff assign scores for each principal based on their assessment of the condition. This process **\2** was **/2/** completed for each district on a regular basis to assess progress towards fulfillment of the planning vision.

\2\ /2/

A-1.5 Benefits.

At Joint Base Lewis-McChord, the plan has been used to focus and guide development across the installation. It helps planners, stakeholders, and installation leadership make effective development decisions that conform to the planning vision but also gives them flexibility through the Regulating Plan to accommodate new and changing mission requirements. The plan found room for two new brigade combat teams and over 2,000 new housing units in a growth boundary defined by cantonment that was previously considered built-out. As a result of incorporating principles of **\2** resilience **/2/** planning, at build-out, the plan will result in forecasted annual reductions of 11.4 million vehicle miles travelled, 12.9 million pounds of carbon emissions, and per-household gasoline costs of $1,500.

A-2 FORT HUNTER LIGGETT INSTALLATION DESIGN GUIDE (IDG).

In 2010 and 2011, planners and other installation staff worked together to create a series of planning documents for Fort Hunter Liggett, California. In addition to crafting ADPs that conform to this UFC, they drafted a new IDG for Fort Hunter Liggett. The Fort Hunter Liggett IDG sets a new standard for these types of planning documents. Previously, such documents were several hundred pages long. Yet, despite the length, they provided little specific guidance for planners. Rather, these documents provided details regarding construction, signage, and interior systems. The intent was that these detailed guides could be included in construction requests for proposals (RFP). The reality, however, was different. These documents were typically too cumbersome to be used in RFPs and, as a result, they were not heavily used. At Fort Hunter Liggett, the goal was to use the IDG to provide specific guidance to planners in as few pages as possible. The Fort Hunter Liggett IDG sets the planning standards for streets, buildings, and landscapes.

A-2.1 Process.

Installation personnel and leaders worked to develop a vision, goals, and a complementary design language to address key planning issues facing Fort Hunter Liggett. The resulting planning vision, principles, and Framework Plan guided the preparation of three ADPs. Using an evaluation of images of the built environment, analysis of the planning strengths and weaknesses found on the installation, and through a series of collaborative workshops and discussions, the group developed a vision for planning at Fort Hunter Liggett:

> “To create a flexible training environment surrounding an attractive small town with walkable main streets and a usable town square, where soldiers, civilians, and their families enjoy living and working.”

A-2.2 Purpose.

The purpose of the IDG is to provide specific design guidance for standardizing and improving the quality of the total environment of the installation. This includes not only the visual impact of features on the installation, but also the impact of projects on the total built and natural environment. The improvement of the quality of visual design and development, and the use of **\2** resilient **/2/** design and development practices has a direct impact on the quality of life for those who live, work, or visit the installation. The IDG is to be used by all individuals involved in decision-making, design, construction, and maintenance of facilities. The primary users include the following: senior mission commander; garrison commander and staff; installation facility planning and design personnel; installation facility maintenance personnel; USACE project managers, design, and construction staff; consulting planners, architects, engineers, interior designers, and landscape architects; as well as supporting agencies such as the exchange, DeCA, DoDDS, MEDCOM, tenants. The IDG is organized to facilitate the preparation and execution of projects to improve the visual image on the installation and ensure the design conforms to Army standards **\2\ /2/**. Part I discusses the process, use, and implementation of the IDG. Part II addresses the BES, including setbacks, building form, building heights, and parking requirements. Part III establishes Street Envelope Standards (SES) for streets, intersections, service areas, and the pedestrian environment, and includes recommended dimensions, treatment of bicycle lanes, street tree spacing, and methods of incompatible use screening. Part IV outlines Landscape Standards, including objectives, guidelines, recommended plant selections, and plant spacing. Appendix A includes installation Regulating Plans for reference purposes. Appendix B describes aesthetic design guidelines, including recommended colors and materials. Appendix C documents the vision, goals, and principles for the installation. Appendix D is a technical design guide that outlines specific requirements for key installation construction elements.

A-2.3 Using the Installation Design Guide (IDG).

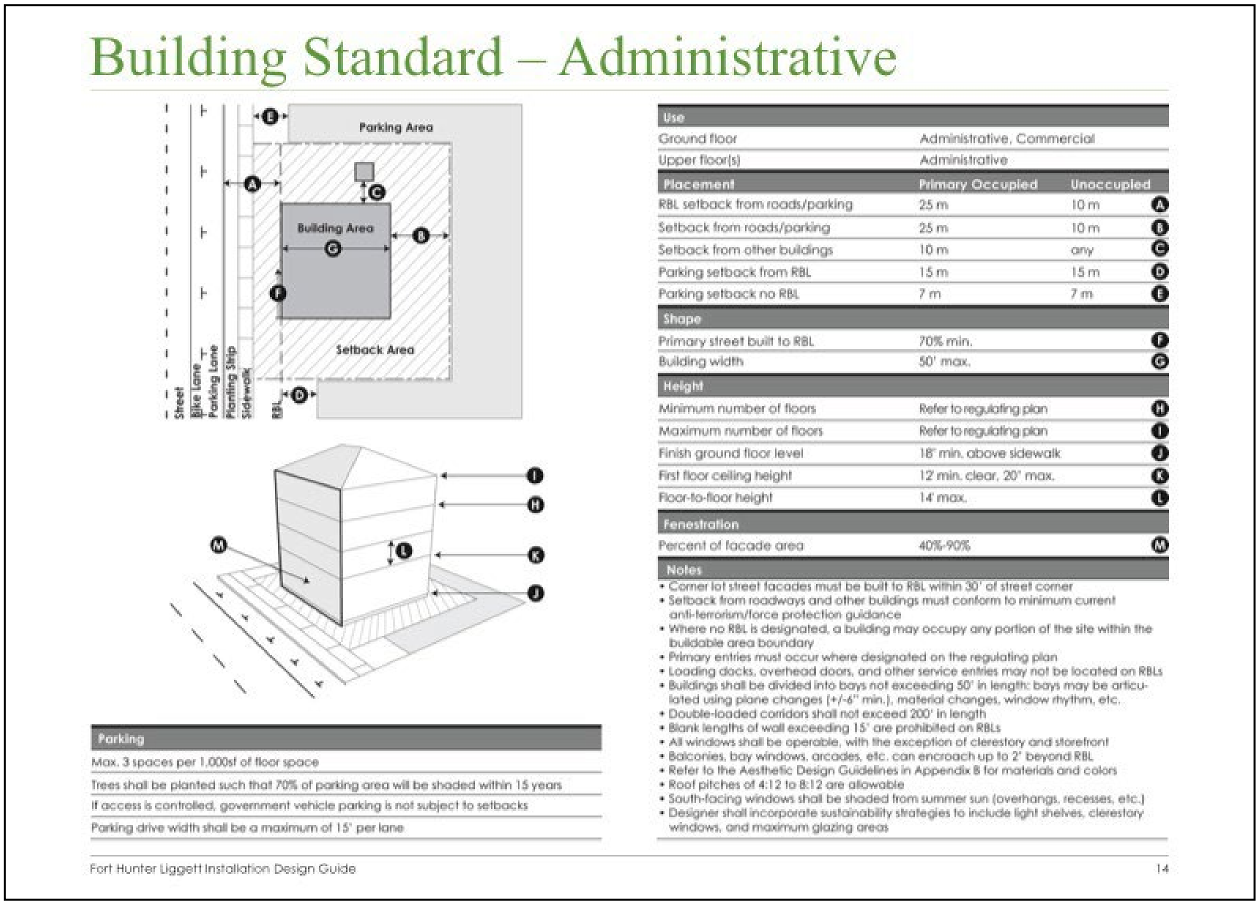
The IDG provides installation-specific design data. The general design concepts, recommendations, and standards addressed therein are applicable to construction and renovation projects at Fort Hunter Liggett, California. Planners use the IDG to determine the general design and construction considerations in the preparation of project plans. The IDG provides design guidelines and Army-wide design standards intended to be used in all projects, regardless of the funding source. The IDG is also used to develop requirements for programming documents for MCA construction (DD Form 1391), as well as cost estimates and preliminary and final designs (from both in- house and external design sources) involving exterior visual elements on the installation. The following steps illustrate how the design guide is used for the preparation of plans for new construction, renovation, and maintenance and repair projects on the installation:

- Step 1: Review the design goals, objectives, and principles included in ADP reports and Appendix C of the IDG.
- Step 2: Consult the regulating plan to determine the applicable standards for buildings, streets, and landscapes.
- Step 3: Review the applicable standards in Parts II through IV of the IDG.
- Step 4: Carefully analyze the existing conditions on the site and pay special attention to mature trees, riparian corridors, and building entries.
- Step 5: Design building form and site the project according to the Regulating Plan and appropriate standards.
- Step 6: Select building materials and colors from Appendix B of the IDG.
- Step 7: Select the appropriate landscape materials.
- Step 8: Assemble all plans documenting conformance to applicable standards and guidelines.

A-2.4 Building Envelope Standards (BES).

The design character of an installation’s buildings affects the installation’s overall image. The building design component encompasses the character of the buildings as well as their relationships to one another and the environment. The continued preservation of historically and culturally significant structures adds to an installation’s character. This section includes BES to regulate the form, setbacks, uses, and support requirements of any given construction project at Fort Hunter Liggett. Together with the Regulating Plan, these standards create a form-based planning practice that will facilitate mission readiness, energy-efficiency, and walkable development patterns in support of the installation’s vision.

Figure A-6 Building Envelope Standards (BES) Graphic



Building Standard – Administrative

Use			
Ground floor	Administrative, Commercial		
Upper floor(s)	Administrative		
Placement	**Primary Occupied**	**Unoccupied**	
RBL setback from roads/parking	25 m	10 m	A
Setback from roads/parking	25 m	10 m	B
Setback from other buildings	10 m	any	C
Parking setback from RBL	15 m	15 m	D
Parking setback no RBL	7 m	7 m	E
Shape			
Primary street built to RBL	70% min.		F
Building width	50' max.		G
Height			
Minimum number of floors	Refer to regulating plan		H
Maximum number of floors	Refer to regulating plan		I
Finish ground floor level	18" min. above sidewalk		J
First floor ceiling height	12' min. clear, 20' max.		K
Floor-to-floor height	14' max.		L
Fenestration			
Percent of facade area	40%-90%		M

Notes

- Corner lot street facades must be built to RBL within 30' of street corner
- Setback from roadways and other buildings must conform to minimum current anti-terrorism/force protection guidance
- Where no RBL is designated, a building may occupy any portion of the site within the buildable area boundary
- Primary entries must occur where designated on the regulating plan
- Loading docks, overhead doors, and other service entries may not be located on RBLs
- Buildings shall be divided into bays not exceeding 50' in length; bays may be articulated using plane changes (+/-6" min.), material changes, window rhythm, etc.
- Double-loaded corridors shall not exceed 200' in length
- Blank lengths of wall exceeding 15' are prohibited on RBLs
- All windows shall be operable, with the exception of clerestory and storefront
- Balconies, bay windows, arcades, etc. can encroach up to 2' beyond RBL
- Refer to the Aesthetic Design Guidelines in Appendix B for materials and colors
- Roof pitches of 4:12 to 8:12 are allowable
- South-facing windows shall be shaded from summer sun (overhangs, recesses, etc.)
- Designer shall incorporate sustainability strategies to include light shelves, clerestory windows, and maximum glazing areas

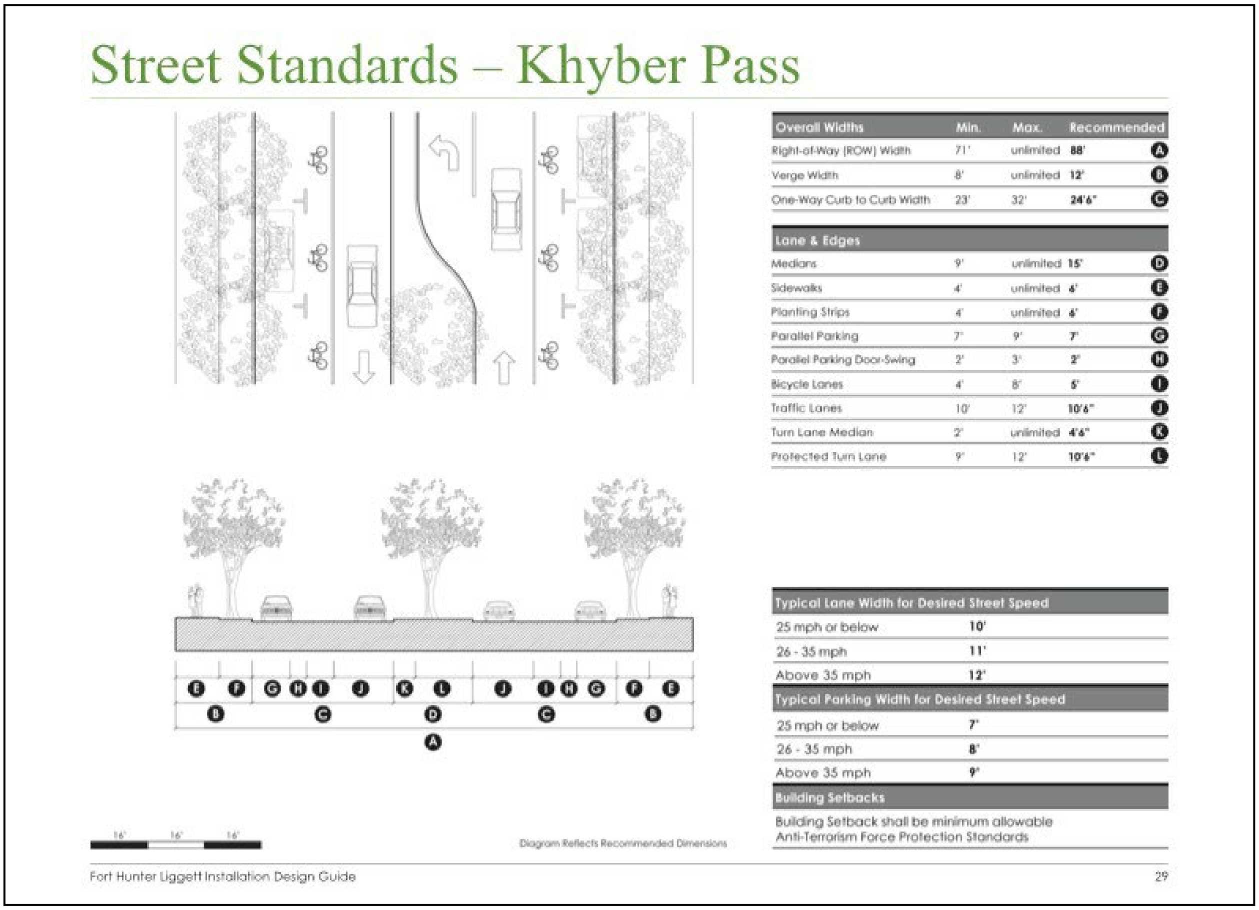
Parking
Max. 3 spaces per 1,000sf of floor space
Trees shall be planted such that 70% of parking area will be shaded within 15 years
If access is controlled, government vehicle parking is not subject to setbacks
Parking drive width shall be a maximum of 15' per lane

Fort Hunter Liggett Installation Design Guide 14

A-2.5 Street Envelope Standards (SES).

The image and functionality of the installation is greatly determined by the design and location of roadways, walkways, entrances, and parking lots. The primary roadway system and parking lots utilize considerable amounts of land and are a visually dominant element of any installation. This section provides detailed street, intersection, and parking standards for the installation.

Figure A-7 Street Envelope Standards (SES) Graphic



A-2.6 Landscape Standards.

The Landscape Standards address the selection, placement, and maintenance of trees, shrubs, and ground cover on the installation. The visual image conveyed by a military installation is defined not just by architectural character and site organization, but also by an attractive, organized landscape design. The presence of plant material on the installation greatly enhances the visual character and environmental quality of the installation. Plantings add an element of human scale to open spaces and can be used functionally to screen undesirable views, buffer winds, reinforce the hierarchy of the circulation system, or provide a visual transition between dissimilar land uses.

Figure A-8 Landscape Standards Graphic

Plant Material Selection – Trees

Pages 58-60 list various trees, shrubs, and ground cover plants to be used at Fort Hunter Liggett. The charts illustrate appropriate usage and spacing for each species. For additional recommendations, reference the plant list provided by Fort Hunter Liggett's Environmental Department.

Tree Species	Street Tree	Specimen/ Individual	Shade	Park	Fire-Tolerant	Drought-Tolerant	Spacing
California Sycamore Platanus racemosa	●	●		●			20' o.c.
Coast Live Oak Quercus agrifolia	●		●		●		25' o.c.
Box Elder Acer negundo var. californicum	●		●	●			30' o.c.
Hollyleaf Cherry Prunus ilicifolia		●			●	●	15' o.c.
California Laurel Umbellularia californica	●	●	●	●			30' o.c.
Western Redbud Cercus occidentalis		●	●	●		●	10-15' o.c.
California Juniper Juniperus californica		●	●	●		●	Individual
Valley Oak Quercuse lobata		●	●	●	●		Individual
Desert Ironwood Olneya tesoto		●				●	15' o.c.

Fort Hunter Liggett Installation Design Guide 59

A-3 OPERATION OF AN INSTALLATION PLANNING BOARD (IPB).

A-3.1 Primary Responsibilities.

The IPB (also called the Facilities Board) ensures the orderly development and management of installation real property in support of the planning vision and the installation mission. The IPB guides the development and maintenance of all components of the Master Plan and helps ensure the Master Plan addresses all real property requirements for all agencies and activities on the installation and supported areas, and reflects changes in installation missions and the military community's current or future development plans, with full consideration of, and respect for, regional and local communities.

A-3.1.1 Coordination.

The IPB ensures the Master Plan is coordinated with:

- Adjacent and nearby installations

- Other activities and land use of DoD and federal agencies
- Federally recognized Native American tribes, recognized Alaskan native entities, and Native Hawaiian organizations
- Local agencies and planning commissions of neighboring cities, counties, and states for mutual development concerns, encroachment issues impacting range operations and training, and environmental issues (Established intergovernmental coordination processes will typically be followed.)
- Interested non-governmental groups and associations, state recognized tribes, businesses, and concerned individuals
- State historic preservation officer (SHPO)

A-3.2 Additional Responsibilities of the IPB.

The IPB will also:

- Approve installation architectural and design themes, as set forth in the Installation Planning Standards; monitor compliance; and adjudicate conflicts and variances from the established standards.
- Develop plans and programs that are in harmony with, protect, and enhance the environment and are observant of **\2** resilient **/2/** design and development policies and objectives.
- Ensure maximum use of existing facilities; oversee the assignment and reassignment of space within existing facilities; monitor land use; and adjudicate conflicts in facility, land use, or assignments.
- Oversee actions to realign, clean up, impose land use controls, and close the installation or locations supported by the installation, as required.
- Resolve Master Plan disputes between competing organizations on the installation.
- Adjudicate variances from the Installation Planning Standards and forward for approval.

A-3.3 Composition of the IPB.

The IPB is comprised of members or alternates, appointed on orders, and organized as follows:

- **Chair.** The chair is designated by each Service and could be the senior commander or garrison/base/installation commander.
- **Voting Members:**
    - Chair

  - Military or civilian commanders of Civil Engineering, Public Works, or appropriate equivalent. This individual also serves as the Executive Secretary of the Board.
  - The director/chief of each principal and special staff section of the organization, the environmental coordinator or NEPA planner, and other staff members designated by the IPB Chair.
  - The commander or appointed representative of each unit or independent activity designated by the commander, including Guard and Reserve activities occupying real property administered by the commander. This includes all activities located within the boundaries of the installation or at physically separate sites for which the commander has real property master planning responsibilities.
  - For installations with a high number of historic properties, recommend including the installation Cultural Resource Manager as an IPB member.
- **Guests.** The Chair may invite guests to IPB meetings. Guests may include representatives of U.S. or host nation regional and local governments, representatives of planning agencies in the community, non-governmental groups, Federally recognized tribes, Alaska Native corporations, Native Hawaiian organizations, and property or business owners in the community affected by IPB planning decisions.

Service-specific requirements may override composition and voting members of the IPB, as appropriate.

A-3.4 Meetings of the IPB.

Each Service determines the meeting schedule and operations of the IPB. Generally, the secretary will prepare the meeting agenda, read-ahead packages, and perform other administrative tasks. The minutes will record voting members present and absent; associate member attendance; and topics discussed, including issues, points of discussion, board recommendations with vote tally, if appropriate, and decisions made.

A-3.5 Approval Responsibilities.

The IPB will recommend formal approval of:

- All components of the Master Plan and the resources required to prepare and maintain them
- Variances from planning requirements established by the Regulating Plan and the Planning Standards
- Priorities and funding of Master Plan projects and other related resource issues

- Real property utilization and space assignment resolutions
- Other items within the purview of the Board’s charter, as designated by the Commander

This Page Intentionally Left Blank

APPENDIX B PLANNING PRINCIPLES

B-1 PURPOSE.

The purpose of this appendix is to outline specific planning principles applicable to military planning. Below is an example scorecard tool that organizes the principles into categories to support the planning strategies discussed in this UFC. This example of a score card is adopted from the principles in the LEED-ND program and adds appropriate principles tailored to military needs. Using a scorecard as a tool is effective in guiding **\2** resilient **/2/** energy-efficient development. While this scorecard is a good foundation, Services and their installations are encouraged to leverage their innovation, originality, and flexibility formulating their unique measurement tools.

B-2 PROCESS.

To use this scorecard, evaluate the existing condition at each district to determine a baseline score and then evaluate the approved ADP to determine the maximum possible score. In this example, requirements are identified with an “R” in the table and credits are identified with maximum points allowable.

Figure B-1 Principles for Military Development Criteria Table

\2\

	Military Development Resilience Credit Designation	Credits Available (note 1)
	Resilience Planning	**59 max**
SP1	Compact Development*	R
SP2	Compact Development*	6
SP3	Mixed-Use Neighborhood Centers*	4
SP4	Reduced Parking Footprint*	1
SP5	Street Network*	2
SP6	Transit Facilities*	1
SP7	Community Outreach and Involvement* (note 3)	2
SP8	Tree-Lined and Shaded Streets*	2
SP9	Water-Efficient Landscape*	1
SP10	Existing Building Reuse*	1
SP11	Historic Resource Preservation and Adaptive Use*	1
SP12	Stormwater Management*	4
SP13	Heat Island Reduction*	1
SP14	Solar Orientation*	1
SP15	On-Site Energy Sources*	3
SP16	District Heating and Cooling*	2
SP17	Wastewater Management*	2
SP18	Solid Waste Management Infrastructure*	1
SP19	Close-in Training	2
SP20	Hidden Parking	6
SP21	Car Parks	6
SP22	Mixed-Use Building	5
SP23	On-Installation Housing	5
	NATURAL AND CULTURAL RESOURCE PRESERVATION	**5 Max**
RP1	Imperiled Species and Ecological Communities*	R
RP2	Wetland and Water Body Conservation*	R
RP3	Floodplain Avoidance*	R
RP4	Range and Training Land Conservation	R
RP5	Steep Slope Protection*	1
RP6	Site Design for Habitat or Wetlands and Water Body Conservation	1
RP7	Restoration of Habitat or Wetlands and WaterBodies*	1
RP8	Long-term Conservation Management of Habitat or Wetlands and Water Bodies*	1
RP9	Minimize Site Disturbance in Design and Construction*	1
	HEALTHY COMMUNITY PLANNING	**17 Max**
HP1	Walkable Streets*	R
HP2	Porches	R
HP3	Walkable Streets*	12
HP4	Access to Civic and Public Spaces*	1
HP5	Access to Recreation Facilities*	1

HP6	Visitability and Universal Design* (note 4)	1
HP7	Local Food Production* (note 5)	1
HP8	Neighborhood Schools*	1
DEFENSIBLE PLANNING		
DP1	AT/FP Compliance	R
MAXIMUM POSSIBLE SCORE		81

/2/

Note 1 – R refers to a required item and credits are indicators of the relative importance of each area.
Note 2 – Deleted
Note 3 – Community outreach and involvement applies to on-installation populations only.
Note 4 – Follow local requirements for accessible housing requirements.
Note 5 – Deleted

B-3 APPLICABILITY.

The principles are applicable at the ADP scale prior to construction. Early in the planning process, establish the planning strategies applicable to the district and in the vision, establish the strategies that are important. In the example criteria above, a successful ADP will score more than 50 points. Districts without housing are exempt from the housing requirements of the criteria.

B-4 MILITARY DEVELOPMENT CRITERIA.

Planners can refer to LEED-ND for detailed explanations for the LEED-ND criteria noted in Figure B-1. However, for military development criteria, refer to the following descriptions.

B-4.1 Prerequisite: AT Compliance – Required.

Ensure that personnel are protected from possible terrorist attack. All new facilities sited as part of the project conform to the latest UFC criteria or approved local guidance on AT.

B-4.2 Prerequisite: Range and Training Land Conservation – Required.

Preserve mission-critical resources by protecting a range complex with associated surface danger zones (SDZ), impact areas, buffer areas, and training land from development. Locate the project such that 0% of the development area is located on installation-designated range and training land.

B-4.3 Prerequisite: Narrow Buildings – Required.

Improve productivity and indoor air quality and reduce energy costs using natural lighting and ventilation.

- As measured by total floor area, 90% of administrative, medical, commercial, and residential type facilities are designed at a maximum width of 50 feet. Hangars, warehouses, and retail facilities are exempt from this requirement.

AND

- The same facilities must be designed to include operable windows that provide daylight and natural ventilation to 75% of all regular occupants of building.

B-4.4 Prerequisite: Multi-Story Buildings – Required.

Reduce automobile use, infrastructure requirements, and land consumption by using vertical construction.

- As measured by total floor area, 90% of all new facilities sited must be two stories or more. Hangars, weapon storage facilities, and warehouses are exempt from this requirement.

B-4.5 Prerequisite: Alleys – Required.

Improve pedestrian safety, reduce automobile use, and support neighborhood cohesion by using alleys in all military family housing neighborhoods, whether funded by MILCON or privatized housing partners.

- Alleys with paving widths of no more than 15 feet will be used for all new housing and incorporated into redevelopment plans for existing housing except in areas with extreme topographic conditions.
- All garages and carports will be placed off of the alleys.

B-4.6 Prerequisite: Porches – Required.

Improve pedestrian safety, reduce automobile use, and support neighborhood cohesion by placing front porches on all single-family, duplex, and triplex homes in military family housing neighborhoods.

- Porches are a minimum 6 feet deep and 10 feet wide.
- Porches should be elevated from the street level by at least three risers. Ensure universal access through alley access or ramps.

- Rowhouses and townhomes with at least four connected units can use stoops in place of porches. Stoops must be a minimum 4 feet deep and 6 feet wide and must be at least three risers above the street level.

B-4.7 Prerequisite: Planting Strips – Required.

Improve pedestrian safety, enhance stormwater management, and provide locations for regularly placed street trees by using planting strips between the curb and sidewalks.

- Ensure planting strips are a minimum of 5 feet wide and located on both sides of all streets where sidewalks are used. This does not apply to "downtown" streets that have sidewalk widths of greater than 14 feet and regularly spaced street trees in tree gates no farther than 25 feet on center.

B-4.8 Credit: Close-In Training – 2 Points.

Provide mission-critical open spaces for physical training and formations needed to train Soldiers within close proximity of their workplaces.

- Site 1 square foot per Soldier of open space within a ¾-mile radius of any company operations facility. The number of Soldiers is determined by the number of occupants currently using (or planned) for that facility.
- Consolidated open spaces are encouraged, provided they fall within the required radius.

B-4.9 Credit: Hidden Parking – up to 6 Points.

Improve health and safety of residents and reduce impacts of automobile use by improving walkability of streets by placing commercial and residential parking to the rear or to the side.

- Locate 90% of off-street parking commercial uses to the rear or to the side of the structure (3 points)
- With the exception of visitor parking, locate all off-street parking for residential units to the rear of the structure and provide alley access (3 points)

B-4.10 Credit: Car Parks – up to 6 Points.

Improve stormwater retention, reduce heat islands, reduce land consumption per parked vehicle, and improve life of paving areas through parking lot design.

- In all surface parking lots with more than one bay of parking, place planting strips between every bay. Planting strips must be at least 15 feet wide and planted with shade-providing trees, placed 25 feet apart (2 points).

- An additional 2 points can be gained if the planting strips are designed to handle the entire stormwater runoff requirements of the parking lot. Design to accommodate a one-year 24-hour design storm (2 points).
- An additional 2 points can be gained if the paving is pervious surfacing (2 points).

B-4.11 Credit: Mixed-Use Buildings – up to 5 Points.

Reduce land use and automobile usage through mixing compatible uses in a single structure.

- Locate at least one mixed-use building within the highest density square mile of the project (1 point), or
- Locate at least two mixed-use buildings within the highest density square mile of the project (2 points), or
- Locate at least three mixed-use buildings within the highest density square mile of the project (3 points), or
- Locate at least four mixed-use buildings within the highest density square mile of the project (4 points), or
- Locate at least five or more mixed-use buildings within the highest density square mile of the project (5 points).

B-4.12 Credit: On-Installation Housing – up to 5 points.

Increase the amount of family housing on the installation to reduce **\2** impact **/2/** associated with commuting, reduce congestion at gates and on local roads, reduce family expenses associated with commuting, and support a more vibrant installation. To calculate the amount of housing per district, first identify the total military population and the total area of the cantonment (installation land area less range and training land). Then identify the total area of the district and determine the percentage of total installation land area within the district. Each district should hold the percentage of housing proportional to its land area. For example, if the installation is providing housing for 30% of assigned military families and the area of the district represents 50% of the area of the cantonment, then, to get 1 point of credit, the district needs to provide for 15% of the total housing inventory.

- Provide proportional housing within the district for 30% of assigned military families on the installation (1 point), or
- Provide proportional housing within the district for 40% of assigned military families on the installation (2 points), or
- Provide proportional housing within the district for 50% of assigned military families on the installation (3 points), or

- Provide proportional housing within the district for 60% of assigned military families on the installation (4 points), or
- Provide proportional housing within the district for 70% of assigned military families on the installation (5 points).

This Page Intentionally Left Blank

APPENDIX C MASTER PLANNING TRAINING

Master planning training is highly encouraged throughout DoD. Noted below are recommended guidelines for continuing education.

C-1 TRAINING FOR DOD MASTER PLANNERS.

All DoD employees employed as master planners are highly encouraged to complete at least 32 hours of professional continuing education related to master planning topics every two years. Training may count for multiple requirements (e.g., for AICP, PE, USGBC, AIA, ASLA, and/or continuing education credits and the fulfillment of this requirement) simultaneously. In addition, training and educational opportunities to support pursuit of AICP certification should be supported by each Service.

C-2 TRAINING FOR INSTALLATION COMMANDERS.

New garrison commanders (Army), installation commanding officers (Navy and Marine Corps), and Wing commanders, mission support group commanders, and civil engineers (Air Force) are highly encouraged to have at least four hours of master planning training before or within the first six months of assuming command, in a venue determined by each Service.

C-3 TRAINING FOR CONTRACTORS.

Contractor training is highly encouraged and joint training with military planners should be made available whenever possible.

C-4 MASTER PLANNING INSTITUTE (MPI).

The MPI, hosted by USACE, is a source for master planning training. The MPI coordinates opportunities to provide education and training for personnel working in planning throughout DoD. The MPI coordinates and publicizes courses available for master planners in each Service. These programs offer a series of planning courses, symposiums, and practicums to promote the strategies of master planning as emphasized in this UFC.

Relevant Army PROSPECT courses include:

- Master Planning Principles (75)
- Master Planning Practices (241)
- Master Planning Programming and Siting (326)
- Master Planning Visualization Techniques (948)
- Master Planning Advanced Techniques (952)

Relevant Air Force Institute of Technology Civil Engineer School Courses include:

- Introduction to Air Force Planning (WENG 519)
- Comprehensive Planning Fundamentals (WENG 520)
- Introduction to Asset Management (WMGT 301)
- Project Programming (WENG 423)

Relevant Naval Civil Engineer Corps Officers School courses include:

- Facilities Planner (A-4A-0016) - Naval Civil Engineer Corps Officers School (CECOS)
- Navy Master Planning – Commander, Navy Installations Command (CNIC)

Additional training opportunities available for master planners are offered through non-government sources, including the American Planning Association (APA). The Federal Planning Division (FPD) hosts a training workshop each year in conjunction with the APA's annual conference. The American Institute of Certified Planners (AICP) also offers courses and various training opportunities throughout the year.

APPENDIX D GIS DATA LAYERS

D-1 When preparing a constraints map, planners should refer to data embedded in the installation's GIS system. DoDI 8130.01 establishes policy, assigns responsibility and provides governance for the collection and maintenance of geospatial data related to DoD installations. The program is the Installation Geospatial Information & Services (IGI&S). Each Service requires adherence to the Spatial Data Standards for Facilities, Infrastructure, and Environment (SDSFIE); refer to Service-specific guidance for the most recent guidance. Geospatial data developed at or for the installation under this guidance and reported to the Service Headquarters is in turn reported and delivered to the Defense Installations Spatial Data Infrastructure (DISDI).

D-2 Datasets such as those identifying buildings, roads and road networks, utilities and utility networks, and environmental and cultural features such as habitat, nesting sites, and burial grounds, are usually collected via GPS or remotely acquired using appropriate technology. Coordinate with their local geospatial staff to ensure the most current datasets are being used for planning products.

D-3 A second group of geospatial datasets are a product of analysis. Airfield constraints, quantity distance arcs, noise contours, anti-terrorism and force protection (AT/FP) buffers, **\2** flood inundation mapping, **/2/** and areas proposed for disposal are layers that fit into the above category. These datasets require subject matter expert (SME) input and control. Acquire current and/or validated datasets from the appropriate SME prior to starting a planning project requiring these data.

D-4 The last group of geospatial datasets are those national datasets governed by non-DoD entities such as soils, wetlands, and floodplains. Coordinate with installation geospatial staff to be sure current and targeted data is acquired for planning projects. For constraints and opportunities maps, typical data layers referenced include, but are not limited to:

- airfield, heliports and isolated helipads, constraints
- at restrictions
- quantity-distance arcs (munitions safety)
- noise contours
- safety buffers (setbacks required)
- former firing ranges and impact areas
- impact areas (dudded and non-dudded)
- chemical storage areas
- topography
- wetlands
- threatened/endangered species habitat

- protected natural/cultural areas
- flood hazard areas
- soil restrictions
- environmental contamination
- desirable and undesirable land use features off the installation
- land use controls
- landfills
- historic districts
- transportation systems
- open space systems
- utility systems
- encroachment areas
- areas proposed for disposal/deconstruction
- cultural resource/archeological sites
- pesticide storage areas
- pesticide-sensitive application facilities and areas
- surface and subsurface hazardous material storage
- existing facility assessment
- future development
- in/out grants
- overall real estate boundaries (borders, easements)
- access control points
- open and closed installation restoration program (irp) sites.
- high-resolution aerial photography/lidar contour mapping
- range complex surface danger zones

APPENDIX E GLOSSARY

E-1 ACRONYMS

AAFES	Army Air Force Exchange Services
ADEP	Area Development Execution Plan
ADP	Area Development Plan
AFI	Air Force Instruction
AICP	American Institute of Certified Planners
AICUZ	Air Installations Compatible Use Zones
AT	Anti-Terrorism
AT/FP	Antiterrorism/Force Protection
BES	Building Envelope Standard
BFE	Base Flood Elevation
BFE	Building Flood Elevation
CO_2	Carbon Dioxide
CONUS	Continental United States
DBT	Design Basis Threat
DCI	Defense Critical Infrastructure
DeCA	Defense Commissary Agency
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDDS	Department of Defense Dependent Schools
DoDEA	Department of Defense Education Activity
DoDI	Department of Defense Instruction
DRSL	DoD Regional Sea Level Database
EO	Executive Order

\2 EWL	Extreme Water Level **/2/**
GIS	Geographic Information System
IDG	Installation Design Guide
IDP	Installation Development Plan
IEP	Installation Energy Plan
IMP	Integrated Management Practices
IPB	Installation Planning Board
LEED-ND	Leadership in Energy and Environmental Design – Neighborhood Development
LID	Low-Impact Development
LIDAR	Light Detection and Ranging
MA	Mission Assurance
MCA	Military Construction, Army
MCCS	Marine Corps Community Services
MEDCOM	US Army Medical Command
MILCON	Military Construction
\2 MIRC	Military Installation Resilience Component **/2/**
MPI	Master Planning Institute
MWR	Morale, Welfare, and Recreation
NAF	Non-Appropriated Funds
NAVFAC	Naval Facilities Command
NDAA	National Defense Authorization Act
NEPA	National Environmental Policy Act
NEX	Navy Exchange
O&M	Operations and Maintenance (Funding)
OCONUS	Outside Continental United States

OSD	Office of the Secretary of Defense
PDP	Project Development Plan
RAICUZ	Range Air Installations Compatible Use Zones
SES	Street Envelope Standard
SRM	Sustainment, Restoration, and Modernization
USACE	U.S. Army Corps of Engineers
USC	United States Code

E-2 DEFINITION OF TERMS

Area Development Plan (ADP): These plans show the proposed detailed development of a district on the installation. The ADP should show both short-term and long-range development. Each ADP includes an Illustrative Plan, Regulating Plan, and Implementation Plan. The ADP supports the Master Plan by addressing and resolving localized comprehensive planning issues. ADPs are created for geographically identifiable districts.

Base Flood Elevation (BFE): The computed elevation to which floodwater is anticipated to rise during the base flood. BFEs are shown on flood insurance rate maps (FIRMs) and flood profiles. The BFE is the regulatory requirement for the elevation or floodproofing of structures.

Biophilic: Relating to, showing, or being the human tendency to interact or be closely associated with other forms of life in nature. Biophilic design recognizes how much human physical and mental well-being relies on the quality of our relationship to the natural world.

Biomass: Plant materials and animal waste used as a source of fuel.

Bioswale: A long, channeled depression or trench that receives rainwater runoff (as from a parking lot) and has vegetation (such as grasses, flowering herbs, and shrubs) and organic matter (such as mulch) to slow water infiltration and filter out pollutants.

Building Envelope Standard (BES): These standards regulate acceptable massing, height, fenestration, exterior envelopes, and uses.

Carrying Capacity: The carrying capacity is the maximum capability of the installation to support designated functions or activities without seriously degrading the function, activity, or assets of the installation or some portion thereof. Some examples are ability of the land to support training at certain levels of intensity, or availability of utilities (water, electricity, sewer) to support an activity, or ability of the transportation network to carry levels of traffic safely and efficiently.

Charrette: An intensive creative work session in which a design team focuses on a particular design problem and arrives at a collaborative solution with stakeholders from the project area. A charrette can be a breakthrough event that helps create a meaningful Master Plan or facility design. Properly executed, this technique can produce a Master Plan or facility design that is more useful, better understood, and more quickly produced than one formed by any other method.

Defense Critical Infrastructure (DCI): Mission Assurance (MA) is a DoD risk management program that seeks to ensure the availability of Defense Critical Infrastructure (DCI). Activities include identifying and determining risks to DCI, implementing DoD-wide procedures to respond to DCI risks, and supporting DoD initiatives to respond to risks to national critical infrastructure. The public works sector, which includes the Services' installations, is the backbone infrastructure that supports most of DoD's mission requirements. The DCI public works sector ranges from the commercial utility provider to the installation distribution system.

District: A district is an identifiable geographic area based on compatible uses. For example, a single district may contain administrative, commercial, and residential uses. All installation real estate should be assigned to a district.

Edge: An edge is the dividing line between districts. When two districts are joined at one edge, they form a seam. The termination of a district is an edge. Edges are linear elements (e.g., shores, railroads, edges of development, riparian corridors, installation boundaries). Paths (e.g., roads) may be considered edges unless they clearly mark a demarcation between geographic areas.

Expansion Capacity: The expansion capacity is the potential for an installation to successfully accommodate mobilization requirements or the stationing of additional missions, units, activities, individuals, or functions.

\2 Extreme Weather: Recurrent flooding, drought, desertification, wildfires, thawing permafrost, sea level fluctuation, changes in mean high tides, or any other weather-related event, or anticipated change in environmental conditions, that present (or are projected to present) a recurring annual threat to the security of the United States or of allies and partners of the United States. **/2/**

Facility: A real property entity consisting of one or more of the following: a building, a structure, a utility system, pavement, and underlying land.

Flood hazard area: A geographic area that has been or could be inundated with water. Water inundation can be caused by multiple sources, independently or in combination, such as precipitation, snowmelt, or riverine, coastal, or tidal flooding. Common types of flood hazard areas are floodplain designations such as the 1% annual chance event (ACE) or 100-year floodplain and the 0.2% ACE or 500-year floodplain. Flood hazard areas can also represent past flooding events (e.g., storm of significant impact) or future inundation areas reflective of **\2** EWL **/2/** scenarios.

Form-Based Planning: Form-based planning guides construction by identifying the form for installation development (building types, height, set-backs, circulation patterns, landscaping, land use) and translating that form into a series of planning requirements. The form that this practice supports reflects mission needs, program requirements, environmental constraints and opportunities, and other development factors.

Framework Plan: This conceptual plan of the entire installation shows the identified ADP districts, key transportation and land use concepts, and other significant features that will influence development patterns. To establish ADP boundaries, planners should use geographic features, key transportation systems, and existing land use patterns. Within the installation, where succinct districts are not identifiable, specific land uses should be identified.

Future Development Plan: The Future Development Plan is an installation-level plan with all projects in the IDP assigned to developable sites in order to deconflict future development.

Geographic Information System (GIS): This is a collection of computer hardware, software, and geographic data for capturing, storing, manipulating, analyzing, and displaying all forms of geographically referenced information.

Historic District: An identifiable geographic area that has been determined to be eligible for or has been listed on the National Register of Historic Places.

Historic Property: As defined in § 106 of the National Historic Preservation Act, an historic property is a building, structure, object, district or site (archaeological) that has been determined eligible for or is listed on the National Register of Historic Places

Illustrative Plan: Illustrative Plans are graphic plans that illustrate potential development supporting the overall planning vision. The Illustrative Plan shows existing and future streets, building footprints, sidewalks, parking, major landscape features, and key mission areas. Each ADP has an Illustrative Plan.

Installation Development Plan (IDP): The IDP is a combined plan that integrates all the installation's ADPs, Illustrative Plans, and Regulating Plans into one consolidated plan. The IDP also includes installation-wide Network Plans for streets, sidewalks, parks and open spaces, and primary utilities.

Installation Energy Plan (IEP): The IEP is an integration of installation- and higher-level strategic guidance, plans, and policies into a holistic roadmap enabling the installation to work constructively towards its goals in energy efficiency, **\2** alternative energy sources **/2/**, and energy resilience.

Installation Planning Board (IPB): The IPB is a board consisting of members of the command, operational, engineering, planning, and tenant interests of the installation or community that advises mission commanders regarding planning decisions. The IPB will assist the installation leadership to manage, develop, and, in some cases, realign, clean up, and close the installation, supported sites, or area facilities and real estate.

Landmarks: Landmarks are readily identifiable objects that serve as reference points. Examples include gates, memorials, and headquarters buildings. Landmarks are singular points on a map.

Landscape Standards: Landscape standards show appropriate type and placement of major landscape elements (street trees). These standards may also include other natural landscape features (trees, ground cover) and manmade landscape features (street furniture, signage, lighting).

\2\ Military Installation Resilience: The capability of a military installation to avoid, prepare for, minimize the effect of, adapt to, and recover from extreme weather events or from anticipated or unanticipated changes in environmental conditions, that do, or have the potential to, adversely affect the military installation or essential transportation, logistical, or other necessary resources outside of the military installation that are necessary to maintain, improve, or rapidly reestablish installation mission assurance and mission-essential functions. **/2/**

Network Plans: Network Plans cover linkages and systems that span ADP district boundaries. These include installation-wide utility systems, street and transit networks, and parks and open space networks.

Nodes: Nodes are centers of activity within a district (e.g., town squares, community centers, plazas, intersections). Walking radii of 0.25 mile and 0.5 mile should be shown around each node, identifying amenities within a 5- and 10-minute walk.

Path: Paths are channels in which people travel. At the installation level, primary roads and transit routes are paths. In a more detailed plan, sidewalks, trails, and secondary streets can also be considered paths.

Phasing Plan: A phasing plan depicts all relocation, demolition, and construction actions as they occur over time and in a way that moves the installation from its current state to the final state shown on the Illustrative Plan.

Regulating Plan: These graphic plans regulate the most important elements of the Illustrative Plan. They are like enhanced land-use plans. Each Regulating Plan will show buildable area, required build-to lines, required entry and parking locations, minimum and maximum building heights, and acceptable uses (as designated by facility envelope standards). Each ADP has a Regulating Plan.

Resilience: Resilience is the ability to anticipate, prepare for, and adapt to changing conditions; and withstand, respond to and recover rapidly from disruptions.

\2\ Resilience Planning: Resilience planning meets the needs of the present without compromising the ability of future generations to meet their needs. The inter-relationship between environments, resources consumed, waste products, and use of facilities and land must be designed and developed to preclude permanent damage to the future environment. In context of a military installation, resilience planning includes preserving the land and operating space for future mission requirements while meeting today's mission requirements. **/2/**

Stationing or Basing Actions: Stationing or basing actions involve the process of combining force structure and installation structure at a specific location to satisfy mission requirements.

Street Envelope Standards (SES): These standards describe and graphically present allowable street types and circulation elements in plan and section. They are also referred to as Street Standards.

Tenant Unit, Agency, or Activity: These terms refer to a unit, agency, or activity that occupies facilities on an installation and receives support services from that installation.

Viewshed: Viewsheds are view corridors that should not be blocked. Development should be appropriately sited to take advantage of natural viewsheds.

Vision: This is the commander's statement on how the installation will develop and improve over the next 20 years to adapt to the modernizing world, the changing military mission, and our changing society. It expresses the desired relationship between the installation and the surrounding communities and the desired interaction of installation functions, activities, and land uses. It also expresses how the installation commander will satisfy future mission needs while maintaining excellent stewardship of the environment. Installations consist of people as well as land and infrastructure; therefore, the vision should express how quality of life remains a paramount issue in operating, managing, and developing the installation.

This Page Intentionally Left Blank

APPENDIX F REFERENCES

US LAWS AND CODE OF FEDERAL REGULATIONS

https://www.govinfo.gov/

\2 10 USC 101, *Definitions* **/2/**

10 USC 2801(c)(4), *Scope of chapter; definitions (Military Construction)*

10 USC 2864, *Master planning for major military installations*

16 USC 470, *National Historic Preservation Act*

36 CFR 800 § 106 of the National Historic Preservation Act

FY20 National Defense Authorization Act (NDAA)

Energy Independence and Security Act of 2007

National Environmental Policy Act (NEPA)

EXECUTIVE ORDER

EO 11988, *Floodplain Management*, https://www.archives.gov/federal-register/codification/executive-order/11988.html

EO 13834, *Efficient Federal Operations*, **\2** Sections 6, 7, and 11. **/2/** https://www.fedcenter.gov/programs/eo13834/

DEPARTMENT OF DEFENSE

DoD 7000.14-R, *Department of Defense Financial Management Regulation*, https://comptroller.defense.gov/fmr.aspx

DoD Directives: https://www.esd.whs.mil/Directives/issuances/dodd/

DoDD 3020.40, *Mission Assurance (MA)*

\2\ /2/

DoD Instructions: https://www.esd.whs.mil/Directives/issuances/dodi/

DoDI 3020.45, *Mission Assurance (MA) Construct*

DoDI 4165.70, *Real Property Management*

DoDI 4170.11, *Installation Energy Management*

\2 DoDI 4715.28, Military Installation Resilience **/2/**

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/unified-facilities-criteria-ufc

UFC 1-200-01, *DoD Building Code*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 1-300-01, *Criteria Format Standard*

UFC 3-201-01, *Civil Engineering*

UFC 3-201-02, *Landscape Architecture*

UFC 3-210-10, *Low Impact Development*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 3-410-01, *Heating, Ventilating, and Air-Conditioning Systems*

UFC 4-010-01, *DoD Minimum Antiterrorism Standard for Buildings*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

UFC 4-020-01, *DoD Security Engineering Facilities Planning Manual*

AIR FORCE

AFI 32-10112, *Installation Geospatial Information and Services (IGI&S)*, https://www.e-publishing.af.mil/

ARMY

USACE ECB 2018-7, *Advanced Modeling Requirements On USACE Projects - Category: Directive And Policy*, https://www.wbdg.org/ffc/dod/engineering-and-construction-bulletins-ecb/usace-ecb-2018-7

NAVY

OPNAVINST 11000, *Facilities and Land Management Ashore*, Ser N/420U045, https://www.secnav.navy.mil/doni/opnav.aspx

\2\\ /2/

US GREEN BUILDING COUNCIL

LEED *Reference Guide for Neighborhood Development* (LEED-ND), https://www.usgbc.org/guide/nd

AMERICAN SOCIETY OF CIVIL ENGINEERS

ASCE 24, *Flood Resistant Design and Construction*, https://ascelibrary.org/doi/book/10.1061/asce24

UFC 3-101-01
16 December 2020
Change 4, 08 January 2024

UNIFIED FACILITIES CRITERIA (UFC)

ARCHITECTURE

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UFC 3-101-01
16 December 2020
Change 4, 08 January 2024

UNIFIED FACILITIES CRITERIA (UFC)

ARCHITECTURE

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	1/5/2021	2-4.3 1407.7.1 ccr 9099; 3-2 ccr 9208; 3-3 ccr 8235 and 8541; 3-6.2 ccr 9570
2	11/1/2022	2-4.2 renumbered per 2021 IBC; 3-6.3 ccr 12024 and 10895; A-3.3 removed semi-permanent construction; A-8 renumbered
3	09/14/23	Revised 2018 IBC references to “2021 IBC” or “IBC” ccr 13329 & 13629; para 3-6.3 deleted second bullet and added Navy / Army note and add separate Air Force bullet ccr 9847; Chapter 3-6.3 revise 4th bullet to “Spaces with large exterior doors . . . “ ccr 11656; para 3-6.3 revise spec section from 07 05 23 to 01 91 19; Chapter 3-7.1 revise title to “Daylighting Design” ccr 11185; retitled references to UFC 4-010-05 to “SCIF/SAPF . . . “; Chapter 2-4.3 Section 1404.13.3, delete first sentence, ccr 13930
4	01/08/24	Updated reference to ASHRAE 90.1 as per Coordinating Panel. Revised 3-6.3 bullet 2 to include “Air Force”. Previously limited to “Navy / Army”. Deleted date references for IBC and IgCC.

This UFC supersedes UFC 3-101-01, dated 28 November 2011, with Changes 1-5, dated 25 September 2019.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering **\3** Systems **/3/** Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website http://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

CHRISTINE T. ALTENDORF, PhD, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Systems Command

NANCY J. BALKUS, P.E., SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW
Deputy Assistant Secretary of Defense (Construction) and Acting Deputy Assistant Secretary of Defense (Housing) Office of the Assistant Secretary of Defense (Sustainment)

UNIFIED FACILITIES CRITERIA (UFC)
[NEW][REVISION] SUMMARY SHEET

Document: UFC 3-101-01, *Architecture*

Superseding: UFC 3-101-01, dated 28 November 2011, with Changes 1-5, dated 25 September 2019

Description: This UFC unifies the architectural criteria for DOD. The format is updated to the standard format of the Criteria Standard Format for all UFC.

Reasons for Document:

- Required update cycle
- Approved Criteria Change Request (CCRs)
- Conform the format to the UFC 1-300-01 *Criteria Format Standard* including alignment of requirements with the International Building Code (IBC).
- Incorporate latest technologies, policies and references

Impact: Improved mission capability through:

- Reduced total ownership costs of buildings through corrosion resistant design requirements
- Use of reference model codes to greatest extent possible
- Unification of service requirements

Unification Issues

- Referenced space planning criteria is contained in service specific publications.
- Service differences in Air Barrier Testing criteria are noted in this UFC.

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC provides technical requirements, model code modifications, and requirements for architectural design services. Architects must use the information in this document in the development of plans, specifications, calculations, construction contract documents, and Design-Build Requests for Proposals (RFP). The information in this UFC serves as the minimum architectural requirements. Project conditions and programmatic requirements may dictate the need for designs that exceed these requirements.

1-2 APPLICABILITY.

This UFC applies to agencies of the U.S. Armed Services and their contractors that are preparing construction contract documents for Department of Defense-owned facilities. These criteria are applicable in the 50 states, the District of Columbia, Puerto Rico, U.S. territories and possessions, and as far as practical, at installations in foreign countries. This UFC applies to all types of construction regardless of funding, including properties listed or eligible for listing on the National Register of Historic Places, as well as National Guard and Reserve projects constructed on military installations or non-military DoD property. Certain specialized facilities carry more stringent requirements. See UFC or other criteria that are applicable to the respective specialized facility that is being designed. This UFC is applicable to the traditional architectural services customary for Design-Bid-Build design services and for Design-Build construction contracts.

1-3 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, DoD Building Code. UFC 1-200-01 provides applicability of model building codes and government unique criteria for design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-3.1 Environmental Severity and Humid Locations.

The architectural design must incorporate systems and details to meet the environmental corrosivity conditions for the specific project location, as defined by its Environmental Severity Classification (ESC). See UFC 1-200-01 for determination of ESC for project locations. The humidity conditions must also be considered during design; humid locations are those in ASHRAE climate zones 0A, 1A, 2A, 3A, 3C, 4C, and 5C (as identified in ASHRAE 90.1).

1-4 BACKGROUND.

UFC 1-200-01 implements and supplements International Building Code (IBC) as the building code for the DoD. Chapter 2 of this UFC further modifies the IBC for architecture-specific design requirements and is organized by the chapter of the IBC that each section modifies. Apply any section in the IBC that is not specifically referenced as it is written in the IBC.

The IBC section modifications are one of four actions, according to the following legend:

[Addition] – Add new section, including new section number, not shown in IBC.

[Deletion] – Delete referenced IBC section or noted portion of a section.

[Replacement] – Delete referenced IBC section or noted portion and replace it with the narrative shown.

[Supplement] – Add narrative shown as a supplement to the narrative shown in the referenced section of IBC.

1-5 OVERVIEW OF THIS UFC.

Brief descriptions of the various chapters and appendices of this UFC follow.

- CHAPTER 2 – MODIFICATIONS TO THE IBC. Chapter 2 provides supplemental requirements for applying the IBC architectural provisions to conventional DoD building design by listing required modifications for specific IBC sections.
- CHAPTER 3 – DESIGN. Chapter 3 includes architectural design requirements, such as design quality, building orientation, and hazard prevention.
- CHAPTER 4 – PROGRAMMING AND PLANNING. Chapter 4 includes requirements for space planning and building area calculations.
- CHAPTER 5 – PRE-DESIGN, DESIGN AND POST-DESIGN SERVICES. Chapter 5 includes a detailed description of these services, including design charrettes, Architectural Compatibility Submittals, Architectural Basis of Design, Specifications, and Drawings.
- APPENDIX A – BEST PRACTICES. This chapter contains useful recommendations and guidance on a number of important topics, such as planning issues, local construction methods, building envelope considerations, air barrier testing, and daylighting data.
- APPENDIX B – GLOSSARY. This section includes acronyms and definitions of terms.
- APPENDIX C – REFERENCES. This section contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

1-6 CYBERSECURITY.

Control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-7 ADDITIONAL REQUIREMENTS.

When performing work for different Activities within the U.S., additional regional or service-specific requirements apply. Confirm with the Authority Having Jurisdiction (AHJ) the applicability of any regional requirements.

This Page Intentionally Left Blank

CHAPTER 2 MODIFICATIONS TO THE IBC

2-1 CHAPTER 7 – FIRE AND SMOKE PROTECTION FEATURES.

2-1.1 SECTION 721 - PRESCRIPTIVE FIRE RESISTANCE.

721.1 – General [Supplement]

Use the UL Fire Rated Assemblies Directory or Nationally Recognized Testing Laboratories for design of fire-resistance-rated wall, floor, and roof assemblies in addition to this section.

2-1.2 SECTION 722 - CALCULATED FIRE RESISTANCE.

722.1 – General [Supplement]

Use the UL Fire Rated Assemblies Directory or Nationally Recognized Testing Laboratories for design of fire-resistance-rated wall, floor, and roof assemblies in addition to this section.

2-2 CHAPTER 8 – INTERIOR FINISHES.

2-2.1 SECTION 802 GENERAL.

802.8 - Paint and Coatings Selection [Addition]

Base paint selection on Master Painters Institute's (MPI's) Detailed Performance Standards for the coating materials and MPI's Architectural Painting Specification Manual for the system. Do not use MPI's "Intended Use" standards. Refer to The Society for Protective Coatings (SSPC) standards, National Association of Corrosion Engineers (NACE) standards, and UFC 3-190-06 for painting steel and concrete structures, particularly in marine and other severe environmental locations.

2-3 CHAPTER 12 – INTERIOR ENVIRONMENT.

2-3.1 SECTION 1202 – VENTILATION.

1202.2.3 - Enclosed Roof Spaces [Addition]

Ventilate enclosed roof spaces created outside the building thermal envelope. For sloped roofs, ventilation must comply with IBC Section 1202 Ventilation. Ensure that moisture transfer from ventilated attics into the building is minimized.

2-3.2 SECTION 1206 - SOUND TRANSMISSION.

1206.1 - Scope [Supplement]

Section 1206.4 applies to other occupancies.

1206.4 - Interior Acoustics for Other Occupancies [Addition]

Design so that interior acoustics coordinate with the architecture, fire protection, mechanical, and structural design. A comprehensive acoustical design must include considerations for sound isolation, building mechanical system noise and vibration control, room finishes, and space adjacencies.

There are basically two types of sound transmission; airborne and structure-borne. Structure-borne sound is transmitted through a material by vibrations and re-radiated to another point (such as upper floor foot traffic). Sound transmission requirements are performance-based. Refer to the Glossary in this guidance for added explanations and definitions of acoustical terms such as STC (Sound Transmission Class) and NIC (Noise Isolation Class). Table 2-1 provides acoustic requirements for common facility and space types.

1206.4.1 - Interior Acoustics Reference Criteria [Addition]

Spaces such as Special Access Program Facilities (SAPF) and Sensitive Compartmented Information Facilities (SCIF) must comply with specific criteria to be accredited for operation. Specialty spaces including television and radio broadcast facilities, music auditoria, large lecture halls (50 people or more), network operations centers, or other spaces will require an acoustical consultant as an integral member of the design team.

The following references include explanations, guidelines, design strategies, and prediction tools to aid in meeting the above required acoustic criteria.

- UFC 3-450-01 “Noise and Vibration Control”
- UFC 4-010-05 “**\3** SCIF/SAPF ***/3/*** Planning, Design and Construction”
- *Sound Matters* from General Services Administration
- ANSI/ASA S12.2, *Criteria for Evaluating Room Noise*
- ASTM E1130, *Standard Test Method for Objective Measurement of Speech Privacy in Open Plan Spaces Using Articulation Index*
- ASTM E2638, *Standard Test Method for Objective Measurement of the Speech Privacy Provided by a Closed Room*

Table 2-1 Interior Acoustic Requirements for Typical Spaces

	Space Acoustic Requirements			
	Sound Isolation [1]		Background Noise Level [3]	Reverberation Time
	Partitions	Doors [2]		
Auditorium [4]	STC 60 or greater	STC 50 or greater	25	< 1.0 sec
Unaccompanied Housing (UH)	STC 50	STC 25	30	n/a
Child Care	STC 50	STC 25	35	< 0.8 sec
Clinic/ Health Unit	STC 50	STC 25	35	< 1.0 sec
Conference Room	STC 50 or greater	STC 30 or greater	30	< 0.8 sec
Classroom	STC 50	STC 30	35	< 0.6 sec
Firing Range	STC 65 or greater	STC 55 or greater	n/a	n/a
Food Service	STC 55	STC 25 or greater	40	< 1.4 sec
Hearing Room	STC 55	STC 35	30	0.6-0.7 sec
Laboratory: Dry	STC 50	STC 25	45	< 1.4 sec
Library	STC 50	STC 30	40	< 1.2 sec
Open Office	n/a	STC n/a	40 [5]	< 1.0 sec
Private Office [6]	STC 35-50	STC 25	35	n/a
Place of Worship	STC 55	STC 35	30	0.8-1.4 sec [7]

1. Sound Isolation requirements are stated in terms of Sound Transmission Class (STC), a laboratory performance metric. See also Facility-Specific UFC for more detailed requirements, which take precedence.
2. STC requirements for most doors (STC 30 and below) can be achieved by using door seals on standard doors. For higher sound isolation requirements, consider using a vestibule, sound rated door(s) or a combination of the two.
3. Background Noise Level requirements are stated in terms of Noise Criteria (NC) or RC Mark II levels. NC and RC Mark II levels are considered equivalent for design purposes; however, RC Mark II noise levels provide additional means to describe the quality of a sound for assessment purposes.
4. Assumes space is primarily used for speech functions. Multipurpose auditoria with music programming must have criteria established by the Government or project acoustical consultant in the response to a proposal.
5. Consider a sound masking system if privacy is important in open office areas. A sound masking system will not alleviate NIC project requirements in other areas of a building. Refer to ASTM E2638 for additional information regarding privacy design considerations in open office areas
6. Criteria dependent on privacy requirements of the occupants.
7. Criteria to be refined by the Government or project acoustical consultant based on specific worship type.

If a space type is not included in the above Table 2-1, the standards in Table 2-2 include interior acoustic requirements for other space/building types.

Table 2-2 Acoustic Requirements for Typical Facilities

Facility/ Space Type	Reference Standard to Meet Project Acoustic Requirements [1, 2]			
	Sound Isolation	Background Noise Level	Room Finishes	Mechanical System Noise & Vibration
Administrative/ Office Buildings • Open Offices • Private Offices • Conference Rooms • Training Rooms • Lobbies	GSA PBS-P100 (see Section 3.5.3)	ASHRAE HVAC Applications Handbook, Ch. 49 – Noise & Vibration Control	GSA PBS-P100 (see Section 3.5.3)	ASHRAE HVAC Applications Handbook, Ch. 49 – Noise & Vibration Control
Child Facilities • Child Care • Day Care • Child Development • K-12 Schools	ANSI S12.60 Parts 1 and 2	ANSI S12.60 Parts 1 and 2	ANSI S12.60 Parts 1 and 2	ASHRAE HVAC Applications Handbook, Ch. 49 – Noise & Vibration Control
Housing • UH • Multifamily Residences • Single Family Residences	IBC (See Section 1206)	ASHRAE HVAC Applications Handbook, Ch. 49 – Noise & Vibration Control	UFC 3-450-01, Noise and Vibration Control	ASHRAE HVAC Applications Handbook, Ch. 49 – Noise & Vibration Control
Medical Care • Hospitals • Clinics	FGI – Sound & Vibration: Design Guidelines for Health Care Facilities	FGI – Sound & Vibration: Design Guidelines for Health Care Facilities	FGI – Sound & Vibration: Design Guidelines for Health Care Facilities	FGI – Sound & Vibration: Design Guidelines for Health Care Facilities
Research Facilities • Laboratories • Associated Lab Support Spaces	NIH – Design Requirements Manual	NIH – Design Requirements Manual (see Section 6.5)	NIH – Design Requirements Manual	NIH – Design Requirements Manual (Section 6.5)
SCIF and SAPF	IC Tech Spec for ICD/ICS 705	ASHRAE Applications Handbook, Ch. 49 – Noise & Vibration Control	UFC 4-010-05	ASHRAE HVAC Applications Handbook, Ch. 49 – Noise & Vibration Control
Legal Facilities • Courts • Associated Court Support Spaces	U.S. Courts Design Guide (Chapter 14)	U.S. Courts Design Guide (Chapter 14)	U.S. Courts Design Guide (Chapter 14)	ASHRAE HVAC Applications Handbook, Ch. 49 – Noise & Vibration Control

1. Chapters and sections referenced are intended to facilitate quick reference of the above standards and not exclude the requirements in the rest of the document.
2. Requirements in the above referenced standards do not supersede requirements stated in Table 2-1 if there is a discrepancy.

2-4 CHAPTER 14 – EXTERIOR WALLS.

2-4.1 SECTION 1401 – GENERAL.

1401.2 - Corrosive Environments [Addition]

For corrosion prone locations as defined in UFC 1-200-01, protect steel surfaces by hot-dipped galvanizing or providing stainless steel. Use Type 316L stainless steel when using stainless steel. Protect hot-dipped galvanized metal with an industrial coating in addition to galvanizing, as galvanized metal will still corrode in these environments. Isolate dissimilar metals (for example, aluminum and steel, stainless steel and carbon steel, and zinc-coated steel and uncoated steel) by appropriate means to avoid the creation of galvanic cells which occur when dissimilar metals come in contact.

2-4.2 SECTION 1404 - INSTALLATION OF WALL COVERINGS.

\2 1404.3.3 **/2/** - Building Envelope Vapor Retarders [Addition]

For building enclosure systems or environmental conditions not covered elsewhere in IBC Article 1404, design the enclosure using simplified or transient design tools referenced in the *ASHRAE Handbook of Fundamentals*, Chapter 25, Heat, Air and Moisture Control in Building Assemblies, and the following sections. Do not provide multiple vapor retarders that trap moisture between the retarders. Select vapor retarders in accordance with ASTM C755. Based on the results of the analysis described in this section, design the assemblies for appropriate diffusion control.

\2 1404.3.3.1 **/2/** Vapor pressure differential calculation.

First determine the vapor pressure difference between indoor and outdoor climates. For exterior vapor pressure, use the mean outdoor dry bulb and dew-point temperatures for the coldest and hottest months in UFC 3-400-02. If the vapor pressure difference is less than 0.25" Hg (847 Pa), place the vapor retarder with appropriate permeance for the application on the predominantly high vapor pressure side of the assembly.

\2 1404.3.3.2 **/2/** Vapor pressure differential greater than 0.25 Hg (847 Pa).

If the vapor pressure difference between indoor and outdoor climates is greater than 0.25" Hg (847 Pa), perform a job-specific simplified or transient vapor transmission (hygrothermal) analysis for walls, roofs, and exposed floors (and floors over crawlspaces) based on project specific climate as defined by UFC 3-400-02, and the specified components and materials. Indicate the temperature and relative humidity for the inside and the outside of the building; a complete listing of building components, including the vapor retarder; their thickness, location, thermal resistance and permanence; and building location and use.

\2 1404.3.3.2.1 ***/2/*** Simplified Hygrothermal Analysis.

Use the steady state dewpoint or Glaser methods described in the *ASHRAE Handbook of Fundamentals (*Chapter 25), using the mean outdoor dry bulb and dew point temperatures for the hottest and coldest months.

\2 1404.3.3.2.2 ***/2/*** Transient Hygrothermal Analysis.

Use a mathematical model that simulates transient hygrothermal conditions, such as WUFI/ORNL (ASTM Manual 40 reviews these models). If the WUFI model is selected, use the climate data included in the WUFI program in lieu of UFC 3-400-02. Users of such methods must understand their limitations, and interpretation of the analysis results must be done by a trained person to reasonably extrapolate field performance approaching the design results. For the mathematical model method, use interior conditions based on a dewpoint of 53°F (12°C) in summer conditions and a dewpoint of 40°F (5°C) in winter conditions. The maximum threshold must be a surface relative humidity of 80% averaged over a period of 30 days to achieve a successful building enclosure assembly for temperatures between 40°F and 120°F (5°C and 50°C) and other criteria described in Chapter 6 of ASHRAE Standard 160. These are thresholds above which mold can grow and building assemblies deteriorate.

\2 1404.3.4 ***/2/*** - Floor Slab Vapor Retarders. [Addition]

Floor slabs on grade must have a vapor retarder of 0.05 perms or less meeting the requirements of ASTM E1745 Class A. Under slab vapor retarders must be durable enough to withstand construction activity and must be terminated around the perimeter and penetrations detailed according to the manufacturer’s instructions. Additionally, specifications must require measurement of slab relative humidity in accordance with ASTM F2170 to meet the requirements of the floor finish manufacturer or must include an application of a topical moisture mitigation material.

\2 1404.3.5 ***/2/*** - Roof Vapor Retarders. [Addition]

Provide moisture analysis of the roof assemblies per paragraph titled, Building Envelope Vapor Retarders. Roof assemblies on concrete slabs must include a vapor retarder on top of the concrete and a vented metal deck to control moisture in the concrete from affecting roof assemblies. However, design low-slope roof assemblies using rigid insulation without a vapor retarder whenever possible. Install vapor retarder in accordance with guidance in the *NRCA Roofing and Waterproofing Manual*.

1404.4.3 - Sill Pan Flashing [Addition]

Penetrations such as windows and louvers in the exterior wall assemblies must have pan flashing installed in the rough opening sill. This pan sill flashing must have end dams at both jambs a minimum of 2 in. (50 mm) high and a rear dam of 2 in. (50 mm) high. Comply with ASTM E2112, the requirements in Chapter 4, Masonry, Brick Industry of America (BIA) Tech Notes, and the *SMACNA Architectural Sheet Metal Manual* recommendations.

1404.13.2 - Selection of Windows and Glazing. [Addition]

Based on a life cycle cost analysis (LCCA), select windows and glazing with the best possible performance from a U-factor, Solar Heat Gain Coefficient (SHGC), daylighting, and Visible Transmittance (VT) for the fenestration. Optimize the emissivity coatings to control both heat gain into the building due to solar radiation and heat loss from the building. Select frames with thermal breaks. Include flashings under fenestration in an appropriate manner. Fenestration must meet both code and UFC 4-010-01 requirements. Do not use steel, wood, or plastic-clad wood windows in locations with Environmental Severity Classifications (ESC) of C4 or C5. See UFC 1-200-01 for determination of ESC for a project location.

1404.13.3 - Aluminum Windows. [Addition]

Aluminum windows must be heavy-duty commercial quality systems; conforming to AAMA/WDMA/CSA 101. For window reinforcing purposes, concealed 316L stainless steel or aluminum reinforcing inserts are required. Internal fasteners must be 316L stainless steel. Aluminum windows must have anodized aluminum finish and color to meet the requirements in the applicable installation exterior architectural guidelines.

1404.13.4 - Operable Windows. [Addition]

Provide locks which discourage the opening of windows during HVAC system operation. Provide window guards at upper floor operable windows of housing projects in compliance with ASTM F2090.

1404.13.5 - Window Installation and Details. [Addition]

Install windows according to ASTM E2112. Provide concrete step detail that prevents water from being driven directly under window sills. Seal exterior window and door rough openings to prevent water infiltration into wall cavities including sealing exterior wall and interior side furred out walls.

1404.13.6 - Window Screens. [Addition]

Window screen must be mounted on the inside of the window frame with aluminum window frame screens matching the color of the window frame. Provide the anodized aluminum screen frames with 316L stainless steel spring clips to hold screen frame securely in window frame. Screen material must be plastic-coated fiberglass or aluminum mesh.

1404.13.7 - Weatherstripping. [Addition]

Provide nonferrous metal and UV-resistant vinyl weather stripping. Weatherstripping must be factory applied, and limit infiltration to 0.25 cubic feet/min/square foot (1.698 cubic meter/min/square meter) in accordance with ASTM E283.

1404.13.8 - Storefronts [Addition]

Exterior storefront systems must be heavy-duty commercial quality aluminum system with anodized aluminum finish and color to meet the requirements in the applicable installation exterior architectural guidelines; and conform to AAMA/WDMA/CSA 101. Storefront doors must be medium stile. Install storefronts according to ASTM E2112.

1404.13.9 - Exterior Glazing [Addition]

Exterior windows must have insulated glazing system (outer lite low E with an air space and interior lite meeting the IBC requirements for wind and windborne debris protection, where applicable, and UFC requirements for Antiterrorism protection). Consider building energy efficiency, occupant comfort, daylighting, acoustic performance, and security when selecting exterior window and glazing systems. Coordinate glazing tint with applicable installation exterior architectural guidelines unless otherwise noted, sustainability recommendations and energy requirements. Unless otherwise required, unshaded glazing must be factory tinted; shaded glazing at storefront requiring see-through visibility may be clear, non-tinted.

2-4.3 SECTION 1407 - EXTERIOR INSULATION AND FINISH SYSTEMS (EIFS).

1407.7 - Exterior Insulation and Finish Systems (EIFS) Use and Detailing [Addition]

Selection of EIFS systems must be based on a LCCA that considers maintenance requirements and frequency of recoating. Use only self-draining EIFS systems. Do not install EIFS within 6 in (150 mm) of grade, or in areas where it will be subject to abuse by moving vehicles or equipment, such as a loading dock. Do not use EIFS in areas of heavy pedestrian traffic, or if such use cannot be avoided, specify high-impact resistant system. Use high-impact systems a minimum of 4 ft. (1220 mm) above grade where subject to damage from pedestrian traffic or lawn maintenance equipment. Construction documents must provide specific design details for windows, trim, expansion joints, and drainage planes. Comply with the criteria listed in the latest version of EIFS Standards & ICC-ES Acceptance Criteria document produced by the EIFS Industry Members Association (EIMA). Where EIFS is applied to a (side) wall which has an eave from the roof, a premolded polypropylene / use PVC kickout flashing to channel the water away from the exterior wall.

1407.7.1 EIFS in High Wind Zones.

In areas with design wind loads up to 35 psf (170 Kg/m2) (118 mph or 190km/h), adhered EIFS must only be permitted provided the EIFS assembly includes a minimum 5/8-in.- (16-mm-) thick glass-fiber-faced siliconized gypsum sheathing fastened with corrosion-resistant screws that have a minimum 3/8-in- (10-mm-) diameter washer heads fastened to engineered light-gage metal framing spaced 16 in (405 mm) on center with screws spaced 4 in (100 mm) on center. In areas with higher wind speeds, the contractor must provide **\1** wind-tested assemblies and submit test documentation establishing performance under design **/1/** wind-loads in accordance with ASCE/SEI 7.

2-4.4 SECTION 1410 - GYPSUM BOARD CONSTRUCTION.

1410.1 - Prevention of Mold [Addition]

Use glass mat gypsum (paperless or non-cellulose facing) sheathing for exterior applications and use glass mat or moisture/mold resistant gypsum wall board for the interior face of exterior walls (prevents food source for mold). On exterior walls, use only interior wall finishes that allow water vapor within the wall to escape into the conditioned space. Do not use vinyl wall coverings, oil-based paint, and other vapor-resistant materials as interior finishes for exterior walls.

2-5 CHAPTER 18 – SOILS AND FOUNDATIONS.

2-5.1 SECTION 1805 - DAMPPROOFING AND WATERPROOFING.

1805.2.2 - Walls [Supplement]

If required to address hydrostatic pressure or as recommended by the geotechnical report, provide drainage planes combined with waterproofing material and a footing drain on below-grade walls.

1805.4.2 - Foundation Drain [Supplement]

Footing drains and under-slab drainage must be incorporated based on the recommendations of the geotechnical engineering report.

2-5.2 SECTION 1808 – FOUNDATIONS.

1808.6.5 - Insulation [Addition]

Where the energy model or code requires insulation for slab-on-ground floors, use high-density (40-100 psi [276-689 kPA] depending on floor loading with a safety factor of 5) extruded polystyrene under the vapor retarder. Apply requirements of ASCE 32-01 to keep soils thawed to minimize frost action in cold regions. Coordinate final assembly U-Factors with the mechanical engineer to comply with overall facility energy requirements. Protect insulation from weather, including rain, ultraviolet solar radiation, mechanical abuse, compression, or accidental or deliberate movement from its location during its service life.

2-6 CHAPTER 20 - ALUMINUM.

2-6.1 SECTION 2002 - MATERIALS.

2002.2 - Corrosion Prone Locations. [Addition]

For corrosion prone locations as defined in UFC 1-200-01, protect aluminum surfaces with an industrial coating or heavy-duty anodized coating. Isolate dissimilar metals (for example, aluminum and steel, stainless steel and carbon steel, and zinc-coated steel and uncoated steel) by appropriate means to avoid the creation of galvanic cells which occur when dissimilar metals come in contact.

2-7 CHAPTER 21 - MASONRY.

2-7.1 SECTION 2115 - MASONRY DETAILING AND MISCELLANEOUS PROVISIONS. [Addition].

2115.1 - Masonry Details [Addition]

Comply with the Brick Industry Association (BIA) Technote 7, Technote 18A, and Technote 21 for specific brick masonry recommendations and other topic specific Technotes as applicable.

2115.2 - Expansion Joint Position and Location [Addition]

No single recommendation for positioning and spacing of vertical expansion joints can be applicable to structures. Analyze each building to determine the potential horizontal and vertical movements and make provisions to relieve excessive stress that might be expected to result from such movement. Place expansion and crack control joints in accordance with BIA Technote 18A. Place expansion joints symmetrically on building elevations. Indicate expansion joints on the contract drawings.

2115.3 - Plastic and Membrane Through-Wall Flashing [Addition]

Plastic flashings and asphalt-impregnated felt flashings are prohibited.

2115.4 - Clearance Between Masonry and Back-up Construction [Addition]

Provide a 2-in. (50 mm) minimum clear dimension from the face of cavity insulation or sheathing material to the back of the exterior wythe of masonry. See American Concrete Institute, ACI 530 for additional information. See BIA Technote 21 for additional guidance.

2115.5 - Flashing at Penetrations and Projections [Addition]

Do not design structural steel frame members to be exposed inside a cavity wall. Provide flashing at penetrations exposed into the cavity such as columns or beams, and at floor slabs, wall projections and recesses, and wall bases. Projections, recesses, and caps must be flashed and sloped away from the wall to ease drainage.

2115.6 - Location of Weep Holes [Addition]

Provide open-head joint weeps at through-wall flashing for brick masonry. Locate weeps on the same course as the flashing. Space weep holes at 24 in. (610 mm) on center for brick masonry and 32 in. (815 mm) on center for concrete masonry. Locate weeps above the level of the finished grade, including landscape mulching, to prevent the weeps from becoming clogged with foreign material. Weeps must be designed to be open-head joints with corrugated plastic inserts only. Provide masonry vents at top of walls and below continuous shelf angles. These provide better ventilation of cavity spaces to prevent buildup of warm, moist air at the tops of cavities. For single-wythe exterior CMU walls, provide a flashing/weep system for open CMU cells to drain to the exterior.

2-8 CHAPTER 22 - STEEL.

2-8.1 SECTION 2203 - PROTECTION OF STEEL FOR STRUCTURAL PURPOSES.

2203.2 - Corrosive Environments [Addition]

For corrosion prone locations as defined in UFC 1-200-01, protect steel surfaces by hot-dipped galvanizing or providing stainless steel. Use Type 316L stainless steel when using stainless steel. Protect hot-dipped galvanized metal with an industrial coating in addition to galvanizing, as galvanized metal will still corrode in these environments. Isolate dissimilar metals (for example, aluminum and steel, stainless steel and carbon steel, and zinc-coated steel and uncoated steel) by appropriate means to avoid the creation of galvanic cells which occur when dissimilar metals come in contact.

2-8.2 SECTION 2211 COLD-FORMED STEEL LIGHT-FRAME CONSTRUCTION.

2211.3 - Above-Grade Finished Floor Elevation [Addition]

Provide a minimum of 18 inches (455 mm) clear space above finished grade for light frame metal floor construction.

2-9 CHAPTER 23 - WOOD.

2-9.1 SECTION 2304 – GENERAL CONSTRUCTION REQUIREMENTS.

2304.12.1.1 - Joists, girders, and subfloor [Replacement]

Provide a minimum of 18 inches (455 mm) clear space above finish grade and crawlspaces for light-frame wood construction. Wood girders that are closer than 12 inches (305 mm) to the exposed ground in crawlspaces or unexcavated areas located within the perimeter of the building foundation must be naturally durable or preservative-treated wood.

2-10 CHAPTER 25 – GYPSUM BOARD, GYPSUM PANEL PRODUCTS AND PLASTER.

2-10.1 SECTION 2515 - TRIM AND MOLDINGS [Addition].

2515.1 - Materials.

In high humidity interior areas (for example, bathrooms, locker rooms, pools, trainers), areas open to the exterior (for example, mechanical rooms, and hangars), and spaces that are not conditioned by design or may not be conditioned during prolonged periods due to deployment, use PVC or plastic trims, casings, and accessories in lieu of metal, which may rust over time.

CHAPTER 3 DESIGN

3-1 DESIGN QUALITY.

The following principles are adapted from GSA's *Guiding Principles for Federal Architecture*:

- Provide facilities in an architectural style and form that is distinguished, and which will reflect the dignity, enterprise, vigor, and stability of the Federal Government. Place emphasis on the choice of designs that embody the finest contemporary American architectural thought relative to the building's function. Pay specific attention to the possibilities of incorporating into such designs qualities that reflect the regional architectural traditions of that part of the country in which buildings are located. Designs must adhere to sound construction practice and utilize materials, methods, and equipment of proven dependability. Buildings must be economical to build, operate and maintain; resilient, sustainable, and accessible.
- The development of an official style must be avoided. Design must flow from the architectural profession to the Services and not vice versa.
- Consider the choice and development of the building site as the first step of the design process. Pay special attention to the general ensemble of streets and public places of which these buildings will form a part. Where appropriate, locate buildings to permit a generous development of landscape.

3-1.2 Installation Exterior Architecture.

Most military installations and service design agencies have published design guidelines that contain criteria relative to achieving, maintaining, and emphasizing a positive exterior visual environment. Follow the design guidance contained in these documents. In the absence of such guidelines, design facilities to harmonize with the character of existing facilities considered historically or architecturally significant to the area. Air Force projects must comply with the Air Force Corporate Facilities Standards and applicable Installation Facilities Standards.

3-1.3 Historic Architecture.

Follow the Secretary of Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings for repair or renovation of historic facilities and new construction near historic facilities.

3-1.4 Projects in the National Capital Region (NCR).

In accordance with the National Capital Planning Act of 1952, as amended, submit all master plans and designs for proposed construction projects in the NCR to the National

Capital Planning Commission (NCPC) for appropriate reviews and approvals consistent with the timelines issued by the NCPC.

3-2 BUILDING ORIENTATION.

Establish building siting in **\1** in accordance with the Regulating Plan of the Installation Master Plan, see UFC 2-100-01, section 2-9.1.2. **/1/** Optimize building layout and orientation with regard to functional arrangement, access, exterior appearance, views, present and expected future site acoustic conditions, and other considerations.

Utilize the site environmental factors to orient buildings to minimize annual facility energy use and to optimize daylighting. Consider seasonal solar angles and prevailing winds to enhance energy performance of the building within the site-specific micro climate. See Appendix A Best Practices, paragraph Daylighting for additional information. See also UFC 1-200-02.

3-3 HAZARD PREVENTION.

Design facilities to comply with 29 CFR Occupational Safety and Health Act (OSHA). Pay particular attention to lead and asbestos particulates, which may be lying on top of materials to be removed, and polychlorinated biphenyls (PCBs) that are part of caulking and sealant materials that may have been absorbed into adjacent building materials and require grinding.**\1**

Design fixed ladders and roof hatches in accordance with 29 CFR 1910.23 and the IBC, according to the most stringent requirements. Design handrails, guardrails, and fall arrest systems to comply with 29 CFR 1910.28, 29 CFR 1910.140, and the IBC, according to the most stringent requirements. **/1/**

3-3.1 Radon.

Evaluate and mitigate radon per the appropriate Service and Installation regulations.

3-3.1.1 Identification of Radon.

3-3.1.1.1 Army, Air Force and Navy.

Check the Environmental Protection Agency’s (EPA's) Map of Radon Zones (by state), EPA 402-R-93-071, to determine the radon area.

3-3.1.1.2 Navy.

For Navy requirements follow OPNAV M-5090.1C Chapter 30 “Radon Assessment and Mitigation”, and the Navy Radon Assessment and Mitigation Program (NAVRAMP) Guidebook for Naval Shore Installations. NAVRAMP provides for compliance with the procedural requirements of the Toxic Substances Control Act (TSCA) related to radon. For existing buildings check the results of the NAVRAMP survey by contacting the NAVFAC Facility Engineering Systems Command (FEC) Air Pollution Engineer.

3-3.1.1.3 Air Force.

Check the results of the AF Radon Assessment and Mitigation Program (RAMP) study of 1987. During that study, Air Force Installations were screened for radon in existing structures. Installations were classified as being of low, medium, or high risk. Incorporate radon reduction measures in the construction of new facilities at those installations designated as medium or high risk if installation not included in EPA Priority Areas No. 1. See AFMAN 48-148 for additional guidance on radon sampling and mitigation.

3-3.1.1.4 Lack of Radon Data.

If no data is available for the area or site to make a prediction of radon levels, then a radon survey must be done, or a passive radon mitigation system installed.

3-3.1.2 Radon Mitigation System Design.

Provide passive under-slab depressurization systems for projects located in Priority Areas No. 1 (predicted average radon level is greater than 4/pCi/L). Change the system to active, if needed, based on follow-up testing. Check the following EPA documents available from the EPA’s Publications about Radon website, https://www.epa.gov/radon/publications-about-radon

- EPA's Model Standards and Techniques for Control of Radon in New Residences, U.S. Environmental Protection Agency, Air and Radiation (6604-J), EPA 402-R-94-009,
- Radon Prevention in the Design and Construction of Schools and Other Large Buildings, EPA/625/R-92-016,

3-3.2 Paints with Lead, Cadmium, and Chromium.

Painted surfaces containing lead, cadmium, and chromium, as well as operations involving these and other heavy metals are regulated by the Occupational Safety and Health Act (OSHA) and the Resource Conservation and Recovery Act (RCRA). Paints containing lead, cadmium, and chromium are often found as protective coatings on structural steel, tanks, piping, metal building components, exterior coatings on metal surfaces, aircraft, and ships. Paints containing lead, cadmium, chromium, and other heavy metals are used in current operational processes in various facilities, such as aircraft maintenance hangars, and ship maintenance and repair facilities. If not properly controlled and managed, dust and particulates containing lead, cadmium, chromium, and other heavy metals can be generated from operational activities resulting in contaminated dust deposits on building surfaces that must be remediated during renovation, alteration, repair, or demolition activities. For Navy and Marine Corps projects involving renovation, alteration, repair, or demolition, comply with UFC 3-810-01N.

Facilities with heavy metal paints or coatings, or facilities that operated or will operate utilizing heavy metals or chemicals in their operations, must comply with the Occupational Safety and Health Act 29 CFR 1910.141 General Environmental Controls, 29 CFR 1910.1025 Lead, 29 CFR 1910.1026 Chromium (VI), and 29 CFR 1910.1027 Cadmium. The requirements found in the CFR may affect facility design requirements, which include but are not limited to: separate toilets and washing/bathing areas, change rooms, decontamination areas, clothes washing facilities, areas for controlled disposal of contaminated waste and work clothes, high-efficiency particulate air (HEPA) systems and filters, and deluge showers. Designate areas of facilities utilizing these heavy metals or chemicals as regulated areas whenever exposure can be expected to be in excess of the permissible exposure limit(s), and demarcate from the rest of the workplace in a manner that adequately establishes and alerts building occupants of the boundaries of the regulated area. Design facilities to allow the performance of the OSHA and EPA air sampling and monitoring as required for the specific hazardous metal or chemical in use.

3-3.3 Beryllium Coatings and Compounds.

Beryllium is an essential material used in the aerospace, electronics, energy, telecommunications, information technology, defense, medical, and nuclear industries. Beryllium is classified as a strategic and critical material by the U.S. Department of Defense. Beryllium is used industrially in three forms: as a pure metal, as beryllium oxide, and most commonly as an alloy with copper, aluminum, magnesium, or nickel. Workers in industries where beryllium is present may be exposed to beryllium by inhaling or contacting beryllium in the air or on surfaces. Beryllium is a highly toxic metal and workers who inhale beryllium are at an increased risk of developing chronic beryllium disease (CBD) or lung cancer. Coatings and compounds containing beryllium are used in current operational processes in various facilities, such as aircraft maintenance hangars, and ship maintenance and repair facilities. If not properly controlled and managed, dust and particulates containing beryllium can be generated from operational activities resulting in contaminated dust deposits on building surfaces which must be remediated during renovation, alteration, repair, or demolition activities. For Navy and Marine Corps projects involving renovation, alteration, repair, or demolition, comply with UFC 3-810-01N.

Facilities that operated or will operate utilizing beryllium in their operations must comply with the Occupational Safety and Health Act 29 CFR 1910.1024 Beryllium, 29 CFR 1915.1024 Beryllium, and 29 CFR 1926.1124 Beryllium. The requirements found in the CFR may affect facility design requirements, which include but are not limited to: separate toilets and washing/bathing areas, change rooms, decontamination areas, clothes washing facilities, areas for controlled disposal of contaminated waste and work clothes, high-efficiency particulate air (HEPA) systems and filters, and deluge showers. Designate areas of facilities utilizing these heavy metals or chemicals as regulated areas whenever exposure can be expected to be in excess of the permissible exposure limit(s), and demarcate from the rest of the workplace in a manner that adequately establishes and alerts building occupants of the boundaries of the regulated area.

Design facilities in a manner to allow the performance of the OSHA and EPA air sampling and monitoring that are required for beryllium.

3-4 MECHANICAL/ELECTRICAL/TELECOMMUNICATION ROOMS.

Design adequate mechanical equipment rooms, electrical rooms, and telecommunication rooms. Provide sufficient floor-to-floor height, vertical distribution space, and mechanical equipment space to accommodate a ducted system to supply preconditioned ventilation air (when a ducted system is used). Provide an adequate volume of space for all building distribution systems and provide access for maintenance. For mechanical equipment room sizing, coordinate with the mechanical designer at the earliest stage to ensure the required clearances for maintenance, servicing, and safety are included. Provide mechanical rooms in accordance with UFC 3-410-01. For telecommunications rooms, coordinate with the electrical designer. Do not route water or sanitary piping above electrical rooms or telecommunication rooms. See UFC 3-580-01 for additional telecommunications system requirements. For noise control, refer to Chapter 2 paragraph, Sound Transmission.

3-5 PLUMBING.

Refer to UFC 3-420-01 for plumbing fixture count and requirements.

3-6 AIR BARRIER DESIGN AND TESTING.

3-6.1 New Construction.

Clearly identify air barrier components of each envelope assembly on construction documents and detail the joints, interconnections, and penetrations of the air barrier components. Clearly identify the boundary limits of the building air barriers and of the zone or zones to be tested for building air tightness on the drawings. Include the calculated six-sided area of the air barrier envelope on the drawings for each test area.

Compartmentalize spaces under negative pressure, such as boiler rooms and laundry rooms, and provide make-up air for combustion. **\1**

3-6.2 Modifications.

When a building is undergoing a modification **/1/** of the building envelope, see Appendix A, paragraph Air Barrier for Modifying an Existing Building, for guidance.

3-6.3 Inspections and Testing.

Continuous air barrier inspection and testing must be in accordance with the requirements of the International Green Construction Code (IgCC) with **\2** building air leakage rate not exceeding 0.25 cfm/ft2 (1.25 L/s-m2) under a pressure differential of 0.3 inches of water (75 Pa) when tested. **/2/**

Detailed inspection and testing requirements and acceptance criteria must be included in the project specifications. Include UFGS Section **\3** 01 91 19 /**3**/ as part of the project specification when testing of the air barrier is required.

The following facility air barriers require inspection only:

- Those facility types outside the scope of ASHRAE 90.1
- **\4** New and existing buildings and conditioned spaces under 10,000 ft2 (929 m2) **/4/**
- Semi-heated buildings
- **\3** Spaces with large exterior doors, such as sliding hangar doors, overhead coiling and, or sectional doors. **/3/**
- Building additions onto non-renovated structures if the interface cannot be adequately sealed for testing.

3-6.4 Mock-Ups.

Mockups for air barrier installation require approval by the AHJ. See Appendix A, Best Practices for guidance.

3-7 FENESTRATION DESIGN.

Develop a comprehensive design that considers both exterior shading devices, including horizontal sunscreens and vertical fins (beneficial in hot southern climates), and interior shading devices (necessary to control glare when direct solar intrusion is inevitable). Optimize the window-to-wall ratio to (1) reduce lighting energy when using daylighting controls and (2) avoid the glare and added energy consumption that can result from large window areas. Glazing areas above 7 ft. (2135 mm) high are useful in increasing daylight penetration, especially when coupled with light-reflecting shelves. Base design on life cycle cost effectiveness. Design glazing to optimize daylighting and views, which has been proven to enhance occupant well-being.

Coordinate the selection among windows, storefronts, and curtain walls with the structural design. Coordinate the final fenestration design with the mechanical and electrical engineers to comply with overall facility energy requirements.

3-7.1 Daylighting \3\ Design /3/.

Design DoD projects to optimize daylight entering occupied spaces while minimizing the effects of solar heat gain and glare. See Appendix A for daylighting best practices.

3-8 ACOUSTICS – OUTSIDE TO INSIDE NOISE CONTROL.

3-8.1 Design.

Design the facility to provide a comfortable inside acoustical environment that limits exterior noise intrusion to noise-sensitive spaces. Develop a comprehensive acoustical design for individual facilities based on the acoustic analysis that uses the tools below. Identify outside noise sources. Utilize the Air Installation Compatible Use Zones (AICUZ) map and determine the Day Night Average Sound Level (DNL) or Community Noise Equivalent Level (CNEL) of the project site. In addition to the AICUZ map noise level, determine if other noise sources are near the project site. Other noise sources include engine test facilities, vehicle traffic, rail line, small arms ranges, or any site noise source that can be identified. Determine if any of the following noise sources are within the following distances:

- Major Road within 1,000 ft. (305 m) project site
- Rapid Transit Line or Rail Line within 3,000 ft. (915 m) of project site
- Engine Test Facility within 3,000 ft. (915 m) of project site
- Firing Range within 3,000 ft. (915 m) of project site

If an AICUZ map is available, use Table 3-1 for noise mitigation measures. If the project site is within the specified distance of a noise generating element listed above, the project will require an acoustical engineer to conduct an analysis including a site noise test for a continuous 72 hours to determine the DNL or CNEL.

If an AICUZ map is unavailable, and the project site is within the specified distance of a noise generating element listed above, the project will require an acoustical engineer to conduct an analysis including a site noise test for a continuous 72 hours to determine the DNL or CNEL. The measurement period must include two weekdays and one weekend day to capture typical site activity and be conducted in accordance with ANSI S12.9 Parts 1 & 2 – Quantities and Procedures for Description and Measurement of Environmental Sound. Based on the AICUZ map and testing results, the table below summarizes the required composite Outdoor Indoor Transmission Class (OITC) values for the building envelope.

Table 3-1 Building Façade Sound Isolation

Required Composite(1) Isolation of Building Façade and Roof Construction Based on Interior Background Noise Levels				
Interior Background Noise Level (2)	Exterior Sound Level at the Site (DNL or CNEL)			
	< 65 dBA	65 dBA - 70 dBA	70 dBA - 75 dBA	> 75 dBA
NC-25 or Lower	OITC 35	OITC 40	OITC 45	OITC 50
NC-30	OITC 30	OITC 35	OITC 40	OITC 45
NC-35	OITC 28	OITC 30	OITC 35	OITC 40
Above NC-35	OITC 25	OITC 28	OITC 30	OITC 35

1. Composite calculations must include all envelope elements including doors, windows, louvers, and other openings.
2. Equivalent RC Mark II noise levels may be used.

Apply the more stringent criteria when the project site has both AICUZ map information and site noise testing measurements.

CHAPTER 4 PROGRAMMING, PLANNING, AND PRE-DESIGN SERVICES

4-1 SPACE PLANNING CRITERIA.

Program non-standardized facility sizes based on a functional analysis of activities to be accommodated to determine the actual amount of space required. Base facility planning on specific requirements for each project, to include all functional, technical, and economic considerations. To obtain the most economical and efficient use of space, design facilities based on the functional organization of adequately sized spaces. The following publications contain tables of allowances for general planning purposes; however, the final size of each project must be based on actual requirements:

- AFMAN 32-1084, “Facility Requirements”
- AR 405-70, Utilization of Real Property
- TM 5-803-5, “Installation Design” and model design-build RFP and standard designs, as applicable
- UFC 2-000-05N, Facility Planning Criteria for Navy/Marine Corps Shore Installations

The documents above are used to determine general facility requirements. Refer to other facility-specific UFC for more detailed requirements.

4-2 BUILDING AREA CALCULATIONS.

Include net and gross floor area calculations in the Basis of Design/Design Analysis to confirm scope and code/criteria compliance. Include a block diagram indicating the building outline and all areas that contribute to the building area. Conform to gross area calculation methods and definitions for military programming and scope validation in this UFC. For Type of Spaces and Definitions, see Table 4-1. Other area calculations and definitions may be required to establish compliance with the IBC and Life Safety codes. Figures 4-1 and 4-2 illustrate a sample gross building area calculation and block diagram.

4-2.1 Scope Changes.

Changes to scope are governed by Title 10 USC 2853, as documented in project Change Management Plans included in the Project Management Plans.

4-2.2 Calculations of Gross Building Area.

Other facility-specific UFC such as those for medical facilities, family housing, and unaccompanied housing provide additional guidance regarding how to calculate the gross area for those facility types. For other facilities, calculate the gross area of a building using Table 4-1 (definitions of spaces per the IBC).

Table 4-1 Gross Building Area

Type of Space	Definition
Enclosed Spaces	The total area of all floors measured from the exterior face of exterior walls or from centerline of walls separating adjoined buildings including: - mezzanines - basements - penthouses - enclosed spaces such as pre-engineered metal building's housing equipment. - enclosed stairwells, elevators, utility chases are included as part of the area of the floor that they occupy.
Unenclosed Programmed Facilities	For covered outdoor facilities with no exterior walls, where the area is programmed by the space function (for example, walls are not required and only a roof is necessary to perform its designated function) the facility gross square footage is the total area measured under the roof. Refer to individual service component planning documents for programmed areas of these spaces.
One-Half Spaces	Include one-half of the gross area of paved or finished attached covered areas, such as: - balconies and porches - covered but not enclosed entrances - covered raised loading platforms - covered ground level or depressed loading facilities - covered but not enclosed walks or passageways - covered and uncovered but not enclosed exterior stairs - covered ramps For Army Unaccompanied Enlisted Personnel Housing (UEPH) calculate interior shared corridors as one-half space; calculate circulation spaces within the living unit as full area.
Excluded Spaces	Exclude the following spaces from the gross area calculations when the average ceiling height is less than 7 ft (2.1 m) measured from the underside of a structural system and with perimeter walls measuring a minimum of 59 in. (1500mm) in height: - mezzanines - interstitial spaces - penthouses - enclosed crawl and utility spaces such as tunnels, raceways, and trenches-catwalks - equipment platforms - exterior uncovered walks, ramps, and stoops - uncovered loading platforms or facilities, either depressed, ground level, or raised

Excluded Spaces	- open courtyards - open paved terraces - roof overhangs - glazing shading devices, and awnings - Prefabricated enclosures provided by the equipment manufacturer which house equipment are considered equipment and are also excluded - the void areas of atria (only include the floor area of the lowest level of atria)

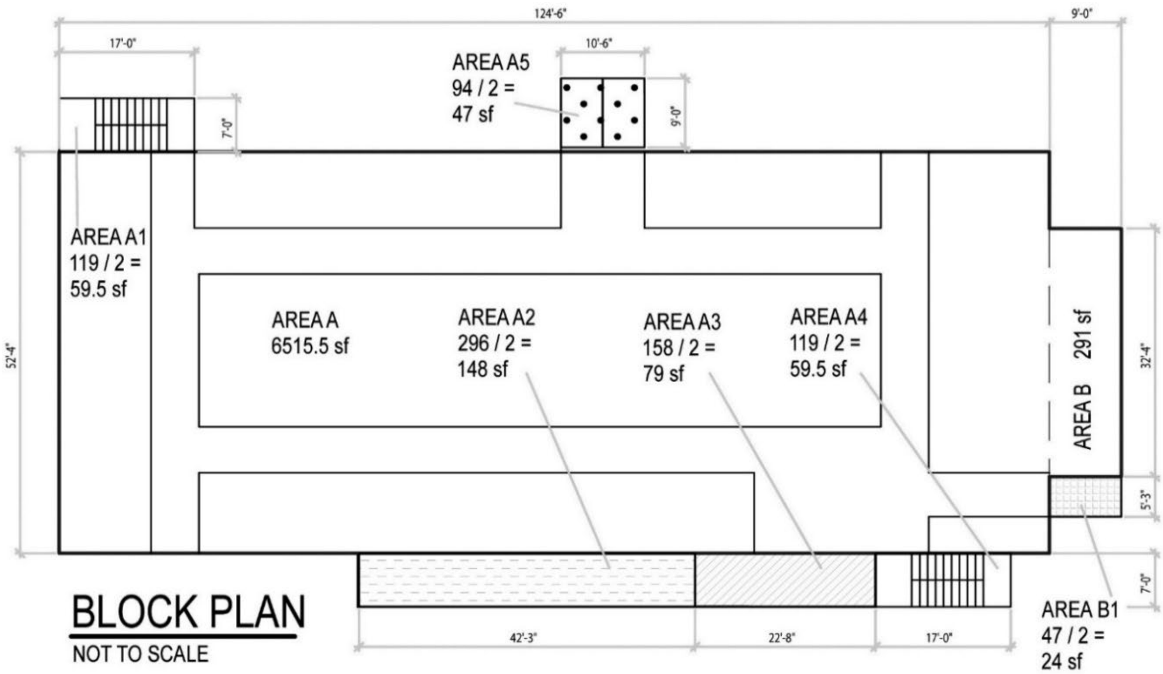
Figure 4-1 Sample Gross Building Area Calculation

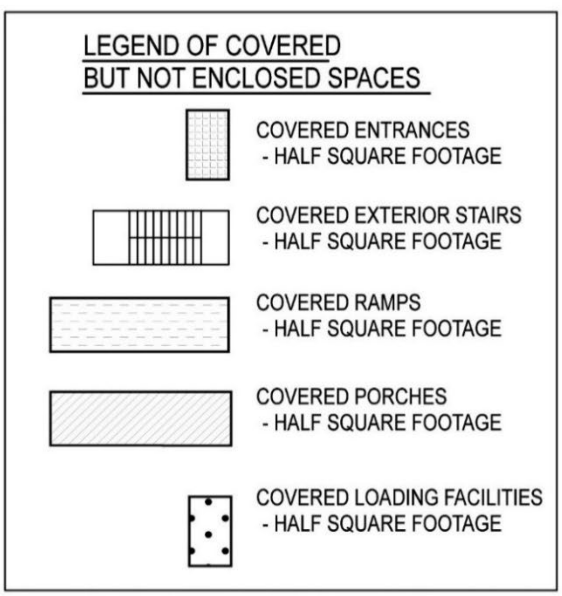
PROJECT LOCATION			
GROSS FLOOR AREA CALCULATION * (SEE BLOCK PLAN EXAMPLE)			
<u>AREA A</u>			
Area A	124’-6” x 52’-4” = 6515.1 sf		
AREA A TOTAL			**6515.1 sf** 605.3 sm
<u>AREAS A1 thru A5 (Exterior Covered – ½ Area)</u>			
Area A1	17’-0” x 7’-0” / 2=	59.5 sf	
Area A2	42’-3” x 7’’-0” / 2=	148.0 sf	
Area A3	22’-8” x 7’-0” / 2=	79.0 sf	
Area A4	17’-0” x 7’-0” / 2=	59.5 sf	
Area A5	10’-6” x 9’-0” / 2=	47.0 sf	
AREAS A1 thru A5 TOTAL			**393.0 sf** 36.5 sm
<u>AREA B</u>			
Area B	9’-0” x 32’-4” =		**291.0 sf** 27.0 sm
<u>AREA B1 (Exterior Covered – ½ Area)</u>			
Area B1	9’-0” x 5’-3” / 2=	24.0 sf	
AREA B1 TOTAL			**24.0 sf** 2.2 sm
BUILDING TOTAL GROSS			**7,223.5 sf** 670.9 sm
SCOPE TOTAL MAX. ALLOWABLE GROSS AREA*			**7,224 sf** 671 sm

Figure 4-2 Sample Block Plan

ARCHITECTURAL BASIS OF DESIGN FOR PROJECT NUMBER ***

EXAMPLE BUILDING PROJECT NAME at the EXAMPLE MILITARY INSTALLATION LOCATION
SERVICE BRANCH SPECIFICATION NUMBER Xxxxxx-xx-x-xxxx





EXAMPLE BUILDING AREA TABULATION

BUILDING AREA A	6,515.5 sf	605.3 sm
OUTSIDE STAIR A1	59.5 sf	5.5 sm
RAMP A2	148.0 sf	13.7 sm
PORCH A3	79.0 sf	7.3 sm
OUTSIDE STAIR A4	59.5 sf	5.5 sm
LOADING AREA A5	47.0 sf	4.4 sm
BUILDING AREA B	291.0 sf	27.0 sm
COVERED ENTRANCE B1	24.0 sf	2.2 sm
TOTAL 1391 AREA	7,223.5 sf	670.9 sm
1391 ALLOWABLE AREA	7,224 sf	671 sm

4-3 PRE-DESIGN SERVICES.

This process involves meeting with the using activity to review the programmed requirements for a new project. Based on these meetings the program documents and the DD Form 1391 are updated for submission to Congress. Prepare DD Form 1391 using the Electronic Project Generator (EPG) for Navy projects. For Army and Air Force projects, use the DD Form 1391 Processor System. Government personnel normally complete this process, but often an Architect/Engineer is contracted to provide planning support for preliminary programming, studying functional adjacencies, providing sketches, and other design-related support. A planning charrette is used to define the user's requirements.

This Page Intentionally Left Blank

CHAPTER 5 DESIGN AND POST-DESIGN SERVICES

5-1 GENERAL.

Provide architectural design services in accordance with this chapter. For the Navy, provide architectural design services in accordance with FC 1-300-09N. For Air Force, projects comply with the Air Force Corporate Facilities Standards and applicable Installation Facility Standards.

5-2 DESIGN SERVICES.

Provide the following design services unless modified by the contract.

5-2.1 Design Charrettes.

Functional Analysis Concept Developments (FACDs) and design charrettes are cooperative efforts by the design team, user/customer representatives, Government design and contract personnel, and other interested parties. They may last a few days, or a week or more, and include on-site development of a consensus conceptual design in response to functional, aesthetic, environmental, base planning, site, budgetary, and other requirements. For Air Force projects, the final document is called a Planning Charrette Report (PCR). In addition to Charrettes, the Navy also uses FACD studies; see FC 1-300-09N for additional information on FACDs. The scope of FACDs, PCRs, and design charrettes are project specific and will be defined in the Scope of Work.

5-2.2 Architectural Compatibility Submittal.

If the project Scope or Statement of Work requires an Architectural Compatibility Submittal, it must meet the requirements herein. On high visibility projects, the designer of record may be asked to provide a presentation of this submittal. If a project does not require a separate Architectural Compatibility Submittal, address exterior building design and compatibility in the Basis of Design, as defined herein, using applicable installation exterior architectural guidelines.

When required, the Architectural Compatibility Submittal documents the exterior architectural design of a new facility or major renovation. Determine architectural compatibility at the concept stage of the project. Provide adequate documentation that indicates that the materials, colors, and design elements used on the exterior of the building are compatible with other facilities nearby and with other design guidance required by the installation or customer. Clearly show that the design meets the requirements of Chapter 3 paragraph, Design Quality.

5-2.2.1 Exterior Finish and Color Schedule.

The Architect is responsible for selection and coordination of final exterior finish and color selections using installation architectural guidelines, after obtaining input from the using activity and the Government’s architectural reviewer. Indicate these selections on a comprehensive schedule located on the contract drawings.

5-2.2.2 Format.

The Architectural Compatibility Submittal consists of the following four elements:

5-2.2.2.1 Statement of Compatibility.

Provide a brief description of the design, stating concisely the architectural compatibility of the project with respect to the existing nearby permanent facilities and the applicable installation exterior architectural guidelines. Include not only building characteristics, but also a site analysis, visual environment concept, and appropriateness of construction materials and colors.

5-2.2.2.2 Drawings.

Provide the following drawings as applicable:

1. Site Plan - Indicate site boundaries, building locations (existing, proposed, and future), drives and roads, parking, pedestrian circulation, pedestrian and service entrances, **\2** dumpsters **/2/** and landscaping.
2. Floor Plans - Indicate main entrances, service areas, room designations, and exterior stairs and ramps.
3. Elevations - Provide all building elevations, and indicate all exterior materials, architectural characteristics and design elements. As an option, provide concept renderings.

5-2.2.2.3 Exterior Color Boards.

Provide tangible samples of all exterior materials and colors. When matching existing materials and colors, it is not sufficient to state, “match existing.”

5-2.2.2.4 Photographs.

Provide enough digital photographs to indicate the character of the existing nearby facilities that have influence on the architectural design of the project. Reference photograph locations on the Site Plan or with a key plan.

5-2.3 Architectural Basis of Design/Design Analysis.

The Basis of Design/Design Analysis is a written document that describes the project at the Preliminary Stage and is updated at each subsequent stage. The Navy uses the term Basis of Design. The Army and Air Force use the term Design Analysis. Include the following items:

1. Scope of Work – Summarize the architectural program or scope of work, listing the overall square footage, the functional requirements of the facility, and a tabulation of rooms with square footages of each space.

2. Type of Construction - Describe the type of construction selected and justify its use relative to building permanency, life cycle cost, functionality, and fire resistance. Coordinate with the Fire Protection Engineer.

3. Life Safety Code Analysis - Provide an analysis of the design to include the required number of exits, travel distances, egress capacity of exits, and fire area separations. Coordinate with the Fire Protection Engineer.

4. Gross Floor Area Calculations - Provide a tabulated breakdown of the net and gross programmed areas to confirm project scope and statutory criteria compliance. Provide a supplemental drawing keyed to the area tabulation. Indicate method of take-off based on calculation and diagram guidance in Chapter 4.

5. Accessibility - Describe accessibility features included in the project and indicate how the design meets the accessibility requirements noted in UFC 1-200-01. If a partial or full exclusion to accessibility requirements has been or is being pursued indicate proper documentation and the status of the exclusion.

6. Architectural Compatibility - Identify the design guidelines that pertain to this project and describe how the proposed design incorporates these guidelines. Discuss the approach to achieving architectural compatibility with other surrounding architecture in accordance with the installation exterior architectural guidelines. Exterior color boards are required for all projects. For Air Force projects, refer to the Air Force Corporate Facilities Standards and applicable Installation Facilities Standards.

7. Roof System Selection - Indicate the construction of the roof, roof membrane selection, substrate, roof slope, roof drainage system, and justify the use of parapets.

8. Thermal Insulation - Describe the types of insulation to be provided and indicate specific “U” values for the wall, roof, and floor construction. Provide a description of all architectural energy conserving and generating features, including any passive solar systems. Provide a moisture vapor analysis in accordance with Chapter 2 of this UFC.

9. Security Requirements - Describe the physical security or hardening requirements such as controlled access, SCIF, and Secure Room requirements that will be used in the design.

10. Antiterrorism – Per UFC 4-010-01, DoD buildings are categorized as low occupancy, inhabited, primary gathering, high-occupancy family housing, or billeting. Describe the occupancy of the facility, if progressive collapse avoidance will be included in the design, if the facility is within a controlled perimeter, and what the standoff distances will be. Include sketches as required to depict the site of the project and standoff distances. Include a summary of how the facility meets each of the applicable Standards in UFC 4-010-01 and Geographic Combatant Commander (GCC) Antiterrorism construction standards. Outline any special requirements, including any requirement for hardening of the facility. Provide the construction information necessary for the installation of all applicable Standards in UFC 4-010-01 and the Geographic

Combatant Commander (GCC) Antiterrorism construction standards. Do not include information on force protection methods, philosophy, explosive weights, and design threats, as this information is considered sensitive and Controlled Unclassified Information.

11. Architectural Acoustics – Include a statement of adherence to the applicable criteria per Chapters 2 and 3 of this UFC. This statement must include, but not be limited to:

- Identify design team members responsible for the acoustical engineering.
- Provide a detailed identification of conditions, materials, or features which will impact the acoustic design of the project.
- Describe Testing, Mock-up, Commissioning, and Quality Control processes.

Upon the completion of a project, if post-construction testing is not included in the project scope, the Government may elect to test the airborne or impact isolation sound isolation, background noise level, or other parameters established as project criteria. Additional modifications or remediation to meet the project acoustical criteria will be at the expense of Design-Build or Construction team.

12. Sustainable Design – Include the architectural description of the sustainable design in the separate chapter “Sustainable Design”. Describe the overall sustainability and energy performance of the project, with the architectural portion leading the process of compliance. Describe the sustainable design features included in the design. Provide an analysis of compliance with applicable requirements of UFC 1-200-02; the High Performance and Sustainable Building (HPSB) Checklist and description of how targets will be met, or justifications for missed targets. When applicable, include the sustainable Third Party Certification checklist and describe how applicable credits align with the HPSB Checklist requirements.

13. Doors and Windows - Indicate the types of doors and windows selected for the project and explain the basis for their selection. Use operable windows where feasible. Indicate any special door requirements such as STC ratings, cipher locks. Indicate any special window requirements such as OITC ratings.

14. Demolition or Deconstruction – Describe the extent of any architectural demolition or deconstruction and items to be salvaged.

15. Special Construction Features - Describe the special construction features built into the facility, such as barred windows, special wall/roof construction, raised flooring, radio frequency electromagnetic radiation (RF) shielding, High-Altitude Electromagnetic Pulse (HEMP) protection, and vaults.

16. Commissioning – Identify architectural systems scheduled for commissioning as required by the Commissioning Plan.

5-2.4 Specifications.

Design-Bid-Build and Design-Build projects have differing specification requirements. Specifications must be concise, definitive, and free of ambiguities and omissions that may result in controversy and contractor claims for additional compensation. For Army and Navy design-bid-build specifications, the use of SPECSINTACT and Unified Facilities Guide Specifications (UFGS) is required. These documents are available on the WBDG website. For Air Force projects, the use of UFGS or other commercial guide specifications is at the discretion of the Air Force Project Manager. For projects using UFGS, comply with UFC 1-300-02. For Navy projects, see also FC 1-300-09N. When preparing a Design-Build Request for Proposal (RFP), see the NAVFAC Design Build Master website located at https://www.wbdg.org/ffc/navy-navfac/design-build-request-proposal.

5-2.5 Architectural Drawings.

Confirm drawing size with the Government Project Manager prior to starting drawings. Provide architectural drawings that comply with the National CAD Standard and Spatial Data Standard (SDSFIE) for Facilities, Infrastructure, and Environment/ Computer-Aided Design and Drafting (SDS/CADD Standards). For projects accomplished using Building Information Modeling (BIM) use the National BIM Standard, along with published Service supplemental standards. Include the following requirements in the final drawings as applicable:

1. Title and General Sheets: Lists all drawings in the set, project title, project name, location map, and vicinity map.

   Floor Plans: Fully dimensioned and referencing other drawings. Indicate plan orientation. Draw building plans parallel to the sheet border with north generally up or to the left or right edge if better suited. Orient floor plans consistently throughout all discipline drawings. Orient site and building plans in approximately the same orientation.
2. Building Code/Life Safety Code Analysis: Conduct a diagrammatic analysis and indicate code compliance (such as remoteness of exits, common path of travel, compartmentalization, and fire extinguisher locations) to graphically demonstrate compliance with the Life Safety Code. Coordinate with Fire Protection Engineer as required.
3. Furniture Placement Plans: Indicate furniture arrangement if separate interior design drawings are not provided in the drawing set.
4. Roof Plans: Completely dimensioned and referencing other details.

   Reflected Ceiling Plans: Fully coordinated with disciplines.
5. Building Elevations: For elevations indicate location of control joints and expansion joints.
6. Building Sections and Wall Sections: For differing conditions, identify air barrier, moisture barrier, and insulation barrier systems.

7. Wall Types: Provide all interior and exterior wall and partition types. Indicate wall type locations on the floor plans.
8. Air Barrier: Indicate the boundary limits of the air barrier components (pressurization area for air barrier testing) on the plan and section. Indicate the actual area of the pressure boundary (ft.2/m2).
9. Interior Elevations: Indicate differing conditions and coordinate with other drawings.
10. Doors, Windows, and Louvers: Provide types, schedules, and details.
11. Room Finish Schedule, Legend, and Finish Notes: For all finishes.
12. Signage Plan, Schedule, Legend, and Notes if not provided on separate interior design drawings.
13. Detail all conditions. Pay particular attention to the moisture barrier system, the continuous air barrier, wall and roof penetration flashing details, surface termination and transitions, roof ridges, roof edges, and parapet and drainage details.

Provide drawing requirements suitable for the project type and scope of work.

5-2.5.1 Exterior Finishes and Colors.

Provide a comprehensive exterior finish and color schedule, indicating selections for all exterior materials. Locate this schedule on the finish schedule sheet or on the sheet with the exterior building elevations. When matching existing materials and colors, it is not sufficient to state, “match existing.” Do not indicate that the Contracting Officer will make color selections.

5-2.5.2 Dimensioning.

Provide floor plans with sufficient dimensions to avoid difficulties during construction. Provide adequate dimensions on each floor plan so that it is not necessary to refer to other drawings in order to determine dimensions. Dimensioning guidelines are as follows:

5-2.5.3 Exterior Dimensions.

- Provide overall building dimensions.
- Provide dimensions to include building expansion joints.
- Provide continuous dimension strings from column centerlines to exterior building surfaces.
- Provide continuous dimension strings from column centerlines to exterior building wall line breaks.
- Provide dimensions to wall and masonry openings.
- Provide vertical dimensions for elevations and sections.

- Coordinate overall architectural dimensions with structural dimensions on the structural drawings.

5-2.5.4 Interior Dimensions.

- Dimensions must indicate design intent. For example, if a door is to be centered on a space, indicate dimensions as “equal-equal.”
- Indicate all statutory dimensions, such as accessibility requirements and egress.
- Provide continuous strings of dimensions through the building in each direction that extend through the exterior wall.
- Dimension masonry walls and stud partitions to one side of the wall. Wall thickness may be indicated with dimensions or by wall types.
- When a dimension string passes through a space that is shown elsewhere at a larger scale, this space may be provided with an overall dimension. The large-scale plan must show additional dimensions. To ensure continuity, take dimensions from the same wall face as shown on the overall plan.
- Where a wall or partition aligns with a column, wall opening, window jamb, or other feature, ensure that other dimensions to that wall or partition are to the same face. Additionally, if a dimension is to a particular wall or partition face, then other dimensions to that wall must be to that face.

5-2.5.5 Referencing.

1. Use reference symbols (section and detail cuts) liberally on the drawings to indicate which section or detail applies. Use material indications to clearly identify construction materials. Generally, provide the following:
2. Floor Plans – Indicate building and wall sections, major details, and areas of large-scale plans.
3. Building Elevations – Indicate building and major wall sections, expansion, control and seismic joints, construction materials.
4. Building Sections – Indicate wall sections, major details, such as air barrier interfaces, and construction materials.
5. Details – Indicate construction materials. Where several sections or details are provided on the same drawing, it is acceptable to reference a single section or detail for materials with additional call-outs as needed for differing conditions.

5-2.6 Color Boards and Binders.

Exterior finish material color boards or binders displaying actual samples of all proposed finishes are required during the design of a project. If binders are provided, provide in accordance with UFC 3-120-10.

This Page Intentionally Left Blank

APPENDIX A BEST PRACTICES

A-1 INTRODUCTION.

This appendix identifies background information, good architectural design practices, and DoD preferences. The designer is expected to review and interpret this guidance and apply the information according to the needs of the project.

A-2 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide provides additional information and discussion on architectural practice and facility design, including a holistic approach to integrated design of facilities.

The WBDG provides access to all Construction Criteria Base (CCB) criteria, standards, and codes for the DoD Military Departments, National Aeronautics and Space Administration (NASA), and others. These include Unified Facilities Criteria (UFC), Unified Facilities Guide Specifications (UFGS), Performance Technical Specifications (PTS), design manuals, and specifications. For approved Government employees, it also provides access to non-government standards.

A-3 PLANNING ISSUES.

Consider the following issues when planning a facility:

A-3.1 Building Orientation.

In general, minimize east- and west-facing glazing. The orientation for rectilinear CONUS buildings is with the long axis parallel to the east/west direction for optimum energy conservation. Typically, orient glazing north (south in the southern hemisphere) to provide daylighting while minimizing glare. South-facing glazing (north in the southern hemisphere) should be appropriately shaded on the exterior to exclude summer (winter in the southern hemisphere) sun.

A-3.2 Design for Flexibility.

Flexibility in architectural design facilitates the change or expansion of an existing structure to accommodate changing functional requirements with minimum expenditure of resources. DoD usually owns and operates its facilities from the time of construction until the end of its useful life. During this long tenure of use, functional requirements of buildings will change, often drastically. Careful planning for reconfigurable technology infrastructure and utility distribution, minimizing permanent interior walls and using systems furniture and demountable partition systems enhances flexibility. When feasible, design facilities to facilitate future expansion in response to mission requirements.

A-3.3 Design for Function and Life Cycle.

- Permanent Construction. Buildings must be energy efficient, and have finishes, materials, and systems selected for low maintenance and low life cycle cost over a life cycle of more than 25 years.
- Temporary Construction. Buildings must use low cost construction, with finishes, materials, and systems selected with maintenance factors as secondary considerations to meet a life cycle of 5 years or less.
- Mobilization and Emergency Construction. Buildings must minimize design and construction time and maximize conservation of critical materials and funds. Maintenance factors and longevity are secondary considerations.
- Contingency Construction. Such structures may not be used for the purpose of satisfying requirements of a permanent nature at the conclusion of combat or contingency operations.
- Manufactured and Pre-engineered Buildings. This type of construction should be considered where it meets the quality, performance, and functional requirements of the project, when it will be architecturally compatible with adjacent structures, and when justified by life cycle cost. Also consider this building technique when there is limited time for on-site construction erection activities due to weather conditions.

A-4 LOCAL CONSTRUCTION METHODS, MATERIALS AND SKILLS.

Design to take advantage of economies resulting from the use of suitable local construction methods, materials, and skills that are consistent with the intent of these criteria. This is particularly important in overseas locations, where local materials may not be common to architects from the United States. Construction means and methods are the responsibility of the construction contractor.

A-5 BUILDING ENVELOPE.

This section provides background on the science of building envelope design and includes additional design recommendations. Review this section in conjunction with the requirements in Chapter 2. The building enclosure functions to control the transfer of the following elements: heat, air, moisture, light/radiation, and noise.

A-5.1 Heat.

Heat, which is energy, is transferred from warm to cold in one of three ways: conduction, convection, and radiation.

A-5.1.1 Conduction.

Conduction is most effectively resisted by low-conduction materials such as insulation. Highly conductive materials when inserted through the insulating layer can cause a loss of efficiency in the overall assembly's ability to resist heat transfer in a phenomenon called thermal bridging. Examples of high-conduction materials interrupting insulation include the following:

- Steel studs
- Cantilever concrete balconies and projections
- Structural steel and aluminum that are outside the thermal envelope and connected to the building structure
- Z-furring supporting cladding interrupting the insulation
- Shelf angles attached continuously and directly to the structure.

Many of these materials can be designed to reduce thermal bridging by intermittent support through insulation and maintaining them outside the insulation layer. Others like cantilever balconies or exterior structure, can be thermally broken by specially designed structural thermal breaks. Structural steel should be within the insulated enclosure, unless thermally broken. Thermal bridges impact energy efficiency and are a likely cause of condensation.

A-5.1.2 Convection.

Convection is the movement of heat transported by fluids, including air. Air movement can transport heat as well as water vapor from warm to cold. Surfaces that can cool the air adjacent to them, such as slabs on grade and basement walls, and cause the air to become heavier and sink. This draws warm, moist air in to replace it in a continuous convective loop. Warm air can have a dew-point higher than the cold surface, which can cause condensation and the ensuing mold, rot and corrosion. Convection in exterior assemblies is caused by designing air spaces adjacent to cold materials. This can happen in a basement on a concrete wall insulated by glass fiber batts (fibrous insulation is mostly air), or adjacent to glass in fenestration. Eliminating air gaps or separating them from warm air by an air barrier is an effective strategy in reducing convective flow of heat and condensation.

A-5.1.3 Radiation.

Radiation is the flow of heat, across space or fluid or gas, from a warm body to a colder one. One example of radiational heat transfer is from the interior to a cold glass surface. Radiational heat gain is direct or reflected solar radiation coming in to a building through glazing or heating up building materials of the enclosure. Heat can be radiated from one sheet of glass to the other in insulating glass. Low emissivity coatings in glass assemblies can be effective in reducing the radiational transfer of heat from the exterior and from the interior, improving both the U-factor and Solar Heat Gain Coefficient. Heat gain from the sun can be effectively reduced by including radiant barriers, such as aluminum foil with an adjacent air gap. Radiant barriers in wall and roof assemblies will only work with an adjacent air gap (see above paragraph on air gaps and convection). Quadruple glazing using heat mirror foils, two low emissivity low-e layers and filled with inert gas such as argon or krypton, is the state of the art for glass selection today and should be considered for extreme climates.

A-5.2 Air.

Air leakage, or unintentional air movement through the enclosure under a pressure difference between inside and out, transfers heat (energy loss), water vapor, smoke, odors, dust, and other pollutants, including chemical, biological, and radiological agents, into and out of buildings. Infiltrating air is unconditioned for temperature and moisture content and can contain pollutants. It causes discomfort and can unbalance spaces such as patient isolation rooms, protected environment rooms, or chemical storage areas that are designed for controlled pressure, thus compromising pollutant control. Mechanical systems attempt to reduce uncontrolled infiltration by introducing more air than is exhausted. This theoretically puts the building under positive pressure, reducing infiltration. The success of this strategy is dependent on how leaky the building is. (As an analogy, a balloon with a big hole in it can't be inflated.)

Air leakage can be the major source of water vapor transfer through building enclosures. Unlike the moisture transport mechanism of diffusion due to a vapor pressure difference, air pressure differentials can transport hundreds of times more water vapor through air leaks in the envelope over the same period of time ("The Difference Between a Vapor Barrier and an Air Barrier," Quirouette, 1985). This water vapor can condense within the envelope in a concentrated manner, depending on the pathway, if the enclosure includes surfaces below the dewpoint of the air, causing building deterioration and mold growth. Internal compartmentalization of a building (floors and demising partitions) is also a key to the control of the unwanted transfer of air, pollutants, noise, and smoke. See the following resources for more information and sample design details

- Building Envelope Design Guide: http://www.wbdg.org/design/envelope.php
- WBDG Resource Webpage for Air Barrier Systems: http://www.wbdg.org/resources/airbarriers.php
- Also see ECB 2012-16 Building Air Tightness And Air Barrier Continuity Requirements Applicability: Directive and Guidance https://www.wbdg.org/ffc/dod/engineering-and-construction-bulletins-ecb/usace-ecb-2012-16.

A-5.3 Moisture.

Moisture in its different forms is the major cause of water intrusion, condensation, shortening of service life, and disruption of operations. Walls leak when three conditions exist simultaneously: (1) Rainwater is on a wall, (2) Openings exist through which the rainwater can pass, and (3) Forces are present to drive or draw the rainwater inward. If any of these three essential conditions is eliminated, rainwater will not penetrate the enclosure.

A-5.4 Walls are Porous.

It is difficult and impractical to keep wind-driven rain off the exterior walls of a building. Overhangs, cornices, and solar shading can be effective in minimizing, but will not prevent, wetting of a wall. Thus, it should be expected that exterior walls will be covered by a film of water during a rain event, and that this film thickens when rain flows down the building wall. It is virtually impossible to build an exterior wall without any unintentional openings or leakage paths. Such openings may be pores, cracks, incompletely filled or poorly adhered mortar joints, or moving joints between elements or different materials. A typical masonry wall contains multiple apertures of various types and sizes yielding many joints between dissimilar materials prone to movement and joint failure. One square foot of brick masonry contains 6.75 modular brick, 6 lineal ft. (1830 mm) of mortar joint, and 12 lineal ft. (3660 mm) of brick-mortar joint interface. For 20,000 ft2 (1858 m2) of wall surface, this equates to 135,000 modular brick, 22.7 miles (36.5 km) of mortar joint, and 45.5 miles (73.2 km) of brick-mortar joint interface. Water can penetrate openings as small as 0.005 in. (.1 mm), which is just slightly more than the thickness of a sheet of bond paper.

A-5.4.1 Drainage Plane.

Even if a good seal is achieved initially, odds are that the seal will deteriorate over time under the action of temperature, water, deterioration due to ultraviolet radiation, and differential movement. For these reasons, a single 4-in. (100-mm) -wythe of masonry conventionally laid up in the field (or any cladding for that matter) should not by itself be expected to be watertight. It is also why sealants cannot be expected to keep water out of building enclosures. There needs to be an underlying drainage plane or WRB and flashings to lead water that penetrates building assemblies out again.

A-5.4.2 Forces Acting on the Wall.

Forces acting on an exterior wall during a rain event that individually or in combination can contribute to rain penetration include the following: (1) raindrop momentum or kinetic energy, (2) capillary suction; (3) external or internal air pressure; (4) gravity, and (5) surface tension. Water hits and wets the tops of buildings first, as well as projections. Water tends to travel over and flow down reveals and channels in the façade in a concentrated manner.

A-5.4.3 Rain Screen Design.

When the joints are well-pointed, brick masonry tends to absorb moisture for 4 - 6 in. (100 to 150 mm) depth after a rain event, and to dry out in dry periods. All masonry mass walls must have ventilation on the interior face of the exterior wall (and parapets) to assure proper drying. Single-wythe concrete block walls are undesirable because they do not manage moisture well. Wall design should be a rainscreen design; in other words, cladding should have a WRB in the wall assembly behind the cladding, with flashings to lead water out. This is true for claddings including EIFS; face-sealed assemblies are not acceptable.

A-5.4.4 Tool Masonry Joints.

Exterior masonry wall joints must be tooled. This will densify the mortar bonding. Joints must be tooled concave, vee, beaded, or weathered types.

A-5.4.5 Coatings on Exterior Walls.

Dependent upon the moisture migration study, it is advisable in cavity or double exterior wall construction to apply a low permeable coating to the exterior walls to help minimize the amount of moisture transfer through the wall. Apply a high permeable coating to the interior side of wall surfaces to ensure that any water vapor that passes through the exterior coating and vapor barriers enters the air-conditioned space and does not remain trapped within the insulation and wall material. Vinyl wall covering may be used in air-conditioned buildings as a vapor barrier if it is required by the moisture migration study and no other vapor barrier is used. Otherwise, vinyl wall covering should not be used on the interior surface of exterior walls as it may act as a vapor barrier.

A-5.5 Air Barrier for Modifying an Existing Building.

The following are five possible scenarios relating to air barriers in existing buildings:

A-5.5.1 Major Envelope Modifications with Existing Air Barrier.

For a renovation project that includes modifying the building envelope that has an existing air barrier: Pressure test the air barrier prior to the renovation to verify the air barrier meets its designated leakage rate goal. The result of this initial pressure test can serve as baseline for comparison to a second pressure test performed after the renovation is completed. If air leakage data for this building envelope is not available prior to design kick-off, develop a separate scope to conduct an initial pressure test with diagnostic evaluation, which may include thermographic evaluation methods. If the air barrier will be disturbed or is damaged during renovation, then repair to maintain its integrity. If, after an initial pressure test is performed, its results indicate that the air barrier failed to meet the current air leakage goal, perform a cost analysis to determine if the building should be outfitted with a new air barrier. The cost analysis evaluation should produce the lowest Life-Cycle Cost (LCC), highest Net Savings (NS), or a Savings to Investment Ratio (SIR) of at least one, or greater. Use Building Life Cycle Cost (BLCC5) to perform cost evaluation; reference the National Institute of Standards and Technology (NIST) *Handbook 135* for cost evaluation guidelines. If SIR is less than one, use best judgment within the scope of the project to determine air barrier feasibility. After construction of the air barrier has been completed, perform a second pressure test to verify that it meets the established leakage rate goal. If the air barrier fails to meet its leakage rate goal, use diagnostic methods to determine the source of leaks. After additional sealing is applied, based on the results of the diagnostic tests, determine the economic feasibility of performing another pressure test.

A-5.5.2 Minor Envelope Modifications without Existing Air Barrier.

For a building undergoing only a minor modification to the building envelope, such as removing/installing new windows or doors or replacing the roofing system: Greater challenges in easily, fully, and cost effectively accessing surfaces upon which to apply a complete air barrier may exist. For this case, sealing select building components may help reduce infiltration; however, component sealing is unlikely to achieve the same level of air tightness that would be achieved in applying a complete air barrier to the building. Install windows and doors with an air leakage rate in accordance with the Unified Facility Guide Specifications (UFGS) or the National Fenestration Rating Council (NFRC).

A-5.5.3 Major Envelope Modifications without Existing Air Barrier.

For projects that include modifying the existing building envelope that are not equipped with an air barrier: Determine if the modification to the envelope is sufficiently extensive, (generally, wherein only the building's structure remains). Perform a cost analysis to determine the cost effectiveness of installing a new air barrier. The cost analysis evaluation should produce the lowest Life-Cycle Cost (LCC), highest Net Savings (NS), or a Savings to Investment Ratio (SIR) of at least one, or greater. Use Building Life Cycle Cost (BLCC5) to perform cost evaluation; reference the National Institute of Standards and Technology (NIST) *Handbook 135* for cost evaluation guidelines. If SIR is less than one, use best judgment within the scope of the project to determine air barrier feasibility. If it is cost effective, install a new air barrier as required for a new building and pressure test it if required to ensure the air barrier meets the current air leakage goal.

A-5.5.4 New Addition to Existing Building.

For a new addition to an existing building that has no air barrier: Install an air barrier on the new addition as required for a new building. If the addition does not have an air plenum in common with the existing building, with some modifications to the testing protocol, it can likely be pressure tested in a manner similar to a freestanding new building. If the addition shares a common air plenum with the existing building, pressure testing just the addition is not possible, unless a temporary air barrier is installed to separate the two spaces.

A-5.5.5 Minor Non-Envelope Modifications without Existing Air Barrier.

For a building undergoing modifications not directly impacting the envelope: Sealing methods can be used in an effort to reduce air infiltration. However, sealing in this manner is not likely to result in achieving a level of airtightness that is nearly as tight as that of a complete air barrier. These sealing methods involve materials intended to achieve airtightness, such as applying closed-cell spray foam or sealant to the assembly, but are not limited to these materials. These materials should meet the permeance criteria of ASTM E2178. Removable ceiling tiles allow easy access to problem areas, and walls require destruction of finishes to expose gaps in the building envelope, such as those around windows. Stuffing glass-fiber insulation in cracks is not an acceptable sealing method, because glass-fiber merely acts as a dust filter and allows air under a pressure differential to pass through it. Also, glass-fiber insulation will hold moisture, which can lead to hidden moisture and mold problems. For minor renovation and repair projects, seal air leaks in building components in the following order of priority:

1. Top of building
    - Attics
    - Roof/wall intersections and plenum spaces
    - Mechanical penthouse doors and walls
    - HVAC equipment
    - Other roof penetrations

2. Bottom of Building
    - Soffits and ground floor access
    - Underground parking access doors
    - Exhaust and air intake vents
    - Pipe, duct, cable, and other service penetrations into core of building
    - Sprinkler hangar penetrations, inspection hatches, and other holes
    - Seal core wall to floor slab
    - Crawl spaces

3. Vertical shafts
    - Gasket stairwell fire doors
    - Fire hose cabinets or toilet room recessed accessories connected to shafts
    - Plumbing, electrical, cable, and other penetrations within service rooms
    - Elevator rooms and electric rooms (reduce size of cable holes, firestop, and seal bus bar)
    - Openings

4. Exterior Walls

- Weatherstrip windows, doors, including balcony/patio doors and seal window trim
- Exhaust fans and ducting
- All service penetrations
- Baseboard heaters
- Electrical receptacles
- Baseboards

5. Compartmentalize

- Garages
- Vented mechanical rooms
- Garbage compactor rooms
- Emergency generator rooms
- High voltage rooms
- Shipping dock
- Elevator rooms
- Workshops
- Compartmentalized walls are sealed at the top, bottom, and penetrations. Include weatherstripping/gasketing on doors and windows.

A-5.6 Light / Radiation.

Generally speaking, light is desirable while the accompanying heat (radiation) is not. They penetrate through the fenestration, which is the least energy-efficient component of the envelope. In addition to effective glazing design and shade structures, building orientation plays a large role in managing the light/heat gain balance. See discussions under Building Orientation and Radiation in this Appendix for more information.

A-5.7 Noise.

Noise by definition is unwanted sound. Project acoustical considerations are intended to limit noise to the building occupants so that the building function is not limited due to noise within or around a building. Best practices will be achieved by meeting the project requirements as stated in Chapters 2 and 3. Standards referenced in Chapter 2 include best practices and suggestions to provide an appropriate acoustic environment for most space types. Thoughtful consideration of the project acoustic requirements is very beneficial early in the design process.

Proper preparation of the required statement of adherence outlined in Chapter 5 to meet requirements established in Chapters 2 and 3 of this UFC is an important basis to understanding the project acoustical requirements; however, the Design or Design-Build team will still need to be mindful of implementing the requirements during the design and meeting the requirements during the construction of the project.

A-6 AIR BARRIER MOCK-UP TESTING.

A-6.1 Guidance on When to Test Mock-Ups.

See Table A-1, Construction Mock-up Guidance Matrix, for recommendations. Approximate suggested definitions of sizes to use for the matrix:

- Small: Up to 10,000 sf (929 sm)
- Medium: 10,000 to 50,000 sf (929 to 4645 sm)
- Large (Common): above 50,000 sf (4645 sm)
- Large (Unique): above 25,000 sf (2323 sm)

Table A-1 Construction Mock-Up Guidance Matrix

Guidance: The Authority Having Jurisdiction (AHJ) may give consideration to implementing construction mock-ups based upon the following decision matrix.		
FACILITY TYPE	**APPLICATION**	**RECOMMENDED GUIDANCE**
Small size facility Common facility such as: mech building; pump house; small and medium warehouses. Size range: square feet	Small facilities that are not unique and provide support functions on an installation	Recommend not requiring construction mock-ups
Medium size facility Common facility types such as MWRs; chapels; child care centers; small and medium size administrative facilities, post offices; post exchanges. Size range: square feet	Medium size facilities that are not unique and utilize typical and proven construction materials, methods and processes. The application of these systems carries littles to no risk of not being constructed satisfactorily.	Recommend not requiring construction mock-ups
Large size facility: Common facility types such as barracks buildings; large dining facilities; laboratories; highly visible headquarters facilities; large company operations facilities, maintenance facilities, large storage warehouses. Size range: square feet	Large size facilities that do not necessarily employ unique construction technology or innovative features but due to size, visibility and interest on the installation; failure of this facility would be detrimental to mission execution and would reflect poorly on the installation command.	Recommend consideration be given to providing construction mock-up at critical connections for windows; advanced structural systems
Large size facility: Unique facilities that utilize un-common or prototype systems; advanced technology or innovative technology for structural systems or window walls. Size range: square feet	Large size facilities that employ unique construction technology or innovative features; maintenance problems or systems failure within this facility would be detrimental to mission execution and would reflect poorly on the installation command.	Strongly recommend providing construction mock-ups at critical connections for window; advanced structural systems or unique curtain wall systems that employ daylighting sensors or integral shading screens.

A-6.2 On Site Mock-Ups.

When approved by the AHJ, a mockup of the wall system will include a representative wall and window constructed on site, complete with its components, and must be tested for air and water infiltration.

Each item that contributes to the moisture control and air barrier performance must be included in the mockup. The installed fenestration must be tested first using ASTM E783 to determine air tightness. ASTM E1105 can then be used to determine if fenestrations and their connections to walls are meeting liquid water leakage requirements.

A-7 EXTERIOR INSULATION AND FINISH SYSTEM (EIFS).

EIFS is not recommended for exterior wall finish, especially in regions where hurricanes and typhoons are a concern and in other regions where water penetration is a particular problem. If EIFS is used, follow the guidance provided in Chapter 2 and also consider the new generations of self-cleaning EIFS finish coatings to reduce maintenance costs.

A-8 DAYLIGHTING.

The introduction of daylight into interior spaces has a well-documented effect on the productivity of occupants and the education of students. In a study done by the Heschong Mahone Group, students who worked in daylighted classrooms progressed 26% faster on reading exams and 20% faster on math exams than students working in a classroom with less daylight. In another study completed by the Heschong Mahone Group, office workers were found to perform 10%-25% better on tests of mental function when the best daylight views were available to them.

Daylighting strategies can be divided into passive or active systems. Passive systems such as overhangs are the most common and refer to the location, profile, orientation, and shading of glazing on a building. See Figure A-2 for passive daylighting strategies. Optimizing these components result in a building that admits daylight without excessive heat gain or glare. Because the devices and components are stationary, these techniques are categorized as passive. In comparison, active daylighting systems have moving parts, typically to track the sun throughout the day. An example of an active system includes a skylight with a moving mirror that captures direct sunlight and redirects it through the skylight, into the building.

A-8.1 Benefits of Daylight.

Daylight in interior spaces has multiple benefits. Daylighted environments provide a connection to the outdoors, are healthier for occupants and have the potential to save energy. Research has shown that children learn better[1], retail stores sell more

[1] The Heschong Mahone Group, “Daylighting in Schools”, http://www.h-m-g.com/projects/daylighting/summaries%20on%20daylighting.htm

product[2], and office workers are more productive[3] [4]in daylighted environments. Since daylight also helps to regulate our circadian cycle [5], introducing daylight into interior spaces is a top priority. Daylight is a natural resource that is more efficient than electric light and should be utilized to its fullest potential. See http://www.wbdg.org/references/mou_daylight.php

A-8.1.1 Maximize Daylight Potential.

Building orientation, views, side and top lighting, shading devices, and selective glazing are critical to maximizing daylight potential. The following recommendations are for the northern hemisphere. In the southern hemisphere, recommendations regarding north and south orientations are reversed. Also, interior spaces should have high ceilings and light reflective surfaces to allow deep daylight penetration. Provide architectural and shading devices for daylight and view windows. In areas of high threat, light shelves tend to be discouraged because of blast mitigation. These objects can become additional projectiles during a blast. Refer to the Whole Building Design Guide, Balancing Security/Safety with Sustainability Objectives, http://www.wbdg.org/resources/balancing_objectives.php.

Over 60% of existing square footage of interior spaces (within the US) has access to roofs for top-lighting and 25% of existing national square footage has access to side-lighting. [6]

A-8.1.2 Considerations.

- Use the building shape to access daylight
- Maximize view windows on the north and south facades
- Provide high ceilings to allow deeper daylight penetration
- Bring daylight high into the space to maximize penetration
- Consider external light shelves to provide shading for view windows, where possible
- Consider internal light shelves to provide shading for clerestories and also a surface for reflecting light onto the ceiling, where possible
- Provide separate shading devices for daylight windows and view windows.

---

[2]The Heschong Mahone Group, "Skylighting and Retail Sales," http://www.h-m-g.com/projects/daylighting/summaries%20on%20daylighting.htm#Skylighting_and_Retail_Sales - PG&E 1999
[3] California Energy Commission. (2003). Windows and Offices: A study of office worker performance and the indoor environment (Catalogue No. P500-03-082-A-9).
[4] "Design Objectives, Productive", Whole Building Design Guide, 22 August 2002 http://www.wbdg.org/design/productive.php
[5] New Buildings Institute, Inc. "Lighting and Human Performance", Advanced Lighting Guidelines, Chapter 2. 2001 Edition, p.2-12-13
[6] Heschong, Lisa, "Daylighting Workshop", Pacific Energy Center, (March 2003).

- Use selective glazing to maximize visible transmittance (high Tvis) and minimize solar radiation (low shading coefficient).
- Use high reflectance values on ceiling and wall surfaces to balance out the daylight.
- Avoid daylight barriers such as solid walls near the building perimeter.

A-8.1.3 Building Shape.

The building shape and massing has a significant impact on how much daylight can reach the occupied spaces and therefore, how well various daylighting strategies will work in the building. Deep floor plates create dark interior spaces that will necessitate electric lighting even during the day. Narrower plates allow daylight penetration throughout the entire building section. See Figure A-1 for the effects of building shape and massing on daylight availability.

Figure A-1 Effects Of Building Massing on Daylight Availability

These four building footprints have equal floor area but provide very different levels of daylight availability.

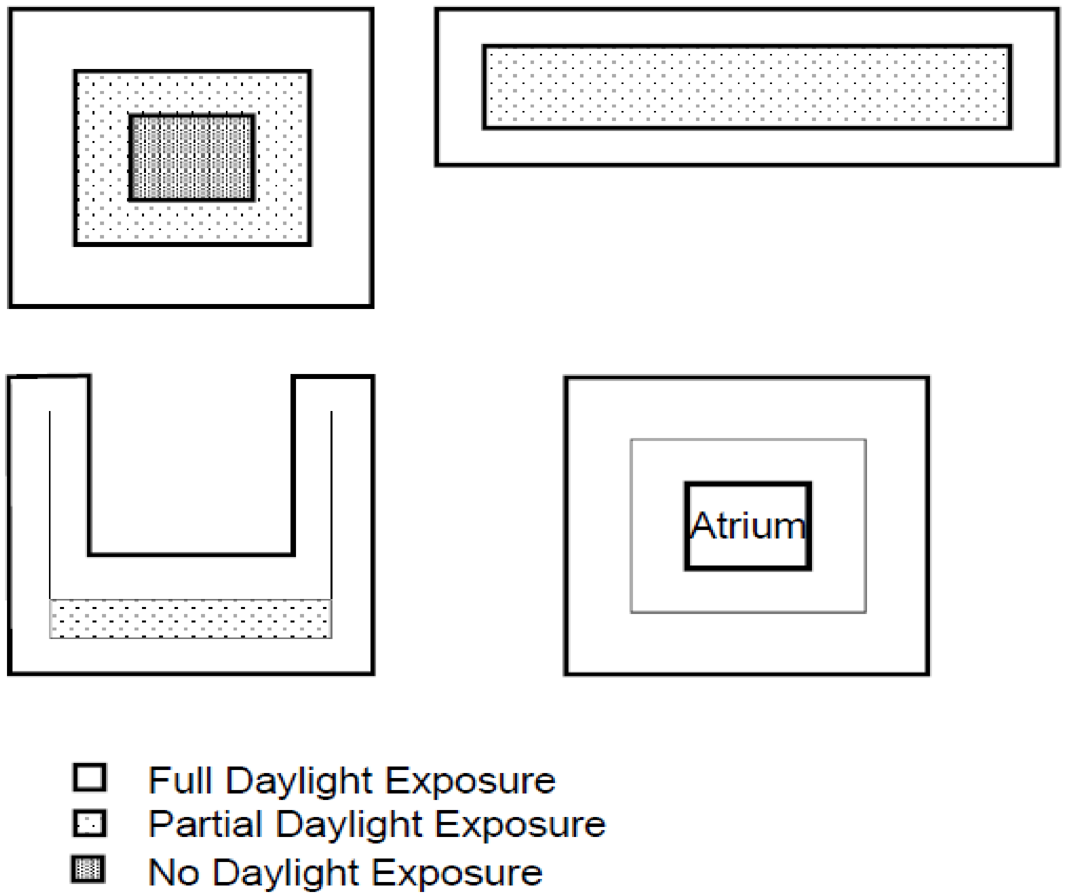
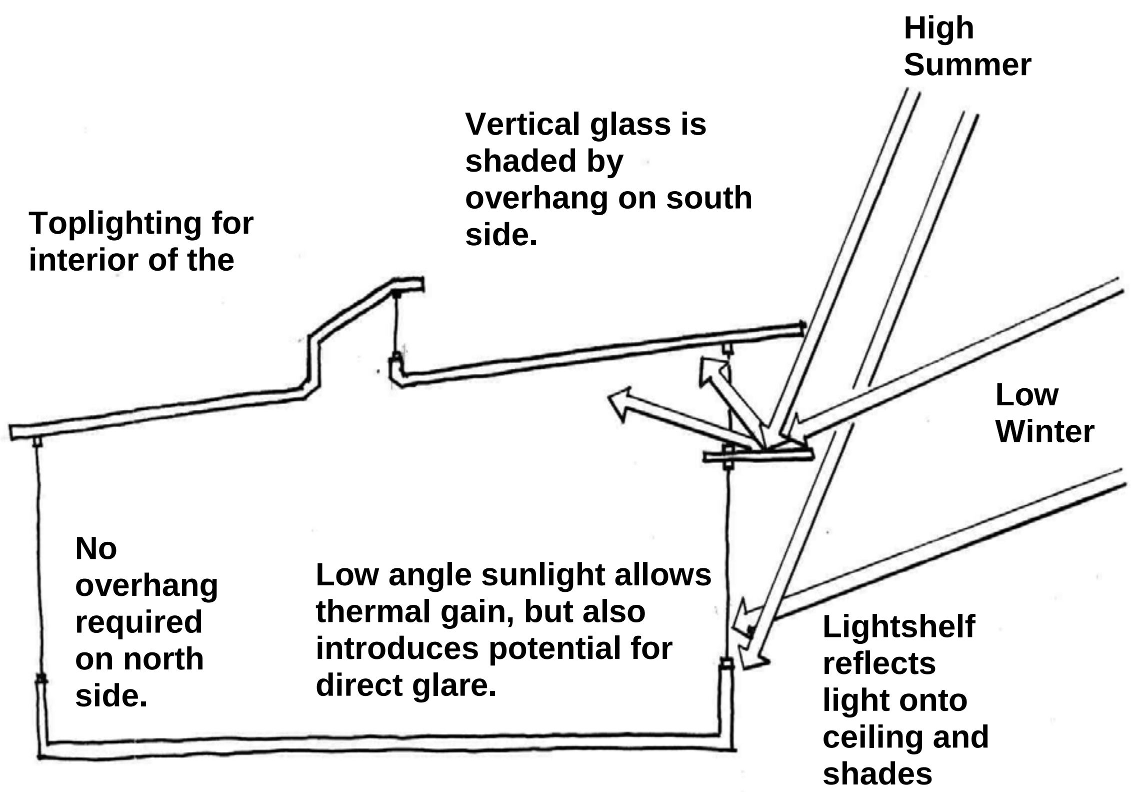


Figure A-2 Examples of Passive Daylighting Strategies



A-8.1.4 Project Types that Benefit from Daylight.

The introduction of daylight into any space has the potential to provide these benefits for the occupants as well as reduce building energy use. However, some project types are better suited than others to take advantage of daylight.

- Open spaces with high ceilings such as hangars, warehouses, recreation centers, and maintenance areas offer good opportunities for toplighting with skylights and clerestories.
- Perimeter spaces such as offices, lobbies, classrooms, cafeterias, and residential areas are all good sidelighting applications. See Figure A-8 for examples of sidelighting applications.

A-8.1.5 Economics.

The use of daylight can produce more comfortable work environments. This benefit may be difficult to quantify, but the energy saved by dimming or switching electric light in response to daylight can be quantified. The implementation of skylights and clerestories as well as lighting control equipment such as dimming ballasts and photocells all increase initial cost. Refer to UFC 4-010-01 for potential additional requirements for Antiterrorism.

A-8.2 Glazing Orientation.

Building orientation is critical to maximizing daylight potential. Building orientations that maximize north and south exposures provide the most effective orientations while East and West exposures may allow excessive heat gain and are hard to control direct sun penetration, see Figure A-3. Southern exposures have the potential of providing over 50% of the daylight for the building space. The success to daylighting on southern exposures is controlling the direct sunlight penetration with shading devices, see Figure A-4 for an example of an Architectural shading device. Northern exposures require minimal shading in the winter months. East and West orientations require manual shading devices. Vertical blinds control daylight well on this orientation.

Figure A-3 Building Orientation Can Maximize Daylight Exposure

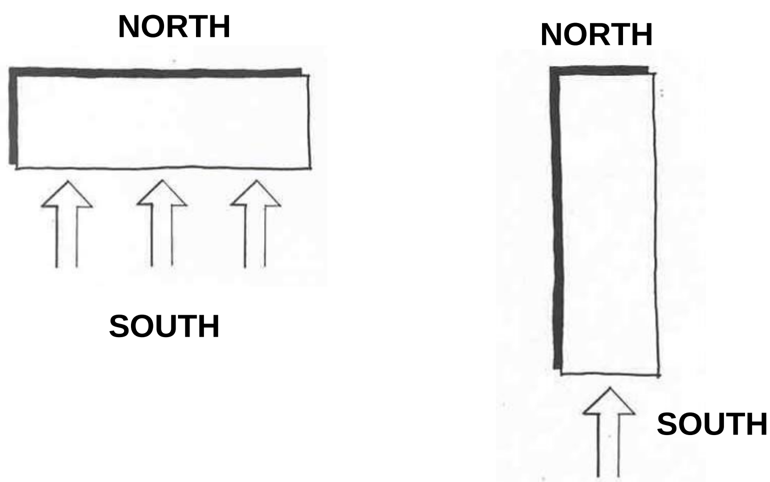


Figure A-4 Example of Architectural Shading Devices

A-8.2.1 Considerations.

- Orient building to maximize north and south exposures.
- North facing windows provide the most even illumination.
- If orientation is off-axis from north and south, provide shading devices for south-east and south-west exposures.
- Provide architectural shading devices for south orientations.
- Provide manual shading devices for south orientations. Horizontal blinds best control the high angle light on southern exposures.
- Provide manual shading devices for east and west orientations. Vertical blinds best control the low angle light on east and west exposures.
- In spaces that include daylight harvesting, provide automated shading devices to maximize the electric lighting energy savings.

A-8.3 Glazing Characteristics.

Use selective glazing to optimize and tune glass based on its purpose and use (clerestory or vision). Clerestory glass may require high visibility transmittance without color distortion while minimizing infrared penetration. See Table A-2 for comparison of glass types.

Table A-2 Comparison Of Glass Types (From Alpenglass Heat Mirror)

Sample Glass Types	Total Daylight Transmittance %	Solar Heat Gain Coefficient
Clear Double Insulating Glass (1/8" thick)	81	0.75
Laminated Glass (1/2" clear)	85	0.72
HM 88/Clear	72	0.57
HM SC75/Clear	62	0.36
HM 55/Clear	47	0.30

A-8.3.1 Considerations.

- Maximize glazing transmittance (Tvis) for daylight glazing (0.70 or greater) for clerestories and other daylight fenestrations.
- Although the visible transmittance selected depends on personal preference, typically, use Tvis values in the medium range for view windows (0.40 or greater).
- Minimize infrared transmittance by specifying a moderate to low shading coefficient (SC) or low solar heat gain coefficient (SHGC) (50% or lower).
- Use high transmittance glazing greater than 60% to maximize daylight. Glazing should also have a high thermal resistance ratio in order to minimize heat gain.
- Do not use tinted or mirrored coatings. Use clear glazing.

A-8.4 Quantity of Glazing.

Toplighting optimization varies between 3% and 9% skylight to floor area ratio. The optimal amount of toplighting area factors in daylight contribution, cooling loads, and potential energy savings. In order to calculate toplighting area optimization, use a calculation program similar to “SkyCalc” . Sunny climates with a cooling load dominated environment will require less toplighting than cooler overcast climates. See Figures A-5, A-6 and A-7 for toplighting strategies and applications.

Figure A-5 Diagram of Toplighting Strategies

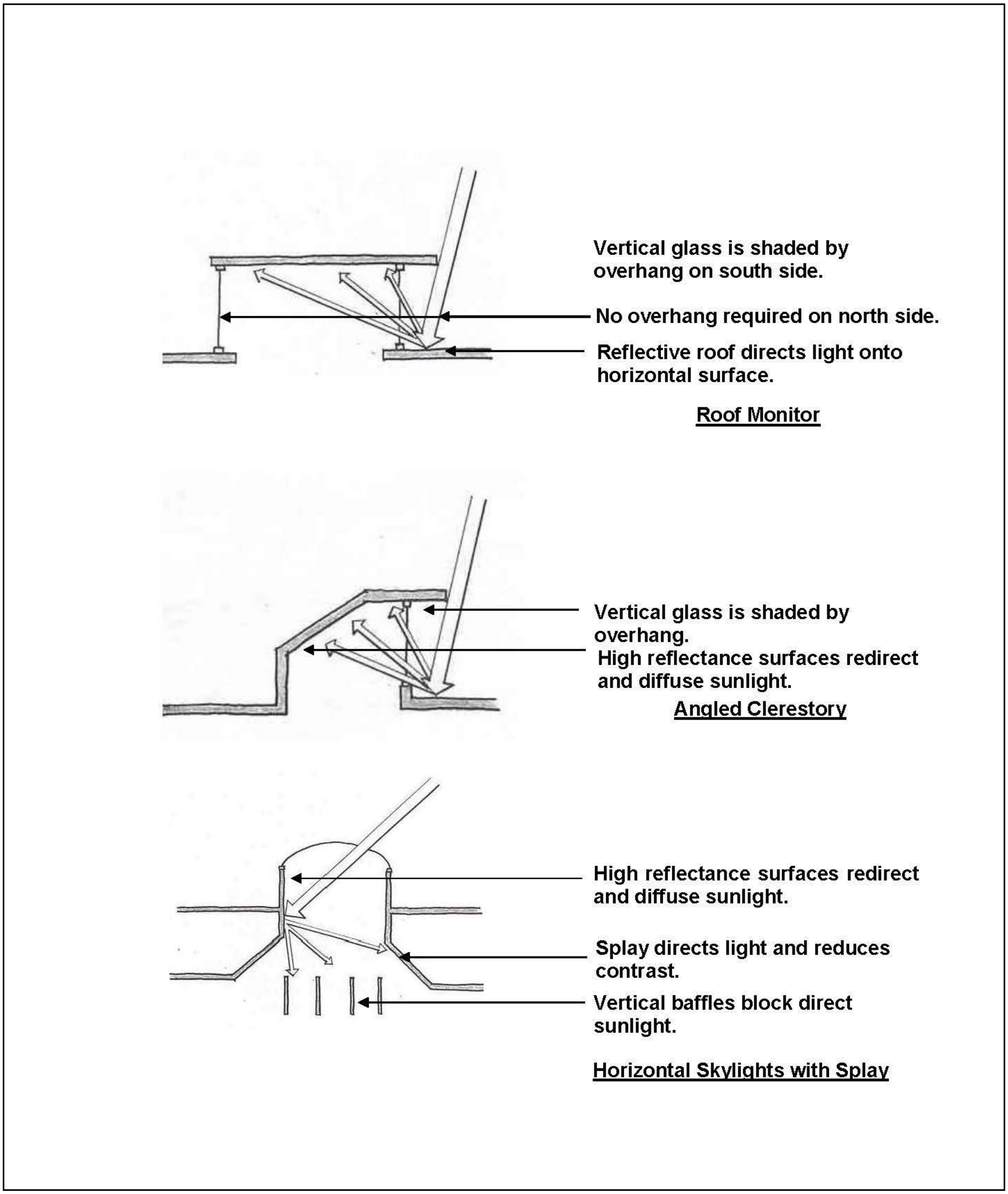


Figure A-6 Examples of Toplighting Applications

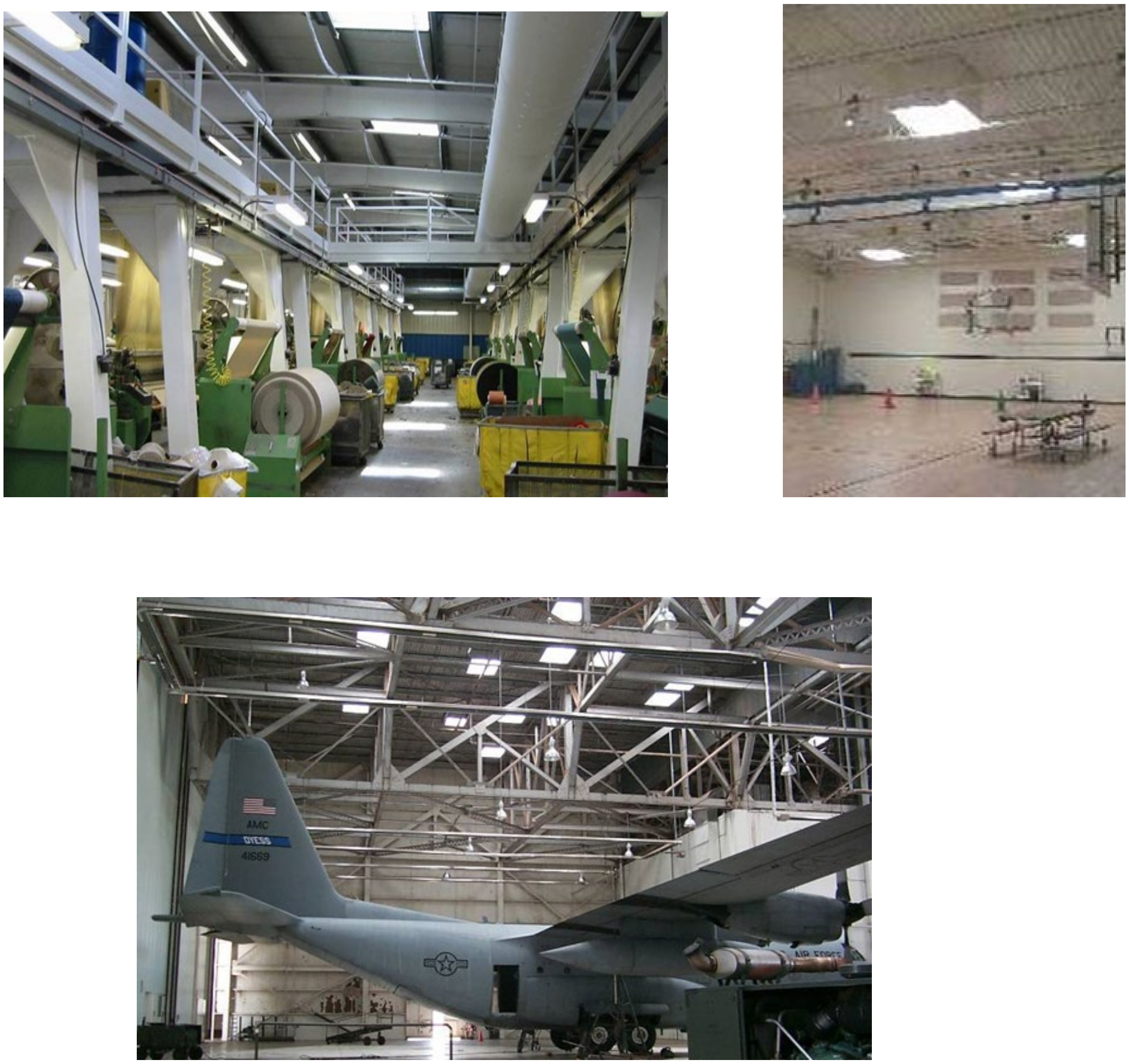
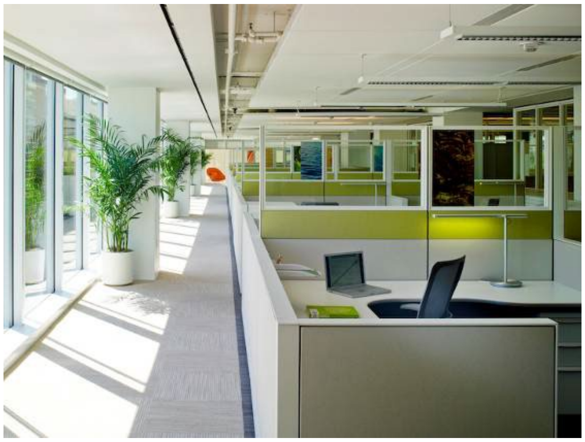


Figure A-7 Example of Clerestory Application

Figure A-8 Examples of Sidelighting Applications



Photograph: Eric Laignel

A-8.4.1 Considerations.

- Sidelighting windows should be located as high as possible since effective daylight penetration from windows is 1.5 times the height of the window .
- Use high continuous clerestories for the deepest daylight penetration and uniformity.
- Provide glazing at eye level in order to provide exterior views,
- Use view windows that have minimal wall area between windows. Avoid small windows located in large wall areas because of the uncomfortable contrast and glare that result.
- 1 sq ft (0.09 m2) of top lighting can provide illumination to about 10 times the area that sidelighting provides yet does not provide the view.
- Space top lighting apertures approximately one and a half times the ceiling height for even illumination. Recess and splay (45º to 60º) skylights to minimize glare.
- Toplighting systems located at least 1.5 times the mounting height on center can provide even daylight distribution.
- Skylight area should be between 2% to 9% of the floor area depending on the climate optimization

A-8.5 Glare and Contrast Control.

Glare and excessive contrast occur when side and top lighting devices allow direct sunlight penetration. Quality daylighting allows skylight and only reflected sunlight to reach the task. Punched openings also can cause uncomfortable contrast ratios. Figures A-9 and A-10 are examples of how the use of roof shapes and splayed skylights can be used to minimize glare and excessive contrast.

Figure A-9 Examples of Roof Shapes

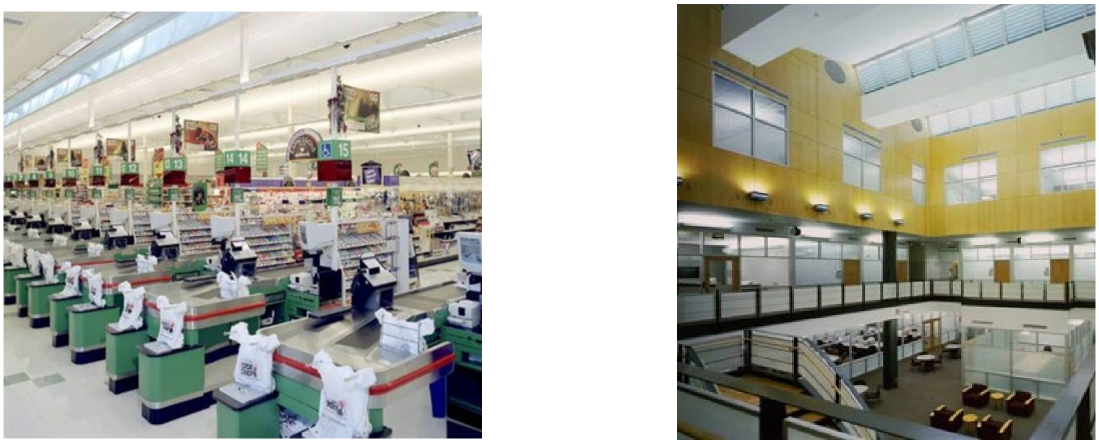
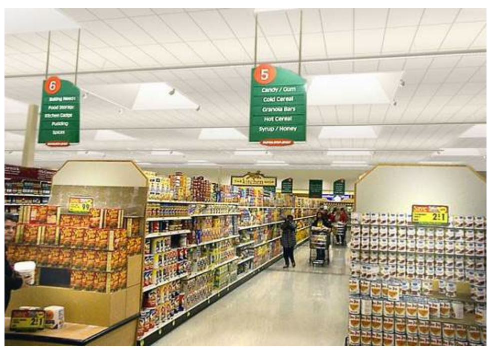


Figure A-10 Example of Splayed Skylights



A-8.5.1 \2\ Considerations. /2/

- Coordinate external and internal shading with architect.
- Utilize top-lighting systems with vertical glazing to control direct radiation.
- If horizontal glazing is designed for top lighting systems, then provide splayed openings or translucent shielding below the skylight in order to minimize the contrast.
- Avoid punched windows; use continuous or mostly continuous side lighting.
- Use high reflectance surfaces for ceiling and walls (90% for ceilings and 60% for walls).
- Consider integrating use of automated window shading or dynamic glazing with the electric lighting control system to optimize the amount of daylight entering the space while minimizing the effects of solar heat gain and glare.

A-8.6 \2\ Automated Shading. /2/

Automated shading should be considered in spaces utilizing daylight harvesting to preserve the functionality of the daylight harvesting system and maximize the energy savings of the system. The shades may be controlled to reduce glare and unwanted heat gain while still allowing natural light to enter the space. When utilizing automated shading the following may be considered:

- For ease of use the automated shades will be operated by common controls with the lighting control system; the controls should have the same appearance and design.
- For maximum energy savings, the automated shading system should position the shades based on a combination of time of day, façade direction, and sky conditions.
- For maximum design flexibility and ease of installation, shade systems should have the capability to address each shade individually.
- The shading system may have a manual override that allows the occupant to temporarily adjust the shades to any desired position. The system will revert back to automatic control after a specified period of time.
- Based on the application and size of the windows or skylights, the shading system may employ drive (motor) technology that is either line-voltage or low-voltage in nature; an overall installed cost assessment of the shading system and the necessary equipment to integrate to the lighting control and building management systems may be done to determine the overall best value, installed cost solution for the project.

A-8.7 \2\ Active Daylighting. /2/

Active daylighting strategies and devices utilize a mechanical component to collect and distribute daylight. Such devices differ from the passive strategies that have previously been discussed which are stationary. The example shown in Figure A-11 turns a series of reflectors as the sun moves throughout the day. These reflectors catch the direct sunlight and redirect it through the skylight.

Such devices add extra initial cost and also pose additional maintenance issues. However, they also can make use of daylight for a longer period of time throughout the day. With tracking devices, effective daylighting can begin earlier in the morning and last later in the day than with stationary skylights.

Figure A-11 Example off an Active Daylighting System that Tracks the Sun and Directs Daylight into the Building

A-8.7.1 \2\ Solar-adaptive Shading. /2/

Another active daylight control technology is solar-adaptive window shading whereby shades automatically adjust throughout the day based on sky conditions or the sun's location. This type of shading system blocks and reflects direct sunlight during the day to reduce solar heat gain and demand on the building's air conditioning system. An example of solar-adaptive shading is shown in Figure A-12.

Figure A-12 Example of Solar-Adaptive Shading

A-8.8 \2\ Physical Modeling. /2/

Daylight levels depend on many factors such as window shapes, orientation, shading, and time of day. Therefore, physical models built to scale can provide information on light quality, shade, shadows, and actual light levels. By building the model with the actual proposed materials and orienting it with adjustments for latitude, season, and time of day, the light quality can be seen in the model. Such models inform the designer about quality issues including light patterns, shade, shadows, contrast, and penetration in the space. An illuminance meter inside the model will provide accurate predictions of expected light levels in the building.

A-8.9 \2\ Computer Simulation. /2/

A wide range of software programs model the sun's path and its impact on building geometry in addition to how it affects heat gain and energy use. In using any of the software, be aware of its limitations and assumptions, as well as the variables under the users' control. These tools provide a prediction of how building components will behave throughout changing conditions. They do not provide actual light levels or energy use. The following web sites detail the features of some of these programs and their applications.

- US Department of Energy – Energy Efficiency and Renewable Energy Building Energy Software Tools Directory:http://www.eere.energy.gov/buildings/tools_directory/
- Whole Building Design Guide Energy Analysis Tools: http://www.wbdg.org/resources/energyanalysis.php

APPENDIX B GLOSSARY

B-1 ACRONYMS

AAMA	American Architectural Manufacturer Association
ASCE	American Society of Civil Engineers
ACI	American Concrete Institute
AF	Air Force
AFCEC	Air Force Civil Engineer Center
AFMAN	Air Force Manual
AHJ	Authority Having Jurisdiction
AICUZ	Air Installation Compatible Use Zones
ANSI	American National Standards Institute
AR	Army Regulations
ASA	Acoustical Society of America
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASTM	American Society of Testing and Materials
AT	Antiterrorism
BIA	Brick Industry Association
BIM	Building Information Modeling
BLCC	Building Life Cycle Cost
C	Celsius
CADD	Computer-aided Design and Drafting
CBD	Chronic Beryllium Disease
CCB	Construction Criteria Base
CCR	Criteria Change Request
CFR	Code of Federal Regulations

CNEL	Community Noise Equivalent Level
CONUS	Continental United States
CSA	Canadian Standards Association
DNL	Day Night Average Sound Level
DoD	Department of Defense
ECB	Engineering and Construction Bulletins
EIFS	Exterior Insulation Finish System
EIMA	EIFS Industry Members Association
EPA	Environmental Protection Agency
EPG	Electronic Project Generator
ESC	Environmental Severity Classification
F	Fahrenheit
FACD	Functional Analysis Concept Development
FEC	Facilities Engineering Command
FGI	Facilities Guidelines Institute
ft	Foot or feet
HEMP	High-Altitude Electromagnetic Pulse
HEPA	High-Efficiency Particulate Air
Hg	Mercury
HNFA	Host Nation Funded Construction Agreements
HPSB	High Performance and Sustainable Building Requirements
HQUSACE	Headquarters, U.S. Army Corps of Engineers
GCC	Geographic Combatant Commander
GSA	General Services Administration
IBC	International Building Code

ICD	Intelligence Community Directive
ICS	Intelligence Community Standard
IESNA	Illuminating Engineering Society of North America
IFS	Installation Facilities Standards
in	Inch or inches
IP	Inch-pound
ISO	International Organization for Standardization
Kg	Kilogram
LCCA	Life Cycle Cost Analysis
m	Meters
mm	Millimeters
MPI	Master Painters Institute
MWR	Moral, Welfare and Recreation
NACE	National Association of Corrosion Engineers
NASA	National Aeronautics and Space Administration
NAVFAC	Naval Facilities Engineering Systems Command
NAVRAMP	Navy’s Radon Assessment and Mitigation Program
NC	Noise Criteria
NCPC	National Capital Planning Commission
NCR	National Capital Region
NFRC	National Fenestration Rating Council
NIC	Noise Isolation Class
NIH	National Institute of Health
NIST	National Institute of Standards and Technology
NRCA	National Roofing Contractors Association

NS	Net Savings
OITC	Outdoor Indoor Transmission Class
OSHA	Occupational Safety and Health Administration
Pa	Pascal (SI unit of pressure)
PBS	Public Buildings Services
PCB	Polychlorinated Biphenyls
PCR	Planning Charrette Report
psi	Pound per square inch
PTS	Performance Technical Specifications
PVC	Polyvinyl Chloride
RAMP	Radon Assessment and Mitigation Program
RC	Room Criteria
RCRA	Resource Conservation and Recovery Act
RF	Radio Frequency
RFP	Request for Proposal
\3 SAPF	Special Access Program Facility **/3/**
SC	Shading Coefficient
SCIF	Sensitive Compartmented Information Facility
SDSFIE	Spatial Data Standard for Facilities, Infrastructure and Environment
SEI	Structural Engineering Institute
sf	square feet
SHGC	Solar Heat Gain Coefficient
SI	International System of Units (Metric System)
SIR	Savings to Investment Ratio
sm	square meters

SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SOFA	Status of Forces Agreement
STC	Sound Transmission Coefficient
TSCA	Toxic Substances Control Act
TM	Technical Manual(s)
UEPH ARMY	Unaccompanied Enlisted Personnel Housing
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
USACE	U.S. Army Corps of Engineers
USGBC	U.S. Green Building Council
VT	Visible Transmittance
WBDG	Whole Building Design Guide
WDMA	Window and Door Manufacturer Association
WRB	Water Resistant Barrier

B-2 DEFINITION OF TERMS

Air Barrier. The term "air barrier" refers to the "continuous air barrier" the combination of interconnected materials, assemblies, and sealed joints and components of the building envelope that minimize air leakage into or out of the building envelope specified by ASHRAE 90.1.

Building System and Subsystems. An assembly of dimensionally and functionally pre-coordinated subsystems which, when combined, produces an essentially complete building. A subsystem is one of many building components designed and manufactured to be integrated with other subsystems to produce an entire building system.

Building Information Model (BIM). A BIM is a three-dimensional digital model of a facility. It incorporates all disciplines and facilitates coordination, calculations of relevant building parameters, and the development of construction documents.

Corrosion. Corrosion is the deterioration of a material or its properties due to a reaction of that material with its chemical environment and is inclusive of the deterioration of all materials, which can be caused through sun exposure, mold and mildew, wind, and other environmental elements.

Environmental Severity Classification (ESC). Environmental severity is defined as the corrosivity of the local environment of a given location or region. Environmental severity contributes directly to the occurrence of corrosion. The effects of corrosion and the rate at which they occur are consequences of the corrosion system, which is comprised of a material or physical system, the environment, and operational conditions.

Noise Isolation Class (NIC). NIC is a method for field transmission ratings. The higher the number the better the noise control. NIC rates a partition's ability to block airborne noise transfer. NIC testing is preferable to STC testing as it is specified on more specific space types (such as spaces with operable walls, unaccompanied housing sleeping rooms to each other or to the adjacent corridor, and the actual work spaces in administration facilities). For a field STC test, the individual transmission loss measurements are modified based upon the reverberation time, the size of the room, and the size of the tested partition. The NIC does not include these modifications and simply measures the transmission loss between 125 and 4,000Hz. The value of this rating is that it better tests the performance of the assembly in the field, though it is highly dependent on field conditions of the tested space.

Outdoor-Indoor Transmission Class (OITC). OITC is defined as the A-weighted sound level reduction of a test specimen (or a space) in the presence of an idealized mixture of transportation noises; aircraft takeoff, freeway, and railroad pass-by. It assigns a single number rating to measure Sound Transmission Loss (TL) data obtained in accordance with ASTM E-90. The higher the number, the better the control.

Sound Transmission Class (STC). STC is a single number developed under laboratory conditions that represents the effectiveness of materials or construction to retard the transmission of air-borne sound. It is not as effective for measurement in low frequency noise sources such as mechanical equipment.

APPENDIX C REFERENCES

ACOUSTICAL SOCIETY OF AMERICA (ASA)

https://acousticalsociety.org/

ANSI/ASA S12.2, Criteria for Evaluating Room Noise

AIR BARRIER ASSOCIATION OF AMERICA

http://www.airbarrier.org/

The Difference Between a Vapor Barrier and an Air Barrier, Quirouette, 1985

AMERICAN ARCHITECTURAL MANUFACTURER ASSOCIATION (AAMA)

http://www.aamanet.org

AAMA/WDMA/CSA 101, Windows, Doors, and Unit Skylights

AMERICAN CONCRETE INSTITUTE (ACI) INTERNATIONAL

http://www.aci-int.org

ACI 530, Building Code Requirements for Masonry Structures

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

http://www.ansi.org/

ANSI S12.9 Part 1, Quantities and Procedures for Description and Measurement of Environmental Sound, Part 1, Basic Quantities and Definitions

ANSI S12.9 Part 2, Quantities and Procedures for Description and Measurement of Environmental Sound, Part 2: Measurement of Long-Term, Wide-Area Sound

ANSI S12.60 Part 1, Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools

ANSI S12.60 Part 2, Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 2: Re-locatable Classroom Factors

AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE)

http://www.asce.org

ACSE/SEI 7, Minimum Design Loads for Buildings and Other Structures

ASCE 32-01, Design and Construction of Frost Protected Shallow Foundations

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS (ASHRAE)

https://www.ashrae.org/

ANSI/ASHRAE/IESNA Standard 90.1, Energy Standards for Buildings Except Low Rise Residential Buildings **\4** (Refer to UFC 1-200-02, for applicable publication date) **/4/**

ASHRAE Standard 160, Criteria for Moisture-Control Design Analysis in Buildings

ASHRAE Handbook-Fundamentals

ASHRAE HVAC Applications Handbook

ASTM INTERNATIONAL

http://www.astm.org

ASTM C755, Standard Practice for Selection of Vapor Retarders for Thermal Insulation

ASTM C1060, Standard Practice for Thermographic Inspection of Insulation Installations in Envelope Cavities of Frame Buildings

ASTM E283, Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen

ASTM E741, Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution

ASTM E783, Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors

ASTM E1105, Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference

ASTM E1130, Standard Test Method for Objective Measurement of the Speech Privacy in Open Plan Spaces Using Articulation Index

ASTM E1186, Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems

ASTM E1745, Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs

ASTM E2112, Standard Practice for Installation of Exterior Windows, Doors and Skylights

ASTM E2638, Standard Test Method for Objective Measurement of the Speech Privacy Provided by a Closed Room

ASTM F2090, Standard Specification for Window Fall Prevention Devices with Emergency Escape (Egress) Release Mechanisms

ASTM F2170, Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes

ASTM Manual 40, Moisture Analysis and Condensation Control in Building Envelopes

BRICK INDUSTRY ASSOCIATION (BIA)

http://www.gobrick.com

BIA Technical Note 7, Water Penetration Resistance - Design and Detailing

BIA Technical Note 18A, Accommodating Expansion of Brickwork

BIA Technical Note 21, Brick Masonry Cavity Walls

EIFS INDUSTRY MEMBERS ASSOCIATION

EIFS Standards & ICC-ES Acceptance Criteria

http://www.eima.com/

FACILITY GUIDELINES INSTITUTE

https://fgiguidelines.org/

FGI – Sound & Vibration: Design Guidelines for Health Care Facilities

GENERAL SERVICES ADMINISTRATION (GSA)

GSA PBS-P100, Facilities Standards for the Public Buildings Services (P-100), https://www.gsa.gov/real-estate/design-construction/engineering-and-architecture/facilities-standards-p100-overview

Guiding Principles for Federal Architecture, https://www.gsa.gov/real-estate/design-construction/design-excellence/design-excellence-program/guiding-principles-for-federal-architecture

Sound Matters, https://wbdg.org/FFC/GSA/gsa_soundmatters.pdf

U.S. Courts Design Guide, Judicial Conference of the United States, https://www.wbdg.org/ffc/gsa/criteria/us-courts-design-guide

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

http://www.iso.org

ISO 6781, Thermal Insulation -- Qualitative Detection of Thermal Irregularities in Building Envelopes -- Infrared Method

INTERNATIONAL CODE COUNCIL (ICC, IBC)

https://www.iccsafe.org/

International Building Code **\4\ /4/**

International Green Construction Code **\4\ /4/**

MASTER PAINTERS INSTITUTE (MPI)

www.mpi.net/

Master Painters Institute

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)

https://www.nace.org/home

NACE Standards

NATIONAL CAPITAL PLANNING COMMISSION (NCPC)

National Capital Planning Act of 1952, http://www.archives.gov/research/guide-fed-records/groups/328.html

NATIONAL INSTITUTE OF BUILDING SCIENCES

https://www.nationalbimstandard.org/

National BIM Standard

NATIONAL INSTITUTE OF HEALTH

NIH – Design Requirements Manual, https://www.wbdg.org/ffc/nih/criteria/nih-design-requirements

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

National Institute of Standards and Technology (NIST) Handbook 135, https://www.wbdg.org/ffc/nist/criteria/nist-handbook-135

NATIONAL PARK SERVICE

Secretary of Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings,

https://www.wbdg.org/ffc/nps/criteria/secretary-interior-standards-rehabilitation-illustrated-guidelines-rehabilitating-historic

NATIONAL ROOFING CONTRACTORS ASSOCIATION (NRCA)

http://www.nrca.net/

NRCA Roofing and Waterproofing Manual

OFFICE OF THE DIRECTOR OF NATIONAL INTELLIGENCE

https://www.dni.gov/index.php

IC Tech Spec for ICD/ICS 705, https://www.dni.gov/files/documents/ICD/ICD_705_SCIFs.pdf

SHEET METAL AND AIR CONDITIONING CONTRACTORS NATIONAL ASSOCIATION (SMACNA)

https://www.smacna.org

Architectural Sheet Metal Manual

SPATIAL DATA STANDARD FOR FACILITIES, INFRASTRUCTURE, AND ENVIRONMENT (SDSFIE)

https://www.sdsfieonline.org/

SDS/CADD Standards

UNITED STATES CODE

10 USC 2853, Authorized Cost and Scope of Work Variations https://www.govregs.com/uscode/10/2853

UNITED STATES DEPARTMENT OF THE AIR FORCE

Air Force Corporate Facilities Standards, http://afcfs.wbdg.org/

Installation Facilities Standards. https://www.wbdg.org/ffc/af-afcec/installation-facilities-standards-ifs

AFMAN 48-148, Ionizing Radiation Protection, https://static.e-publishing.af.mil/production/1/af_sg/publication/afman48-148/afman48-148.pdf

AFMAN 32-1084, Facility Requirements, https://www.wbdg.org/ffc/af-afcec/manuals-afm/afman-32-1084

UNITED STATES DEPARTMENT OF THE ARMY

DD Form 1391 Processor System, https://www.hnc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/482078/dd1391-processor-system/

AR 405-70, Utilization of Real Property

Spatial Data Standard for Facilities, Infrastructure, and Environment/ Computer-Aided Design and Drafting (SDSFIE), https://www.sdsfieonline.org/Home/Index

TM 5-803-5, Installation Design, https://www.wbdg.org/ffc/army-coe/technical-manuals-tm/tm-5-803-5

USACE ECB 2012-16 Building Air Tightness And Air Barrier Continuity Requirements Applicability: Directive and Guidance, https://www.wbdg.org/ffc/dod/engineering-and-construction-bulletins-ecb/usace-ecb-2012-16

UNITED STATES DEPARTMENT OF DEFENSE, UNIFIED FACILITIES CRITERIA PROGRAM

http://dod.wbdg.org

UFC 1-200-01, DoD Building Code

UFC 1-200-02, High Performance and Sustainable Building Requirements

UFC 1-300-02, UFGS Format Standard

FC 1-300-09N, Navy and Marine Corps Design Procedures

UFC 2-000-05N, Facility Planning Criteria for Navy/Marine Corps Shore Installations

UFC 3-120-10, Interior Design

UFC 3-190-06, Protective Coatings and Paints

UFC 3-400-02, Design: Engineering Weather Data

UFC 3-410-01, Heating, Ventilating, and Air Conditioning Systems

UFC 3-420-01, Plumbing Systems

UFC 3-450-01, Noise and Vibration Control

UFC 3-580-01 Telecommunications Interior Infrastructure Planning and Design

UFC 3-810-01N Navy and Marine Corps Environmental Engineering for Facility Construction

UFC 4-010-01, DoD Minimum Antiterrorism Standards for Buildings

UFC 4-010-05, **\3** SCIF/SAPF **/3/** Planning, Design, and Construction

UFC 4-010-06, Cybersecurity

UNITED STATES DEPARTMENT OF DEFENSE, UNIFIED FACILITIES GUIDE SPECIFICATIONS

https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs

UFGS Section 07 05 23 Pressure Testing an Air Barrier System for Air Tightness

UNITED STATES DEPARTMENT OF LABOR, OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

http://www.osha.gov

29 CFR Occupational Safety and Health Act (OSHA)

29 CFR 1910.27, Scaffolds and Rope Descent Systems

29 CFR 1910.141 General Environmental Controls

29 CFR 1910.1025 Lead

29 CFR 1910.1026 Chromium (VI)

29 CFR 1910.1027 Cadmium

29 CFR 1910.1024 Beryllium

29 CFR 1915.1024 Beryllium

29 CFR 1926.1124 Beryllium

UNITED STATES DEPARTMENT OF THE NAVY

OPNAV M-5090.1 Environmental Readiness Manual (10 Jan 2014) http://www.navybmr.com/study%20material/OPNAV%20M-5090.1.pdf

Navy Radon Assessment and Mitigation Program Guidebook for Naval Shore Installations https://www.cnic.navy.mil/content/cnic/cnic_hq/regions/ndw/installations/nas_patuxent_river/om/environmental_support/radon-survey/_jcr_content/par1/pdfdownload_0/file.res/NAVRAMP%20Nonresidential%20Guidebook%20-%20Final%206%20JUN%202015.pdf

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

https://www.epa.gov/radon/publications-about-radon

EPA 402-R-93-071, *EPA's Map of Radon Zones (by State)*

EPA 402-R-94-009, *EPA's Model Standards and Techniques for Control of Radon in New Residences*

EPA/625/R-92-016, *Radon Prevention in the Design and Construction of Schools and Other Large Buildings*

UNITED STATES NATIONAL CAD STANDARD

https://www.nationalcadstandard.org/ncs6/index.php

UFC 3-110-03
1 May 2012
Change 5, 12 June 2020

UNIFIED FACILITIES CRITERIA (UFC)

ROOFING

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

ROOFING

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	22 May 2014	1-8.4, 2.2, 2-3.5, 2-3.6, 2-5.1, 2-8.1.3, 6-9.2: Miscellaneous editorial changes 2-8.4: Thickness of weldable thermoplastic membranes changed to 60 mil (1.52 mm) 5-2.4: Insulated metal roof panels allowed in limited circumstances. 6-3.1, 6-3.2, 6.4: MREC rewritten
2	01 Jan 2017	1-8.5 ccr #5041 revisions. 1-8.8 ccr #4878 clarification on cool roofing; removed date from ASHRAE 90.1 reference. 1-8.9 ccr #5222 rewrote to clarify application to new and existing roof. 2-3.1 ccr #4153 added ref to IPC. Ccr #4476, #5098 and #4668 TPO changes: Paragraphs 2-7 and 2-8 rewritten to include TPO membranes as suitable roofing type. Table 2-1 updated. B-8 revised. B-14 added. These are USACE TPO Roofing lessons learned.
3	06 Mar 2019	Added Environmental Severity Classification and humidity design requirements and updated corrosion prevention requirements in 1-8.4, 2-8, 2-8.3, 2-8.3.2, 2-8.3.4, 3-5, 5-2.5, 6-10 and Appendix C. ccr# 6437; ccr #6514 Misc. fall protection updates; ccr #6852 1-8.12 clarify warranty; ccr #6743 1-8-11 clarify projects for RRC; ccr #5919 5-2.11 clarify metal roof terminations; ccr #6089 2-4.2.3 FRT wood and plank prohibited per UFC 3-600-01.

4	29 Oct 2019	Reinforced requirement in 2-8.2.1 to evaluate roofing materials for combustibility and prohibit use of torch applications when combustible materials are present; added note for modified bitumen reroofing to Table 6.1; added requirement for inspection of existing conditions to confirm the presence of combustible materials to 6-4.1; added Chapter 7, “Roof Systems Operations and Maintenance”; added Appendix G to provide decision criteria for installation of an extensive vegetative green roof.
5	12 Jun 2020	3-5 Deleted prohibition on clay tile roofs in humid environments;3-5.3 added when to use lead-coated copper flashing; 3-5.10 Added “Eave closure” paragraph.3-5.1 ccr#8849 fall protection on tile roofs

This UFC supersedes UFC 3-110-03, dated 26 September 2006; UFC 3-320-03A, dated 1 March 2005; UFC 3-330-02A, dated 1 March 2005; MIL-HDBK-1001/5, dated 28 February 1990; UFC 3-110-04, *Roofing Maintenance and Repair*, dated 11 January 2007; and Air Force ETL 11-8, *Decision Criteria For Installing Vegetative Green Roofs at CONUS Installations*, dated 13 January 2011.

This Page Intentionally Left Blank.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Refer to UFC 1-200-01, *General Building Requirements*, for implementation of new issuances on projects.

AUTHORIZED BY:

JAMES C. DALTON, P.E.
Chief, Engineering and Construction
U.S. Army Corps of Engineers

JOSEPH E. GOTT, P.E.
Chief Engineer
Naval Facilities Engineering Command

TERRY G. EDWARDS, P.E.
Director, Air Force Center for Engineering and the Environment
Department of the Air Force

MICHAEL McANDREW
Director, Facility Investment and Management
Office of the Deputy Under Secretary of Defense (Installations and Environment)

UNIFIED FACILITIES CRITERIA (UFC)
NEW DOCUMENT SUMMARY SHEET

Subject: UFC 3-110-03, *Roofing,* dated 1 May 2012.

Cancels: UFC 3-110-03, *Roofing*, dated 26 September 2006, UFC 3-320-03A, *Structural Considerations for Metal Roofing*, dated 1 March 2005 with Change 2 dated October 2010, UFC 3-330-02A, *Commentary On Roofing Systems*, dated 1 March 2005 and MIL-HDBK-1001/5, *Roofing and Waterproofing*, dated 28 February 1990.

Description of Changes: UFC 3-110-03 updates the roofing design criteria for DOD.

Reasons for Changes: Updated to coordinate with the latest editions of the National Roofing Contractor Association's Roofing Manual and Metal Building Manufacturer's Association Roofing Manual and to meet the latest DOD requirements.

Impact: There are negligible cost impacts. However, the following benefits should be realized.

- Elevates awareness that maintenance is necessary to achieve expected service life of roofing systems.
- Makes UFC 3-110-04 rescindable by including pertinent criteria in this publication and updating references.

TABLE OF CONTENTS

TABLES

FIGURES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

Use this UFC in conjunction with the current editions of the National Roofing Contractors Association (NRCA) *Roofing Manual*s (NRCA Manual) and the NRCA technical bulletins and the Metal Building Manufacturers Association (MBMA) *Metal Roofing Systems Design Manual* (MBMA Roofing Manual) to provide specific design guidance for Military roofing projects. This UFC explains how to apply the NRCA Manual and the MBMA Roofing Manual to the design of Military projects (including **Army**, **Navy**, and **Air Force**).

1-2 APPLICABILITY.

This UFC is applicable to all military projects and planners, design professionals and contractors responsible for roofing planning, system design, installation, and maintenance. Family housing requirements may differ from the requirements stated herein. Where one Military Service's criteria vary from the other Services' criteria, it is noted in the text.

1-3 GENERAL BUILDING REQUIREMENTS.

UFC 1-200-01, "DoD Building Code (General Building Requirements)", provides applicability of model building codes and government-unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, sustainability, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-4 CONTENTS.

Roofing design begins with system selection documented in this UFC, the NRCA Manual, and the MBMA Roofing Manual.

1-4.1 System Design.

The NRCA Roofing Manual and the MBMA Roofing Manual provide information regarding the design and construction of roofing systems. However, because of the emphasis on low life cycle cost, this UFC limits the applicability of certain techniques permitted by NRCA and MBMA. The NRCA Roofing Manual CD 2010 comprises five volumes (collectively referred to as NRCA Manual). Table 1-1 illustrates the relationship of this UFC with the NRCA Manual. Use the MBMA Roofing Manual for the design of metal roof systems in combination with the NRCA Manual.

TABLE 1-1. RELATIONSHIP WITH NRCA MANUAL

UFC 3-110-03	Primary Design Criteria	Additional Criteria (Reference Only)
Chapter 2 - Low-slope Roofing Design Requirements (except metal roofing)	The NRCA Manual: Membrane Roof Systems – 2007 The NRCA Manual: Metal Panel and SPF Roof Systems – 2008 NRCA Construction Details CD – 2010	
Chapter 3- Steep-slope Roofing Design Requirements (except metal roofing)	The NRCA Manual: Steep-slope Roof Systems – 2009 NRCA Construction Details CD - 2010	
Chapter 4 – Roof System Related Sheet Metal Flashing	The NRCA Manual: Architectural Metal Flashing, Condensation Control & Reroofing – 2010	SMACNA Architectural Sheet Metal Manual
Chapter 5 – Standing Seam Metal Roofing Design Requirements	MBMA Roofing Manual (for Hydrostatic systems) NRCA Construction Details CD – 2010 (for Hydrokinetic systems)	The NRCA Manual: Metal Panel and SPF Roof Systems – 2008 & SMACNA Architectural Sheet Metal Manual
Chapter 6 - Reroofing Requirements	The NRCA Manual: Architectural Metal Flashing, Condensation Control and Reroofing	

1-4.2 Appendices.

Appendix A is a reference list. Appendix B provides background information and design best practices. Appendix C is the glossary of acronyms and abbreviations. Appendix D provides considerations on roof warranties. Appendix E provides quality assurance guidelines. Appendix F provides other resource documents.

1-5 BACKGROUND.

There are a variety of materials and roofing systems available. Satisfactory roofing performance comes from careful system and material selection, design, contract document preparation, specification, installation, and maintenance.

Roofing systems are exposed to the full brunt of the weather and can allow moisture intrusion or fail prematurely if not properly designed, installed, and maintained. Moisture intrusion can be costly, adversely affect the functions within the building, and result in roof system failure. Since modern roofing systems contain considerable thermal insulation, moisture intrusion lowers thermal efficiency and hinders energy conservation. Wet materials support fungus or mildew, cause deterioration of other roofing system components, and can emit odors leading to sick buildings and occupants.

1-6 SYSTEM SELECTION.

There are two starting points in roofing system selection.

1-6.1 New Construction.

In new construction, the roof system selection is an integral part of the overall building design and must take into account interior building usage and climate. For example, the building can be designed to prevent outward moisture drive, support heavy roof systems (such as garden roofs or paver systems), or sloped for the desired durability (life cycle cost benefit) and aesthetic considerations.

1-6.2 Existing Structures.

See Chapter 6 for more information on reroofing. When dealing with existing structures, weight, slope, existing and hazardous materials, and historic preservation may become constraints. For example, the thickness, weight, and reflectivity of the roof system has a major impact on roof/structure as already designed. Further, with an occupied building, construction noises, fumes, fire hazards, and roof access all take on increased importance.

1-7 SYSTEM TYPES.

For the purposes of this UFC, roofing is categorized as low-slope, steep-slope and metal roofing. Low-slope roofing systems are weatherproof membrane types of roof systems installed on slopes at or less than 3:12 (14 degrees). Steep-slope roofing systems are water-shedding types of roof coverings installed on slopes greater than 3:12 (14 degrees). Standing-seam metal roofing (SSMR) systems are either hydrostatic that are designed and constructed to be totally water resistive (like a roof membrane) or hydrokinetic that are not totally resistive to water intrusion and rely on slope to shed water.

1-8 GENERAL DESIGN REQUIREMENTS

The following requirements apply to all military roofing projects, regardless of system type:

1-8.1 Unified Facilities Guide Specifications (UFGS).

All roofing projects, including both design-build and design-bid-build, shall be designed consistent with this UFC and requirements of the applicable UFGS. Design-bid-build projects are required to utilize the applicable UFGS. Appendix A lists the applicable UFGS documents.

1-8.2 Wind Resistance Rating.

The designer of record shall determine wind uplift pressures and dimensions of the corners, perimeter, and field of the roof in accordance with ASCE-7, *Minimum Design Loads for Buildings and other Structures*. Delineate calculated values in the roof specification or drawings. Utilize independently tested and rated roof systems, such as Factory Mutual (FM), Underwriters Laboratory (UL), and Single Ply Roofing Industry (SPRI).

1-8.3 Thermal Expansion.

The design of the roof and building thermal expansion systems shall consider the selected roof system and shall comply with the roofing system manufacturer requirements.

1-8.4 Environmental Severity and Humid Locations.

\3\ The roof design must incorporate systems and details to meet the environmental corrosivity conditions for the specific project location, as defined by its Environmental Severity Classification (ESC). See UFC 1-200-01 for determination of ESC for project locations. The humidity conditions must also be considered during roof design - humid locations are those in ASHRAE climate zones 0A, 1A, 2A, 3A, 3C, 4C, and 5C (as identified in ASHRAE 90.1). /3/

1-8.5 Air and Vapor Barriers.

Coordinate the roofing design with UFC 3-101-01, "Architecture", which provides design criteria for the building envelope as a whole, including the roof. UFC 3-101-01 includes requirements for air and vapor barriers associated with roofing systems as well as the required \1\ /1/ calculation to determine the need for a vapor retarder and to verify that the vapor retarder has been positioned correctly in the roof assembly. Care must be taken to maintain the continuity of the roof vapor retarder, which is critical to its performance. Moist air leakage through poorly installed vapor retarders defeats their purpose and creates interior moisture problems.

1-8.6 Elimination, Prevention and Control of Fall Hazards.

\2\Incorporate fall protection control measures in the design of roofs. Any part or component of the building, facility, structure or equipment requiring future maintenance work at roofs must incorporate in the design fall prevention \3\and control/3/ methods or techniques to eliminate fall hazards during occupancy and when performing maintenance work. \3\/3/The preferred order of control measures or the hierarchy of controls is to eliminate the need to work at heights (design out fall hazards), followed by prevention (installing guards) and protection and control of fall hazards by identifying, designing and installing anchorages (hard points) for safe use of \3\restraint or/3/ fall arrest equipment and systems. Select materials used in fall protection equipment for metal compatibility in order to minimize corrosion; type 316 stainless steel is recommended.

Elimination, prevention or control of fall hazards must comply with the provisions and requirements of American National Standards Institute, ANSI/ASSE Z359 Fall Protection Code, ANSI/ASSE A1264.1 Standard and DOL - 29 CFR Part 1910, Subpart D \3\and Subpart 1. /3/ For Navy projects, comply with the *Department of the Navy Fall Protection Guide. /2/*

1-8.7 Roof Hatches.

All buildings over two stories, excluding family housing, shall have a roof hatch with an interior ladder or building-attached exterior ladder for roof access. This includes metal roof overbuilds. Provide roof hatches with fully lined and insulated curbs. Coordinate curb height with tapered insulation heights; standard curb height is 12 in. (305 mm), 16, 18, and 24 in. (405, 455, and 610 mm) are available. The height of the roof curb shall be selected to provide 8 inch minimum curbing above the surface of the roof. Also, provide ladders up to the roof hatch, ladder up safety posts, and safety rails per OSHA requirements. Coordinate with UFC 4-010-01, “DoD Minimum Antiterrorism Standards for Buildings”.

1-8.8 Skylights.

If skylights are included, specify fully lined and insulated curbs. Coordinate curb height with tapered insulation heights; standard curb height is 12 in. (305 mm), 16, 18, and 24 in. (405, 455, and 610 mm) are available. The height of the roof curb shall be selected to provide 8 inch minimum curbing above the surface of the roof. Skylight framing and flashing shall extend over and beyond the curb’s vertical wall.

1-8.9 Cool Roofs.

\2\If a cool roof is selected; meet the ASHRAE 90.1 Chapter 5 values for cool roofing. If a cool roof is not selected in climate zones 1-3, meet one of the exception requirements listed in ASHRAE 90.1 Chapter 5./2/

Mechanically fastened single-ply roof systems shall comply with the requirements for mechanically fastened single-ply systems in Chapter 2. Condensation on the underside of mechanically fastened systems can result in ice build-up in winter, mold growth on the facers, moisture dripping into the interior, and replacement of the roofs with less than four years of service. See Appendix B for more information.

1-8.10 Photovoltaic Systems – Rack Mounted Systems

If a photovoltaic system is selected, the contractor must adhere to the following guidelines:

- Building Owners Guide to Roof-mounted Photo Voltaic Systems published by NRCA.
- Guidelines for Roof-mounted Photovoltaic Systems published by NRCA.

\2\PV supports must be permanently affixed stanchions that are anchored to the building structure.

Undertake installation of a photovoltaic roof system over roof systems with caution. Include the following when planning and designing PV systems located on new or existing roofs:

- Determine if the roof structure can handle the anticipated roof load increase. /2/
- Design to ensure that roof drainage is maintained considering the additional roof deflection due to load.
- Design the roof related details for anticipated roof replacement work. Coordinate with the photovoltaic system designer to anticipate and plan for future roof replacement.
- PV equipment on a roof places an entirely new set of roof protection requirements during initial installation and throughout the maintenance cycle. Specify a roof protection program to be applied during the PV system installation.
- Inspect and determine that the existing roof system has at least 10 years of service life remaining. If not, the existing roof shall be removed and a new replacement roof system designed in tandem with the photovoltaic system.
- If 10 years remaining service life remains, contact the warranty holder and involve them in the design of the intersecting details, required roof protection, re-inspections, and their requirements for maintaining the roofs guarantee.

1-8.11 Design Professional Qualifications.

Both design-build and design-bid-build projects with more than 15,000 ft.2 (1400 m2) of roof area or that are defined as “critical use” or “mission critical” in the project DD Form 1391 shall have a Registered Roof Consultant (RRC) or a registered PE or RA that derives his or her or in-house time charges or principal income from roofing design on the quality control staff of the In-house Design, \3\AE Design or Contractor/3/ Design-Build (DB) team. However, it is also highly recommended that this requirement be applied to all projects with more than 15,000 ft.2 (1400 m2) of roof area.

1-8.12 Warranty Requirements.

Any new \3\ roof on a/3/ permanent construction facility shall be designed and specified with a warranty that meets the following requirements:

- Has "no dollar limit,"
- Covers full system water-tightness,
- Is from the single source manufacturer, and
- Has a minimum duration of 20 years.

Manufacturers' warranties that require periodic inspections or repairs at the Government's expense to maintain the warranty are not permitted. The warranty terms, exclusions, and limits must be enumerated in the specifications and require that all roof curbs and penetration flashings \1\ (these include snow guard and lightning protection attachments) /1/ integrated into the roof system are covered under the warranty. For additional background on warrantees, refer to Appendix D.

1-8.13 Roof Information Card.

Per the UFGSs for each roof installation, furnish a typewritten information card for facility records and a card laminated in plastic and framed for interior display at roof access point.

This Page Intentionally Left Blank

CHAPTER 2 LOW-SLOPE ROOFING DESIGN REQUIREMENTS

2-1 GENERAL.

The NRCA Manual provides a wide range of information for design and construction of low-slope roofing assemblies. This chapter does not address low-slope metal roofing (see Chapter 5). This chapter reinforces particularly salient information with regard to military use or limits the applicability of certain techniques in the NRCA Manual. Where contents of the NRCA Manual are acceptable without modification, those sections are not mentioned herein.

2-2 DESIGN-BUILD.

Because of the wide variety of materials available and the variation in quality in similar materials, design-build contracts for low-slope roofing systems must name the specific desired low-slope roofing system (BUR, \1\ Modified Bitumen, MREC, /1/ EPDM, etc.) and identify relevant performance requirements to be provided under the contract. It is not sufficient to simply specify a low-slope roofing system per this UFC.

2-3 GENERAL LOW-SLOPE ROOFING REQUIREMENTS.

2-3.1 Positive Drainage.

The minimum slope for construction of new buildings is ½:12 to achieve positive drainage. Consult with a plumbing engineer to determine the appropriate number of roof drains and the size of drain pipes. \2\ Refer to the International Plumbing Code (IPC), Chapter 11, Storm Drainage. /2/ Retrofit drains are not permitted.

2-3.2 Roof Curb Heights.

Curbs height shall be a minimum of 8 in. (200 mm) above the roof surface, but shall not be less than 6 in. (150 mm) above the high point of a cricket. Roofs with slope may need additional crickets on the upslope side of all non-round penetrations to assure positive drainage around equipment. Crickets are required on the upslope side of all penetrations greater than 24-in. (610-mm) wide

2-3.3 Horizontal Roof Top Duct Work.

Horizontal roof-top ductwork shall have a minimum clearance of 18 in. (455 mm) above the roof plane to ensure ease of re-roofing. Ductwork larger than 48-in. (1220-mm) wide will require a minimum clearance of 24-in. (610-mm) and shall be coordinated with the HVAC engineer.

2-3.4 Snow and Ice.

Over-the-eaves drainage in cold climates can be problematic if snow and ice issues are not addressed early in the design process. Issues that designers shall address are contained in the Cold Regions Research & Engineering Laboratory (CRREL) report MP-01-5663, *Minimizing the Adverse Effects of Snow and Ice on Roofs.*

Locate downspouts to avoid ice build-up on pedestrian circulation paths.

2-3.5 Hail.

Some geographical areas of the United States are more prone to severe hail events. Roof assemblies shall be capable of resisting impact from reasonably expected hail storms for a given geographical area in accordance with IBC-2009 Paragraph 1504.7. Typical enhancements include a thicker membrane combined with a rigid coverboard directly below the membrane.

Owners of critical facilities, such as hospitals, schools, computer centers, airports and sensitive government buildings have come to realize the importance of installing a hail resistant roof assembly over critical facilities. Hail-resistant roof assemblies shall incorporate high-density cover boards when fully-adhered roof covers are specified. Examples of roof covers that have been shown to perform well in hail prone areas (up to 2-in. (50-mm) hail stone size) include the following:

- Aggregate surfaced built up roofing
- Aggregate surfaced modified bitumen
- \1\ /1/
- Fully adhered 90 mil (2.28 mm) EPDM
- Granule or smooth with coating polyester reinforced modified bitumen

2-3.6 Vegetative Roofing Systems.

Vegetative roof systems are a roof area of plantings/landscaping installed above a waterproofed substrate at any building level that is separated from the ground beneath by its manmade structure. A vegetative roof system consists of a waterproofing system and its associated components such as protection course, root barrier, drainage layer, thermal insulation and aeration layer, and an overburden of growth medium and plantings. See *NRCA Vegetative Roof Systems* for additional information.

Vegetative roof systems must be installed over newly installed roof systems and cannot be installed over existing roof systems. Knowledgeable selection of compatible building materials, quality vegetative roof system materials, and systems that will withstand the conditions of the location where a building is located are vital to a quality vegetative roof assembly design. Properly prepared contract documents with accurate drawings and details are essential. Vegetative roof systems shall be designed by an RRC or a registered PE or RA that derives his or her principal income from roofing design. Test the final assembly with a 48-hour water test per ASTM D5957 and/or using an electric field vector mapping (EFVM) system (see Appendix B for more info on EFVM).

Recommended waterproof membrane systems for use in vegetative roofs include:

- Hot fluid applied modified asphalt membrane, fabric reinforced – 215 mils minimum thickness
- Atactic polypropylene polymer (APP) and Styrene butadiene styrene (SBS) polymer modified bitumen sheet membrane, 2-layer minimum
- 1\ /1/
- PVC reinforced – 72 mils (1.82 mm) minimum thickness

2-4 ROOF DECKS.

2-4.1 Deck Slope.

For new construction, the minimum slope noted in Chapter 2, Positive Drainage, must be accomplished in the structural deck.

2-4.2 Types of Roof Decks.

2-4.2.1 Steel Decks.

Steel roof decks are common on military facilities. When properly designed, they provide an economical and dependable roof deck. They are lightweight and are particularly useful where relatively large clear spans are desired. Mechanically attach roof insulation for this type of roof deck. Design to prevent mechanical fasteners from backing out enough to disengage the deck. In addition, the design of the roof insulation must be tolerant of a small degree of fastener back out. Two layers of insulation are required. Depending on wind resistance requirements, all layers of insulation may be mechanically fastened or the bottom layer may be mechanically fastened and the top layer adhered. Wood fiberboard may not be in direct contact with steel decks.

2-4.2.2 Structural Concrete Decks.

Structural precast and poured-in-place concrete roof decks are also commonly used on military projects. They are heavy and are best suited to roof decks with relatively short spans. Use mechanically fastened insulation only when fully adhered roof systems will not meet the required wind uplift resistance. Due to the inherent moisture in the concrete, proper drying time is required. Ensure during system selection and installation that adequate bonding takes place between the roof system and the deck. Prior to installing any roof system on a concrete deck, conduct a test per ASTM D4263. The deck is acceptable for roof system application when there is no visible moisture on underside of plastic sheet after 24 hours.

2-4.2.3 Wood-Plank and Structural Wood-Panel Decks.

Wood-plank and structural wood-panel decks were used in the past on many military facilities. Generally, this material may only be used on small buildings or in reroofing when the existing material is in fair or better condition. Use of this material on new buildings must be supported with strong arguments demonstrating that neither steel nor structural concrete decks fulfill the specific functional requirements. \3\Use of FRT treated plywood and FRT treated wood panels is prohibited. /3/

2-4.2.4 Cement-Wood Fiber Deck Panels.

Cement-wood fiber deck panels have limited utility due to concerns about moisture susceptibility. This type of deck shall not be used for new construction.

2-4.2.5 Lightweight Insulating Concrete Decks.

Lightweight insulating concrete decks have limited utility due to its hydroscopic nature and difficulty of reroofing. Do not use this type of roof deck for new construction.

2-4.2.6 Poured Gypsum Concrete Decks.

Poured gypsum concrete decks have limited utility due to difficulty in attaching membranes to the deck and difficulty in repair. Do not use this type of roof deck for new construction.

2-4.2.7 Precast Gypsum Panel Decks.

Precast gypsum panel roof decks have been used on many military facilities. However, where membrane leaks have occurred, these roof decks pose a safety hazard due to structural instability. Do not use this type of roof deck for new construction.

2-4.2.8 Thermosetting Insulating Fills.

Thermosetting insulating fills have limited utility. Do not use this type of roof deck for new construction.

2-5 RIGID BOARD ROOF INSULATION.

2-5.1 General.

Roof insulation is a very cost-effective means of reducing energy consumption. Depending on climate and the type of membrane selected, the position of the insulation in the roof system greatly affects the performance of the roof system. Insulation system shall be selected and designed to meet the requirements in UFC 3-101-01, “Architecture”, and \1\ UFC 1-200-02, “High Performance and Sustainable Building Requirements”. /1/

2-5.2 Types of Roof Insulation.

2-5.2.1 Cellular Glass Insulation.

Cellular glass roof insulation is not widely used due to its high cost. It is most commonly used in cold storage facilities and other areas where excessive amounts of moisture would degrade the insulating capabilities of other types of insulation.

2-5.2.2 Perlite Board Insulation.

Perlite board insulation is commonly used and may be specified where factors other than insulating efficiency per unit thickness are the primary design considerations. It is particularly useful in roof assemblies where fire resistance is of primary concern and the potential for water vapor intrusion is limited. Perlite board shall not be used in high-wind areas.

2-5.2.3 Polyisocyanurate Foam Board Insulation.

Polyisocyanurate foam board is the most commonly used roof insulation. It is often specified where insulating ability is the primary design consideration. The minimum compressive strength of polyisocyanurate foam board shall be 25 psi (172 kPa).

2-5.2.4 Polystyrene Board Insulation.

Polystyrene board roof insulation is used by the military and is made in two types: expanded polystyrene board (EPS) and extruded polystyrene board (XPS). In terms of moisture resistance and insulating capability, XPS is superior to EPS. It is also more expensive but appropriate for use in inverted membrane systems and cold storage facilities. Do not use polystyrene in direct contact with hot mopped systems. It is typically necessary to use underlayment board and cover board with polystyrene insulation in order to provide for necessary fire interior and exterior ratings and membrane adhesion properties, except when used as part of a loose-laid, inverted roof system assembly on concrete deck. When polystyrene is used on the interior of a building, it must be encased with a fire resistive material.

2-5.2.5 Composite Board Insulation.

Composite board roof insulation may be specified where a multiple layer type of insulation does not satisfy all design requirements, and where there are cost savings available from reducing the number of construction operations needed to install two different kinds of roof insulation. Single layer applications shall be limited when possible.

2-5.2.6 Phenolic Foam Board Insulation.

Phenolic foam board insulation causes severe corrosion when in contact with steel roof decks. It is no longer manufactured in the United States. Phenolic foam board insulation shall not be specified for use.

2-5.2.7 Tapered Insulation Systems.

Tapered rigid board roof insulation systems are more expensive per square unit than non-tapered insulation. As a result, do not use tapered insulation to create the primary slope in new construction. Use tapered insulation in crickets and saddles to ensure positive drainage when adequate drainage already exists in the roof deck as a whole. The slope of crickets and saddles shall be twice that of the main slope.

2-6 COVER BOARDS.

2-6.1 General.

Coverboards installed directly below the roof membrane shall be used within all roof assembles except single-ply ballasted roof systems. Coverboards provide the following functions:

1. Separate incompatible material
2. Minimize the effects of thermal drift; and
3. Protect the thermal insulation and provide a rigid support for the roof membrane.

2-6.2 Types of Cover Boards.

2-6.2.1 Glass Mat Silicon-modified Gypsum Boards.

Provides improved impact and moisture resistance to roof covers and improved fire resistance.

2-6.2.2 High Density Wood Fiber.

Provides improved impact resistance to roof covers, but is hydroscopic in nature.

2-6.2.3 Paper-faced Gypsum Board.

This shall not be used as a cover board.\2\

2-7 SUITABLE ROOF MEMBRANES.

The NRCA Manual discusses all available roof membranes; however, some membranes do not provide the long-term performance requirements for military buildings. Some new products may not be judged suitable because of the lack of proven performance. Other membrane systems may not be suitable because experience has shown a lack of cost effectiveness over the required life cycle.

Generally, low-slope roof membranes that are suitable for use by the military are limited to the following:

1. Asphalt built-up roof (BUR) membranes
2. Styrene butadiene styrene (SBS) or atactic polypropylene polymer (APP) modified bitumen (MB) membranes
3. Ethylene propylene diene monomer (EPDM) single-ply membranes
4. Weldable thermoplastic polyvinyl chloride (PVC) single-ply membranes
5. Weldable Thermoplastic Polyolefin (TPO)
6. Spray applied polyurethane foam (SPF) membranes
7. Hot rubberized reinforced fluid-applied membranes. /2/

2-8 GUIDANCE FOR ROOF MEMBRANES.

This Section provides requirements and considerations for the design and construction of the above roof membrane types. \2\ Consider the use of any membrane type for which there is not a corresponding UFGS on a case-by-case basis, subject to approval by the project manager. \3\

a) Acrylic Elastomers are usually water based, which makes them easy to apply and to clean up; and they are relatively inexpensive. Select material that has a short cure time.

b) Polyurethane Elastomers can be either one- or two-component and are usually spray applied. Granules are often added to the final coat to provide traction (silicone can be slippery) and to harden the final coat. These coatings are prone to pinholing when applied in thick coats (over 30 mils (0.76 mm) wet).

c) Vinyl, Hypalon, and Neoprene are not recommended because of their low volume solids. Butyl coatings are not recommended because they are not resistant to high levels of ultraviolet light. /3/

2-8.1 Asphalt BUR Membranes.

/2/ BUR systems have broad applicability for dependable low-slope roof systems with low service life cost. Consider this roof system unless it can be shown that it fails to meet important design criteria. Positive attributes of BUR membranes include:

- Durability with long service life
- Low maintenance
- Well-understood maintenance procedures

However, the success of this roofing system is based upon sound installation techniques accompanied by suitable quality control. Quality control can be influenced by the warranty. More information on warranties may be found in Appendix D and more information on quality assurance may be found in Appendix E.

2-8.1.1 Cant Strips.

Provide cant strips for all built-up roof systems.

2-8.1.2 Fiberglass Mat Material.

BUR systems must use fiberglass mat material and no less than three-ply or as limited by the UFGS.

2-8.1.3 Roof Vents.

\1\ Ventilating base sheets are required on all concrete roof deck systems. Roof vents are not permitted for new construction. /1/

2-8.1.4 Types of BUR Membrane Surfacing.

The allowable types of top surfacing for BUR membranes are granulated modified bitumen cap sheet and aggregate.

2-8.1.4.1 Granulated Modified Bitumen Cap Sheet.

Ceramic granules reduce the temperature effect on BUR systems. However, as granules are lost, degradation due to ultraviolet (UV) radiation will negatively affect performance. Longevity of these systems on average is not as great as aggregate surfaced BUR systems.

2-8.1.4.2 Aggregate Surface.

The most common type of BUR surfacing is aggregate embedded in a bituminous flood coat. The thickness of 400 lb. (180 kg) gravel surfacing per square of roofing is 0.5 to 0.75 in. (12 to 18 mm). This surfacing allows the temperature of the BUR membrane to remain somewhat cooler than mineral surfaced cap sheet BUR systems. Aggregate surface BUR systems tend to have a longer expected service life than mineral surfaced cap sheet BUR systems because of lower membrane temperature and due to protection of the membrane by the aggregate.

Aggregate surfaced roof system coverings shall be designed and installed in accordance with the IBC Code and Table 1504.4 based on the exposure category and basic wind speed at the building site. The aggregate shall comply with the ASTM D1863 No. 6 aggregate in hurricane prone regions as defined by the IBC Section 1609.2. Aggregate is not permitted when the basic wind speed is 100 mph or greater or at airfields.

2-8.2 MB Membranes.

MB roofing systems have low maintenance cost, and must be considered when long service life is required. The polymers used to modify the asphalt bitumen improve the performance characteristics of the asphalt. The addition of polymers increases low temperature flexibility and high temperature stability. MB membranes are reinforced with fiberglass, polyester, or a combination of both. MB membranes must have at least two-ply or as specified by the UFGS.

\4

2-8.2.1 Polymer Modifiers and Application Methods.

The two major types of bitumen modifiers are an elastomeric styrene butadiene styrene (SBS) polymer and a thermoplastic atactic polypropylene (APP) polymer. SBS systems are usually applied by hot mopping asphalt; however, torch varieties of SBS membranes are gaining prominence. Some SBS products are applied with cold adhesive or torching. APP systems are typically applied with propane torches, which necessitates special requirements for safe handling and storage.

2-8.2.2 System Selection and Fire Safety.

Evaluate roofing materials and characteristics of roof decks and structures for combustibility. If materials or structures are “combustible” as defined by NFPA 101, torch application of the roofing system is prohibited and an alternate method of application must be used.

Use non-combustible materials for torch-applied systems, including the roof deck, parapets, insulation, cant strips, nailers, and structure. In addition, the roofing contractor must conduct an on-site two-hour fire watch after the last torch is extinguished. Provide access to the building interior for the fire watch personnel. **/4/**

2-8.2.3 MB Membrane Surfacings.

The three common types of surfacing used for the top sheet of MB systems are granulated surfaced, metal foil faced, and coated smooth surfaced.

2-8.2.3.1 Granulated Surface.

Ceramic granules reduce the temperature effect on MB systems. However, as granules are lost, degradation due to ultraviolet (UV) radiation will negatively affect performance. Longevity of these systems on average is not as great as aggregate surfaced MB systems.

2-8.2.3.2 Metal Foil Surface.

Metal foils surfaced MB roof systems may be used to achieve solar reflectivity or to improve fire resistance.

2-8.2.3.3 Smooth Surface.

Uncoated smooth surfaced systems are not permitted. Smooth surface membranes must be factory coated for heat reflection and UV protection.

2-8.3 Thermoset EPDM Membranes.

EPDM roof membranes provide predictable serviceability in roof systems in all climates. The minimum sheet thickness shall be 90 mil. All lap seams shall be fabricated with 6-in. (150 mm) seam tape and stripped-in with self-adhering, semi-cured EPDM cover strips.

\3\ EPDM roofing is not resistant to grease and oil and therefore should not be installed near exhaust vents from food preparation areas. /3/

\1\ /1/

2-8.3.1 Mechanically fastened EPDM Systems.

Mechanically fastened EPDM are not permitted.

2-8.3.2 Fully Adhered EPDM Systems.

Fully adhered EPDM systems do not allow billowing of the membrane and are the preferred method of EPDM installation. \3\ Fully-adhered systems, only, are recommended for use in ESC locations C4 and C5, and especially in the areas subject to hurricanes and typhoons. /3/

2-8.3.3 Ballasted EPDM Systems.

Ballasted EPDM roof systems use larger sheets with factory made seams, which are proven superior to field seams. The downside of ballasted roof systems is the need for stone ballast or concrete pavers, and the increased difficulty in detecting sources of leaks. The ballast is relatively heavy at 10 to 12 lbs. per sf. (49 to 59 kg per sm) and may affect the structural system. All ballasted systems shall comply with ANSI/SPRI RP-4, *Wind Design Standard for Ballasted Single-ply Roofing Systems.* \2\\3\

2-8.3.4 Coating of EPDM Systems.

In ESC locations C4 and C5, coat the EPDM. Recoating will be necessary in 3 to 5 years to maintain high reflectivity. A factory-laminated reflective surface is recommended as the life of the membrane will far out last the field-applied coating. After the factory-applied surface has deteriorated (about 10 years in tropical locations) the EPDM membrane can be field-coated for reflectivity. /3/

2-8.4 WeldableThermoplastic Membranes.

Thermoplastics are materials that soften when heated and regain their physical properties upon cooling. Weldable thermoplastic membranes are appealing as roofing systems because when the seams are properly heat welded they can exhibit seam strengths comparable to the membrane sheet. \2\ Weldable thermoplastic membranes are available in many different colors and are often rated as a cool roof. to reduce energy consumption. While the material costs are higher than bituminous-based roofing, labor costs are generally lower. Properly constructed weldable thermoplastic membrane systems may last 15 years or more. Thermoplastic systems permitted in DON are Polyvinyl Chloride (PVC), and Thermoplastic Polyolefin (TPO). Both systems have been used successfully for over 15 years. The minimum thickness of weldable thermoplastic membranes shall be \1\ 60 mils (1.52 mm) /1/ for PVC and 72 mils for TPO. /2/

2-8.4.1 Mechanically Fastened Weldable Thermoplastic Systems.

Mechanically fastened weldable thermoplastic systems allow some billowing of the roof membrane ; however, this is greatly limited by reinforcement fabrics. Cool roofs in ASHRAE Climate Zones 4-8 shall be fully adhered and not mechanically fastened. \2\ Mechanically fastened TPO is not allowed.

2-8.4.2 Fully Adhered Weldable Thermoplastic Systems.

Fully adhered weldable thermoplastic systems do not allow billowing of the roof membrane and are the preferred method of installation.

2-8.5 Thermoplastic Polyolefin (TPO).

TPO membranes are typically white in color and, as a thermoplastic, the seams are heat welded. Specify TPO with 72 mil (1.8 mm) minimum thickness.

Mechanically fastened systems are popular but are restricted to the ‘rhino bond’ system and therefore not allowed due to lack of competition. Fully adhered systems are required. A cover board shall be utilized in all systems. /2/

2-8.6 Hot Rubberized Reinforced Fluid-applied Membranes.

Hot rubberized reinforced fluid-applied membranes are only permitted when designed and shop drawings reviewed by an RRC or a registered PE or RA that derives his or her principal income from roofing design. Further, the membrane shall be applied to a minimum 4-inch (100-mm) thick concrete surfacing. \2\ /2/

2-9 LOW-SLOPE CONSTRUCTION DETAILS.

Use the NRCA Construction Details CD - 2010 construction details as applicable, except as noted in Table 2-1 in this UFC. For details pertaining to low-slope metal roofing, refer to Chapter 5 of this document. Design documents for individual projects must supplement these standard details with additional information related to closures, terminations, transitions, corners, lap and joint conditions, materials interface, sealant requirements, and other project specific conditions. Address all flashing requirements with a complete set of detail drawings. Minimize the use of pitch (or pourable sealer) pans.

\2

TABLE 2-1. LOW-SLOPE ROOFING CONSTRUCTION DETAIL LIMITATIONS	
NRCA Detail	**Comments**
BUR-4	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
BUR 4S	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
BUR-7A	Do not use.
BUR-7AS	Do not use.
MB-4	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
MB-4S	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
MB-7A	Do not use.
MB-7AS	Do not use.
TS-4	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
TS4S	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
TS-5	Termination Bar holes must be slotted for expansion and contraction.
TS-5S	Termination Bar holes must be slotted for expansion and contraction.
TS-7A	Do not use.
TS7AS-	Do not use.
TP-4	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
TP-4S	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
TP-7A	Do not use.
TP-7AS	Do not use.
SPF-(FB)-1	Fleece-backed membrane not applicable.
SPF-(FB)-2	Fleece-backed membrane not applicable.
SPF-(FB)-3	Fleece-backed membrane not applicable.
SPF(FB) -4	Fleece-backed membrane not applicable.
SPF(FB)-5	Fleece-backed membrane not applicable.
SPF(FB)-6	Fleece-backed membrane not applicable.
SPF(FB)-11(FB)&18(FB)	Fleece-backed membrane not applicable.
SPF-4	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
SPF-4S	For use only with concrete parapet walls where installation of a reglet and counter flashing inserted into the reglet joint is not possible.
SPF-5	Termination Bar holes must be slotted for expansion and contraction.
SPF-5S	Termination Bar holes must be slotted for expansion and contraction.
SPF-7A	Do not use.
SPF-7AS	Do not use.

/2/

This Page Intentionally Left Blank

CHAPTER 3 STEEP-SLOPE ROOFING DESIGN REQUIREMENTS

3-1 GENERAL.

Steep-slope roofs provide more efficient drainage than low-slope systems and, as a result, are less likely to leak. This chapter does not cover steep-slope metal roofing (see Chapter 5). Chapter 3 limits the applicability of certain techniques permitted by the NRCA to focus on long life cycle military requirements. Where contents of the NRCA Manual are acceptable without modification, those sections are not mentioned.

3-2 DESIGN-BUILD.

Because of the wide variety of materials available and the variation in quality in similar materials, design-build contracts for steep-slope roof systems must name the specific roofing material desired and identify relevant performance requirements to be provided under the contract. It is not sufficient to simply require a steep-slope roof system per this UFC.

3-3 GENERAL STEEP-SLOPE ROOFING REQUIREMENTS.

3-3.1 Self-Adhering Underlayment.

At a minimum, the self-adhering polymer-modified asphalt bitumen membrane underlayment shall be placed as follows:

- At a minimum in ASHRAE Climate Zones 4 and above, place from the eave roof edge to 36 in. (915 mm) past the interior face of the exterior wall on rafter lengths of up to 30 ft. (9.1 m). On rafter lengths between 30 and 45 ft. (9.1 and 13.7 m) place 72 in. (1830 mm) past the interior face. On rafter lengths greater than 45 ft. (13.7 m) place 98 in. (2490 mm) past the interior face.
- 36 in. (915 mm) out from the centerline of all valleys
- 24 in. (610 mm) out from side walls and 8 in (200 mm) vertically up sidewalls
- Over roof curbs and 24 in. (610 mm) out from each side of the curb
- 18 in. (455 mm) out from plumbing vents
- 36 in. (915 mm) along all rake roof edges

Additionally, locate self-adhering polymer-modified asphalt bitumen membrane where moisture intrusion due to snow and ice build-up and/or where frequent infiltration is anticipated. Coordinate self-adhering underlayment design with other roof system vapor barriers (see Chapter 1, Air and Vapor Barriers) to prevent creating two vapor barriers that will not allow the roof system to breath.

3-3.2 Overhangs.

The roof deck and the roof panels shall extend a minimum of 8 in. (200 mm) beyond the exterior wall, with 12 to 24 in. (305 to 610 mm) preferred.

3-3.3 Curb Heights.

Provide crickets on the up-slope side of all non-round penetrations on steep-slope roofs. Curbs shall be a minimum of 8 in. (200 mm) above the roof surface, but shall not be less than 6 in. (150 mm) above the high point of a cricket.

3-3.4 Metal Flashing.

Flashing (excluding gutters, copings, and expansion joints) must be one of the following materials:

- Pre-finished aluminum at a minimum thickness of 0.050 in. (1.30 mm) and shall not come in direct contact with mortar,
- Aluminum at a minimum thickness of 0.050 in. (1.30 mm) and shall not come in direct contact with mortar,
- Copper at a minimum thickness of 16 ounces (454 g),
- Stainless steel at a minimum thickness of 24 ga. (0.64 mm),
- Pre-finished galvanized (G90) at a minimum 24 ga. (0.70 mm) may be used in locations expecting significant physical abuse or a building/roof life less than 15 years,
- Pre-finished 55% AlZn (such as Galvalume) at a minimum 24 ga. (0.70 mm) may be used in locations expecting significant physical abuse or a building/roof life less than 15 years,
- Galvanized steel (G90) at a minimum 24 ga. (0.70 mm) may be used for a building/roof life less than 10 years,
- 55% AlZn (such as Galvalume) at a minimum 24 ga. (0.70 mm) may be used for a building/roof life less than 10 years, and
- Tin-Zinc Alloy coated copper 16 oz. (454 g) minimum may be used at historical sites.

In extreme environments, also refer to *Materials Selection Guide for Army Installations Exposed to Severely Corrosive Environments.*

3-3.5 Gutters and Downspouts.

Prepare calculations to determine the minimum drainage requirement using the calculation method as specified in the Sheet Metal and Air Conditioning Contractors National Association's (SMACNA) Architectural Sheet Metal Manual (current edition).

Obtain the rainfall component for the project site from UFC 3-400-02, "Design: Engineering Weather Data". Locate downspouts and leaders to preclude water and ice build-up on pedestrian paths.

3-3.6 Snow and Ice Considerations.

Most steep roofs drain over their eaves. Some low-slope roofs also drain to eaves, but most drain internally. Over the eaves drainage in cold climates can be problematic if snow and ice issues are not considered early in the design process. Consider design contained in the CRREL report MP-01-5663, *Minimizing the Adverse Effects of Snow and Ice on Roofs*; CRREL MP 5106, *Attic Ventilation Guidelines to Minimize Icings at Eaves;* and CRREL MP 5420, *Ventilating Cathedral Ceilings to Prevent Problematic Icings at their Eaves.*

3-3.7 Hail Resistance.

Roof assemblies shall be capable of resisting impact from reasonably expected hail storms for a given geographical area. In geographical areas of the United States prone to severe hail events, specify impact resistant shingles conforming to UL 2218/ASTM 2218 Class 4 (there are four classes).

3-3.8 Fall Protection.

\3\If maintenance work is required,/3/ roofs with a slope greater than 3:12 shall have permanently installed fall protection per Chapter 1.

3-4 ASPHALT SHINGLES.

Asphalt shingles provide versatile, low-cost steep-slope roofing. As with all roof system selections, a life cycle cost analysis must be performed to determine the appropriate system for a specific project application. To ensure a quality consistent with other roofing systems the following requirements apply.

3-4.1 Wind Pressure.

In areas where the roof deck design is required to resist wind pressures of 45 lbs./ft.^{2} (220 kg/m^2) or more as determined by ASCE 7, the manufacturers' high wind design and installation requirements apply. This may include requiring six nails per shingle as determined by applicable building code, wind speed, slope, and building height.

3-4.2 Perimeter Drip Edge.

Perimeter drip edges are required for all steep-slope roof systems.

3-4.3 Valley Flashing.

Open metal valleys are the preferred system. Woven valleys are allowed on family housing only. Closed cut valley flashing may be used with architectural-grade shingles.

3-4.4 Underlayments.

The use of underlayment requires a continuous substrate to support the underlayment material. The underlayment shall be a minimum 30-pound, non-perforated organic asphalt saturated roofing felt meeting ASTM D226/D226M Type 2 or ASTM D4869/D4869M Type 4. The underlayment shall be applied over the entire roof deck and the self-adhering underlayment before or during the application of shingles. On roofs with a slope less than 4:12, apply two layers of underlayment with staggered side laps. Underlayment(s) shall be vapor-permeable unless it is intentionally designed to perform as a vapor retarder. An underlayment performs several functions:

- Weather protection for a limited time until a roof covering is installed.
- A secondary weatherproofing barrier should moisture infiltrate the asphalt shingles
- Separation between a roof covering and a substrate

In addition, underlayments generally are necessary with asphalt shingle roof systems for the following reasons:

- To comply with the applicable building code
- To maintain a Class A, B or C fire rating for a roof assembly
- To meet the requirements of the manufacturer for a material or system warranty

3-5 TILE ROOFING.

Clay and standard concrete tiles are the preferred tile system. Avoid using lightweight concrete tiles unless required for structural and aesthetic reasons. Use tile for reroofing projects to match existing when required on projects included on the National Register of Historic Places. For other historic reroofing projects, consult with the State Historic Preservation Office (SHPO) or equivalent host nation organization prior to commencing design work. \5\ /5/ The following requirements apply to tile roofing.

3-5.1 Slope.

Tile roofing systems shall not be placed on slopes greater than 6:12.\5\ Install permanent fall protection at clay or concrete tile roofs of any slope at locations where roof access for maintenance may occur./5/

3-5.2 Fasteners.

All roof tiles shall be anchored using stainless steel or copper fasteners, 1-in. (25 mm) engagement in the substrate. Fastener heads shall be of sufficient diameter to prevent pull over of tile. Galvanized fasteners may not be used. Do not use wire ties to fasten tiles to the roof deck.

3-5.3 Flashing.

Flashings must be copper, lead, or stainless steel. \5\Copper must be lead coated when run-off from copper would stain the building./5/

3-5.4 Perimeter Drip Edge.

Perimeter drip edges are required for all steep-slope roof systems.

3-5.5 Batten Boards.

Provide batten boards under tiles in cold climates to assure the coldest roof surface possible. Batten board applications also promote ventilation and drying of tile and under tile. Battens should be considered in all climates where tiles can be lug-hung.

3-5.6 Snow Guards.

Evaluate the need for snow guards and/or fences in cold climates, considering roof slope and anticipated snowfall, and provide the guards over entryways, pedestrian walkways, and parking areas. Also, provide where one roof eave is above another roof.

On roofs with slopes of 10:12 or greater, install a snow fence at the eave. Continuous snow guards around the building perimeter and above all roof penetrations are strongly recommended in ASHRAE Climate Zones 4 and above.

3-5.7 Roof Cement.

Use polymer modified bitumen roof cement.

3-5.8 Self-Adhering Underlayment.

Use a self-adhering modified bitumen membrane installed per Chapter 3, General Steep-slope Roofing Requirements, Self-Adhering Underlayment. Use high temperature polymer modified bitumen membrane as underlayment at high altitudes and the extreme south and southwest regions of CONUS.

3-5.9 Felt Underlayment.

Use non-self-adhering polymer modified bitumen membrane as felt underlayment installed per Chapter 3, Underlayments. \5\

3-5.10 Eave Closure

In order to prevent bat and bird access, pack stainless steel mesh for 3 feet minimum up under the barrel trim tiles at the eaves of hips and gables, and at rake walls, depending on how it is trimmed and flashed. /5/

3-6 SLATE ROOFING.

Slate roofing materials are extremely long lasting but expensive. Consider slate for new construction only when it is required for architectural compatibility with adjacent buildings. Use slate for reroofing projects to match existing when required on projects included on the National Register of Historic Places. For other historic reroofing projects, consult with SHPO or equivalent host nation organization prior to commencing design work. In order to receive full value for the use of slate roofing, other building materials shall provide comparable longevity. A structural analysis must be made prior to installing slate where other roofing systems were used before. Comply with the National Slate Associations, *Slate Roofs: Design and Installation Manual.* Only slate conforming to ASTM C406/C406M *Standard Specification for Roofing Slate* may be used.

3-6.1 Roof Cement.

Use polymer modified bitumen roof cement.

3-6.2 Self-Adhering Underlayment.

Use a self-adhering modified bitumen membrane installed per Chapter 3, General Steep-slope Roofing Requirements, Self-Adhering Underlayment.

3-6.3 Felt Underlayment.

Use non-self-adhering polymer modified bitumen membrane as felt underlayment installed per Chapter 3, Underlayments.

3-6.4 Snow Guards and Fences.

Evaluate the need for snow guards and/or fences in cold climates, considering roof slope and anticipated snowfall; provide the guards over entryways, pedestrian walkways, and parking areas. Also, provide where one roof eave is above another roof.

Continuous snow fences around the building perimeter and above all roof penetrations are strongly recommended in ASHRAE Climate Zones 4 and above. On roofs with slopes of 10:12 or greater, install a continuous snow fence at the eave.

3-7 OTHER STEEP-SLOPE ROOFING.

Other roofing materials are presented in the NRCA Manual. Designers who chose to specify these materials must research the products and demonstrate their life-cycle cost benefits.

Wood roofing materials shall not be used.

3-8 STEEP-SLOPE CONSTRUCTION DETAILS.

Use the NRCA Manual Volume 4 details as applicable, except as noted in Table 3-1 in this UFC.

TABLE 3-1. STEEP-SLOPE ROOFING CONSTRUCTION DETAIL LIMITATIONS	
NRCA Vol 4 Details & Figures	**Comments**
Shingles	
Figure 1, page 26	Do not use.
Figure 25, page 45	Do not use.
Figure 32, page 48	Use only when building life expectancy is less than 20 years.
Figure 35B, page 49	Do not use.
Figure 35C, page 49	Do not use.
Asphalt Shingles	
SM-44-1	Flashing to be 200 mm (8 in.) minimum height.
SM-47	Flashing to be 200 mm (8 in.) minimum height.
SM-46-1	Must have an integral (welded) cricket attached to curb for roof penetrations greater than 305 mm (12 in.) (i.e. no dead valleys wider than 305 mm (12 in.).
ASPH 1	Eave and rake flashing to extend a minimum of 305 mm (12 in.) under shingles.
ASPH 10	Closed cut valleys strongly discouraged (woven or open valley encouraged).
Clay Tile	Historic Roof Consultant to design or review details.
Figure 9, page 102	Do not use flat interlocking, French interlocking, plain tiles.
Figure 10, page 103	Do not use unless matching existing.
Figure 21, page 111	Do not use.
Slate Tile	Roof Design Professional to design or review details, consult National Slate Associates Manual.
Wood Shakes	Not allowed.
Wood Shingles	Not allowed.
Sheet Metal	
SM 11-18	Sealant beneath cover plate to be high quality non-curing butyl, Depth of face side metal to be 200 mm (8 in.) minimum
SM 14,16,18	Fasteners may not penetrate both pieces of sheet metal, must allow for thermal expansion.
SM 23	Surface mounted counter flashing should be limited to non-permanent construction. Use thru wall or recessed counter flashing with lead wedge securement in permanent construction.
SM 3, 5-7, 27	Concealed sealant to be non-curing butyl.
SM 6	Not allowed.
SM-7	Not allowed.
SM-3	Not recommended for permanent construction.
SM-27	Not recommended for permanent construction.
SM-28	Not allowed.
SM-42	Minimum of two lines of non-curing butyl tape, three lines for permanent const.
SM-35	Not allowed.
SM-36	Not allowed.
SM 36	Recommended but normally will include two end dams with UV resistant sealant.
SM-1	Not recommended: Lap seam, mechanically fastened seam, overlap standing seam.
A-Mtl	Do not reference NRCA details, use SMACNA.
S-Mtl	Do not reference NRCA details, use MBMA.

CHAPTER 4 ROOF SYSTEM RELATED SHEET METAL FLASHINGS

4-1 GENERAL.

Architectural sheet metal is integrated into both low- and steep-slope roof systems to assist those systems in achieving protection against moisture intrusion. Typical uses include copings, fascias, gutters, downspouts, and counter-flashings.

4-2 REFERENCE STANDARDS.

Use the latest edition of the NRCA Roofing Manual: Architectural Metal Flashing, Condensation Control, and Reroofing as the primary design guide reference. Additional design assistance can be found in SMACNA *Architectural Sheet Metal Manual.* Certain codes will require compliance with ANSI/SPRI ES1.

4-3 SHEET METAL.

4-3.1 Sheet Metal Type.

Use pre-finished aluminum, pre-finished galvanized steel, 55% AlZn (such as Galvalume), or stainless steel. On historic projects copper, terne coated copper or terne coated stainless steel may be required.

4-3.2 Sheet Metal Gauge and Thickness.

Sheet metal thickness is defined by either gauge or thickness depending on the material. Steel is defined by gauge such as 22 and 24 gauge. Aluminum is defined by thickness such as .040, .050 and .063. Stainless steel is defined by gauge such as 22 and 24 gauge and shall be a minimum of 304 alloy. The architectural sheet metal location on the roof, its width and vertical face will define the thickness or gauge required to prevent distortion. Use minimum 24 gauge pre-finished steel and .063 aluminum for large sheet metal components such as copings, fascias, expansion joint covers, gutters and counterflashings.

4-3.3 Organic Coatings.

When paint coatings are used for exterior applications they must be 1 mil (0.0254 mm) dry film thickness consisting of 0.25 mil (.00635 mm) prime coat and 0.75 mil (0.019 mm) finish coat minimum applied by the continuous coil coating method. Paint resin, with noted exceptions, must be 70% polyvinylidene fluoride (PVDF) containing 100% inorganic pigments. Many other resin types (including PVF) are available but shall only be considered for unusual environments or uses.

Paint coatings must be applied over metallic coatings for carbon steel. Organic coatings must be directly applied to aluminum material.

4-4 MATERIAL COMPATIBILITY.

Use sheet metal anchors that are compatible with the main material. Use stainless steel with pre-finished steel material and use aluminum or type 304 stainless steel with the pre-finished aluminum material. When exposed, fasteners shall incorporate a stainless steel washer with an EPDM washer below. Mill-finished or clear anodized aluminum shall not be used with alkali masonry mortar exposure.

Separate sheet metal components from contact with preservative pressure-treated wood to avoid the corrosive effects of the wood treatment. The following shall be used to attach sheet metal components to pressure-treated wood:

- Type 304 or type 316 stainless steel,
- Double hot dipped galvanized complying with ASTM A153/A153M
- Other specially treated corrosion-resistant fasteners complying with ASTM A653/A653M, Class G185

4-5 EXPANSION AND CONTRACTION.

Allow for the sheet metal expansion and contraction in both the main metal and continuous cleats per SMACNA. This can be accomplished with cleated joints such as drive cleats and predrilled pilot holes for fastener locations.

Wood blocking shall be designed and installed per FM 1-28 and sheet metal designed and installed per ANSI/SPRI ES-1.

CHAPTER 5 STANDING SEAM METAL ROOFING SYSTEM DESIGN REQUIREMENTS

5-1 INTRODUCTION.

SSMR systems can be either hydrostatic that are designed and constructed to be totally water resistive (like a roof membrane) or hydrokinetic that are not totally resistive to water intrusion and rely on slope to shed water. Both hydrostatic and hydrokinetic systems are permitted per the requirements of MBMA and this chapter.

5-2 GENERAL REQUIREMENTS.

The following general requirements apply to all SSMR, regardless if they are hydrostatic or hydrokinetic.

SSMR systems may be installed over open structural framing, or over structural decks. They may be used for new roofing, roofing removal and replacement, and are notably effective for recover of aged metal roofs. They can also be used in low-slope to steep-roof conversions without tear-off. There are many metal roof types. This chapter addresses steel and aluminum materials. Materials and roof types other than described herein may only be used when approved by the appropriate Service Subject Matter Expert (SME). These include special site-formed projects, curved applications of profiles other than described herein, crafted metals (soft metals such as copper, terne, and zinc), and all face-fastened panel types. The roof geometry and layout shall be simplified to the degree possible for SSMR systems. Complicated geometries increase the potential for performance problems.

5-2.1 Design-Build.

Design-build contracts for metal roofing systems must name the specific type of metal roofing system desired (including rib type and watertight or water shedding detailing) and identify all critical performance requirements. It is not sufficient to simply require a metal roofing system per this UFC.

5-2.2 Panels Type.

Ultimately, the panel type decision is aesthetic, economic, and functional. It may also be dictated by wind uplift performance. The effects of oil canning are minimized by fluting, striation, pencil rib or other formations to disrupt the flat panel. However, formations such as these that result in an offset dimension greater than 0.125 in. (3 mm) in height are not allowed due to excessive voids created at panel termination points. When flat pan configurations are used (no disruptions in the flat), tension level coil must be specified to ensure flatness. Panel width must be between 12 and 24 in. (305 and 610 mm). A 16 in. (405 mm) panel type is widely available. Panels must be furnished in lengths of 60 ft. (18.3 m) or longer, when possible, to minimize or eliminate end-to-end joints (panel laps). Panels must be factory fabricated wherever possible.

Site forming can be considered when a roof panel exceeds the allowed length for shipping. Avoid end laps in metal roofs.

5-2.3 Overhangs.

The roof deck and the roof panels shall extend a minimum of 8 in. (200 mm) beyond the exterior wall, with 12 to 24 in. (305 to 610 mm) preferred.

5-2.4 Insulated Metal Panels.

Insulated metal panel roof systems \1\ must only be used without end lap joints and should be limited to maximum 25 foot (7.62 m) length of panel due to thermal expansion/1/

5-2.5 Corrosion Treatment.

The preferred protective coating for carbon steel is 55% (by weight) aluminum-zinc alloy (such as Galvalume) in application rate of .55 oz. minimum per $ft.^2$ (15.6 g minimum per 0.1 m^2) for unpainted material (AZ55) and .50 oz. minimum per $ft.^2$ (14.2 g minimum per 0.1 m^2) for pre-painted material (AZ50). When unpainted 55% AlZn (such as Galvalume) material is used it must have an additional protective coating of acrylic applied at a nominal thickness of 0.3 mil (.0076 mm).

In environments \3\with an Environmental Severity Classification (ESC) C3 or higher, /3/ aluminum metal panels with PVDF coating is the preferred material. Steel with AZ55 with PVDF coating is also acceptable. Galvanized steel (G90) with or without a coating is not acceptable unless the building is temporary. These environments also require careful design of dissimilar metals. The underside of metal roof panels in these areas must have a minimum 0.5 mil (.0127 mm) DFT factory applied primer.

Steel and aluminum shall not be in contact in any environment unless separated with a coating, sealant, or other impervious non-metallic or non-conductive material.

5-2.6 Organic Coatings.

When paint coatings are used for exterior applications they must be a minimum 1 mil (0.0254 mm) dry film thickness consisting of 0.2 mil (.0051 mm) prime coat and 0.8 mil (0.02 mm) finish coat minimum applied by the continuous coil coating method. Paint resin, with noted exceptions, must be 70% polyvinylidene fluoride containing 100% inorganic pigments. Exceptions include interior applications, soffit applications, and surfaces painted white. Many other resin types (including PVF) are available but shall only be considered for unusual environments or uses. Paint coatings must be applied over the corrosion treatment for carbon steel.

If aluminum is used it shall be pre-finished with a factory-applied polyvinylidene fluoride (PVDF) coating. Organic coatings must be directly applied to aluminum material.

5-2.7 Metal Thickness.

When aluminum substrates are used the minimum required thickness is .032 in. (.81 mm). When coated steel substrates are used, the minimum required thickness is 24 ga. (0.0239 in. (0.6071 mm)) not including metallic coating. The minimum thickness is 0.0209 in. (0.5309 mm).) Heavier gauges may be necessary to meet wind uplift criteria per Chapter 1 of this UFC. The specification mandate of heavier section thickness such as 0.040 in. (1 mm) for aluminum and 22 ga. (0.76 mm) for steel may improve the aesthetic with respect to oil canning.

The minimum panel material thickness must be consistent with the material thickness as it was tested for structural capacity in ASTM E1592 *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference.*

5-2.8 Panel Attachment.

Attach panels with concealed clips. Thermal expansion clips are to be of a two-piece design with a top portion that folds into the panel seam and a base that attaches to the structure with two screw fasteners. The joining of base to top components must anticipate the full range of thermal cycling of the panels, using panel temperature differential of 200 degrees Fahrenheit (93 degrees Celsius). In northern/cold climates, at elevations over 8000 ft. (2440 m), or when using dark roof colors use a panel temperature differential of 220 degrees Fahrenheit (104 degrees Celsius). Maximum frictional resistance between top and base components must not exceed 5 lbs. (2.25 kg) in the finished, folded seam. When eave-to-ridge in-plane dimensions are less than 25 ft. (7.6 m), fixed (one-piece) clips may be employed.

Concealed clips shall accommodate twice the anticipated maximum panel series expansion and contraction based on the temperature differentials noted above.

5-2.8.1 Fixed Point.

Panels must be rigidly fixed (pinned) to the building structure at a single point along their length and allowed to float at other attachment points in order to accommodate inherent thermal movement. Normally that point is at the panel’s ridge or eave end. Such attachment must be designed to resist all in-plane service loads including snow and other environmental loads, thermal cycling and frictional resistance experienced at the clips, and the interface of the panel to the supporting structure or deck. Fixed clips shall be used in addition to the through panel fasteners to provide fixity.

5-2.8.2 Exposed Fasteners.

Minimize the use of fasteners that penetrate the weathering surface of the roof panels and flashings. Use these fasteners in panels only at end-to-end joining and at the lower termination point (point of fixity) of the panel. Fastening through the flat of the roof panel in the ridge or hip areas shall be concealed behind rib closures and under flashings. Sealing washers shall be EPDM (not neoprene) to improve durability and service life. When fastening sheet-to-sheet, back-up plates are required to stiffen the joint and provide solid attachment for screws.

5-2.9 Flashings and Penetrations.

In the design phase, care needs to be taken to locate penetrations within the central portion of the panel and design flashings that will accommodate the anticipated climate. At all times the thermal movement characteristics and hydrostatic performance shall be preserved. Panels shall be free to cycle thermally independent of building structure. Curbs, flashings, and penetrations shall not restrict movement by pinning the panels to the structure. With limited exception, all connections of flashings, curbs, and penetrations must be hydrostatic in design to a minimum height of 6 in. (150 mm) above the drainage plane, above which they may be hydrokinetic. In some cases, especially where differential thermal movement occurs, consider using sheet membrane material, such as EPDM, for a hydrostatic connection. When doing so, the membrane shall be protected from exposure using a sheet metal shroud flashing.

Exceptions to these practices may be where a ridge is a venting design. In these cases, hydrostatic construction will be to the height of the panel rib seam (top of ridge closure). Such exceptions to hydrostatic construction should be scrutinized. Concealed sealants must be non-curing polyisobutylene tapes, supplemented with butyl tube grade when necessary to improve flow characteristics into crevices and other difficult areas. These compounds shall be sandwiched between joint components, in concealed locations, and not exposed. Curing compounds are not permitted. Exposed sealants are to be high-grade polyurethane.

5-2.9.1 Round Pipes, Flues, and Soil Stacks.

Flash small, round penetrations with pre-manufactured EPDM black rubber boots having a laminated aluminum compression ring at their base and secure at the top using a stainless steel draw band. Penetrations shall be coordinated to be in the center of the panels and the application of the pre-manufacturer flashing boot shall not interrupt a seam location. Large penetrations (wider than roof panel width minus 5 in. (mm)) require a fully detailed curb.

5-2.9.2 Roof-mounted HVAC Equipment Curb Flashing.

Large and heavy roof-mounted HVAC equipment is not recommended on metal roof systems. If the HVAC equipment is not to be at ground level, provide a platform with access within the roof system and that uses a single-ply roof system such as PVC (with good watertight details). For smaller hoods, ducts and fans, use minimum 0.080-in (2-mm) thick aluminum or 304 type stainless steel, welded prefabricated curbs for curb-mounted HVAC. The upslope curb flange must underlay roof panels and the down slope flanges must overlay the roof panels. The side curb flanges shall extend to the vertical seam on either side. Panel seams must terminate well before the curb wall and use built-in curb crickets to prevent ponding at curb wall.

5-2.9.3 Perimeter, Parapet, and other Miscellaneous Flashings.

Utilize the same factory finished material as roof panels for exposed flashings and shrouds. Provide slope for all parapet and coping caps and all horizontal projections of transitions.

5-2.10 Other Rooftop Appurtenances.

Minimize other roof accessories that penetrate the roof panels. When painted products are used, every effort shall be made to use the same sheet material as the roof, incorporating the same factory finish.

5-2.10.1 Snow Retention Devices.

In ASHRAE climate zones 4 and above, all metal roofs shall include continuous snow retention devices at all eaves that are non-corrosive, non-penetrating, and mechanically attached with convex setscrews to the standing seams and penetrations and roof curbs. Select snow retention devices to resist all in-service loads considering roof slope and design snow load. Prove adequacy on a site-specific basis by calculation and lab-tested holding strengths of devices. Snow retention devices that glue to panel surfaces or use attachments that penetrate roof panels are prohibited. Avoid using any device that voids material and coating warranties.

5-2.10.2 Lightning Protection.

Use aluminum lightning protection on metal roofs where appropriate. Install lightning protection system in accordance with the roof system warranty requirements (no penetration of roof panel at the valley or eave, limited or no penetrations elsewhere). If lightning protection is included on a roof that also includes snow retention devices, attach the lightning protection system to the snow retention devices.

5-2.10.3 Dormers and Mountings.

When possible, avoid interrupting roof planes with geometries that impede drainage, interrupt the drainage surface, or require valleys. Ensure positive drainage on the upslope side of dormers.

All mountings must be attached to the seams with non-penetrating seam clamps—avoiding breach of the weathering surface. Attach other appurtenances (lightning arrestors, condensate lines, conduits, roof walks, satellite dishes, etc.) with non-penetrating seam clamps. Avoid the use of dissimilar metals. Jacket any copper lines to isolate and prevent copper ion water runoff.

5-2.10.4 Fall Protection.

\3\If maintenance work is required,/3/ roofs with a slope greater than 3:12 shall have permanently installed fall protection in accordance with Chapter 1. Select the fall-protection equipment metal and fasteners to minimize corrosion.

5-2.11 Wind Design.

5-2.11.1 In submittals provide a roof assembly which has been tested in accordance with ASTM E1592; and the roof manufacturer's technical staff will provide the necessary clip spacing based on the ASTM E1592 test results. The metal roof assembly shall replicate the ASTM E1592 tested assembly with respect to clip type, gauge, spacing, and attachment. Because the ASTM E1592 test is conducted with attachment to heavy gauge purlins, the actual construction assembly needs to match the pullout resistance of the tested assembly but may attach to a steel deck or other structural element. The ASTM E1592 tested assembly and the structural performance characteristics must be used when performing the ASCE 7 wind uplift calculations.

5-2.11.2 The maximum clip spacing for metal roof assemblies shall be \3\ as designed by ASCE 7 and tested per ASTM 1592.or UL 1897./3/

5-2.11.3 \3\Eaves and rakes must have metal flashing of heavier gauge than roof panel material. Terminate structural metal panels at ridge with heavy-gauge end stiffening metal panel closure. Wood blocking (treated or untreated) must /3/not be used in metal roof assemblies.

5-3 HYDROSTATIC SYSTEM REQUIREMENTS.

5-3.1 General.

A hydrostatic system is a metal roof system in which the metal standing seam, laps at the eave and valley are constructed with positive attachment and non-curing sealant to provide a watertight assembly. Fixity will typically be at the eave and valleys in this roof system.

Use the MBMA Roofing Manual, latest edition, as the primary reference for design. This chapter limits the applicability of certain techniques permitted by the MBMA Roofing Manual. Where contents of the MBMA Roofing Manual are acceptable without modification, those sections are not mentioned herein.

5-3.2 Material.

Material must be either sheet aluminum or Galvalume coated sheet steel. Galvalume coated steel materials may be pre-finished, and in either case, substrate life will exceed paint life. Galvalume steel does not perform as well when in direct contact with salt spray. It is commonly used in coastal applications but will render a shorter service life. In some of the environments, aluminum may be the better choice, albeit at increased cost, greater thermal expansion and lesser availability. Contact of either metals with strong acids and alkalis shall be avoided. Avoid the use of dissimilar metals. Jacket any copper lines to isolate and prevent copper ion water runoff.

5-3.3 Panel Type.

Use a flat pan (pencil ribs and/or striations are recommended) standing seam profile with minimum finished seam height of 2.0 in. (50.8 mm), with a double fold (180 degree) seam or single fold (90 degree), bulb rib or trapezoidal rib. In general, greater seam heights lead to greater beam bending strength. This increases the wind resistance of the panel and reduces the potential to leak in ice damming situations.

5-3.3.1 Seam Configuration.

5-3.3.1.1 Panel edges must be of male and female interlocking design with integral sealant and machine folded (mechanically seamed) finishing of the seam. There can be no gap between any surface of interlocking male and female seam portions. Finished seam configuration may be either 90-degree, single fold (resembling an inverted “L”) with horizontal dimension of 0.62 in. (16 mm) minimum, or a 180-degree, double fold.

5-3.3.1.2 There are a variety of hydrostatic roof panel seam profiles. Metal roofs are most often 90-degree mechanically seamed, single-lock, vertical rib. The trapezoidal seam profile is also common and provides a raised standing seam elevated out of the water plane by a series of offsets, which also allow for cross seam (roof) expansion and contraction. The trapezoidal seam has an industrial appearance and requires end plugs to seal the profile at the end of the panel at eaves, penetrations, and valleys, which can be problematic. Trapezoidal rib panels shall only be used on roofs with minimal/no curbs and minimal/no valleys.

5-3.3.1.3 The raised mechanically seamed panel seam is made possible due to the profiles of the panel, which allow it to span between purlins. The vertical rib profile is seamed by a mechanical fold and either single or double locked depending on wind uplift requirements and desired aesthetics. A modification on this seam type is the mechanically seamed T rib.

5-3.3.1.4 The bulb seam is a raised standing seam that uses a bulbous top profile to provide seam strength. A differing look, the seam can easily be rendered watertight and can provide a unique seam profile.

5-3.3.1.5 Illustrations of a variety of hydrostatic roof panel seam profiles can be found in Appendix B.

5-3.3.2 Panel Attachment.

Clips must be “wetted” to the male seam component with butyl sealant as necessary to ensure complete hydrostatic performance of the joint and as required by ASTM E2140.

5-3.3.3 Seam Sealant.

Each seam must have a pre-applied bead of non-curing, non-hardening polyisobutylene-isoprene copolymer or terpolymer (butyl) to ensure complete hydrostatic performance. Sealant may be a hot melt butyl formulation if applied at the point of panel manufacture. Gas entrainment of sealant is permitted. The roll-forming machine must apply sealant. Continuity of seal with field applications through all panel termination points is critical. Silicone sealant is not allowed. Primary seals must always be concealed within a joint. When secondary seals are used, they may be exposed one-part polyurethane.

5-3.4 Slope.

The minimum allowable slope for hydrostatic roofs is 1:12.

5-3.5 ASTM Test Method.

Hydrostatic joint performance shall be tested per ASTM E2140, *Standard Test Method for Water Penetration of Metal Roof Panel Systems by Static Water Pressure Head.* The test normally tests only the panel side and end-joints, but it can be adapted to test other assemblies also. In addition to the standard standing seam testing, test the eave of the metal roof system.

5-3.6 Hydrostatic Specifications.

Use the UFGS instead of the specifications shown in the MBMA Roofing Manual.

5-3.7 Recommended Hydrostatic Construction Details.

Regardless of actual project slope, use the “Vertical Rib Low-slope Details” (2-1 through 2-30) in the MBMA Roofing Manual, as applicable, as the basis for the design and detailing principals. Do not use NRCA or SMACNA details for hydrostatic metal roofing.

5-4 HYDROKINETIC SYSTEM REQUIREMENTS.

5-4.1 General.

A hydrokinetic system is a metal roof system in which the metal standing seam, eaves, and valleys accommodate expansion and are constructed in a way that allows some water infiltration. The infiltrating water is drained through weeps in the roof assembly and with a watertight underlayment membrane under the roof. The fixity will typically be at the ridge in this roof system.

Use the NRCA Manual: Metal Panel and SPF Roof Systems – 2008, NRCA Manual: Architectural Metal Flashing and the SMACNA Architectural Sheet Metal Manual to guide the design of the roof system and details.

5-4.1.1 General Hydrokinetic Roof System Requirements

5-4.1.1.1 Hydrokinetic metal roof panels require support and need to be installed over a roof deck. Insulation can be installed over the roof deck if desired. The hold-down clips shall be secured to the roof deck for wind uplift resistance.

5-4.1.1.2 The seams and laps of a hydrokinetic metal roof system are not watertight themselves, so a watertight continuous high-temperature self-adhering underlayment shall be provided under the entire roof. Designer will evaluate the required vapor permanence of the underlayment. In ASHRAE climate zones 3 and above, high-temperature self-adhering ice dam protection shall be installed to the substrate to a height of 36 in. (915 mm) minimum above the interior face of the exterior wall. In these zones, the underlayment can be laid over the self-adhering ice dam protection.

5-4.1.1.3 Roof panels with lengths less than 50 ft. (15.2 m) shall be fixed at the ridge with the expansion being accommodated at the eaves and valleys.

5-4.1.1.4 Rosin paper is not allowed as a separation sheet.

5-4.1.1.5 When roof panels run parallel to masonry sidewalls, the through-wall flashing shall incorporate a counter-flashing receiver and the transitional flashing incorporated into the stepped counter-flashing receiver. The counter-flashing receiver shall be integral with the through-wall flashing.

5-4.2 Material.

Material must be either sheet pre-finished aluminum or pre-finished steel. In some of the environments, aluminum may be the better choice. Contact of either metals with strong acids and alkalis shall be avoided. Avoid the use of dissimilar metals. Jacket any copper lines to isolate and prevent copper ion water runoff.

On historic projects raw copper, pre-patinized copper, zinc coated copper or terne coated stainless steel may be appropriate to match the existing historical context.

5-4.3 Panel Type.

Panels are typically flat with upturned ribs of 1.5 in. (40 mm) minimum. For Military projects, use panel widths from 12 to 18 in. (305 to 455 mm).

5-4.3.1 Seam Configuration.

Panel edges may be either male or female interlocking design or vertical matching legs designed to be covered with a separate seam cover cap installed over the vertical legs. Wood batten strips are only allowed on historic projects.

Illustrations of a variety of hydrokinetic roof panel seam profiles can be found in Appendix B.

5-4.3.2 Seam Sealant.

Factory applied sealant within the standing seams is recommended.

5-4.4 Flashing Details.

All flashings at vertical surfaces shall be integrated and coordinated with the through-wall flashing to assure water tightness and drainage. A water resistant membrane shall be incorporated into the flashing detail to prevent moisture intrusion from wind driven rain and water from ice damming.

5-4.5 Slope.

The minimum slope for hydrokinetic roofs is 4:12. In ASHRAE Climates Zones 4 and above, which have the potential for ice damming, use a minimum slope of 6:12.

5-4.6 Hydrokinetic Roofing Specifications.

Use the UFGS instead of the specifications shown in the NRCA Manual.

5-4.7 Recommended Hydrokinetic Construction Details.

Use the NRCA Construction Details CD - 2010 listed in and as modified by Table 5-1 in this UFC. SMACNA Manual details may also be used. Use these details as the basis for design and detailing principals.

TABLE 5-1. HYDROKINETIC METAL ROOFING CONSTRUCTION DETAIL LIMITATIONS	
NRCA Detail	**Additional Requirements**
AM-1	Must have self-adhesive underlayment or sealant between underlayment and flashing
AM-1A	
AM-2	
AM-3	
AM-3A	
AM-4	Must have fixity provided at the ridge(a structural attachment at ridge closure fasteners)
AM-5	Must have fixity provided at the ridge(a structural attachment at ridge closure fasteners)
AM-6	Vertical joints will be sealed and fixity will be provided at hip
AM-7	
AM-7A	Only if skilled sheetmetal workmanship to be provided
AM-8	Must have fixity at head wall
AM-8A	Must have fixity at head wall
AM-10	
AM-11	
AM-12	
AM-13	With rain collar
Curb Detail to be in standard drawings – NRCA’s are not acceptable	
AM-16	
AM-17	
AM-17A	
AM-18	

This Page Intentionally Left Blank

CHAPTER 6 RE-ROOFING REQUIREMENTS

6-1 OVERVIEW.

Eventually every roofing system will reach the end of its economic life. Reroofing options are presented under Terminology below.

6-2 GENERAL CONSIDERATIONS.

The NRCA Manual provides typically allowable re-roofs over existing roofing. See below for other considerations.

6-2.1 Terminology.

For the purposes of this UFC, use the following terminology to describe the re-roofing options:

- Roof Replacement: The removal of the existing roof system down to the roof deck and the installation of a new roof system.
- Roof Recover: The installation of a new roof system over an existing roof system. Table 6-1 notes the roof systems allowable for recover.
- Metal Roofing Retrofit: The process of installing a new metal roof system over an existing metal roof system.
- Metal Roofing Overbuild: The installation of a new metal roof system, including structural framing system over a low-slope roof system.

6-2.2 Life Cycle Cost Analysis.

It is unlikely that a recover will last as long as a total tear-off and replacement. Therefore, carefully weigh the life-cycle cost of recover versus replacement. See Appendix B for information on how to conduct at Life Cycle Cost Analysis. The cost of replacement is greatly affected by ease of access, the need for slope buildup, and the need to raise mechanical equipment for access. Reroofing is an excellent time to remove obsolete equipment and stacks from the roof.

6-2.3 Low-sloped Versus Steep-Sloped Considerations.

The low-slope and steep-sloped roof present different challenges in reroofing. An attic space, typically found in steep-slope roof construction, provides separation of construction activities from the interior of the building. However, on steeper slope roofs, scaffolding and protected access to the building may be major construction cost items.

TABLE 6-1. ALLOWABLE RECOVER OVER EXISTING ROOFING*									
Existing Roofing	**New Overlay Roofing Material**								
	Built-up	**Shake**	**Asphalt Shingle**	**Tile Roof**	**Metal Roof**	**Mod Bit****	**SPF**	**MREC[2]**	**Single-ply**
Slate	No	No	No	No	No	No	No	No	No
Built-Up	Yes	No	No	No	Yes (w/ framing)	Yes**	Yes	Yes	Yes
Asphalt Shingle[1]	No	No	Yes	Yes (2.5:12)	Yes	No	No	Yes	No
Asphalt Shingle over Wood	No	No	No	No	No	No	No	Yes	No
Asphalt Shingle (AS) over AS	No	No	No	No	No	No	No	No	No
Tile Roof	No	No	No	No	No	No	No	No	No
Metal Roof	No	No	No	No	Yes	No	Yes	Yes	Yes
Modified Bitumen	Yes	No	No	No	Yes (w/ framing)	Yes**	Yes	Yes	Yes
Single-ply	No	No	No	No	No	No	No	No	No

* See Chapter 3 for Military limitations on roofing types.
4\ **See Chapter 2 for prohibition of torch application when combustible materials are present. /**4**/
(X:X) = (Minimum Roof Slope)
[1] See specific requirements
[2] Mesh reinforced elastomeric coatings.

\1\

6-3 MESH REINFORCED ELASTOMERIC ROOF COATINGS (MREC).

6-3.1 Mesh reinforced elastomeric roof coatings can be used in two general ways:

- Mesh Reinforced Elastomeric Roof Coating (MREC): The application of a liquid applied elastomeric coating to an existing roof in order to sustain the roof at low cost.
- Mesh Reinforced Elastomeric Roof: The application of a liquid applied elastomeric coating to an existing substrate such as concrete or mechanically fastened overlayment.

For either application, the minimum dry film thickness is 40 mils (1 mm) applied in stages over 100% polyester fabric reinforcing.

6-3.2 MREC has a wide range of use in reroofing, repair, and sustainment. As indicated in Table 6-1, MREC may be used over most roof systems such as built up, metal, and modified bitumen. These coatings provide not only waterproofing, but can achieve cool roof ratings as well. At a fraction of the cost of replacing, MREC offers a high return on investment with low risk.

/1/

6-3.3 Elastomeric coatings may provide an inexpensive alternative to metal roof removal and replacement.

6-4 LOW-SLOPE ROOFING REMOVAL AND REPLACEMENT.

6-4.1 Analysis of Existing System.

Replacement of an existing roof requires a detailed analysis of the existing roof deck, roof insulation and the roof structure. **4**\ This analysis must include a test cut of the existing roof system to determine the composition of the existing roofing system; a thorough inspection using non-destructive and/or destructive methods as necessary to confirm combustibility of existing roofing materials, and penetration treatments to include the underside of the roof deck, attic, and plenum spaces; a non-destructive moisture test; core sampling; and a review of the structure by a licensed structural engineer. /**4**/

Examine the clearances between the anticipated re-covered roof plane and any above-roof horizontal ductwork, mechanical units, and wall flashings. Based on the required clearances, determine if they will need to be raised. \1\ If this would result in significant cost or disruption of operations, consider MREC to prolong life until equipment can be raised. /1/See NRCA Manual for additional information.

6-4.2 Phenolic Foam Board Insulation.

When this material is found in existing installations with steel roof decks, it must be replaced as part of the project and an in-depth evaluation of the steel deck condition conducted to determine if replacement is required. Even if replacement is not required, the steel roof deck shall be painted prior to the installation of the new roof system. Following are approved paints:

- (IL) Rust-Oleum High Performance Epoxy 9100 System Coating, manufactured by Rust-Oleum, 11 Hawthorn Parkway, Vernon Hills, IL; (708) 367-7700.
- Rust-Inhibitive Steel Deck Coating: DTM Acrylic Primer/Finish manufactured by Sherwin Williams, 161 Greenwood Drive, Bridgeville, PA; (412) 247-2228.
- Amerlock 400 High Solids Epoxy Coating, mixed with equal amount Amerlock resin; manufactured by Ameron Protective Coatings, 201 N. Berry Street, Brea, CA 92622; (714) 529-1951.

- ZRC Cold Galvanizing Compound; manufactured by ZRC Products Company; 21 N. Newport Avenue, Quincy, MA; (617) 328-6700.

6-4.3 Testing for Asbestos Containing Materials (ACM).

If testing of the existing roof system to be removed uncovers the presence of ACM, this fact shall be communicated to the roofing contractor in the contract documents so that the appropriate removal and disposal efforts can be determined by the contractor and included in their costs.

6-4.4 Slope.

In existing construction, every effort must be made to achieve the ½:12 slope required for new construction. However, where ½:12 slopes cannot be achieved, ¼:12 may be used with specific approval by the following authorities:

- Army. District-level Authority Having Jurisdiction
- Navy. Project Manager
- Air Force. Project manager

When increasing slopes of existing roof decks, clearances for rooftop structures such as curbs, base flashings, access doorsills, etc. must be increased to the minimums recommended in the NRCA Manual. Comply with the following:

- Four-way tapered insulation is the most effective method to drain a roof, followed by two-way tapered with saddles. The width of the saddles is critical to move water to the drains.
- Saddles and crickets to the high side of curbs shall be a minimum of twice the roof slope.
- Consult with a plumbing engineer to determine the appropriate number of roof drains and the size of drainpipe.
- See Metal Roofing Overbuild below for additional slope issues.

6-5 REPLACING SINGLE-PLY SYSTEMS.

Single-ply systems shall not be recovered but shall be replaced in full. If the existing membrane is not removed, it may drag and distort the new membrane. The removed membranes shall be recycled.

6-6 LOW-SLOPE CONVERSIONS.

In poorly draining low-slope roofs where the use of tapered insulation cannot improve drainage, the roof may be a candidate for conversion to a steep-slope system. Refer to CERL Technical Report M85/05 *Steep Roof Conversions*. Slope conversions are often more expensive than in-kind reroofing, but may offer the opportunity to convert to a system that requires less maintenance.

6-7 TAPERED ROOF INSULATION SYSTEMS.

Tapered rigid board insulation shall be used when the existing facility has inadequate slope, and other means of providing adequate slope are more expensive over the lifecycle of the facility. Tapered rigid board roof insulation systems are more expensive per square unit than non-tapered insulation. Do not use wet fill to accomplish slope in existing systems. Use tapered rigid board in crickets and saddles to ensure positive drainage.

6-8 RECOVERING STEEP-SLOPE ROOFS.

Re-covering steep roofing such as asphalt shingles is easily done, provided that shingles being overlaid are in acceptable condition and the shingle being installed is of the same size. Building codes permit either one or two direct recovers with missing shingles replaced first and curled shingles flattened. No more than one layer of re-cover roofing may be specified on Military buildings. In recover, new metal flashing is required. Do not re-cover over wet or deteriorated materials. See Table 6-1.

Generally, underlayment is not required in shingle re-covers. Wood shakes and shingles are not a suitable substrate for new shingle or shake recover and must be removed.

6-8.1 Historic Buildings.

Existing roof system shall be replaced in kind, if possible.

6-9 METAL ROOFING.

6-9.1 Metal Roofing Recover.

When tearing off and replacing a failed hydrostatic SSMR system that is attached to a structurally sound roof substructure, one option is to use a standing seam metal roof and retrofit sub-purlin framing system. A structural evaluation of the framing system and the attached roof panels is required. The sub-purlins are custom fabricated with slot depth and spacing to nest over the existing metal roof profile and provide a level surface on which to attach the new metal roof panels.

6-9.2 Metal Roofing Overbuild.

Metal roofing is frequently selected for steep roof conversion since new lightweight structural members easily accommodate increased slope requirement, and the new metal roof may not need a new deck. The fire hazard concern about the newly created attic space must be addressed (FM Global Data Sheet 1-31). Ventilation concerns must also be addressed. Provide a watertight seal at penetrations of new framing connections through the old roof and maintain adequate drainage of the old roof during construction. In hurricane-prone areas, the original roof watertightness shall be maintained. The existing drainage system shall be disconnected and overflows provided at the roof surface level.

Also comply with the following:

- The new truss system shall be installed to the existing structure. This will require cutting the roof and removing in the attachment areas. Therefore, the old roof assembly will not be considered a complete vapor barrier, vapor retarder, air barrier, or insulation layer.
- All wet insulation shall be removed.
- The new attic space shall comply with all code and UFC requirements and may require a separate sprinkler system. The new attic space needs to be detailed to either be a venting attic space or semi-conditioned attic space.
- Although some slope built-up systems have a structural system of trusses and purlins, a roof assembly using a metal deck is recommended. If trusses and purlins are used, the trusses shall be no more than 36 in. (915 mm) apart (even if this exceeds the ASCE 7 wind uplift requirements). The spacing of trusses will not exceed 60 in. (1525 mm) on center (oc). The cross members will be spaced in accordance with the clip spacing determined to meet the wind uplift forces and will not exceed 60 in. (1525 mm) oc. If the cross members are steel hat channels on a spacing of 48 in. (1220 mm) oc or greater, they will be 20 gage and a minimum of 1.5 in. (37 mm) in height.
- New slope built-up metal roofs will have a minimum of 2 in. (50 mm) fiberglass batt insulation and continuous sealed vapor barrier installed directly underneath the roof panels to prevent corrosion from condensation.
- In ASHRAE climates zones 4 and up, it is strongly recommended that the assembly provided include an insulation layer and vented attic. \1\ Use of cool roofs in these climate zones can result in condensation and deterioration of the roof system, see Appendix B Best Practices Chapter 8. /1/
- The new roof system will provide overhangs over the existing building unless infeasible.
- It is strongly recommended that an RRC or a registered PE or RA that derives his or her principal income from roofing design be used in the design and shop drawing review.

6-10 SPRAY APPLIED POLYURETHANE FOAM.

Spray Applied Polyurethane Foam (SPF) roof systems may be considered as a repair option. It is particularly useful for repairing leaking metal roof systems and there is a desire to insulate or add insulation to the existing metal roofed building. SPF is also suitable for curvilinear shapes that do not permit the use of other approved roof systems. 3\In the tropics, due to windy conditions or difficulty in obtaining skilled applicators, the use of polyurethane foam as a roof insulation is not recommended. /3/

SPF roof integrity is highly dependent on the proper mechanical field mixing of components, weather conditions at time of application, the foam's surface texture, and full coverage of the foam with the waterproofing coating materials. Manufacturer involvement during the application is encouraged and final inspection by the manufacturer is required prior to Government acceptance.

6-10.1 Foam.

Trained and certified applicators are required for installation because the foam is difficult to apply in uniform thickness and is highly sensitive to moisture, UV radiation, and wind velocities in excess of 12 miles/hr (19 km/hr). Even brief exposure to UV radiation in sunlight significantly degrades the foam. Degradation is progressive and will eventually result in system failure.

6-10.2 Coating.

Coatings are required for all SPF roof systems and ceramic granules shall be broadcast into the coatings installed over SPF. The coating protects the foam from UV degradation and must be applied to the foam as soon as possible after the foam has cured, but not more than 72 hours after foam installation. The granules provide protection against birds “pecking” the foam, provide better tracking on the coating when wet, and improve UV protection.

The base coating shall be a distinctly different color to provide an indication of the need for re-coating the roof system. The cost of replacing coatings is a significant component of the life cycle cost of SPF roof systems.

6-11 NEW TRUSSES AND DECKING.

Adding lightweight steel or wood trusses or rafters and a nailable deck permits the use of most conventional steep roofing systems.

6-12 SECONDARY PROTECTION.

Re-roofing invariably means disruption of building operations. For some sensitive occupancies (e.g., top floor computer rooms, surgical suites, laboratories, or telephone equipment) a total tear-off may be an unacceptable risk. The addition of a secondary membrane should be analyzed for condensation considerations.

6-13 CLIMATE/WEATHER CONSIDERATIONS.

A complete tear-off requires good weather since the building is usually occupied and nightly tie-offs may not provide adequate protection. The demands of protecting the building may prompt the use of a temporary roof—especially when a thicker insulation system is being added and it is not feasible to run from eave to ridge in a single day.

6-13.1 Night Seals.

At the end of each work period on a re-roofing project, the existing and new roof system shall be completely sealed from moisture intrusion and able to withstand a head of water. Existing drains must remain in working order until the new roof and associated drainage system is completely functional.

6-13.2 Upgrading Insulation.

Adding new insulation and/or an air space above the existing roof will change snow-melting characteristics. Generally, the added insulation reduces vapor condensation problems; however, the effect of the new insulation on vapor condensation must be determined.

6-14 LOGISTICAL CONSIDERATIONS.

Planning a re-roofing project must include all the logistics of the project, especially if the re-roofing occurs over an occupied building. Items to consider in the planning include the following:

- Protecting the newly applied roof covering from tear-off debris and construction traffic. This is critical to the longevity of the new roof;
- Planning for the possible presence of asbestos-bearing materials and landfill or recycling rules and regulations that may require separation of construction materials;
- Staging of new materials when existing materials are being torn off;
- Providing for material removal when dust management is used;
- Removing surface dirt and loose aggregate on aggregate-surfaced roofs prior to tear-off;
- Providing protection of building interior and protection of exterior finishes to remain;
- Providing interior dust control;
- Evaluating potential impact of new work on deck underside fireproofing; and

- Identifying and controlling fire risk from roof installation—especially torch-applied systems.

6-14.2 System and Site Safety Considerations.

Safety is of paramount importance. Protect occupants from fumes by coordinating the shutdown of air handling units. Protect occupants in areas where roofing work is taking place directly overhead by directly cordoning off the area, especially if deck repairs are taking place. Protect all occupants entering or leaving the building from falling materials. Exercise extreme care when reroofing over existing gypsum or wet fill deck systems. Identify the location of underground tanks and other sensitive, sub-surface items so that heavy vehicles do not overload these areas.

6-14.3 Deck Replacement.

If deck replacement is necessary, the operations directly beneath the deck being replaced will require shut down for safety and leakage reasons. Additionally, since it may be impossible to maintain HVAC services, humidity control, and air exchange with the building roof being open, a more extensive shutdown may be required.

This Page Intentionally Left Blank

\4\

CHAPTER 7 ROOF SYSTEMS OPERATIONS AND MAINTENANCE

7-1 PURPOSE AND SCOPE.

The objective of a roof management program is to optimally manage roof systems over their life-cycle to meet the required levels of service for Department of Defense (DoD) real property. Roof management involves an asset management approach, taking into account performance measures, periodic inspections, routine maintenance and repair, and correct application of quality roofing products.

7-2 ASSET MANAGEMENT OF ROOF SYSTEMS.

Executive Order (EO) 13327, *Federal Real Property Asset Management* (2004), requires all DoD components to adopt a common process for conducting built infrastructure assessment. A roof system database is helpful to effectively manage those assets by tracking the life-cycle cost attributes of a roof system that are important for developing and executing investment strategies. A DoD Memorandum, *Standardizing Facility Condition Assessments* (2013), requires all DoD components to adopt a common process that incorporates the BUILDER™ Sustainment Management System (SMS) modules developed by the United States Army Corps of Engineers' (USACE) Engineering Research & Development Center's (ERDC) Construction Engineering Research Laboratory (CERL). The Memorandum also requires all DoD components to properly record a facility condition index (FCI) for each real property asset on their installations in their respective real property databases. BUILDER™ SMS can serve as the roof system database when roof system data is maintained. It tracks information on the type and age of the roof and helps to assign a condition to the roof based on a fixed set of criteria. With this information, it can provide a remaining service life prediction and reveal when to execute corrective maintenance or repair actions. There are several commercial off-the-shelf (COTS) tools available and in use at DoD installations; there is no prohibition against continuing to use these. However, the condition rating of the roof system must be assigned using the SMS criteria that is the DoD standard, namely the condition rating using BUILDER™ SMS criteria. Contact your Service's subject matter expert (SME) for information regarding continued use of other COTS tools as the roof system management database for your installation. Maintenance of the database is best accomplished by in-house shops.

7-3 NONDESTRUCTIVE INSPECTIONS.

Nondestructive inspections can aid inspectors when conducting condition assessments. Nondestructive inspection methods can reveal roof areas where leaks are occurring or have occurred. Three methods are infrared thermography, electrical capacitance, and nuclear detection. The infrared method has the advantage of surveying 100 percent of the roof surface area while the others survey only 2 percent when using a typical 10-foot by 10-foot (3-meter by 3-meter) grid pattern. These methods can supplement but never replace a visual inspection. Confirm an anomaly identified by nondestructive methods by taking a roof core sample and testing it.

7-4 INSTALLATION-LEVEL SURVEY.

An aerial infrared survey of the installation is an excellent aid to a roof management program. Combined with a rooftop visual inspection and destructive verification of aerial findings, these surveys confirm leak tightness of newly constructed roofs, pinpoint leak sources and extent of wet insulation to allow spot repairs or partial replacement, or confirm the total number of roof sections that need to be replaced.

7-5 MAINTENANCE.

Maintenance is the proactive effort expended on a recurrent, periodic schedule that is necessary to preserve the condition of the roof components and systems as they were designated for their anticipated service life. Preventive maintenance efforts generally occur prior to failure of the roof system to perform as intended and include periodic inspections and resulting diagnosis of required repairs. The work may consist of the correction of minor defects in small areas, such as resurfacing bare spots, or it may involve the treatment of the entire roof area, such as recoating smooth-surfaced built-up roofing. With good maintenance, the service life of a roof is extended many years and the life-cycle cost of roofing is reduced.

7-6 MAINTENANCE INSPECTION PROCEDURES.

Inspect all roofs at least once annually (NRCA recommends inspecting roofs at least twice annually and after significant storm events like high winds, hail, heavy rain, or snow accumulation). At a minimum, conduct housekeeping, clear drainage system, secure loose fasteners, replace sealant, and note conditions that require further attention. Pay special attention to flashings because most leaks originate at these areas. Make a detailed inspection of flashings at locations such as skylights, perimeters, walls, penetrations, equipment curbs, and drains. Inspect the field of a roof for items such as surface wear, lap integrity, and overall degradation. Identify signs of weakness, unnecessary or improperly installed items, deterioration, or hazard. Identify needed repairs.

7-6.1 Use the NRCA Manuals.

Supervisors and roof maintenance personnel should use the NRCA manuals to the fullest extent possible, consistent with local operating conditions and capabilities. See Appendix A for NRCA manual resources.

7-6.2 Qualifications of Personnel.

Roofing work can be difficult and dangerous for inexperienced, untrained workers. The repair standards and procedures cited in this UFC require varying levels of competency and training to be effective. The use of hot asphalt, torches, and solvent-containing materials is common in roof repair work and misuse can create problems. To make roof work safer and more effective, ensure that qualified personnel are assigned or contracted to accomplish repair work, routinely review fall protection procedures, and conduct the work with at least two people.

7-6.3 Identifying Leaks.

The initial phase of repairing defects in roofs related to moisture infiltration is accurately identifying and locating the defect that is the source of the moisture infiltration. This can be relatively simple or complex, depending on the circumstances. Interior moisture infiltration that is observed and reported as a roof leak can be a result of defects or inadequate systems at adjacent elements of the structure, such as walls, windows, and mechanical units. Maintenance personnel shall perform an investigation to identify and locate leak damage related to roof defects prior to repairs.

7-6.4 Locating Leaks.

Locate the interior leak damage by measuring from a reference point on the roof. If roof defects are apparent at the correlated location on the roof, proceed with the roof repair work. If roof defects are not readily apparent and adjacent building elements are located close enough to be potential sources of the moisture infiltration, continue to investigate to determine the source of the leak causing the damage.

7-7 ROOFS UNDER WARRANTY.

Roofs under warranty, guarantee, or performance agreement must be inspected in accordance with the terms of the warranty. The appropriate personnel shall determine the applicability of warranties prior to performing repairs to roof components or systems. If a warranty is in effect, the warrantor should be contacted for recommendations as to the correct course of action. The warranty should cover most leaks and defects in the membrane and flashing systems. Debris must not be allowed to accumulate on the roofs and minor defects should be noted and relayed to the warranty provider.

7-8 ROOFS AWAITING REPLACEMENT.

If a roof continues to leak despite repeated repair efforts, that roof should be scheduled for replacement. Normal maintenance efforts on these roofs are ineffective and will only result in neglect of essential preventive maintenance on the fully functioning roofs. Perform safety inspections only on these roofs. Check drainage systems and remove all debris from roofs to prevent excessive ponding of water and possible roof collapse. These roofs should be replaced or the building evacuated and demolished.

7-9 REPAIRS.

Repairs are the efforts necessary to restore functionality to roof components and systems. This is the treatment to repair at least partial failures. Repairs may be minor, involving small areas such as the replacement of a broken slate or tile, or it may be major, involving the whole roof such as the application of additional layers of felt over built-up roofing.

7-10 NON-GOVERNMENT STANDARDS.

This UFC adopts available industry reference sources as non-government standards describing repair methods and materials for various types of roof systems. The following publications form a part of this UFC to the extent specified herein.

- Refer to *NRCA Repair Manual for Low-Slope Roof Systems*, 2nd Edition, for membrane, flashing, and sheet metal, and penetration repairs of BUR, modified bitumen, thermoplastic, and thermoset membranes. See paragraph 7-11.
- Refer to the SMACNA *Architectural Sheet Metal Manual* for technical information, specifications, and drawings related to replacement of sheet metal components.
- SPFA-127, *Maintenance Manual for Spray Polyurethane Foam Roof Systems*

7-11 DETAILED REPAIR REQUIREMENTS.

See the referenced sections of *NRCA Repair Manual for Low-Slope Roof Systems*, 2nd Edition, for certain roof systems and repairs, as follows:

- Built-up roof membranes: Section 1
- Modified bitumen membranes: Section 2
- Thermoplastic membranes: Section 3
- Thermoset membrane repairs: Section 4
- Mechanically attached metal flashings: Section 5. /**4**/

APPENDIX A REFERENCES

Also see Appendix F for additional reading.

Architectural Sheet Metal Manual, Sheet Metal and Air Conditioning Contractors National Association (SMACNA), 4201 Lafayette Center Drive, Chantilly, VA, 22021, www.smacna.org/

ASCE 7-02, *Minimum Design Loads for Buildings and other Structures,* latest edition, American Society of Civil Engineers (ASCE) 1801 Alexander Bell Drive, Reston, VA, 20191-4400, www.asce.org/

ASHRAE Standard 90.1, *Energy Standards for Buildings Except Low-Rise Residential*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (ASHRAE), 1791 Tulle Circle, NE, Atlanta, GA, 30329, www.ashrae.org/

ASHRAE Standard 90.2, *Energy-Efficient Design of Low-Rise Residential Buildings*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (ASHRAE), 1791 Tulle Circle, NE, Atlanta, GA, 30329, www.ashrae.org/

4\ ASHRAE 189.1, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*, www.ashrae.org/ **4**\

ASHRAE Handbook – Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (ASHRAE), 1791 Tulle Circle, NE, Atlanta, GA, 30329, www.ashrae.org/

ANSI/ASSE Z359, *Fall Protection Code,* American National Standard Institute/American Society of Safety Engineers, 1800 East Oakton Street, Des Plaines, Illinois, 60018, www.asse.org

ANSI/ASSE A1264.1*,* Safety Requirements for Workplace Walking/Working Surfaces and Their Access; Workplace Floor, Wall and Roof Openings; Stairs and Guardrails Systems, American National Standard Institute/American Society of Safety Engineers, 1800 East Oakton Street, Des Plaines, Illinois, 60018, www.asse.org

ANSI/SPRI ES1, *American National Standard for Edge Systems Used with Low-slope Roof Systems,* Single Ply Roofing Industry (SPRI), 411 Waverley Oaks Road, Suite 331, Waltham, MA 02452, www.spri.org

ANSI/SPRI RP-4, Wind Design Standard For Ballasted Single-ply Roofing Systems, SPRI, 411 Waverley Oaks Road, Suite 331, Waltham, MA 02452, www.spri.org

ASTM A153/A153M, *Standard Specification for Zinc Coating (Hot Dip*) *on Iron and Steel Hardware*, American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM A653/A653M, *Standard Specification for Steel Sheet, Zinc Coated (Galvanized) or Zinc-Iron Alloy Coated (Galvannealed) by the Hot Dip Process*, American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM C406/C406M, *Standard Specification for Roofing Slate*, American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM C1289, *Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board*, ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM D226/D226M, *Standard Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing,* ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM D448, *Standard Classification for Sizes of Aggregate for Road and Bridge Construction*, ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM D1863, *Standard Specification for Mineral Aggregate Used on Built-Up Roofs,* ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM D3746, *Standard Test Method for Impact Resistance of Bituminous Roofing Systems,* ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM D4263, *Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method*, ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org

ASTM D4272, *Standard Test Method for Total Energy Impact of Plastic Films By Dart Drop,* ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM D4869/D4869M, *Standard Specification for Asphalt-Saturated Organic Felt Underlayment Used in Steep-slope Roofing,* ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM D5957-96, *Standard Guide fir Flood Testing Horizontal Waterproofing Installations,* ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM E96/E96M, *Standard Test Method for Water Vapor Transmission of Materials,* ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM E1592, *Standard Test Method for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference*, ASTM, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM E2140, *Standard Test Method for Water Penetration of Metal Roof Panel Systems by Static Water Pressure Head*, ASTM ,100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

ASTM F1869, *Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride,* ASTM 100, Barr Harbor Drive, West Conshohocken, PA, 19428-2959, www.astm.org/

Building Design Elements for Enhanced Fall Protection for Construction and Maintenance Personnel: An NRCA Perspective, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

CERL Report M85/05, *Sloped Roof Conversions for Small, Flat-Roofed Buildings*, (1985), Construction Engineering Research Laboratory (CERL), 5285 Port Royal Road, Springfield, VA, 22161(order from NTIS: www.dtic.mil)

CRREL Report MP-01-5663, *Minimizing the Adverse Effects of Snow and Ice on Roofs*, Cold Regions Research and Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH, 03755, www.crrel.usace.army.mil/library/technicalpublications.html

CRREL MP 5106, *Attic Ventilation Guidelines to Minimize Icings at Eaves,* Cold Regions Research and Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH, 03755, www.crrel.usace.army.mil/library/technicalpublications.html

CRREL MP 5420, *Ventilating Cathedral Ceilings to Prevent Problematic Icings at their Eaves,* Cold Regions Research and Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH, 03755, www.crrel.usace.army.mil/library/technicalpublications.html \2\

4\ DoD Memorandum, *Standardizing Facility Condition Assessments*, 2013, https://www.acq.osd.mil/eie/Downloads/FIM/DoD%20Facility%20Inspection%20Policy.pdf /**4**/

Department of the Navy, Fall Protection Guide, US Department of the Navy, /2/\3\https://www.public.navy.mil/NAVSAFECEN/Documents/OSH/FP/DoN_FP_Guide_July17-1.pdf/3/

4\ EO 13327, *Federal Real Property Asset Management*, 2004, https://www.archives.gov/federal-register/executive-orders/2004.html /**4**/

FM Global Property Loss Prevention Data Sheets, Factory Mutual Global (FM), 1301 Atwood Avenue, P.O. Box 7500, Johnston, RI, 02919, www.fmglobal.com/

FM 4470, *Approval Standard for Single-Ply, Polymer-Modified Bitumen Sheet, Built-Up Roof (BUR) and Liquid Applied Roof Assemblies for Use in Class 1 and Noncombustible Roof Deck Construction,* Factory Mutual Global (FM), 1301 Atwood Avenue, P.O. Box 7500, Johnston, RI, 02919, www.fmglobal.com/

International Building Code, International Code Council, 500 New Jersey Avenue, NW, 6th Floor, Washington, DC 20001, www.iccsafe.org

Materials Selection Guide for Army Installations Exposed to Severely Corrosive Environments, Construction Engineering Research Laboratory, J.R.Myers, Ashok Kumar, and L.D. Stephenson, March 2002, 5285 Port Royal Road, Springfield, VA, 22161 (order from NTIS: www.dtic.mil)

MBMA Roofing Manual, *Metal Roofing Systems Design Manual*, Metal Building Manufacturers Association (MBMA), 1300 Sumner Avenue, Cleveland, OH, 44115-2851, www.mbma.com

\3\/3/

4\ *NRCA Repair Manual for Low-Slope Roof Systems*, 2nd Edition, www.nrca.net /**4**/

NRCA Building Owners Guide to Roof-mounted Photo Voltaic Systems, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

NRCA Guidelines for Roof-mounted Photovoltaic Systems, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

NRCA Roofing Manual, *Comprised of Five Manuals,* National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

NRCA Vegetative Roof Systems, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Peterson AFB Green Roof Study Findings and Recommendations, https://cs2.eis.af.mil/sites/10159/SitePages/Service%20Page.aspx?Service=Roofing

Slate Roofs: Design and Installation Manual, National Slate Association, P.O. Box 172, Poultney, VT 05764, slateassociation.org/

SMACNA Architectural Sheet Metal Manual; Sheet Metal and Air Conditioning Contractors' National Association, 4201 Lafayette Center Drive Chantilly, Virginia 20151-1219, www.smacna.org/

4\ SPFA-127, *Maintenance Manual for Spray Polyurethane Foam Roof Systems*, http://www.sprayfoam.org/technical/spfa-technical-documents /**4**/

UFC 1-200-01, *DoD Building Code (General Building Requirements)*, Unified Facilities Criteria Program, dod.wbdg.org

\1\ UFC 1-200-02 *High Performance and Sustainable Building Requirements,* dod.wbdg.org /1/

UFC 3-101-01, *Architecture*, Unified Facilities Criteria Program, dod.wbdg.org

UFC 3-400-02, *Design: Engineering Weather Data,* Unified Facilities Criteria Program, dod.wbdg.org

UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings,* Unified Facilities Criteria Program, dod.wbdg.org

UL 2218/ASTM 2218, *Impact Resistance of Prepared Roof Covering Materials/Standard Test Method for Determining Forming Limit Curves,* 2600 NW Lake Road, Camas, WA 98607-8542, www.ul.com

Unified Facilities Guide Specifications (UFGS):
dod.wbdg.org

UFGS 01 62 35 *Recycled/Recovered Materials*

UFGS 07 22 00, *Roof and Deck Insulation*

UFGS 07 31 13, *Asphalt Shingles*

UFGS 07 31 26, *Slate Roofing*

UFGS 07 32 13, *Roof Tiles*

UFGS 07 32 14, *Clay Tile Roofing Replacement or Repair*

UFGS 07 41 13, *Metal Roof Panels*

UFGS 07 41 63, *Fabricated Roof Panel Assemblies*

UFGS 07 42 13, *Metal Wall Panels*

UFGS 07 51 13, *Built-Up Asphalt Roofing*

UFGS 07 52 00, *Modified Bituminous Membrane Roofing*

UFGS 07 53 23, *Ethylene Propylene Diene Monomer Roofing*

UFGS 07 54 19, *Polyvinyl Chloride (PVC) Roofing*

UFGS 07 55 00, *Protected Membrane Roofing (PMR)*

UFGS 07 57 13, *Sprayed Polyurethane Foam (SPF) Roofing*

UFGS 07 60 00, *Flashing and Sheet Metal*

UFGS 07 61 01, *Copper Roof System*

UFGS 07 61 14.00 20, *Steel Standing Seam Roofing*

UFGS 07 61 15.00 20, *Aluminum Standing Seam Roofing*

APPENDIX B BEST PRACTICES

B-1 INTRODUCTION.

This appendix identifies background information, good design practices, and DoD preferences. The designer is expected to review and interpret this guidance and apply the information according to the needs of the project.

B-2 SUSTAINABILITY.

Over the past two decades, responsible roofing professionals have sparked a drive toward greater interest in and adherence to the concept of sustainability. Beyond the desire to improve return on investment on such a significant part of the building envelope, adopting roof systems to fit within environmental parameters has great resonance in modern times.

In the roofing industry, the essence of sustainability is long-term performance. Except for very large roof areas, steep-slope roofs often offer the most life-cycle cost effective solution when considering maintenance, repair, and replacements costs. Military roof systems should be designed to meet the recommended warranty coverages in Appendix D.

As roofing professionals have applied the concept of sustainability to their construction and reroofing projects, they have come to learn that several key areas provided opportunities for improvement. These areas were identified by the CIB (International Council for Research and Innovation in Building Construction) Working Commission W.83 or RILEM (International Union of Testing and Research Laboratories for Materials and Structures) Technical Committee 166RMS (CIBW.83/RILEM166RMS). The areas that were identified include:

1) Minimize the burden on the environment by responsible use of materials.
2) Conserve energy by improving thermal efficiency of roofs; and
3) Extend roof lifespan by improving long-term performance.

B-2.1 21 Tenets of Sustainability.

Within this framework, 21 Tenets of Sustainability were developed for design compliance as follows:

A. Minimize Burden on the Environment

1. Use products made from raw materials whose extraction is least damaging to the environment.
2. Adopt systems and working practices that minimize wastage.
3. Avoid products that result in hazardous waste.
4. Recognize regional climatic and geographical factors.

5. Where logical, use products that can be reused or recycled.
6. Promote the use of 'green roofs' supporting vegetation, especially on city center roofs.
7. Consider roof designs that ease the sorting and salvage of materials at the end of the roof life.

B. Conserve Energy

8. Optimize the real thermal performance, recognizing that thermal insulation can greatly reduce heating or cooling costs over the lifetime of a building.
9. Keep insulation dry to maintain thermal performance on durability of the roof.
10. Use local labor, materials and services wherever practical to reduce transportation.
11. Recognize that embodied energy values are a useful measure for comparing alternative constructions.
12. Consider the roof surface color and texture with regard to climate and the effect on energy and roof system performance.

C. Extend Roof Lifespan

13. Employ designers, suppliers, contractors, trades people and facility managers who are adequately trained and have the appropriate skills.
14. Adopt a responsible approach to design, recognizing the value of the robust and durable roof.
15. Recognize the importance of a properly supported structure.
16. Provide effective drainage to avoid ponding.
17. Minimize the number of penetrations through the roof.
18. Ensure that high maintenance items are accessible for repair or replacement.
19. Monitor roofing works in progress and take corrective action, as necessary.
20. Control access onto completed roofs to reduce punctures and other damage, providing defined walkways and temporary protections.
21. Adopt preventative maintenance, including periodic inspections and timely repairs.

B-3 ROOFING SYSTEMS.

B-3.1 Low-slope Roof Drains.

Roof drains should incorporate sump pans provided by the roof drain manufacturer, under-deck clamps to prevent wind uplift, and a clamping ring with bolts. Generally, the best performing roof drains and strainers are made of galvanized cast iron.

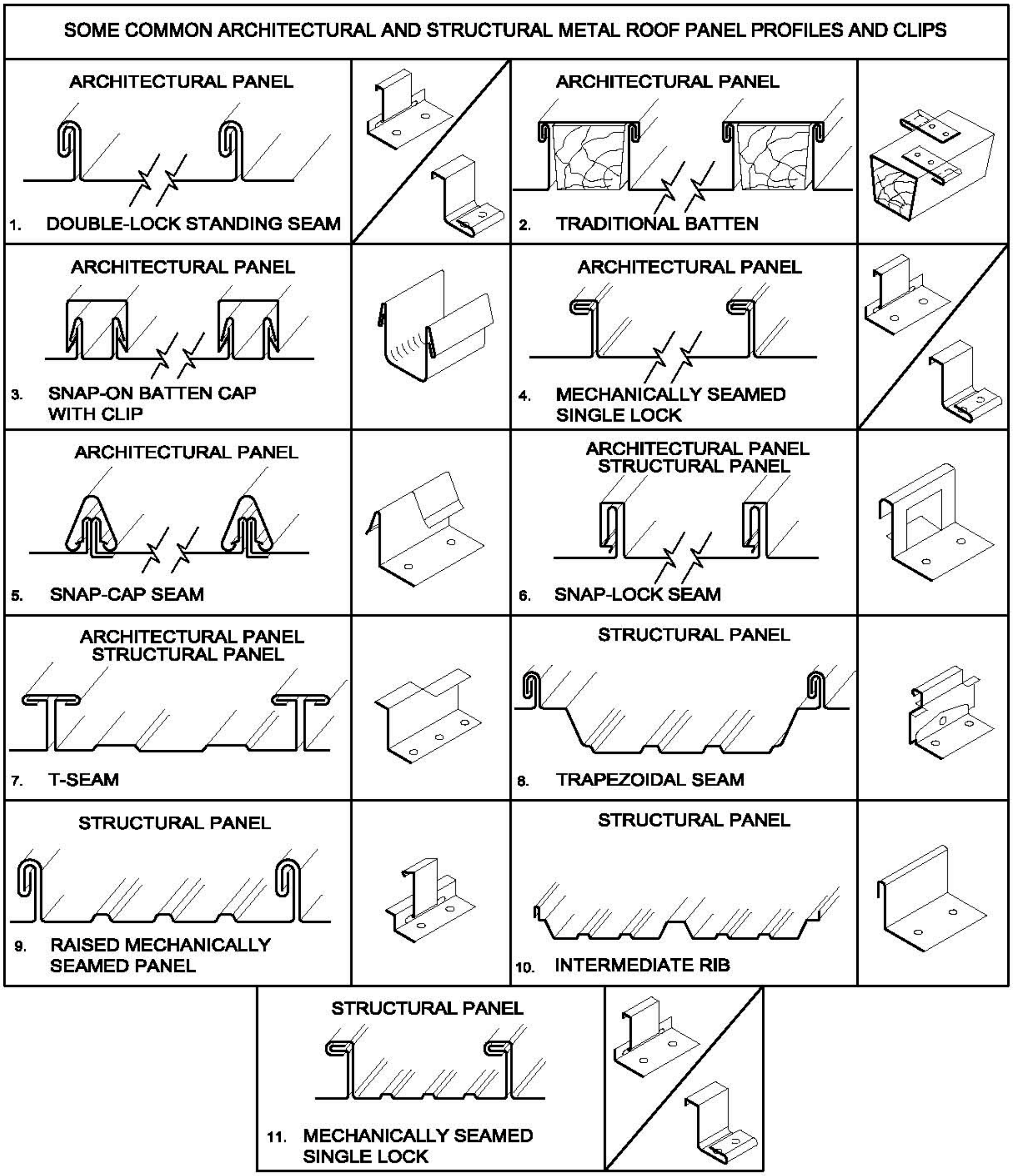
B-3.2 Cover Boards.

Per Chapter 3, cover boards are required on all low-slope roof systems except ballasted. Note that cover boards also protect the polyisocyanurate insulation from physical damage, improve fire resistance, and provide a suitable surface for adherence of the roof membrane.

B-3.3 Common Metal Roof Panel Profiles.

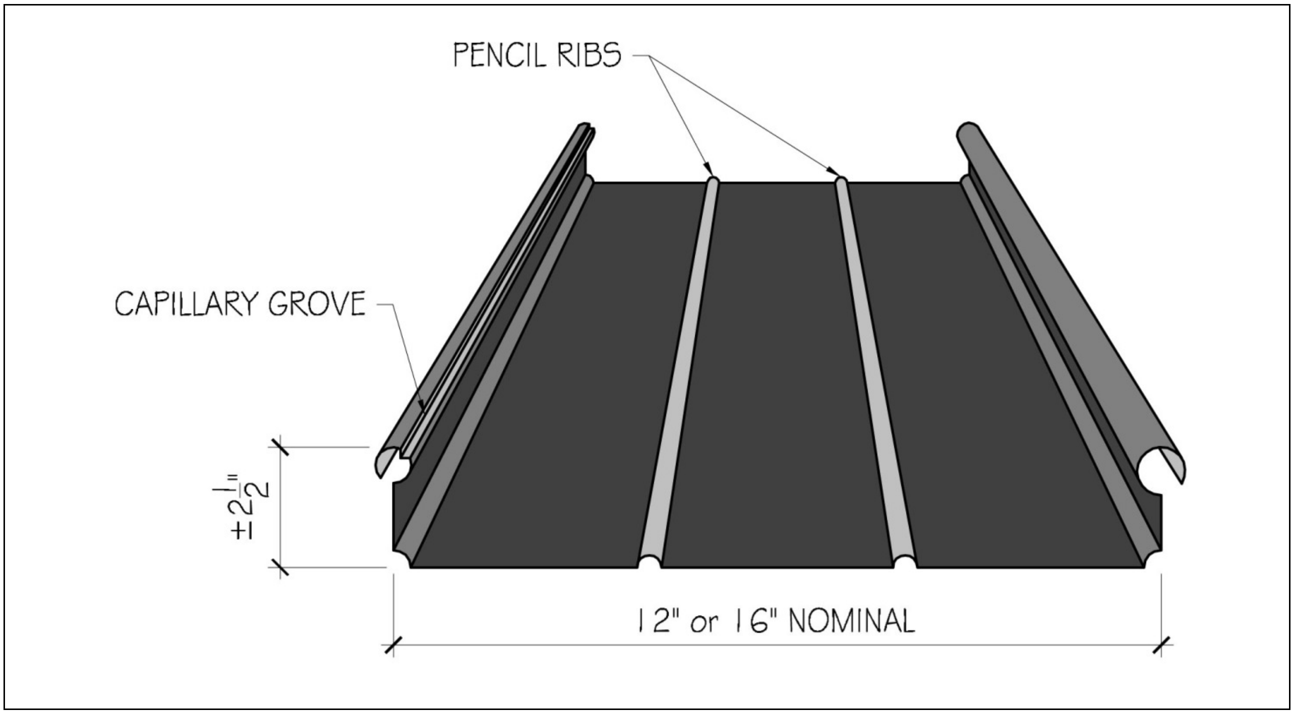
Figures B-1 and B-2 illustrate some common metal roof panel profiles.

FIGURE B-1. COMMON METAL ROOF PANEL PROFILES AND CLIPS



Used with permission, National Roofing Contractors Association

FIGURE B-2. BULB SEAM ZIP RIB



B-4 TEMPORARY ROOFS

Roof system design and construction can often be enhanced by the use of a temporary roof, often a vapor retarder. However, there are conditions and climates where caution must be taken to ensure a second vapor barrier is not created that will trap moisture once the new roof is completed. In southern climates (ASHRAE Climate Zones 1 thru 3), the temporary roof and resulting vapor barrier shall be removed once the new roof is completed. When used appropriately, this design element provides several key quality assurance benefits during new construction:

- Allows for roof related construction such a wood blocking and HVAC work to take place over the temporary roof and not the final roof thus reducing the potential for physical damage to the new roof system.
- Allows for building construction above the roof, such as masonry walls, curtain walls, metal panels, etc., to take place over the temporary roof, thus reducing the potential for physical damage to the new roof system.

Temporary roofs provide the following quality assurance benefits during roof removal projects:

- Permits the full removal of the existing roof without the need to install the new roof in small sections that would result in multiple tie-ins.

- Allows for roof interfacing work such as the installation of new roof drains or renovation of existing roof drains. Wood blocking installation, masonry restoration, HVAC equipment disconnection, curb installation and reinstallation can take place over the temporary roof rather than the new roof system.
- Allows for the large monolithic installation of the new roof system.
- Enhances the roof installation quality.

B-5 ELECTRIC FIELD VECTOR MAPPING (EFVM).

Electric Field Vector Mapping (EFVM) is a non-destructive leak detection method recommended for all waterproofing membranes particularly when waterproofing systems are to be covered with over burden, such as soil for vegetative roofing, pavers for a plaza, or an inverted roofing membrane assembly (IRMA). It is suitable for all waterproofing membranes possessing electrically insulating properties.

B-5.1 How EFVM Works.

EFVM detects the concentration of current flowing across a membrane indicating a breach. If water has flowed through a breach in the membrane, an electrical pathway is set up, which when wetted and energized creates a completed circuit. Whether the membrane is exposed or overburdened, EFVM quickly and accurately locates all breaches.

B-5.2 Locating a Breach in the Membrane.

EFVM locates breaches by measuring electrical flow. One lead from the pulse generator goes to a conductor, placed on the membrane while the other is grounded to the structure. The area of the membrane to be tested is wetted to create continuity that will carry an electrical charge. The trained and certified inspector applies a low voltage electrical potential above and below the membrane in regular pulsed intervals and reads a potentiometer while systematically measuring the current flow at the surface of the roof membrane or any other component of the wet field such as wetted drainage mat, insulation or overburden. Each area of membrane must be thoroughly wetted.

Sensitive equipment reads through all typical water permeable overburden medium such as soil, sand, crushed stone or even pavers and garden plants to measure current flow. Any breach allowing even minute amounts of water past it will conduct electricity, completing a circuit and creating a concentration of current flow measurable by the inspector reading the gauge attached to the probes.

The EFVM trained and certified inspector quickly detects and locates with pinpoint accuracy any individual defect that allows the flow of water from above the membrane to structure. EFVM tests commonly reveal breaches missed by previous flood testing. The contractor can repair the defects found and have them retested within the same day.

B-6 RECYCLING.

The ability to recycle roofing material is now available. When existing roof systems are being removed various components such as the following can be recycled:

- Ballasted and mechanically attached EPDM
- Ballasted and mechanically attached PVC
- Roof related sheet metal
- Extruded and expanded polystyrene
- Chlorosulfonated Polyethylene (CSPE)

Designers are encouraged to specify the recycling of these roof related materials and require certification of same. Refer to the UFGS 01 62 35 on Recycled/Recovered Materials.

B-7 LIFE CYCLE ASSESSMENT.

Consider conducting a Life Cycle Cost Analysis (LCCA) on major roof components, such as the membrane and insulation, to determine the lowest life cycle cost for the component. LCCA is a scientific approach to compiling and evaluating the inputs, outputs and the potential environmental impact of a product or system throughout its life cycle. The environmental impact of all the materials used to manufacture building products, including roofing is slowly making its way into standards. Each product will have a LCCA number and will influence building design in the future. Additional information on LCCA and definition of terms can be found at the American Center for Life Cycle Assessment (ACLCA) web site: www.lcacenter.org/about-lca.aspx

B-8 COOL ROOFING AND HEAT ISLAND ISSUES.

\2\Sustainable Third Party Certifiers (TPC) and industry standards promote the use of cool roofing, and increased energy conservation through additional insulation, when appropriate for climate zone. For cool roof design follow the requirements in Chapter 1, Cool Roofs. /2/ Consider that when cool roofing is used with insulation R values greater than 24, the ‘cool roof’ surface has little if no influence on the energy performance of the building. Additionally, designers should be aware of the possible negative impacts of using cool roofing that may result in unintended consequences.

Poor design of cool roofs in ASHRAE climate zones 4 and higher have resulted in the unintended consequence of condensation below the membrane—a result of the material’s inability to warm and drive moisture downward. Roofs that experience this condensation have had to be replaced. Other unintended consequences include the overheating of masonry walls, interior spaces, roof top piping and mechanical equipment because of the reflected UV rays.

B-9 GUTTERS AND DOWNSPOUTS.

Consider methods to ensure gutters and downspouts do not become clogged. The best options for DoD projects include oversizing downspouts, minimizing turns or offsets in the downspouts, providing strainers at the downspouts, and providing clean-outs at the base of the downspouts. Strainers should not be used in areas with a lot of leaves or tree debris.

B-10 PARAPETS.

If parapets are to be used, the metal coping will have an ice and water shield membrane completely lapping the wall from edge to edge. If a stone/masonry coping is used, it will have through wall flashing under the coping including watertight welded caps over the posts used to secure the coping stone.

On all masonry drainage plane walls with roofs running beside, stepped through wall flashing will be provided to protect the interior wall below.

B-11 DESIGN PROFESSIONAL QUALIFICATIONS.

In addition to the criteria required in Chapter 1, all projects that have more than 15,000 $ft.^2$ (1400 m^2) of roof area or that are defined as “critical use” or “mission critical” in the project DD Form 1391 should have an RRC or a registered PE or RA that derives his or her principal income from roofing design on the design team.

B-12 REROOFING.

Re-roofing can be considered a problem or an opportunity. Re-roofing can be a problem since the work is typically performed while the structure is occupied. Often there are concerns with noise, fumes, access, and interruption of building use. Re-roofing can be an opportunity since there is no better time to upgrade the roof system than while re-roofing. Changes in the roof system may be mandated by revisions to ASCE 7 or by needed improvement in drainage or thermal performance. It can be an opportunity to elevate or redesign problem roof elements, to install deck supported curbs that are flashed independently of the wall (resolving persistent flashing problems due to differential movement), and to resolve condensation problems or thermal insulation deficiencies.

Re-roofing decisions begin with a survey of existing conditions. This may include visual inspection, infrared moisture surveys, and roof cut analysis. Structural analysis may also be required, especially if a different type of roof is contemplated which affects dead load, drainage, or seismic behavior. One method of analyzing the condition of an existing roof is to use the ROOFER *Sustainment Management System* (SMS). The ROOFER SMS is a decision-making tool to help manage an installation’s low-slope membrane and asphalt shingle roofing assets. It includes procedures for collecting inventory and inspection information, evaluating roof conditions, identifying repair/replacement strategies, prioritizing projects, and developing work plans. ROOFER, a Web-based application, provides data storage and analysis and generates management reports.

B-13 RECOVERING.

Re-covering of existing low-slope roofs is not recommended. When the best option based on a detailed analysis, including risk analysis, LCCA, and a moisture survey, is to recover a low-slope roof, comply with the criteria in Chapter 6.

Re-cover of existing built-up and MB roofing may take the form of mechanically or spot attaching a base sheet (to aggregate-free substrates), or mechanically or spot attaching re-cover insulation when aggregate is present (where only the loose aggregate is removed). Full attachment to a severely compromised membrane is never recommended. \2\

B-14 TPO ROOFING

TPO Roofing has energy efficient properties as well as being recyclable. These features and cost effectiveness makes TPO membranes an attractive roof system for large scale industrial applications. Below are some considerations for obtaining the best life cycle performance when this roof type is selected:

- Reduce the number of rooftop mounted items which significantly reduce the number of roofing membrane penetrations.
- Wherever penetrations in the roofing membrane must occur, encapsulate penetration by using either a preformed TPO boot or a pitch pocket. This method of encapsulation should be used whether the penetration is vertical or horizontal.
- Require test strips for the membrane hot air welder on any day the contractor is performing hot air welding of seams. The test strips can be inspected to assure that the machine is hot enough and reduces chances of non-adhered seams.
- Scuppers contained in the TPO roof system require hand welded seams. Special attention should be given to performing inspection in these areas due to the space constraints to assure the membrane is fully adhered.
- It is important to address/control fall protection early in the project to avoid having to install fall protection measures that penetrate the TPO membrane after installation or use heavy objects that may get dragged across the TPO membrane.
- Due to TPO membranes being a single-ply system, it is important to ensure that any structural components that are underneath the membrane and may rub against the membrane are fully protected so that they do not

inadvertently puncture the membrane. An example may be structural welded plates or other components along the perimeter edge of the roof. /2/

APPENDIX C GLOSSARY, ACRONYMS AND ABBREVIATIONS

ACM. Asbestos containing material

ANSI. American National Standards Institute

APP. Atactic Polypropylene

ASCE. American Society of Civil Engineers

ASHRAE. American Society of Heating, Refrigerating and Air Conditioning Engineers

ASTM. American Society of Testing and Materials

BASH. Bird/wildlife aircraft strike hazard

BUR. Built-up roof

CERL. Construction Engineering Research Laboratories

CONUS. Continental United States

CRREL. Cold Regions Research and Engineering Laboratory

CSSB. Cedar Shake and Shingle Bureau

DB. Design Build \2\

DD 1391. Department of Defense Form 1391

DoD. Department of Defense

DON. Department of the Navy /2/

EFVM. Electric field vector mapping

EPDM. Ethylene Propylene Diene Monomer

EPS. Molded expanded polystyrene board.

ERA. EPDM Roofing Association

\3\ ESC. Environmental Severity Classification **/3/**

FM. Factory Mutual

HVAC. Heating, ventilation, and air conditioning

IBC. International Building Code

IGCC. International Green Construction Code

LCCA. Life cycle cost analysis \2\ /2/

MB. Modified bitumen

MBMA. Metal Building Manufacturers Association

MREC. Mesh Reinforced Elastomeric Roof Coating

NRCA. National Roofing Contractors Association

NSA. National Slate Association

OSHA. Occupational Safety and Health Administration

PE. Professional engineer

PUF. Polyurethane foam (also see SPF)

PV. Photovoltaic

PVC. Polyvinyl chloride

PVDF. Polyvinylidene fluoride (also PVF)

PVF. Polyvinylidene fluoride (also PVDF)

RA. Registered architect

RCI. Roof Consultants Institute

RICOWI. Roofing Industry Committee on Weather Issues

ROI. Return on investment

RRO. Registered roofing observer

RRC. Registered roofing consultant

SBS. Styrene Butadiene Styrene

SHPO. State Historic Preservation Office

SMACNA. Sheet Metal and Air Conditioning Contractors National Association

SME. Subject matter expert

SMS. Sustainment Management System

SPF. Spray-applied polyurethane foam (also see PUF)

4\ **SPFA.** Spray Polyurethane Foam Alliance /**4**/

SPRI. Single Ply Roofing Industry

SSSMR. Structural standing-seam metal roof

TPO. Thermoplastic Polyolefin

TRI. Tile Roofing Institute

UFC. Unified Facilities Criteria

UFGS. Unified Facilities Guide Specification

UV. Ultraviolet

XPS. Extruded polystyrene board

UL. Underwriters Laboratories Incorporated

DEFINITIONS

See UFC 3-101-01 and the NRCA Roofing Manual for a more complete list of definitions.

Aggregate. (1) Crushed stone, crushed slag, or water-worn gravel used for surfacing a built-up roof. (2) Any granular mineral material.

Alloys, polymeric. A blend of two or more polymers, e.g., a rubber and a plastic to improve a given property, e.g., impact strength.

Asphalt. A dark brown to black elastomeric cementitious material whose predominating constituents are bitumen's that occur in nature or are obtained in petroleum processing.

Asphalt felt. An asphalt-saturated felt.

Atactic. A chain of molecules in which the position of the side methyl groups is more or less random. (Amorphic; Low Crystallinity)

Ballast. Loose aggregate, concrete pavers, or other material designed to prevent wind uplift or flotation of a loose-laid roof system.

Base sheet. A saturated or coated felt placed as the first ply in a multi-ply bituminous roofing membrane.

Batten. (1) Raised rib, in a metal roof, or a separate part or formed portion in a metal roofing panel. (2) One of a series of strips laid in a matrix under tile roof applications.

Bitumen. (1) A class of amorphous, black or dark colored, (solid, semisolid, or viscous) cementitious substances natural or manufactured, composed principally of high molecular weight hydrocarbons, soluble in carbon disulfide, and found in asphalts, tars, pitches, and asphaltites; (2) A generic term used to denote any material composed principally of bitumen; (3) In the roofing industry there are two basic bitumens: asphalt and coal-tar pitch. Before application, they are either (a) heated to a liquid state, (b) dissolved in a solvent, or (c) emulsified.

Bituminous (adj.). Containing or treated with bitumen. Examples: bituminous concrete, bituminous felts and fabrics, bituminous pavement.

Bond. The adhesive and cohesive forces holding two roofing components in intimate contact.

Boot. A bellows type covering to exclude dust, dirt, moisture, etc., forming a flexible closure.

British thermal unit (BTU). Heat energy required to raise the temperature of one pound of water by 1^0F (= 1055 joules).

Building Code. Published regulations and ordinances established by a recognized agency describing design loads, procedures, and construction details for structures. Usually applying to designated political jurisdiction (city, county, state, etc.). Building codes control design, construction, and quality of materials, use and occupancy, location and maintenance of buildings and structures within the area for which the code was adopted (see Model Codes).

Built-Up Roofing (BUR). A continuous, semiflexible membrane consisting of plies of saturated felts, coated felts, fabrics or mats assembled in place with alternate layers of bitumen, and surfaced with mineral aggregate, bituminous material, or a granule surfaced sheet (abbreviation, BUR).

Butyl Rubber. A synthetic rubber based on isobutylene and a minor amount of isoprene. It is vulcanizable and features low permeability to gases and water vapor and good resistance to aging, chemicals and weathering.

Cant. In SPF-based roofing, a beveling of foam at horizontal/vertical joints to increase strength and promote water runoff.

Cant strip. A beveled strip used under flashings to modify the angle at the point where the roofing or waterproofing membrane meets any vertical element.

Cap flashing. See Flashing.

Cap sheet. A granule-surfaced coated felt used as the top ply of a built-up roofing membrane.

Caulk. To seal joints, seams, or voids by filling with a waterproofing compound or material.

Caulking. A composition of vehicle and pigment, used at ambient temperatures for filling joints, that remains plastic for an extended time after application.

Chalk Resistance. A measurement of performance for paint systems; the ability to resist a dusty/chalky appearance over time.

Chalking. A powdery residue on the surface of a material resulting from degradation or migration of an ingredient, or both.

Chlorinated polyethylene (CPE). Family of polymers produced by chemical reaction of chlorine on the linear backbone chain of polyethylene. The resultant rubbery thermoplastic elastomers presently contain 25- 45 % chlorine by weight and 0-25% crystallinity. CPE can be vulcanized but is usually used in a nonvulcanized form.

Chlorosulfonated polyethylene (CSPE). Family of polymers that are produced by polyethylene reacting with chlorine and sulfur dioxide. Present polymers contain 25-43% chlorine and 1.0-1.4% sulfur. They are used in both vulcanized and nonvulcanized forms. Most membranes based on CSPE are nonvulcanized. ASTM designation for this polymer is CSM. Best known by the DuPont Tradename “Hypalon.”

Closure Strip. A resilient strip such as neoprene, flat on one side and formed to the contour of ribbed sheets on the other, used to close openings created by joining metal sheets and flashings.

Coal Tar. A dark brown to black cementitious material produced by the destructive distillation of coal.

Coal Tar Felt. A felt saturated with refined coal tar.

Coating Weight. Weight of coating on surface (both sides), usually expressed in g/m^2 or $oz./ft.^2$.

Coefficient of Thermal Expansion. The change in length per unit of length for a unit change in temperature. (Thus the coefficient per ^oF must be multiplied by 1.8 for the coefficient per ^oC.)

Condensation. The conversion of water vapor or other gas to liquid as the temperature drops or atmospheric pressure rises (see also Dew point).

Conductance, Thermal. The thermal transmission in unit time through unit area of a particular body or assembly having defined surfaces, when unit average temperature difference is established between the surfaces. C=(W/ m^2•K) C=(Btu/h•ft^2•^{0}F).

Conductivity, Thermal. The time rate of transfer of heat by conduction through a unit thickness across unit area for unit difference of temperature.

Copolymer. A mixed polymer, the product of polymerization of two or more substances at the same time.

\3\ Corrosion. The deterioration of a material or its properties due to a reaction of that material with its chemical environment; it is inclusive of the deterioration of all materials, which can be caused through sun exposure, mold and mildew, wind, and other environmental elements. /3/

Counterflashing. Formed metal or elastomeric sheeting secured on or into a wall, curb, pipe, rooftop unit, or other surface, to shield the upper edge of a base flashing and its associated fasteners.

Coverage. The surface area to be continuously covered by a specific quantity of a particular material.

Covering. The exterior roof and wall covering for a metal building system.

Cricket. A relatively small, elevated area of a roof constructed to divert water from a horizontal intersection of the roof with a chimney, wall, expansion joint or other projection.

Curb. A raised member used to support roof penetrations such as skylights, hatches, etc.

Cure. To change the properties of a polymeric system into a more stable, usable condition by the use of heat, radiation, or reaction with chemical additives. NOTE: Cure may be accomplished, for example, by removal of solvent or cross-linking.

Deck. The structural substrate to which the roofing or waterproofing system (including insulation) is applied.

Degree-Days. The sum of the positive or negative differences between a reference temperature (usually 18ºC (65ºF)) and the mean temperature for each day in the heating or cooling season). Degree-days are used to compare the severity of cold or heat during the heating or cooling season

Delamination. Separation of the plies in a membrane or separation of insulation layers after lamination.

Design loads. The “live load” and “environmental load” (i.e. superimposed loads) that a structure is designed to resist (with appropriate safety factor) plus “dead load” (i.e., weight of permanent loads).

Dew point. The temperature at which water vapor starts to condense in cooling air at the existing atmospheric pressure and vapor content.

Dry (n.). A material that contains no more water than one would find at its equilibrium moisture content.

Eave. The line along the sidewall formed by the intersection of the planes of the roof and wall.

Eave Height. The vertical dimension from finished floor to the eave.

Edge venting. The practice of providing regularly spaced protected openings at a low-slope roof perimeter to relieve water vapor pressure in the insulation. (It is of doubtful efficacy.)

Elasticity. The property of matter by virtue of which it regains its original size and shape after removal of stress.

Elastomer. A macromolecular material that returns rapidly to its approximate initial dimensions and shape after subsequent release of stress.

Embedment. (1) the process of pressing a felt, aggregate, fabric, mat, or panel uniformly and completely into hot bitumen or adhesive to ensure intimate contact at all points; (2) the process of pressing granules into coating in the manufacture of factory prepared roofing, such as shingles.

Emulsion. A dispersion of fine particles or globules of a liquid in a liquid. Asphalt emulsions consist of asphalt globules, an emulsifying agent such as bentonite clay and water.

Endlap. The overlap where one panel or felt nests on top of the end of the underlying panel or felt.

\3\ Environmental Severity Classification (ESC) - Environmental severity is defined as the corrosivity of the local environment of a given location or region. Environmental severity contributes directly to the occurrence of corrosion. The effects of corrosion and the rate at which they occur are consequences of the corrosion system, which is comprised of a material or physical system, the environment, and operational conditions. /3/

EPDM. A synthetic elastomer based on ethylene, propylene, and a small amount of a non-conjugated diene to provide sites for vulcanization. EPDM features excellent heat, ozone and weathering resistance, and low temperature flexibility.

EVA. Family of copolymers of ethylene and vinyl acetate used for adhesives and thermoplastic modifiers. They possess a wide range of melt indexes.

Fabric. A woven cloth of organic or inorganic filaments, threads, or yarns.

Fabrication. (1) The manufacturing process performed in a plant to convert raw material into finished metal building components. The main operations are cold-forming, cutting, punching, welding, cleaning, and painting; (2) the creation of large panels of rubber from smaller calendar width sheets as in EPDM.

Fascia. A decorative trim or panel projecting from the face of a wall, serving as a weather closure at gable and end wall.

Felt. A flexible sheet manufactured by the interlocking of fibers through a combination of mechanical work, moisture, and heat, without spinning, weaving, or knitting. Roofing felts are manufactured from vegetable fibers (organic felts), glass fibers (glass fiber felts) or polyester fibers (synthetic fiber mats).

Fiberglass insulation. Blanket insulation, composed of glass fibers bound together with a thermoset binder, faced or unfaced, used over or under purlins to insulate roofs and walls; semi-rigid boards, usually with a facer.

Field. The “job site,” “building site,” or general market area.

Fixity. Fixity is the location in which a single metal roof panel is attached to the building structure and is the point from which all thermal expansion radiates. The line of fixity is the line created from the individual points of fixity.

Flashing. The system used to seal membrane edges at adjacent perpendicular surfaces (walls), expansion joints, drains, gravel stops, and other places where the membrane is interrupted or terminated. Base flashing covers the edges of the membrane. Cap or counterflashing shields the upper edges of the base flashing.

Flood coat. The top layer of bitumen used to hold the aggregate on an aggregate surfaced roofing membrane.

Fluid-applied elastomer. An elastomeric material, fluid at ambient temperature, that dries or cures after application to form a continuous membrane. Such systems may not incorporate reinforcement.

Galvalume. Trade name for steel coated with aluminum-zinc alloy for corrosion protection (55% AIZn).

Galvanized steel. Steel coated with zinc for corrosion resistance.

Glass felt. Glass fibers bonded into a sheet with resin and suitable for impregnation in the manufacture of bituminous waterproofing, roofing membranes, and shingles.

Granule. See Mineral Granules.

Gravel. Coarse, granular aggregate, with pieces larger than sand grains, resulting from the natural erosion of rock.

Green Building Technology. Technology that reduces impact on the earth. Includes recyclability, reduction in carbon dioxide, ozone or other atmospheric pollutants, and reduction of urban heat islands.

Gutter. A channel member installed at the eave of the roof for the purpose of carrying water from the roof to the drains or down spouts.

Heat Seaming. The process of joining two or more thermoplastic films or sheets by heating areas in contact with each other to the temperature at which fusion occurs. The process is usually aided by a controlled pressure. In dielectric seaming, the heat is induced within films by means of radio frequency waves.

Heat transfer. The transmission of thermal energy from a location of higher temperature to a location of lower temperature. This can occur by conduction, convection or radiation.

Humidity. The amount of moisture contained in the atmosphere. Generally expressed percent relative humidity. (The ratio of the vapor pressure to the saturation pressure for given conditions times 100.)

Hydrocarbons. An organic chemical compound containing mainly the elements carbon and hydrogen. Aliphatic hydrocarbons are straight chain compounds of carbon and hydrogen. Aromatic hydrocarbons are carbon-hydrogen compounds based on the cyclic or benzene ring. They may be gaseous (CH4, ethylene, butadiene), liquid (hexene, benzene), or solid (Natural rubber, napthalene, cispolybutadiene).

Hydrokinetic Metal Roof System. This is a metal roof system in which the metal standing seam, eaves and valleys accommodate expansion and are constructed in a way which allows some water infiltration. The infiltrating water is drained through weeps in the roof assembly and with a watertight underlayment membrane under the roof. The fixity will typically be at the ridge in this roof system.

Hydrostatic Metal Roof System. The metal standing seam, laps at the eave and valley are construction with positive attachment and non-curing sealant to provide a watertight assembly in this metal roof system. Fixity will typically be at the eave and valleys in this roof system.

Inorganic (adj.). Comprising matter other than hydrocarbons and their derivatives, or matter not of plant or animal origin.

Insulation. See Thermal Insulation.

Internal Pressure. Pressure inside a building, a function of wind velocity, building height, and number and location of openings.

Isocyanate. A highly reactive chemical grouping composed of a nitrogen atom bonded to a carbon atom bonded to an oxygen atom: =N=C=O; a chemical compound, usually organic, containing one or more isocyanate groups.

Isoboard. Abridgement of polyisocyanurate foam insulation board.

Lap. Dimension by which a felt covers an underlying felt in BUR membrane. “Edge” or side lap indicates the transverse cover; “End” lap indicates the cover at the end of the roll. These terms also apply to single-ply membranes.

Lapped joint. A joint made by placing one surface to be joined partly over another surface and bonding the overlapping portions.

Loose-laid Membrane. An unadhered roofing membrane anchored to the substrate only at the edges and penetrations through the roof and ballasted against wind uplift by loose aggregate or pavers.

Mastic. Caulking or sealant normally used in sealing roof panel laps.

Membrane. A flexible or semi-flexible roof covering or waterproofing whose primary function is the exclusion of water.

Metal flashing. See Flashing—frequently used as through-wall, cap, or counterflashing.

Mineral fiber. Inorganic fibers of glass, asbestos or mineral wool (slag).

Mineral granules. Natural or synthetic aggregate, ranging in size from 500µm (1µm = 10-6m) to 1/4 in. diameter, used to surface BUR or modified bitumen cap sheets, asphalt shingles, and some cold process membranes.

Model Codes. Codes established to provide uniformity in regulations pertaining to building construction. Example: International Building Code published by the ICC.

Moisture conduction. Migration by wicking as contrasted to vapor movement.

Monomer. A simple molecule which is capable of combining with a number of like or unlike molecules to form a polymer.

Mopping. Application of hot bitumen with a mop or mechanical applicator to the substrate or to the plies of a built-up or modified-bitumen roof. There are four types of mopping: (1) solid—a continuous coating; (2) spot—bitumen is applied in roughly circular areas, generally about 460 mm (18 in.) in diameter, leaving a grid of unmopped, perpendicular area, (3) strip— bitumen is applied in parallel bands, generally 200 mm (8 in.) wide and 300 mm (12 in) apart; (4) sprinkle—bitumen is shaken on the substrate from a broom or mop in a random pattern.

Nailer. Wood member bolted or otherwise anchored to a nonnailable deck or wall to provide nailing anchorage of membrane or flashing.

Nailing. (1) Exposed nailing of roofing wherein nail heads are bare to the weather; (2) Concealed nailing of roofing wherein nail heads are concealed from the weather (see also blind nailing).

Neoprene. Synthetic rubber (polychloroprene) used in liquid or sheet-applied elastomeric roofing membranes or flashing.

Nondestructive Testing (NDT). Methods for evaluating the strength or composition of materials without damaging the object under test.

Nonwoven Fabric. A sheet material produced by bonding or interlocking of fibers (or both) by mechanical, thermal or solvent means (or combinations thereof).

Olefin. An unsaturated open-chain hydrocarbon containing at least one double bond: ethylene or propylene.

Olefin Plastics. Plastics based on polymers made by the polymerization of olefins or copolymerization of olefins with other monomers, the olefins being at least 50 percent of the mass.

Organic (adj.). Composed of hydrocarbons or their derivatives; or matter of plant or animal origin.

Organic coating. Coatings that are generally inert or inhibited. May be temporary (e.g., slushing oils) or permanent (paints, varnishes , enamels, etc.).

Organic content. Usually synonymous with volatile solids in an ashing test; e.g., a discrepancy between volatile solids and organic content can be caused by small traces of some inorganic materials, such as calcium carbonate, that lose weight at temperatures used in determining volatile solids.

Panel clip. Independent clip used to attach roof panels to substructure.

Panel Creep. Tendency of the transverse dimension of a roof panel to gain in modularity due to spring-out or storage-distortion.

Parapet. Portion of wall above the roofline.

Pea Gravel. Small gravel with a diameter approaching that of a pea. Size roughly defined by ASTM D448 *Standard Classification for Sizes of Aggregate for Road and Bridge Construction,* Number 7 or smaller.

Peak. The uppermost point of a gable.

Penetration. The consistency of a bituminous material expressed as the distance in tenths of a millimeter (0.1 mm) that a standard needle or cone vertically penetrates a sample of material under specified conditions of loading, time, and temperature.

Percent Elongation. In tensile testing, the increase in the gauge length, measured after fracture of the specimen within the gauge length.

Perlite. An aggregate used in lightweight insulating concrete and in preformed perlite insulating board, formed by heating and expanding siliceous volcanic glass.

Permeability. (1) The capacity of a porous medium to conduct or transmit fluids; (2) The amount of liquid moving through a barrier in a unit time, unit area and unit pressure gradient not normalized for but directly related to thickness; (3) The product of vapor permeance and thickness (for thin films, ASTM E96-00e1 *Standard Test Methods for Water Vapor Transmission of Materials*—over 3.2 mm (.125 in.), ASTM C355 Usually reported in perm inches or grain/h•ft2•in. Hg per inch of thickness. 1 perm inch = 1.46 x 10-12 kg/Pa•s•m.

Permeance. The rate of water vapor transmission per unit area at a steady state through a membrane or assembly, expressed in ng/Pa•s•m^2 (grain/ft^2•h•in. Hg).

Phenolic Plastics. Plastics based on resins made by the condensation of phenols, such as phenol and cresol, with aldehydes.

Pitch. See Incline, Coal tar pitch, or Petroleum pitch.

Plastic. A material that contains as an essential ingredient one or more organic polymeric substances of large molecular weight. It is solid in its finished state and at some stage in its manufacture or processing into finished articles can be shaped by flow.

Plasticizer. Material, frequently solvent-like, incorporated in a plastic or a rubber to increase its ease of workability, flexibility, or extensibility. Adding the plasticizer may lower the melt viscosity, the temperature of the second order transition, or the elastic modulus of the polymer.

Plasticizers. May be monomeric liquids (phthalate esters), low molecular weight liquid polymers (polyesters) or rubbery high polymers (EVA). The most important use of plasticizers is with PVC where the choice of plasticizer dictates under what conditions the membrane may be used.

Ply. A layer of felt in a roofing membrane; a four-ply membrane should have at least four plies of felt at any vertical cross section cut through the membrane.

Plywood. A flat panel built up of sheets of wood veneer called plies, united under pressure by a bonding agent to create a panel with an adhesive bond between plies as strong as or stronger than, the wood. Plywood is constructed of an odd number of layers with grain of adjacent layers perpendicular. Layers may consist of a single ply or two or more plies laminated with parallel grain direction. Outer layers and all odd numbered layers generally have the grain direction oriented parallel to the long dimension of the panel.

Polyester Fiber. Generic name for a manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of an ester of a dihydric alcohol and terephthalic acid. Scrims made of polyester fiber are used for fabric reinforcement.

Polyisobutylene. The polymerization product of isobutylene varying in consistency from a viscous liquid to a rubberlike solid, with corresponding variation in molecular weight from 1,000 to 400,000.

Polyisocyanurate. Thermoset polymer formed by polymerization of isocyanate; rigid foam insulation meeting ASTM C1289 *Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation Board;* a thermal insulation similar in appearance to polyurethane foam, but with improved fine resistance or rating.

Polymer. A macromolecular material formed by the chemical combination of monomers having either the same or different chemical composition. Plastics, rubbers, and textile fibers are all high molecular weight polymers.

Polyvinyl Chloride (PVC). A synthetic thermoplastic polymer prepared from vinylchloride. PVC can be compounded into flexible and rigid forms through the use with plasticizers, stabilizers, filler, and other modifiers; rigid forms used in pipes; flexible forms used in manufacture of sheeting.

Ponding. Water in low or irregular roof areas that remains longer than 48 hours after the cessation of rainfall, under conditions conducive to evaporation.

Preventive Maintenance. The regular, scheduled, inspection for and the repair of normal, expected breakdown of materials and equipment.

Prime coat. First liquid coat applied in a multiple coat system.

Primer (bituminous). A thin liquid bitumen applied to a surface to improve the adhesion of heavier applications of bitumen and to absorb dust.

Protected Membrane Roof (PMR). Roof assembly with insulation on top of membrane instead of vice versa, as in conventional roof assembly (also known as inverted or upside-down roof assembly).

Puncture Resistance. Index of a material's ability to withstand the action of a sharp object without perforation.

R-Factor. Resistance to heat flow. The summation of individual thermal resistances in an assembly.

Rake. The sloped edge of a roof at the first or last rafter.

Rake trim. A flashing designed to close the opening between the roof and end wall panels.

Re-covering. The process of covering an existing roof system with a new roof.

Reglet. A groove in a wall or other surface adjoining a roof surface for the insertion and attachment of counterflashing.

Relative Humidity. The ratio of the mass per unit volume (or partial pressure) of water vapor in an air-vapor mixture to the saturated mass per unit volume (or partial pressure) of the water vapor at the same temperature, expressed as a percentage.

Replacement. The removal of all roof system components down to the structural deck followed by installation of a completely new roofing system.

Reroofing. Replacement or re-cover of an existing roof system.

Resistance, Thermal. See Thermal resistance.

Retrofit. The modification of an existing building or facility to include new systems or components.

Ridge. Highest point on the roof of the building, a horizontal line running the length of the building.

Ridge Cap. A transition of the roofing materials along the ridge of a roof. Sometimes called ridge roll or ridge flashing.

Roll Goods. A general term applied to rubber and plastic sheeting, usually furnished in rolls.

Roll Roofing. Coated felts, either smooth or mineral surfaced.

Roof Curb. An accessory used to mount and level units (such as air conditioning and exhaust fans) on the sloped portion of the building roof.

Roof Jack. An accessory used to cover pipes (such as vents or flues) that penetrate the roof covering.

Roof Seamer. Machine that crimps panels together or that welds laps of E/P systems using heat, solvent or dielectric energy.

Roof Slope. The angle a roof surface makes with the horizontal, measured in a ratio such as ½:12.

ROOFER Sustainment Management System (SMS). The ROOFER SMS is a practical decision-making tool to help manage an installations or bases low-slope membrane and asphalt shingle roofing assets. It includes procedures for collecting inventory and inspection information, evaluating roof condition, identifying repair/replacement strategies, prioritizing projects, and developing work plans. Micro ROOFER, software provides data storage and analysis, and generates management reports. Contact the Service-specific SME to gain access to ROOFER SMS.

Roofing System. A combination of interacting components designed to weatherproof, and normally to insulate, a building's top surface; does not include the roof deck.

Rubber. A material capable of quickly recovering from large deformations, normally insoluble in boiling solvent such as benzene, methyl ethyl ketone, and ethanol toluene azeotrope. A rubber in its modified state retracts within 1 mm to less than 1.5 times its original length after being stretched to twice its length.

Sacrificial Protection. Reducing the extent of corrosion of a metal in an electrolyte by coupling it to another metal that is electrochemically more active in the environment, i.e., galvanic protection.

Scupper. Channel through a low-slope roof edge or parapet, designed for peripheral drainage of the roof, usually a safety overflow to limit accumulation of ponded rainwater caused by clogged drains or intense rainfall.

Scrim. A woven, open mesh reinforcing fabric made from continuous filament yarn. Used in the reinforcement of polymeric sheeting.

Sealant. Any material used to close up cracks or joints to protect against leaks. Lap sealant is applied to exposed lap edges in E/P systems.

Sealing Washer. A metal-backed rubber washer assembled on a screw to prevent water from migrating through the screw hole.

Seam Strength. Strength of a seam of material measured either in shear or peel modes, reported either in absolute units, e.g., pounds per inch of width—or as a percent of the sheeting strength.

Service Life. Anticipated useful life of a building, building component or building subsystem (e.g., roof system).

Shelf Life. Maximum safe time to store a fluid construction material or non-cured sheet before use.

Shingle. (1) A small unit of prepared roofing designed for installation with similar units on overlapping rows on inclines normally exceeding 25%; (2) To cover with shingles, and (3) To apply any sheet material in overlapping rows like shingles.

Shingling. (1) The procedure of laying parallel felts so that one longitudinal edge of each felt overlaps, and the other longitudinal edge underlaps an adjacent felt. (See also Ply). Normally, felts are shingled on a slope so that the water flows over rather than against each lap; (2) The application of shingles to a sloped roof.

SI. The international symbol for the metric unit (Le Systeme International d'Unites).

Sidelap. The continuous overlap of closures along the side of a panel or sheet material.

Sill. The bottom horizontal framing member of an opening such as a window or door.

Single Slope. A sloping roof with one surface. The slope is from one wall to the opposite wall of rectangular building.

Skylight. A roof accessory to admit light, normally mounted on a curbed, framed opening.

Slippage. Relative lateral movement of adjacent felts (or sheets) in a roof membrane. It occurs mainly in roofing membranes on a slope, sometimes exposing the lower plies or even the base sheet to the weather.

Slope. Tangent of the angle between the roof surface and the horizontal plane, expressed as a ratio. (See also roof slope)

Smooth Surfaced Roof. A roof membrane without mineral aggregate surfacing.

Soffit. The underside covering of any exterior overhanging section of a roof, gable or sidewall.

Softening Point. Temperature at which a bitumen becomes soft enough to flow as determined by an arbitrary, closely defined method.

Square. A roof area of 100 ft^2 (9.29 m^2), or enough material to cover 100 ft^2 (9.29 m^2) of deck.

Stack Vent. A vertical outlet designed to relieve pressure exerted by water vapor between a membrane and the vapor retarder or deck.

Stainless Steel. An alloy of steel which contains a high percentage of chromium. Also may contain nickel or copper. Has excellent resistance to corrosion.

Standing Seam. Watertight seam type featuring an upturned rib, which may also be structural. It is made by turning up the edges of two adjacent metal panels and then folding them over in one of a variety of ways.

Stress. (1) A measure of the load on a structural member in terms of force per unit area (MPa) (kips per in.^{2}); (2) The force acting across a unit area in solid material in resisting the separation, compacting or sliding that tends to be induced by external forces. Also the ratio of applied load to the initial cross sectional area, or the maximum stress in the outer fibers due to an applied flexural load.

Stress Concentration. A condition in which stress is highly localized, usually induced by an abrupt change in the shape of a member or at a substrate joint (e.g., between insulation joints)

Substantial Completion. The stage in the progress of the work when it is sufficiently complete for the owner to occupy or utilize the space for its intended use.

Surface Cure. Curing or vulcanization which occurs in a thin layer on the surface of a manufactured polymeric sheet or other items.

Susceptibility. When not otherwise qualified, the degree of change in viscosity with temperature.

Tear off. Removal of a failed roof system down to the structural deck surface.

Tensile Strength. (1) The maximum tensile stress per unit of original cross sectional area applied during stretching of a specimen to break; units: SI-metric—Megapascal or kilopascal, customary—lb. per in.^{2}; (2) The longitudinal pulling stress a material can bear without tearing apart; (3) The ratio of maximum load to original cross-sectional area. Also called ultimate strength.

Tensile Test. A test in which a specimen is subjected to increasing longitudinal pulling stress until fracture occurs.

Therm. A unit of heat commonly used by utilities, equivalent to 100,000 BTU = 1.05 x 108 joules.

Thermal Conductivity (k). The rate of heat flow through a stated thickness of material with a stated temperature differential Btu/h.ft^2•^{0}F (W/m2•^{0}C).

Thermal Insulation. A material designed to reduce the conductive heat flow.

Thermal Resistance (R). Resistance to heat flow. The reciprocal of conductance (C).

Thermal Shock. Stress-producing phenomenon resulting from sudden temperature drops in a roof membrane—when, for example, a rain shower follows brilliant sunshine.

Thermoplastic Elastomers. Polymers capable of remelt, but exhibiting elastomeric properties; related to elasticized polyolefins. They have a limited upper temperature service range.

U-Factor. The heat flow across an entire assembly e.g., from air within a building to outside air; the inverse of R-Factor. Also known as U-value.

Uplift. Wind load on a building which causes a load in the upward direction.

Vapor Barrier. See Vapor retarder.

Vapor Pressure. The pressure exerted by a vapor that is in equilibrium with its solid or liquid form.

Vapor Retarder. A material that resists the transmission of water vapor.

Vent. Opening designed to convey water vapor or other gas from inside a building or a building component to the atmosphere.

Viscoelastic. Characterized by changing mechanical behavior, from nearly elastic at low temperature to plastic, like a viscous fluid, at high temperature.

Viscosity. Index of a fluid's internal resistance to flow, measures in centistokes (cSt) for bitumens. (Water has a viscosity of roughly 1 cSt, light cooking oil 100 cSt.)

Waterproofing. Treatment of a surface or structure to prevent the passage of water under hydrostatic pressure.

APPENDIX D WARRANTIES

D-1 GENERAL.

Many roofing systems include a warranty or guarantee. To safe guard the interest of the client, it is necessary to have a thorough understanding of what is and is not covered by the installer or manufacturer under the warranty. Careful attention to written details of the contractor's obligations and field installation of the products will improve the viability of the roof and enhance its performance. Although warranties by themselves will not guarantee a long lasting, watertight roof, they can be an important part of the process.

Meet the requirements of Chapter 1, Warranty Requirements. In addition, a 20-year full system water-tightness warranty is recommended on all projects regardless of anticipated service life because this yields better materials, better design details, and improved construction quality. A five-year general contractor warranty is also recommended. This appendix provides additional background information on warranty options.

D-2 WARRANTY TYPES.

D-2.1 Manufacturers' Warranties.

Manufacturer's warranties are often offered as an "off the shelf" item. Most manufacturers offer several different warranties for the same products and systems based on level of installation quality.

D-2.1.1 Materials Warranty (five to 20 years).

Material warranties focus on the durability of the product installed on the roof. Labor to remove and reinstall may not be included in this warranty unless specifically required by the contract. Exclusions should be carefully reviewed since they vary widely—from reasonable exclusions such as unusual weather conditions and owner neglect to unreasonable exclusions.

D-2.1.2 Water-tightness Warranty (System Warranty) (five to 20 years)

Watertight warranties are used to obtain quality installation. Manufacturers will list requirements in the warranty necessary for the warranty to remain intact—such as regular inspections (two or more times a year). The watertight roof system warranty should include all roof penetrations and flashing (interface with all adjacent surfaces). To maintain the warranty, the roof must be installed according to manufacturer's requirements—which often specify the roof installers. When other than an approved roof installer installs features on the roof (mechanical contractors, etc.), problems may occur in obtaining watertight warranty coverage for those features. This issue should be addressed in the contract specification. Signatures on Warranty must be from the roof SYSTEM manufacturer and the Government User, not the General Contractors. This helps to avoid issues if the general contractor goes out of business. Watertight warrantees include Weathertight, Pro-Rated and Non Pro-rated. The Pro-Rated warranty functions much as a Tire or Battery warranty that reduces coverage the longer the roof is in use—do not use Pro-Rated warranties.

Full System Warrantees are single sources warranties in which all materials provided by the roof cover manufacturer are covered under the terms of the warranty. Full system warranties should be required if possible as they eliminate the ‘finger pointing’ if and when concerns arise. However, note that Full System Warrantees are issued jointly by the manufacturer and the roofing contractor. The manufacturer does not warrant workmanship. Should the roofing contractor go out of business there is no recourse through the manufacturer for workmanship issues.

D-2.1.3 No Dollar Limit Warranty (System Warranty) (10 to 20 years).

The best standard warranty issued in the roofing industry today is the No Dollar Limit Warranty. No Dollar Limit means there is no cap on what the manufacturer must pay to bring the roof back to a watertight condition. This warranty is issued by the manufacturer and covers both labor and materials.

It is standard in the industry for the roofing contractor to have responsibility for workmanship issues the first two years of a warranty. However, with a No Dollar Limit Warranty, if a contractor goes out of business during that time the material manufacturer automatically picks up the responsibility.

D-2.2 General Contractor’s Warranties (one to five years).

Recently some government roof specifications call for a General Contractor’s Watertight Warranty to add another method of ensuring a quality roof installation.

Unless stated otherwise in the Scope of Work in the RFP, all permanent new construction and replacement roofs require a Five Year General Contractor Bonded Watertightness Warranty. The scope of work in the RFP may waive the Bonding requirement, but if not specified, the Bonded 5 year watertightness warranty is required. The required wording of the warranty will be provided in the applicable UFGS.

D-2.3 Roof Installers Warranty to General Contractor (one to two years).

The government does not have a direct contractual relationship with any subcontractor, including a roof subcontractor. General Contractors will attempt to achieve the same legal protection as the government by requiring the roof subcontractor be responsible to maintain the roof. Because the roof subcontractor may go out of business, the government specification shall require the General Contractor be responsible for the required repairs.

D-3 BONDING.

Bonding may be appropriate for mission critical buildings. The signatures on the bond must be between the Bonding Company and the Government User. A bond is an insurance policy with a maximum monetary value. The holder of the bond will receive the bond value in case of default, so it is important that the government be the agency named on that bond. Bonds are typically for one or five years. Bonding may be an issue for some contractors because it reduces their bonding capacity for those five years.

D-4 WARRANTY REVIEW.

The warranty wording must be carefully reviewed during the shop drawing review.

D-5 CONTRACTOR'S WARRANTY.

The final Contractor's warranty wording must be compared to the requirements included in the contract specification.

D-5.1 Roof Manufacturer's Warranty.

The wording of the roof manufacturer's warranty must be carefully reviewed. The Roofing Materials Guide published each year by NRCA is a good source of information on what different manufacturers offer in manufacturer warranties. Key elements to review are listed below:

D-5.1.1 Qualified Installer.

Most if not all manufacturers' warranties are available ONLY if a certified contractor is used to install the material. As a quality assurance item, specify that only contractors certified to install twenty-year, no-monetary-limit full-system warranties be allowed to install the roof system.

D-5.1.2 Length of Warranty.

Verify that the length of full-system warranty matches the contract specification. Verify that the full-system warranty value is not prorated over the warranty period.

D-5.1.3 Exclusions.

Exclusions can reduce the value of the warranty to user AND prevent normal legal options to enforce standard construction rights. Some typically exclusions include the following:

D-5.1.3.1 Legal.

Note that the term "sole and exclusive remedy" often takes away other legal rights.

D-5.1.3.2 Technical.

Technical exclusions must be carefully reviewed. As an example, excluding wind coverage for commonly occurring wind speeds shall not be allowed.

D-5.2 Warranty Claim.

Review process for claiming under warranty. Verify that the warranty's procedure for creating a warranty claim is reasonable and alert the building user and all stakeholders to the procedures.

D-6 CLOSE-OUT.

Warranty information needs to be provided to the building user during the project close-out phase.

D-7 BUILDING MAINTENANCE.

Roof maintenance is a key element to maintaining a roof warranty. While contracts that include prepaid yearly inspections to comply with manufacturer's requirements are common in the private sector, they are less common for the Military. Annual inspections shall be the responsibility of the building facility support personnel and will not void warranties when not performed.

D-8 POST-CONSTRUCTION ROOF MODIFICATIONS.

User requirements may result in roof modifications. Generally this means cutting into an existing roof that is under warranty. Such modifications must be in accordance with warranty requirements in order to not void the warranty.

APPENDIX E QUALITY ASSURANCE CONSIDERATIONS

E-1 GENERAL.

The success of a roof's performance over its expected lifespan depends upon using qualified designers familiar with local conditions and engaging qualified contractors to construct the project. Quality Assurance is the determination that the designer and contractor followed established quality control guidelines.

The NRCA Manual provides excellent guidance. Quality control requirements must be clearly defined and enforced. The cost and benefits of roof installation observation by a registered roof consultant (RRC) or a registered roof observer (RRO) or a registered PE or RA that derives his or her principal income from roofing design should be considered for all Military roofing projects.

The NRCA Quality Control Guidelines are particularly well suited for reference in design-build contract requirements where BUR, MB and single-ply systems are to be constructed. The benefits of full time observation through an RRC or a registered PE or RA that derives his or her principal income from roofing design are particularly high when this type of contract is used. In addition to inspecting the construction process, the full-time inspector shall review contract documents prior to the commencement of construction.

E-2 DESIGN.

Roof system design is the purvey of RRC or a registered PE or RA that derives his or her principal income from roofing design. A qualified architect or engineer shall be employed to design and oversee the preparation of contract documents. One of the major decisions in developing a quality roofing system is the choice of roof type. Many factors will influence a designer's roof choice, and many of these factors will be regional. The critical elements are climate, wind force, resistance to ultraviolet rays, and design for local conditions. In addition to these critical elements, the experience of the local contractor will greatly affect the quality of the installation.

E-3 SPECIFICATIONS.

Once the roof system is designed, the project specifications will be developed. The UFGS must serve as the basis for the project specifications. Key elements to consider in development of the specifications are listed below:

E-3.1 Roof System.

Specify a complete roof system—not just the components—to assure clear responsibility for correction. The requirement of a full system warranty will also provide a level of enhanced coverage.

E-3.2 Maintainability.

The designer will factor into the design process the ability of the user to maintain the roof. Some roof systems require more maintenance than others. The warranties of some roofs require inspection at least two times a year.

E-3.3 Submittals.

Require submittals (shop drawings) to verify quality in the details and in components. Assure that the roof specification requires complete shop drawings.

E-3.4 Roof Manufacturer Inspection.

Consider requiring roof manufacturer's representative to inspect the roof at least three times (beginning, middle, and end) during installation. If so desired, this requirement needs to be specified in the contract documents. These types of inspections shall only be required on projects of some complexity and intricacy.

E-3.5 Warranty Selection.

Warranties shall be utilized for fully conditioned human occupied spaces. Refer to Appendix D for more information on warranties.

E-3.6 Pre-installation/Pre-construction Meeting.

Attendance at the pre-installation/pre-construction meeting is required for all key players, including the government representative, general contractor, roof contractor, and representatives from all trades whose work impinges upon the roof system: plumbing, HVAC, carpentry, masonry, steel deck erectors. The roof manufacturer's technical staff shall be present at this meeting if the project is unique, has special conditions, and/or questions in regard to various concerns exist.

E-3.7 Minimum Installer Qualifications.

Require sufficient qualifications from the installer to achieve good workmanship. Minimum installer qualifications include the following:

- Proof of at least three years of membership in a professional or trade roofing-related organization such as NRCA, RCI, a state Roofing Contractors Association or SMACNA.
- Documented five years of experience and five jobs of similar complexity, size and cost.
- Proof of certification by the manufacturer that the installer is qualified to install the roofing system specified.

- Letter from a RRC, RA or PE that they are familiar with the installer's work and the installer has demonstrated the skill and workmanship necessary to meet NRCA, SMACNA and industry standards.

E-4 FIELD INSPECTION(S)/CQM.

E-4.1 Installation.

The field inspector shall verify that roof is installed according to shop drawing details. The inspector shall look for complex situations not previously identified and discuss with QC personnel and the on-site roof installer foreman. He must also spot check critical areas for quality watertight construction.

The field inspector shall keep a daily journal of roofing activities, weather conditions, number of workers, visitors to the job site and accidents or incidents. In addition, daily photos of the work and worksite shall be taken. Many things are hidden in roofing. Photos take the guesswork out of reconstructing what actually took place and can benefit the contractor as well as the owner. All photos and daily journal shall be part of the close out documents.

E-4.2 Leaks.

If leaks exist before closeout, do not accept the roof per the contract or pay the General Contractor in full. Test and remove defective material/installation to locate problem and repair. Consult a roof consultant with an RRC or a registered PE or RA that derives his or her principal income from roofing design if local expertise is not adequate.

E-5 CLOSE OUT OF CONTRACT.

Warranties are the legal means of users to get a new roof repaired. The facility manager shall be provided a copy of the warranty and be familiar with all requirements to keep the warranty in force.

This Page Intentionally Left Blank

APPENDIX F OTHER RESOURCES

GOVERNMENT PUBLICATIONS:

Air Force Instruction 32-1051, *Roof Systems Management*, 1994, Air Force Civil Engineer Service Center (AFCESA), Tyndall Air Force Base, 139 Barnes Drive, Florida, 32403, www.wbdg.org/ccb/AF/AFI/afi_32_1051.pdf

APA Form N335 , Guidelines for Proper Installation for APA Rated Sheathing for Roof Applications, Residential and Commercial Manual, Design/Construction Guide, APA-The Engineered Wood Association, 7011 South 19th Street, Tacoma, WA, 98411-0700, www.apawood.org

FM-93/11, ROOFER: Membrane and Flashing Condition Indexes for Single-Ply Membrane Roofs - Inspection and Distress Manual, 1993, Construction Engineering Research Laboratory (CERL), 5285 Port Royal Road, Springfield VA, 22161 (order from NTIS: www.dtic.mil)

M87-13, Membrane and Flashing Condition Indexes for BURs: Inspection and Distress Manual, Vol II, 1987, Construction Engineering Research Laboratory (CERL), 5285 Port Royal Road, Springfield VA, 22161 (order from NTIS: www.dtic.mil)

M-90/04, ROOFER: An Engineered Management System for Bituminous Built-up Roofs, 1989, Construction Engineering Research Laboratory (CERL), 5285 Port Royal Road, Springfield VA, 22161 (order from NTIS: www.dtic.mil)

MP 2489, Vapor Retarders for Membrane Roofing Systems, 1989, Cold Regions Research & Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH, 03755, www.crrel.usace.army.mil/library/technicalpublications.html

MP 2866, New Wetting Curves for Common Roof Insulations, 1991, Cold Regions Research & Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH, 03755, www.crrel.usace.army.mil/library/technicalpublications.html

MP 3233, Standing Seam Metal Roofing Systems in Cold Regions, 1993, Cold Regions Research & Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH, 03755, www.crrel.usace.army.mil/library/technicalpublications.html

MP 3443, General Considerations for Roofs, 1994, Cold Regions Research & Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH, 03755, www.crrel.usace.army.mil/library/technicalpublications.html

MP 3527, Ventilating Attics to Minimize Icings at Eaves, 1994, Cold Regions Research & Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH, 03755, www.crrel.usace.army.mil/library/technicalpublications.html

NIST Special Publication 811, Guide for the Use of International System of Units (SI), 1995, National Institute for Standards and Technology (NIST), Structures and Materials Division/Center for Building Technology, Gaithersburg, MD, 20899 (order from NTIS: www.dtic.mil)

ORNL-6520, Decision Guide for Roof Slope Selection, 1988, Air Force Civil Engineer Service Center (AFCESA), Tyndall Air Force Base, 139 Barnes Drive, Tyndall AFB, Florida, 32403, www.afcesa.af.mil/

TR 99/100, ROOFER: Steep Roofing Inventory Procedures and Inspection and Distress Manual for Asphalt Single Roofs, 1999, Construction Engineering Research Laboratory (CERL), 5285 Port Royal Road, Springfield VA, 22161 (order from NTIS: www.dtic.mil)

UFC 3-330-02A, Commentary On Roofing Systems, Unified Facilities Criteria Program, dod.wbdg.org

NON-GOVERNMENT PUBLICATIONS:

ARMA Form 207-RR-85, *Plain Facts About Buckled Shingles*, Asphalt Roofing Manufacturer Association, 750 National Press Building, 529 14th Street, NW, Washington, DC 20045, www.asphaltroofing.org/

ARMA Form 210-RR-71, *Color Shading of Asphalt Shingle Roofs*, Asphalt Roofing Manufacturer Association, 750 National Press Building, 529 14th Street, NW, Washington, DC 20045, www.asphaltroofing.org/

Building Materials Directory, Underwriters Laboratories (UL), 333 Pfingsten Road, Northbrook, IL, 60062, www.ul.com

Clay Roof Tile Manual, Western States Roofing Contractors Association (WSRCA), 465 Fairchild Drive, Mountain View, CA 94043, www.wsrca.com/

Commercial Roofing Materials Guide, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Concrete and Clay Roof Tile Installation Manual, Tile Roofing Institute, 35 East Wacker Drive, Suite 850, Chicago, IL 60601-2106, www.tileroofing.org

Concrete and Clay Tile Roof Design Criteria Manual for Cold, Snowy Regions, Tile Roofing Institute, 35 East Wacker Drive, Suite 850, Chicago, IL 60601-2106, www.tileroofing.org

Copper In Architecture, Copper Development Association, 260 Madison Avenue, New York, NY, 10016, www.copper.org

Florida Building Code, Florida Department of Community Affairs, 2555 Shumard Oak Boulevard, Tallahassee, FL, 32399-2100, www.floridabuilding.org

Manual of Construction with Steel Deck, Steel Deck Institute (SDI), P.O. Box 25, Fox River Grove, IL, 60021, www.sdi.org

Manual of Inspection and Maintenance of Built-Up and Modified Bitumen Roof Systems, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

NRCA/ARMA Manual of Roof Maintenance and Repair, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Manual for Inspection and Maintenance of Sprayed Polyurethane Foam-based Roof Systems, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Quality Control Guidelines for Built-Up Roofing, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Quality Control Guidelines for Application of Polymer Modified Bitumen Roofing Systems, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Quality Control Guidelines for the Application of Thermoset Single-ply Roof Membranes, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Repair Manual for Low-Slope Roof Systems, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Repair Methods for Re-Attaching EPDM Membrane and Flashing Experiencing Shrinkage, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Roofing Materials and Systems Directory, Underwriters Laboratories (UL), 333 Pfiingsten Road, Northbrook, IL, 60062, www.ul.org

SPRI/NRCA Manual of Roof Inspection, Maintenance and Emergency Repair for Existing Single-ply Roofing Systems, National Roofing Contractors Association (NRCA), 10255 West Higgins Road, Suite 600, Rosemont, IL, 60018-5607, www.nrca.net

Standard Practice in Sheet Metal Work, Sheet Metal and Air Conditioning Contractors National Association, 4201 Lafayette Center Drive, Chantilly, VA, 22021, www.smacna.org

\4\

APPENDIX G DECISION CRITERIA FOR INSTALLATION OF VEGETATIVE GREEN ROOFS AT CONUS INSTALLATIONS BASED ON COST

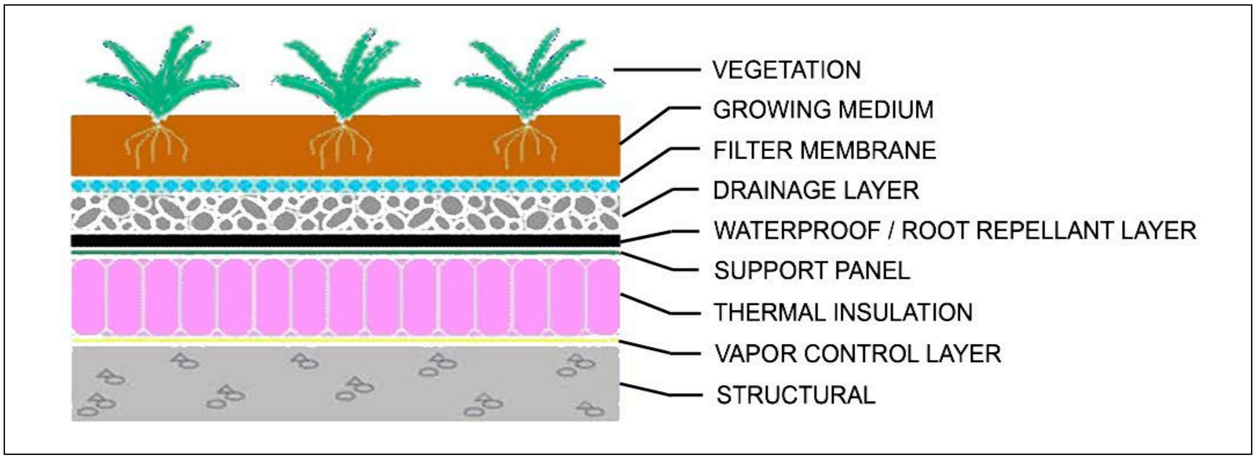
G-1 PURPOSE.

This paper was written to provide guidance for determining if installing a vegetative roof on an Air Force facility is suitable. The wording is Air Force-focused but offered as useful information to all UFC users. The intent is to give the base a simple tool to justify selection or non-selection of a green roof based entirely on return on investment (ROI). Selection of a vegetative green roof for environmental or social reasons can certainly be valid but is not part of the selection criteria here. Vital to the ROI are the facility characteristics, occupancy type, and the local climate. Tables G-1 and G-2 list installation locations and facility types along with their potential to benefit from a vegetative roofing system.

G-2 REQUIREMENTS.

Green roofs are building roof systems planted with vegetation to achieve a variety of benefits. They are categorized as “intensive,” “semi-intensive,” or “extensive,” depending on the depth of planting medium and the amount of maintenance required. Intensive green roofs have the greatest depth, support a variety of plants (including trees), and have significant structural and maintenance requirements. Extensive green roofs have a shallow planting medium and a low-growing, easily maintained vegetative installation. Semi-intensive roofs have characteristics somewhere in between the other two. This document will focus on extensive systems, since they are the most likely type of green roof to be constructed on installations. They are the most economical, easily maintained, and somewhat lightweight.

Figure G-1 Typical Green Roof Components



G-2.1 The use of vegetative green roofs is beneficial in many ways. It reduces storm water runoff, improves the quality of storm water runoff, improves air quality, can extend roof membrane service life, and saves energy. The cost to install this type of roof is typically about 75 percent higher than a conventional low-sloped roof. Service life expectancy is 40 years but this is a projection without historical data to support it and assumes diligent inspection and maintenance of the roof's waterproofing and drainage components. If this service life is achieved, an ROI of 145 percent to 204 percent is realized. Table G-1 shows which CONUS installations have the greatest potential to benefit while Table G-2 shows which types of facilities are most appropriate.

G-2.2 There is a requirement to irrigate the roof during the establishment period, and possibly beyond that, so the plants do not perish. It is important to note that ASHRAE 189.1 stipulates the use of potable water for irrigating green roofs is prohibited once the plants have been established. ASHRAE 90.1 is the current standard but ASHRAE intends AHRAE 189.1 to be used for high-performance green buildings. In addition, knowledgeable inspection and maintenance of the vegetative cover is required. Since locating and repairing leaks in the membrane will be difficult, leak-detection sensors should be installed under the roof membrane. These requirements and the associated maintenance burden should be considered prior to choosing a green roof. Maintenance requirements will depend on the selection of vegetative cover, rooftop equipment and penetrations, foot traffic, and even BASH considerations.

G-2.3 Suitability of a green roof to provide a positive ROI is determined by regional climate, building dimensions, structural capacity, and building occupancy.

G-2.4 Hot locations see the greatest benefits from lowering the roof temperature but dry climates require more irrigation. Table G-1 provides climate-related information for every CONUS Air Force installation. OCONUS installations were not included in the study. Hawaii and Guam are worth investigating. Each CONUS base is given a total that corresponds to a poor, fair, or good potential to benefit from a green roof.

G-2.5 High roof-to-wall ratios are desirable and the structure should be able to support the additional weight without extensive upgrades. The building should be fully conditioned and occupied for long hours. Table G-2 shows suitability by facility type.

G-2.6 The Green Roof Installation Decision Tree in Figure G-2 will help guide the selection of vegetative green roofs.

G-2.7 Maintenance costs for green roof systems vary depending on roof size and the entity selected to provide this service. Typically, the larger the roof, the more labor hours are required to maintain its healthy upkeep. Regularly scheduled maintenance is intended to keep major repairs at a minimum. Proper performance of maintenance tasks should catch significant cost issues before they happen. Other items that may drive up cost are difficult roof access and equipment accessibility to the roof. Maintenance staff members that are not trained for green roof upkeep may drive up costs by inflicting damage on the green roof system, drainage system, or roofing membrane.

G-2.8 The ROI over the 40-year projected service life of the green roof ranges from 145 percent to 204 percent, depending on the local climate. The most significant factor affecting the ROI is not energy savings but the savings derived from the extended service life of the roof membrane system. Successfully achieving this service life demands a sustained commitment to maintenance. A green roof may be considered for reasons other than energy savings. They improve storm water runoff, improve air quality, and have other social benefits. If installation of a green roof is for these reasons, this UFC serves to remind and highlight the maintenance requirements for a green roof to perform as expected.

G-2.9 Green roofs will continue to grow in North America as their environmental, economic, and social benefits are recognized and green design is embraced by the public and private sectors. Relationships between conventional roof manufacturers and green roof manufacturers and installers are now well established. It is anticipated that as the green roof market expands and the industry matures in North America, green roof systems will become more commonplace, more competitive, and more standardized. Green roofs can save energy at facilities. They also make financial sense as long as they are properly designed, properly installed, and a long-term commitment is made to ensure appropriate maintenance throughout their potentially long service lives. Without this commitment, consider a cool roof, if appropriate, which will provide similar energy savings and maintenance requirements at a cost comparable to traditional low-slope roof construction.

Table G-1 Appropriateness Table - Green Roof Benefits By Location

Base	Energy Benefits[a]	Irrigation Demands[b]	**Total score[c]**
Air Force Region 1			
Beale AFB, California	8	2	**10**
Edwards AFB, California	9	2	**11**
Los Angeles AFB, California	9	2	**11**
Travis AFB, California	8	2	**10**
Vandenberg AFB, California	10	3	**13**
Air Force Region 2			
Creech AFB / Nellis AFB, Nevada	8	1	**9**
Davis-Monthan AFB, Arizona	9	1	**10**
Fairchild AFB, Washington	4	2	**6**
Hill AFB, Utah	6	2	**8**
Luke AFB, Arizona	9	1	**10**
McChord AFB, Washington	5	3	**8**
Mountain Home AFB, Idaho	6	2	**8**
Air Force Region 3			
Buckley AFB, Colorado	7	2	**9**
Ellsworth AFB, South Dakota	5	2	**7**
F.E. Warren AFB, Wyoming	6	2	**8**
Grand Forks AFB, North Dakota	4	3	**7**
Malmstrom AFB, Montana	4	2	**6**
Minot AFB, North Dakota	4	3	**7**
Offutt AFB, Nebraska	6	2	**8**
Peterson AFB, Schriever AFB, Colorado	7	2	**9**
Air Force Region 4			
Altus AFB, Oklahoma	8	2	**10**
Cannon AFB, New Mexico	8	2	**10**
Dyess AFB, Texas	9	2	**11**
Goodfellow AFB, Texas	10	1	**11**
Holloman AFB, New Mexico	9	1	**10**
Kirtland AFB, New Mexico	8	2	**10**
Lackland AFB, Texas	10	2	**12**
Laughlin AFB, Texas	10	1	**11**
McConnell AFB, Kansas	7	2	**9**
Randolph AFB, Texas	10	2	**12**
Sheppard AFB, Texas	9	2	**11**
Tinker AFB, Oklahoma	8	2	**10**
Vance AFB, Oklahoma	8	2	**10**
Air Force Region 5			
Barksdale AFB, Louisiana	9	2	**11**
Little Rock AFB, Arkansas	9	2	**11**
Scott AFB, Illinois	7	2	**9**

Base	Energy Benefits[a]	Irrigation Demands[b]	**Total score[c]**
Whiteman AFB, Missouri	7	2	**9**
Air Force Region 6			
Columbus AFB, Mississippi	8	2	**10**
Eglin AFB, Florida	10	2	**12**
Keesler AFB, Mississippi	10	2	**12**
MacDill AFB, Florida	10	2	**12**
Maxwell AFB, Alabama	9	2	**11**
Patrick AFB, Florida	10	2	**12**
Tyndall AFB, Florida	10	2	**12**
Air Force Region 7			
Arnold AFB, Tennessee	8	2	**10**
Charleston AFB, South Carolina	8	2	**10**
Moody AFB, Georgia	9	2	**11**
Pope AFB, North Carolina	7	2	**9**
Robins AFB, Georgia	8	2	**10**
Seymour Johnson AFB, North Carolina	7	2	**9**
Shaw AFB, South Carolina	8	2	**10**
Air Force Region 8			
Andrews AFB, Maryland	6	2	**8**
Bolling AFB, Washington D.C.	6	2	**8**
Dover AFB, Delaware	6	2	**8**
Langley AFB, Virginia	6	2	**8**
Wright-Patterson AFB, Ohio	7	2	**9**
Air Force Region 9			
McGuire AFB, New Jersey	6	2	**8**
Hanscom AFB, Massachusetts	5	2	**7**

a. Energy benefits scoring: 4 (minimum) to 10 (maximum)
b. Irrigation demand scoring: 1 (high), 2 (medium), 3 (low)
c. Total Score <7 is poor; 7 ≤ total score <11 is fair; total score ≥ 11 is good

Table G-2 Green Roof Suitability Based on Facility Type

General Facility Type or Use/Activity	Recommended?	Comments - Conditions
AIR TERMINALS		
Freight	No	—
Freight/passenger	Yes	passenger only - fully conditioned
Passenger	Yes	depending on frequency of use
BAKERIES	No	—
COMMUNICATIONS AND IT FACILITIES (ALL)	Yes	fully conditioned
Air Force communications-computer maintenance facility	Yes	fully conditioned
Audiovisual & TV facilities	Yes	fully conditioned
COMMUNITY & SUPPORT FACILITIES		
Commissary	Yes	fully conditioned
Post office	Yes	fully conditioned
Exchange	Yes	fully conditioned
Commercial shops	Yes	fully conditioned
Religious facilities	No	part-time use
Dependent school support facilities	Yes	fully conditioned
Dependent school	No	unless year-round use and fully conditioned
Banks, credit unions	Yes	fully conditioned
Day care center - preschool	Yes	fully conditioned
Community activity center	Yes	fully conditioned
Theater	No	—
Recreation facilities	Yes	excludes gyms - fully conditioned
Library	Yes	fully conditioned
DINING HALLS	Yes	depending on make-up air requirements - fully conditioned
FITNESS FACILITIES	No	high make-up air requirements
FIRE STATION	Yes	excludes apparatus bays - fully conditioned
GUARD AND RESERVE FACILITIES	No	part time use
HANGARS	No	
HOUSING		
Housing - all types - fully conditioned	Yes	depending on configuration
Housing - all types - heat only	No	—
LAUNDRY AND DRY-CLEANING PLANTS	No	
MEDICAL/DENTAL		
Clinics - all types	Yes	fully conditioned
Ambulatory health care center	Yes	fully conditioned
Composite medical facility	Yes	fully conditioned

NOTE: If facility type is not listed, compare with most similar type listed. Facility should be recommended if it meets the following criteria:

- Fully conditioned building with normal and not high make-up air requirements.
- Facility is occupied a minimum of 8 hours per day for 5 days a week
- Building has a high roof area to wall area ratio (tall buildings have a low roof area to wall area ratio)

General Facility Type or Use/Activity	Recommended?	Comments - Conditions
Hospitals	Yes	fully conditioned
Aerospace medical facility	Yes	fully conditioned
Occupational health clinic	Yes	fully conditioned
MUSEUM	No	if part-time use
OPERATIONS FACILITIES & OFFICES		
Offices - all types	Yes	fully conditioned
Squadron operations facilities	Yes	fully conditioned
Base operations facilities	Yes	fully conditioned
Administrative facilities - all types	Yes	fully conditioned
Legal facilities	Yes	fully conditioned
PARKING FACILITIES	No	
SHOPS & MAINTENANCE FACILITIES		
Shops/maintenance facilities - all types - fully conditioned	Yes	only if standard make-up air requirements
Shops/maintenance - unconditioned or semi-conditioned	No	—
STORAGE & WAREHOUSE FACILITIES	No	
TRAINING FACILITIES		
Education center	Yes	fully conditioned
Classroom facilities	Yes	fully conditioned
Automotive skills centers	No	—
Airman Leadership School	Yes	fully conditioned

NOTE: If facility type is not listed, compare with most similar type listed above. Facility should be recommended if it meets the following criteria:

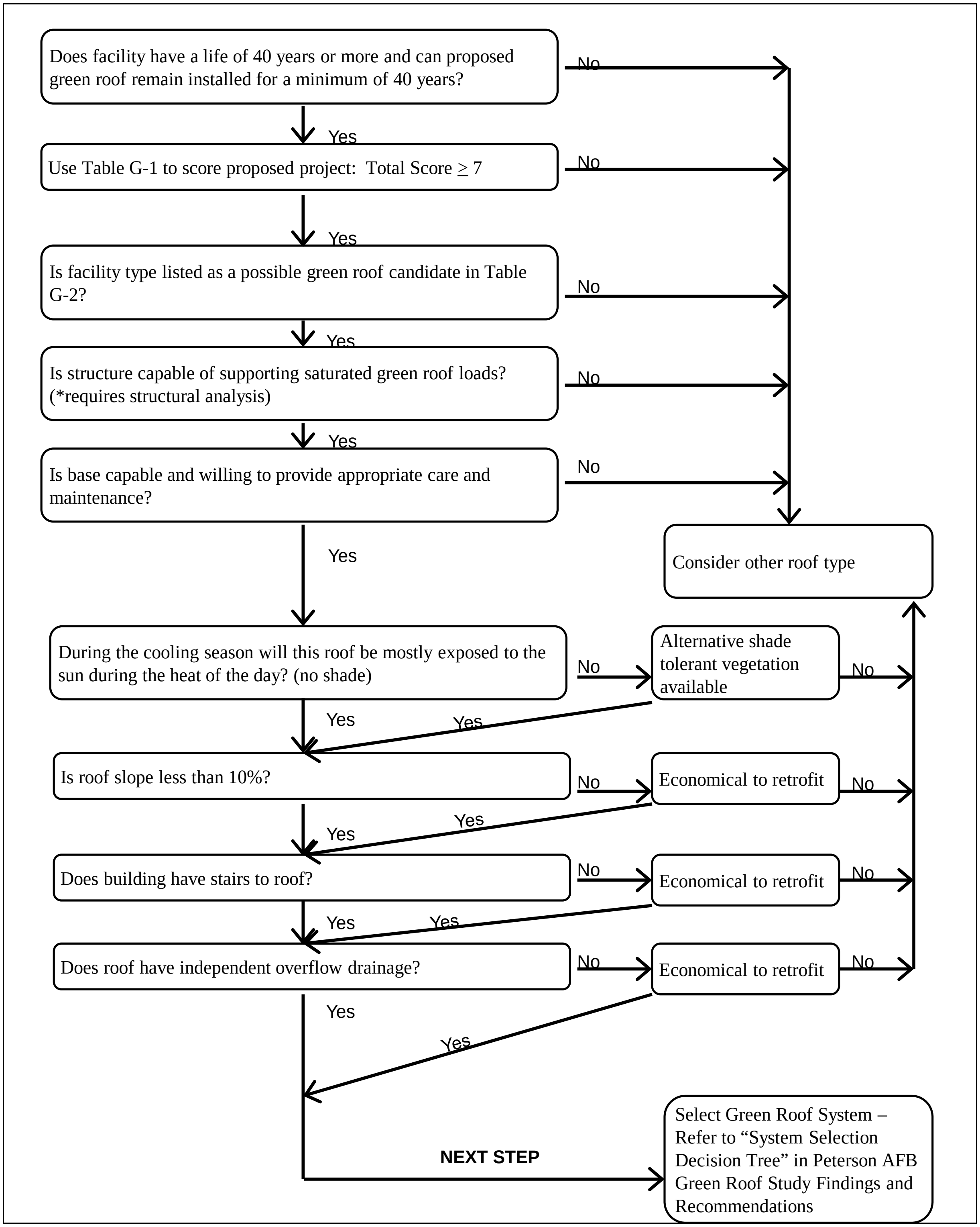
- Fully conditioned building with normal and not high make-up air requirements.
- Facility is occupied a minimum of 8 hours per day for 5 days a week
- Building has a high roof area to wall area ratio (tall buildings have a low roof area to wall area ratio)

G-3 GREEN ROOF INSTALLATION DECISION TREE.

The decision tree shown in Figure G-2 should be used in combination with Tables G-1 and G-2 to help determine whether an existing or proposed new building is an appropriate candidate for a green roof.

The fourth question in the decision tree addresses the capacity of a structure to support the anticipated saturated green roof loading. A structural engineer should provide the appropriate analysis both for existing facilities and new construction. System weights vary and may be a determinant in the specific system selected.

Figure G-2 Green Roof Installation Decision Tree



/4/

UFC 3-120-01
1 March 2014
Change 4, 1 February 2023

UNIFIED FACILITIES CRITERIA (UFC)

DESIGN: SIGN STANDARDS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

DESIGN: SIGN STANDARDS

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

Record of Changes (changes are indicated by **1**\\…/**1**/)

Change No.	**Date**	**Location**
1	May 2014	Revised paragraph 2-2.5; revised Figures 4-1 through 4-6, 4-10, 4-11, 4-13 through 4-15
2	October 2014	Revised paragraph 3-7.2; revised Figures 3-12, 3-13, 4-1, and 4-2
3	December 2017	Revised Figure 3.8 and 4-2.
4	February 2023	Revised paragraph 3-2.1

This UFC supersedes UFC 3-120-01, dated February 6, 2003.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request. The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Refer to UFC 1-200-01, *General Building Requirements*, for implementation of new issuances on projects.

AUTHORIZED BY:

JAMES C. DALTON, P.E. Chief, Engineering and Construction U.S. Army Corps of Engineers	JOSEPH E. GOTT, P.E. Chief Engineer Naval Facilities Engineering Command
JOE SCIABICA, SES Director Air Force Civil Engineer Center	MICHAEL McANDREW Director, Facilities Investment and Management Office of the Deputy Under Secretary of Defense (Installations and Environment)

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-120-01, *Design: Sign Standards*

Superseding: UFC 3-120-01, *Air Force Sign Standards*

Description: This document is a wholesale change from the previous version, which was based on AFPAM 32-1097, dated 1 November 1997.

Reasons for Document:

- Purpose: The purpose of this change is to provide clear standards and guidelines for all Service branches to develop consistent signage programs.
- Application: This UFC is applicable to military installations worldwide.
- Need: This UFC is needed to bring uniformity to many different types of signage used at military installations across the DoD.
- Reasons for Revised UFC: The previous version of this UFC addressed only Air Force sign standards. That document included outdated information that provided little assistance in the implementation of new or replacement signs.

Impact: The following direct benefits will result from publication of this UFC:

- Initial Costs: The costs of implementing new or replacement signs may be lower due to the synergies found in the design guidance of this UFC.
- Life Cycle Costs: Effective application of the design guidance provided will reduce maintenance and minimize overall life cycle costs.
- Safety: Effective application of the strategies in this UFC will improve safety and help ensure building code compliance.
- Convenience: Service members, civilian employees, contractors, and visitors will enjoy improved wayfinding and less stress associated with poor signage.
- Public Image: Compliance with the Service branch identification guidelines in this UFC will help contribute to the positive reinforcement of the brand identity for each Service branch.

TABLE OF CONTENTS

FIGURES

This Page Intentionally Left Blank

CHAPTER 1 GENERAL INFORMATION

1-1 PURPOSE AND SCOPE.

This UFC provides criteria for new and replacement signage appropriate for each Service branch. It establishes requirements for the graphic identification of registered trademarks that are easily recognized in the community. It also provides criteria for standardizing sign materials, colors, styles, and placement throughout an installation. Information on unique sign programs and design requirements of local projects must be obtained at the installation level. Some installations may deviate from these general standards in order to be compatible with their existing signage. Alteration and renovation projects should update existing signage to meet the guidance and criteria provided in this UFC where possible. Non-conforming signs should be replaced when their useful life has ended or modified as required to be compatible with the intent of these standards where practical and economically justifiable.

1-1.1 Background.

This UFC was developed through the collaborative efforts of the U.S. Army Corps of Engineers (USACE), the Air Force Civil Engineer Center (AFCEC), and Naval Facilities Engineering Command (NAVFAC). The intent of this UFC is to provide comprehensive criteria for evaluating, planning, programming, and implementing interior and exterior signs for all military and other Department of Defense (DoD) installations worldwide. This UFC uses non-government standards to the greatest extent possible.

1-1.2 Intended Use.

This UFC applies to the design of all new construction projects, including additions, alterations, and renovation projects on military installations of the Army, Air Force, Navy, and Marines, in the continental United States (CONUS) and overseas (OCONUS). This UFC may also apply to off-installation facilities of these four Service branches, such as recruiting stations or other similar facilities. This UFC does not apply to visual air navigation facility signs placed in and around airfield environments to provide information for operating aircraft. Some installations may require unique sign solutions that reflect their cultural heritage or historical significance, as appropriate.

1-2 GENERAL.

Signs are a highly visible component of the built environment and the public impression expressed by military installations. Each installation must establish both interior and exterior sign standards as part of their Installation Planning Standards (IPS), which include Navy Installation Appearance Plans (IAP), Army Installation Design Guides (IDG), and Air Force Facilities Excellence Guides (FEG). These standards will help provide visual and functional signage consistency for all installations. This consistency will also help improve wayfinding by providing familiar signage components and directional information. Sign programs should be designed with materials and fabrication techniques that maximize the durability of signs and minimize maintenance. Effective sign programs will reduce the number of signs on each installation to the absolute minimum required for directions, identification, and customer service. This eliminates visual clutter and results in an efficient, cost-effective, and attractive system that creates a unified professional appearance for all military installations. Efficient signage and wayfinding programs help provide support for installation-specific mission requirements. Using sign standards will simplify the design/procurement process and reduce construction/maintenance costs.

1-2.1 Sustainability.

The sign contractor must coordinate with the project team to ensure signage materials and components comply with current DoD or Service-specific sustainable design policies, as applicable.

1-3 CODES AND STANDARDS

This UFC is intended to supplement, not replace code requirements and standards, which continue to be the authority for the issues to which they apply.

1-3.1 Exterior Sign Codes and Requirements.

Most exterior signs require approvals and/or permitting at the installation level before installation. Exterior signage programs require compliance with a wide variety of sometimes conflicting criteria, such as:

- American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide*
- Architectural Barriers Act Accessibility Standard for Department of Defense Facilities (ABAAS)
- Federal Highway Administration (FHWA) *Manual on Uniform Traffic Control Devices* (MUTCD)
- FHWA *Standard Highway Signs*
- Institute of Transportation Engineers (ITE) *Traffic Control Devices Handbook*
- Surface Deployment and Distribution Command Transportation Engineering Agency (SDDCTEA) DoD supplement to the MUTCD
- SDDCTEA Pamphlet 55-14
- SDDCTEA Pamphlet 55-15
- SDDCTEA Pamphlet 55-17
- UFC 2-100-01
- UFC 3-535-01
- Unified Facilities Guide Specifications (UFGS) 10 14 01

The location and placement of all exterior signs must comply with guidance provided in the MUTCD.

1-3.2 Interior Sign Codes and Requirements.

Interior signage programs require compliance with a wide variety of different code issues and requirements, such as:

- ABAAS
- *International Building Code* (IBC)
- National Fire Protection Association (NFPA) 101
- UFGS 10 14 00.20

These building codes have specific requirements regarding signage and vary with the building design and other details.

1-3.2.1 ABA Accessibility Standard.

The ABAAS has many requirements that specifically address interior signage, such as:

- Permanent room and space identification
- Requirements for Braille and tactile characters on certain signs
- Sign mounting height and location requirements
- Utilization of the international symbol of accessibility (ISA)
- Specialized elevator signage requirements

These specialized requirements have been considered for the interior sign design parameters provided in Chapter 4.

1-3.2.2 International Building Code.

The IBC has many requirements that specifically address interior signage, such as:

- Stair identification
- Two-way communication systems
- Elevator life safety signs
- Means of egress signs
- Maximum occupancy signs

1-3.2.3 National Fire Protection Association.

Comply with the interior signage requirements of NFPA 101. These requirements address life safety issues, such as:

- Stair identification and stairway landing information
- Tactile level identification requirements (in specific circumstances)
- Tactile exit sign requirements

- Egress identification and information requirements
- Fire extinguisher identification and information
- Elevator sign requirements

1-3.2.4 UFGS 10 14 00.20.

This UFGS addresses such issues as:

- Sustainability requirements
- Submittals
- Warranty
- Various types of interior signs
- Installation requirements
- Protection and cleaning

CHAPTER 2 DESIGN STANDARDS

2-1 GRAPHICS STANDARDS.

Standardization of graphic and text information used on military installation signs helps establish consistent visual communication and brand identity. The graphic standards in this chapter provide general guidelines for most sign message requirements, such as the use of logos, seals, fonts, and colors.

2-1.1 Service Branch Logo Identification.

Service branch logo identification includes seals, symbols, and text that are registered trademarks. Use the approved Service branch seals and text of the Army, Navy, and Marines on installation identification signs as specified in this UFC in Figures 2-1 through 2-5. Use the approved Air Force symbol and text on installation identification signs as specified in this UFC. Restrict the use of these logos to installation identification signs and water towers. There are no such restrictions on the use of these logos on interior signs. The logos must not be altered or modified in any way.

Figure 2-1 Army Logo Identification.

Figure 2-2 Air Force Logo Identification.

U.S. AIR FORCE

Figure 2-3 Navy Logo Identification.

DEPARTMENT OF THE NAVY
UNITED STATES OF AMERICA

U.S. NAVY

Figure 2-4 Marine Corps Logo Identification.

U.S. MARINE CORPS

Figure 2-5 Joint Base Logo Identification.

U.S.ARMY®

U.S. JOINT BASE

2-2 FONT STANDARDS.

The term “font” is used in this UFC for references to typography. Most sign messages should use upper- and lowercase text for optimum readability. Use the Helvetica Neue family of fonts. The font standards for sign message content include the following:

- Helvetica Neue – 95 Black
- Helvetica Neue – 85 Heavy
- Helvetica Neue – 75 Bold
- Helvetica Neue – 65 Medium
- Helvetica Neue – 55 Roman

This family of fonts provides a hierarchy for messages used on signs. Use the Adobe OpenType family of fonts to provide the maximum flexibility on both the Macintosh and PC operating systems. Traffic control signs must follow the *Standard Alphabets for Highway Signs and Pavement Markings* published by the FHWA and used in conjunction with the MUTCD.

2-2.1 Helvetica Neue – 95 Black

Use the font Helvetica Neue 95 Black (see Figure 2-6) in all applications for letter descriptions of the Air Force, Army, Navy, Marines, and joint bases on installation/gate identification signs and water towers.

Figure 2-6 Helvetica Neue – 95 Black.

Helvetica Neue - 95 Black
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz0123456789

2-2.2 Helvetica Neue – 85 Heavy

Use Helvetica Neue 85 Heavy (see Figure 2-7) for the names of military units on freestanding primary building identification signs and building-mounted identification letters.

Figure 2-7 Helvetica Neue – 85 Heavy.

Helvetica Neue - 85 Heavy
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz0123456789

2-2.3 Helvetica Neue – 75 Bold

Use Helvetica Neue 75 Bold (see Figure 2-8) to identify the installation name on installation/gate identification signs. This font may also be used as the larger font where a hierarchy of typestyles is beneficial.

Figure 2-8 Helvetica Neue – 75 Bold.

Helvetica Neue - 75 Bold
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz0123456789

2-2.4 Helvetica Neue – 65 Medium

Helvetica Neue 65 Medium (see Figure 2-9) is the approved font for primary or "headline" messages on both interior and exterior signs unless otherwise specified.

Figure 2-9 Helvetica Neue – 65 Medium.

2-2.5 Helvetica Neue – 55 Roman

Helvetica Neue 55 Roman (see Figure 2-10) is the approved font for secondary or "body text" messages on both interior and exterior signs unless otherwise specified. **\1** This font should also be used for all tactile messages on interior signs. **/1/**

Figure 2-10 Helvetica Neue – 55 Roman.

2-2.6 Alternative Fonts.

Alternative fonts may be used on signs for historic buildings or installations with unique architectural character. Alternative fonts must comply with ABAAS when used for tactile characters associated with Braille requirements.

2-2.7 Letter Spacing.

Appropriate letter spacing is important for consistency and the visual appearance of message content on signs. Kerning refers to the spacing between letters and optical kerning of letters is desired for digital sign message layouts. Comply with the letter spacing examples provided below for all installation and gate identification signs. All other sign message requirements will use optical kerning and zero letter spacing. Refer to Figures 2-11 and 2-12 for examples.

Figure 2-11 Installation Name Letter Spacing.

Figure 2-12 Letter Spacing Standards.

Headline Copy

Headquarters

Optical Kerning, 0 (zero) Letter Spacing

Sub-Headline and Body Copy

87th Medical Group

Optical Kerning, 0 (zero) Letter Spacing

CHAPTER 3 EXTERIOR SIGN STANDARDS

3-1 EXTERIOR SIGN DESIGN GUIDANCE.

Provide exterior signage as part of a total wayfinding system that includes directional guide signs, building identification signs, pedestrian directional signs, street signs, and orientation maps. Develop installation-specific sign designs in accordance with this UFC, giving consideration to the existing IPS, cultural heritage, regional influences, and historical significance. Signs should coordinate with nearby landscape and structures. Design exterior signs for maximum durability and sustainability based upon regional weather impacts. Sign message panels should be easy to update or replace to allow for flexibility of future message updates. Integrate new signs with existing signs to provide the most cost-effective and practical solutions for each facility or installation. A standardized sign system ensures consistency, improves wayfinding, and is compatible with existing base standards.

3-1.1 Exterior Sign Types.

Develop a standard family of installation-specific sign designs in accordance with this UFC and any specific requirements defined in the IPS. Integrate new signs with existing signs to provide the most cost-effective and practical solutions for each facility or installation. There are six basic categories of exterior signs:

- Installation and gate identification
- Building identification
- Traffic control devices
- Directional and wayfinding
- Mandatory and prohibitory
- Informational and motivational

3-1.2 Prohibited Exterior Signs.

Prohibited signs include any sign with animated, blinking, chasing, flashing, or moving effects. Other types of prohibited signs include rotating signs, windblown or inflated signs, neon signs, and portable signs. Specific prohibitions on certain sign types may also be established at the installation level. These restrictions do not apply to traffic control devices.

3-1.3 Historic Signs.

Specialty historic signs for facilities on the National Historic Register or within a historic district must be coordinated and approved through the state historic preservation office (SHPO). These are freestanding and wall-mounted exterior signs that may use a special typeface, materials, or fabrication techniques to complement the character of historic buildings.

3-1.4 Exterior Color Standards.

The goal of this UFC is to establish a consistent color scheme for all installation and building signs that works for all Service branches. A consistent dark background should be used for standard installation and gate identification signs, with light text to provide sufficient contrast, to meet all visibility and required legibility objectives. Accent colors help reinforce the brand identity of the Service branch.

Service branch-specific color schemes are permitted exceptions to the standard color scheme where needed to maintain consistency with existing sign programs, IPS, or other special considerations at some installations. These color standards and special Service branch exceptions do not apply to traffic control signs that have color and material requirements specified in the MUTCD.

3-1.5 Engineering and Shop Drawings.

All signs, foundations, and connections must be engineered to resist wind loads and thermal movement according to the local climate requirements without distortions and excessive deflections. Shop drawings submitted by the sign contractor must include fabrication details such as elevations, message layouts, sections, side views, plan views, mounting details, and electrical or communication details. Submittals for all freestanding signs must include design calculations and the signed seal of a registered structural engineer licensed in the required area or follow approved state department of transportation standards to ensure compliance with all design and load requirements. Shop drawings must illustrate all means of mounting and attachment for proper coordination for connections to building structures.

3-2 INSTALLATION AND GATE IDENTIFICATION SIGNS.

Provide installation and gate identification signs according to the design guidelines provided in this UFC to help provide consistency for installation identification signs among all Service branches. These sign designs also address joint Service installation identification issues.

3-2.1 Message Content.

These signs may contain graphic information on one or both sides, depending upon the orientation of the sign and visibility requirements. These signs contain only the following information:

- **\4** "Service branch and Component logo or Seals" identification text in all caps. **/4/**
- Service branch or "U.S. Joint Base" identification text in all caps. The font must be Helvetica Neue 95 Black. The logo for the lead Service branch **\4** or Component **/4/** of a joint base must be mounted on the left side of the sign.
- Installation name in upper- and lowercase letters. Font must be Helvetica Neue 75 Bold. The name for the lead Service branch **\4** or Component **/4/** of

a joint base must be mounted on the left side of the sign and must match the logo placement.

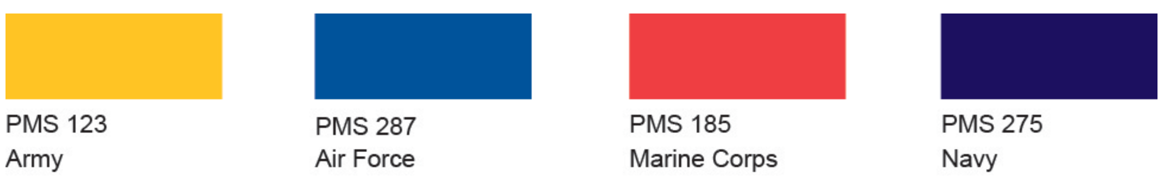
- Optional gate identification information may be added to the base of the sign. The font must be Helvetica Neue 65 Medium.

3-2.2 Materials and Colors.

The sign and background material should be fabricated from aluminum with a painted finish. All logo symbols and seals must be 0.5 inch (13 millimeters [mm]) thick and fabricated from highly durable materials with full color graphics, except the Air Force logo must be brushed aluminum. All letterforms must be constructed of 0.5-inch (13-mm) -thick aluminum. Use a paint to match a “brushed aluminum” finish for the center part of the sign cabinet. Provide a dark bronze painted finish for the background of the sign face unless there are installation-specific color standards. The supporting structure materials may vary to match the architectural character of the surrounding environment or installation-specific standards.

Service branch-specific color schemes are permitted exceptions to the standard color scheme where needed to maintain consistency with existing sign programs. These special considerations should be established in the IPS. Provide a vertical brushed finish with a factory-applied coating to aluminum letterforms on dark backgrounds. Provide dark painted letterforms if using a light-colored sign background to provide sufficient contrast and allow these signs to meet all required visibility and legibility objectives. These color standards and special Service branch exceptions do not apply to traffic control signs that have color and material requirements specified in the MUTCD. Accent colors shown in Figure 3-1 are used to help reinforce the brand identity of each Service branch.

Figure 3-1 Installation and Gate Identification Sign Accent Colors.



3-2.3 Illumination.

Provide external illumination for all primary, secondary, and wall-mounted installation entrance signs where required for visibility. Use high-efficiency floodlights. Minimize the use of illuminated signs to reduce initial costs, prevent maintenance issues, and avoid driving distractions.

3-2.4 Primary Installation and Gate Identification Signs.

The structure supporting the sign may vary to complement the predominant architectural style of the installation, but the design of the sign itself must conform to Figures 3-2 through 3-9 to the maximum extent practical. Installation and gate identification signs at the entrances to installations are the only signs that will incorporate the brand identity of each Service branch.

Figure 3-2 Primary Installation and Gate Identification Sign Fabrication.

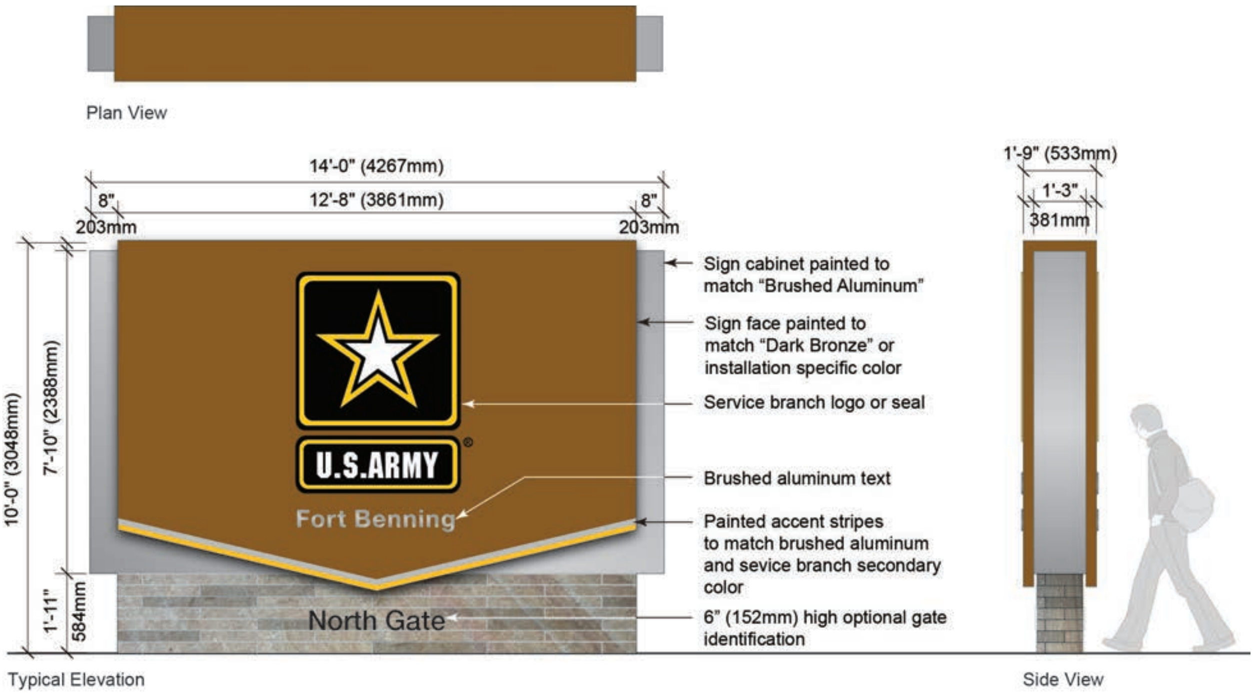


Figure 3-3 Primary Installation and Gate Identification Signs.

Figure 3-4 Primary Installation and Gate Sign Layout Details.

Figure 3-5 Primary Joint Installation and Gate Identification Signs.

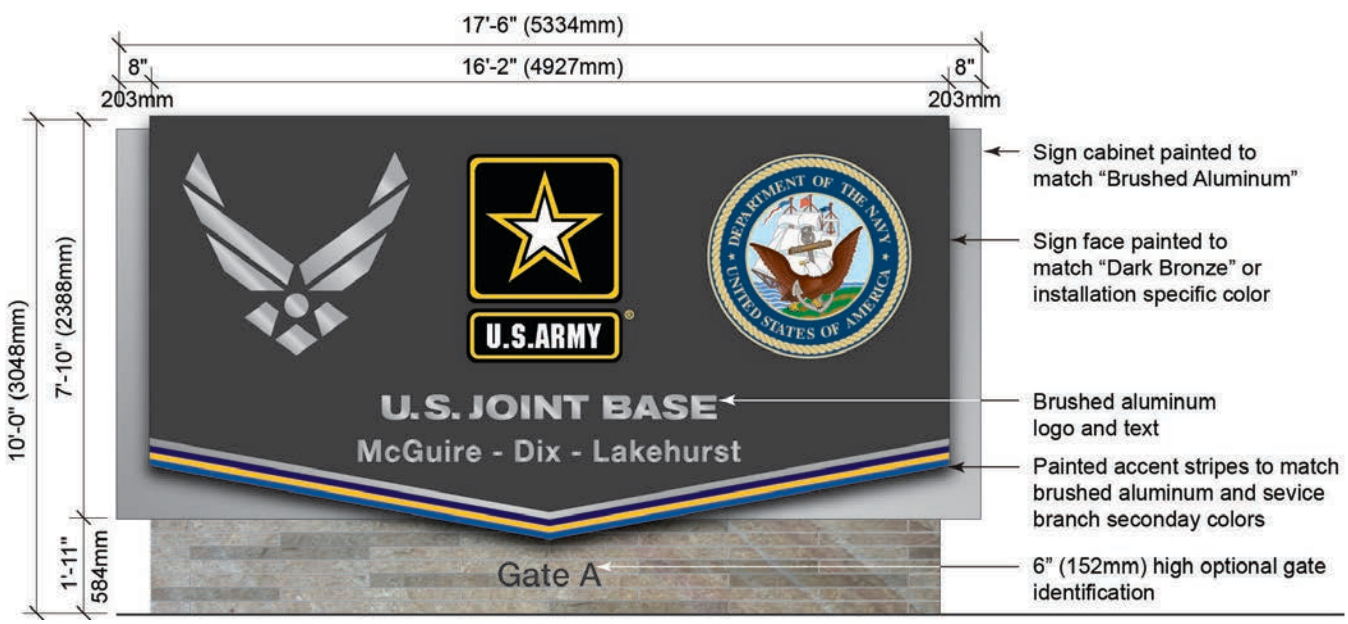
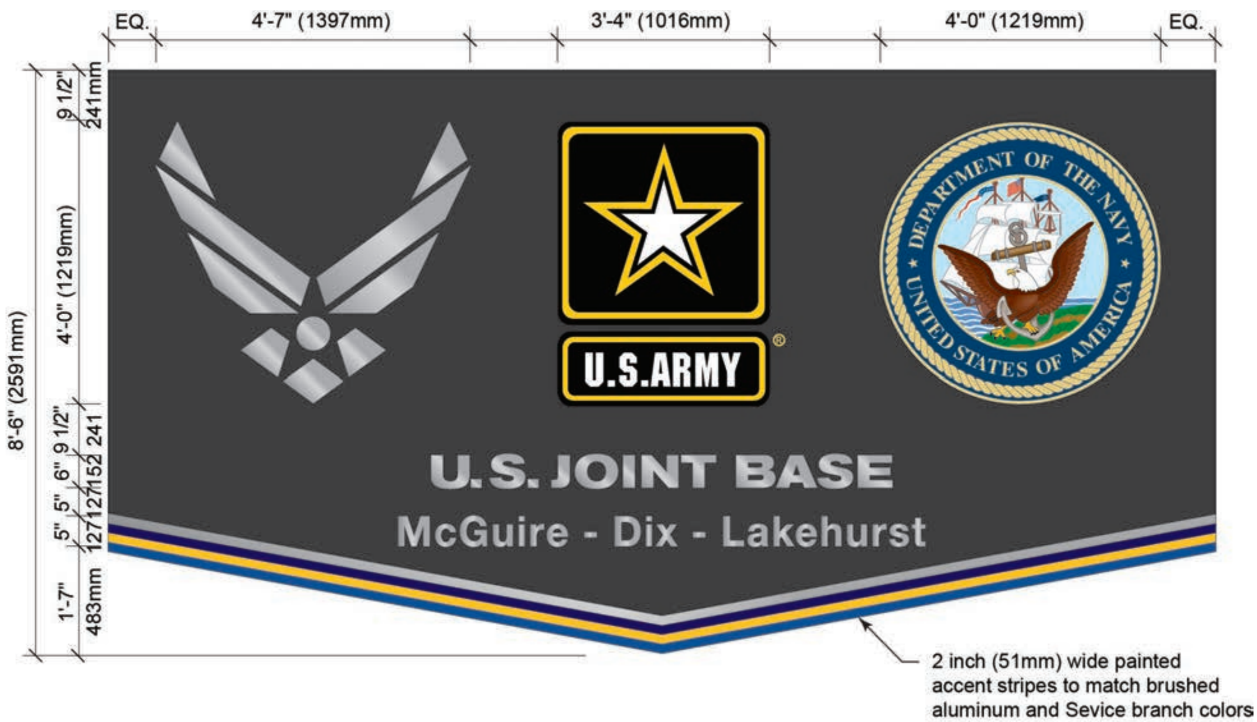


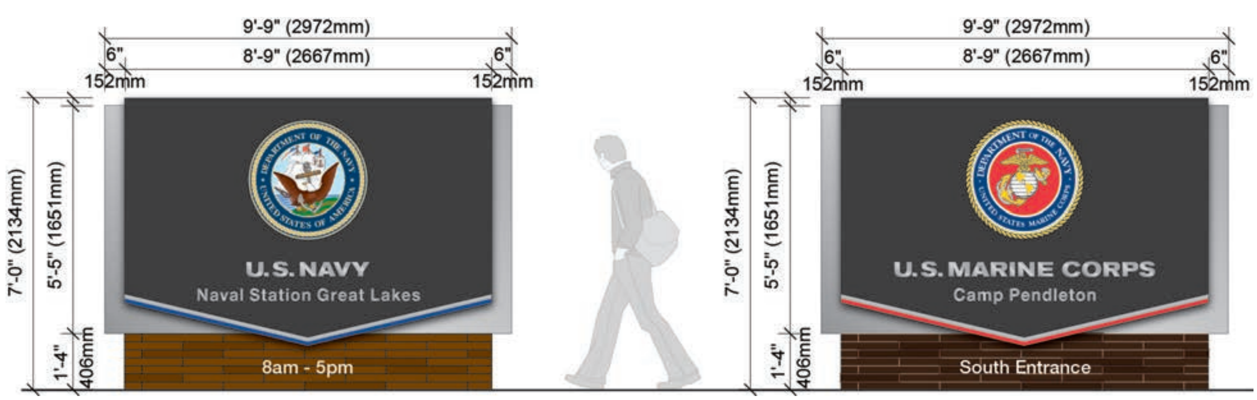
Figure 3-6 Primary Joint Installation Sign Layout Details.



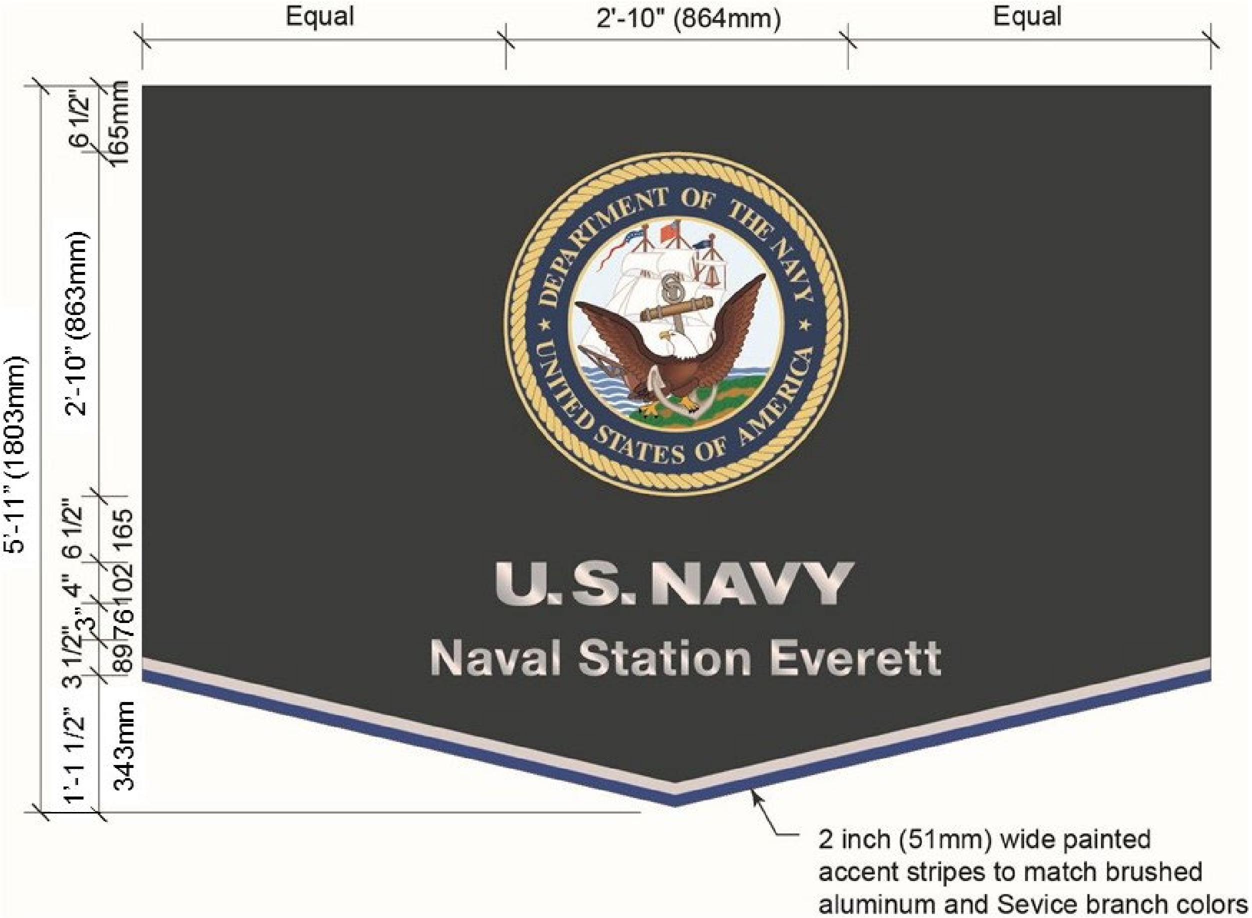
3-2.5 Secondary Installation and Gate Identification Signs.

Secondary installation and gate identification signs are used to identify secondary installation entrances that receive high volumes of traffic (see Figures 3-7 through 3-9). These entrances are primarily for active duty and other DoD personnel with proper identification. These signs must use the same materials and information as the primary installation identification signs except they must be slightly smaller in size. Supplemental messages may be provided on the sign base, such as gate identification or hours of operation.

Figure 3-7 Secondary Installation Identification Signs.



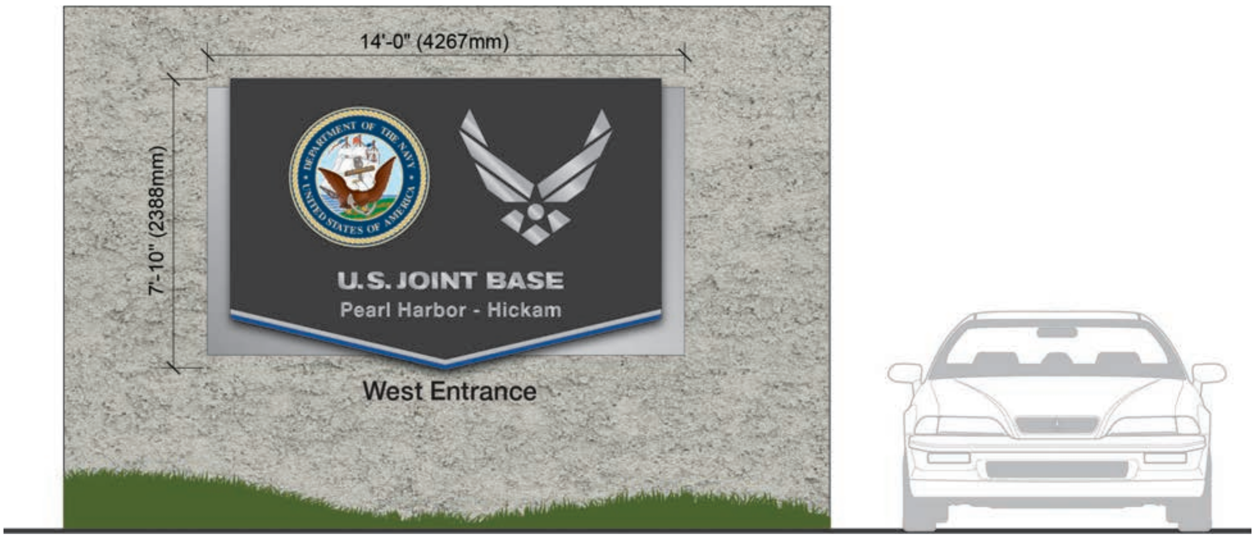
\3\ Figure 3-8 Secondary Installation Sign Layout Details. /3/



3-2.6 Wall-Mounted Installation Identification Signs.

Installation identification signs may need to be placed on existing walls, gates, or buildings at or near the main installation entrances to identify and introduce the installation to visitors. The fabrication techniques, materials, and colors should be consistent with freestanding installation identification entrance gate signs. These signs should use the background materials as shown to provide a consistent background for the symbols and letterforms regardless of the color of the object where it may be installed. Provide installation identification mounted on an aluminum sign panel because it requires fewer holes to be drilled into the existing structure than individual logo symbol/letters, resulting in less damage to the structure in the event of a future name change.

Figure 3-9 Wall-Mounted Installation Identification Sign.



3-2.7 Tertiary Gate and Entrance Signs.

Tertiary gate and installation entrance signs are used to identify non-public access control points, such as commercial/delivery gates. Use MUTCD standard guide signs to direct vehicles to these entrances. Message content should include the installation name and the function of the tertiary entrance.

3-3 BUILDING IDENTIFICATION SIGNS.

Building identification signs are used inside the installation to provide information about buildings, major tenants within buildings, areas within the installation, and organizational or functional units. Different sizes and design elements are used to identify the different organizational levels. The signs should carry one unit name and any secondary information to identify the unit component (such as headquarters) and may also include a street address. No unit mottoes, names, or titles of individuals are permitted.

3-3.1 Freestanding Building Identification Signs.

Most buildings can be best identified by using a freestanding building identification sign in front of the building near the main entrance or at the main entrance to the associated parking area (see Figures 3-10 and 3-11). There are three basic types of freestanding building identification signs:

- Primary - These signs identify high-level organizations such as command, squadron, or unit headquarters.
- Secondary - These signs identify lower-profile buildings. These signs use the same basic principles as primary facility signs, only these are somewhat smaller.
- Tertiary - These signs identify buildings or other miscellaneous facilities that do not require a street address or building number, such as recreational facilities, training areas, and maintenance or storage facilities.

The appropriate sign type required is based upon the importance of the building or tenant identification required. Place primary identification signs as close as possible to the building entrance and perpendicular to the roadway to permit viewing by traffic moving in both directions. If the building is set back from the roadway and is not visible or is only partially visible from the roadway, place the sign next to the entrance driveway and on the side of the driveway closest to the building. Provide one sign for each building unless additional signs are required due to unique site conditions. Consider intersection sight distances provided in AASHTO *A Policy on Geometric Design of Highways and Streets* (Green Book), in addition to the lateral offsets included in the MUTCD.

Figure 3-10 Freestanding Building Identification Signs.

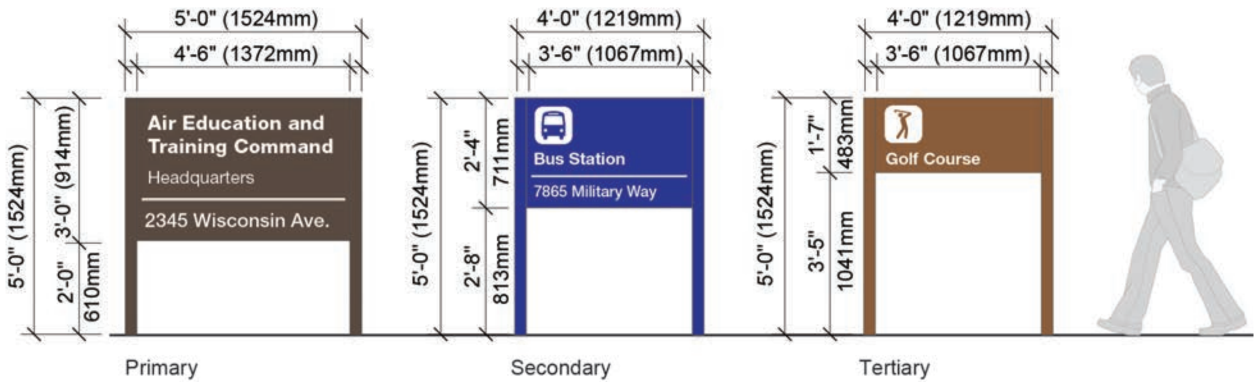


Figure 3-11 Freestanding Building Identification Sign Layouts.

3-3.1.1 Materials and Colors.

Freestanding building identification signs must be non-illuminated and use a standard post-and-panel type construction. Use extruded aluminum square posts with flat aluminum sign message panels that are removable for easy replacement. Sign post and panel sizes must be engineered by the sign contractor according to wind loads and other requirements at each installation. Minor deviations from these general specifications are permitted where needed to align with installation-specific standards and pre-existing sign programs.

Provide a dark bronze painted finish for the background of the message panels and support posts. Sign message content must be white reflective engineering-grade vinyl. Use these standard materials and colors unless there are specific requirements established in the IPS. These color standards and special Service branch exceptions do not apply to traffic control signs that have color and material requirements specified in the MUTCD.

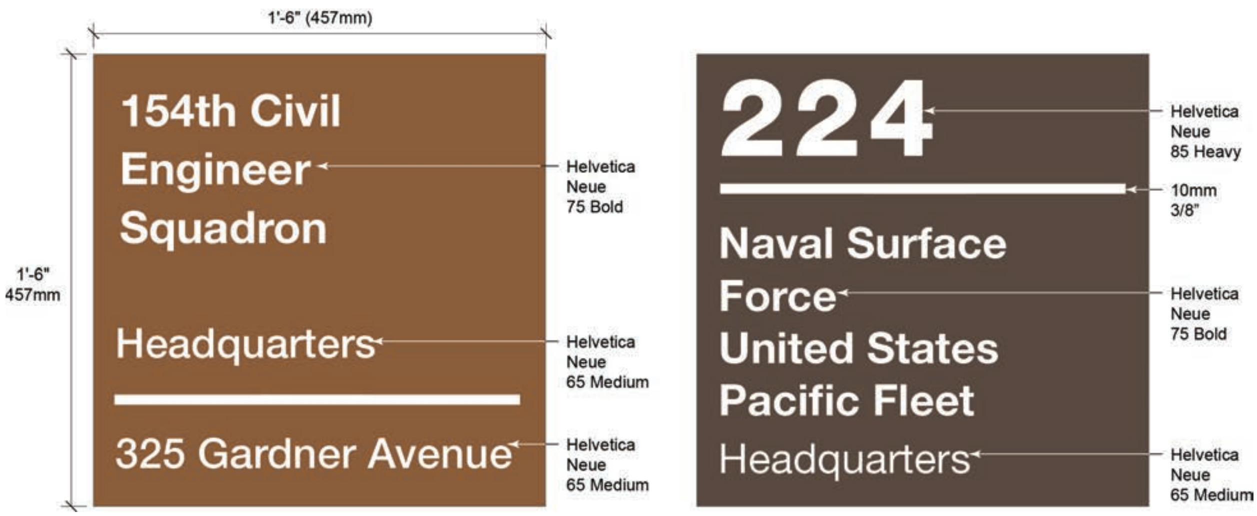
3-3.1.2 Street Address and Building Numbers.

Include the street address or building numbers (if used) on all building and facility identification signs, where possible. Include this information at the main entrance to the building and on other exterior portions of the building as necessary for wayfinding.

3-3.2 Building Entrance Signs.

Only one identification sign is permitted at each building entrance (see Figures 3-12 through 3-14). Place the building entry signs directly on the wall next to the entry point. If the building is set back from the roadway and is not visible or only partially visible from the roadway, place the sign next to the main entrance of the building to confirm the information shown on the sign at the entrance driveway. Some buildings have more than one primary entrance. Use building-mounted entry signs to identify organizations that are reached through the alternate entries of these types of buildings.

\2\ Figure 3-12 Building Entrance Signs. /2/



\2\ Figure 3-13 Building Entrance Sign Layouts. /2/

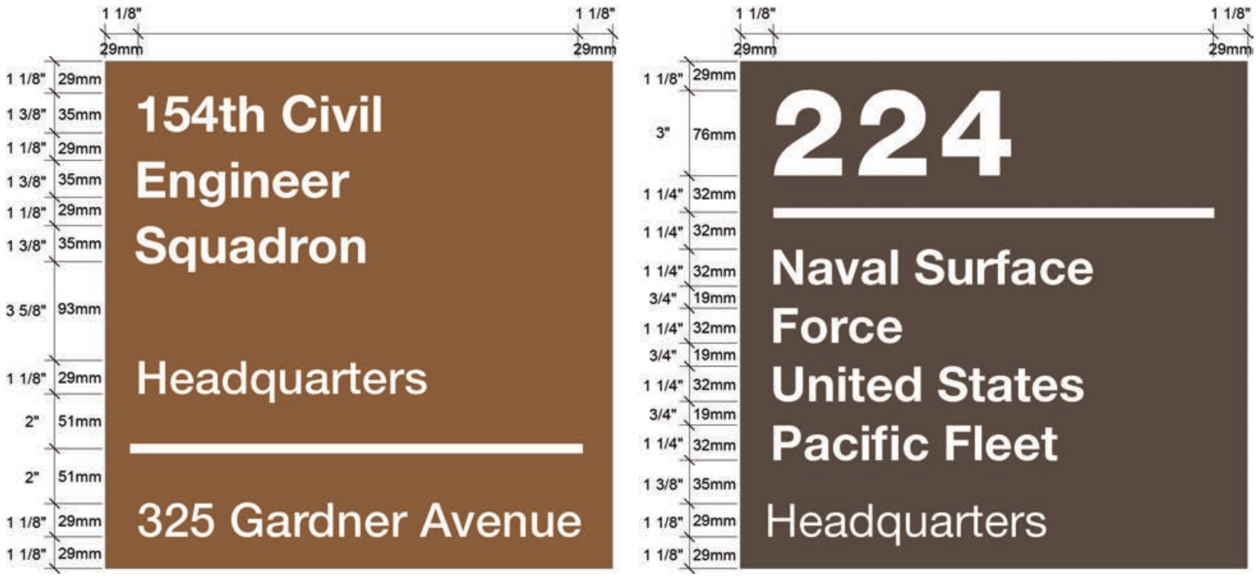


Figure 3-14 Building-Mounted Entry Sign Placement.

3-3.2.1 Materials and Colors.

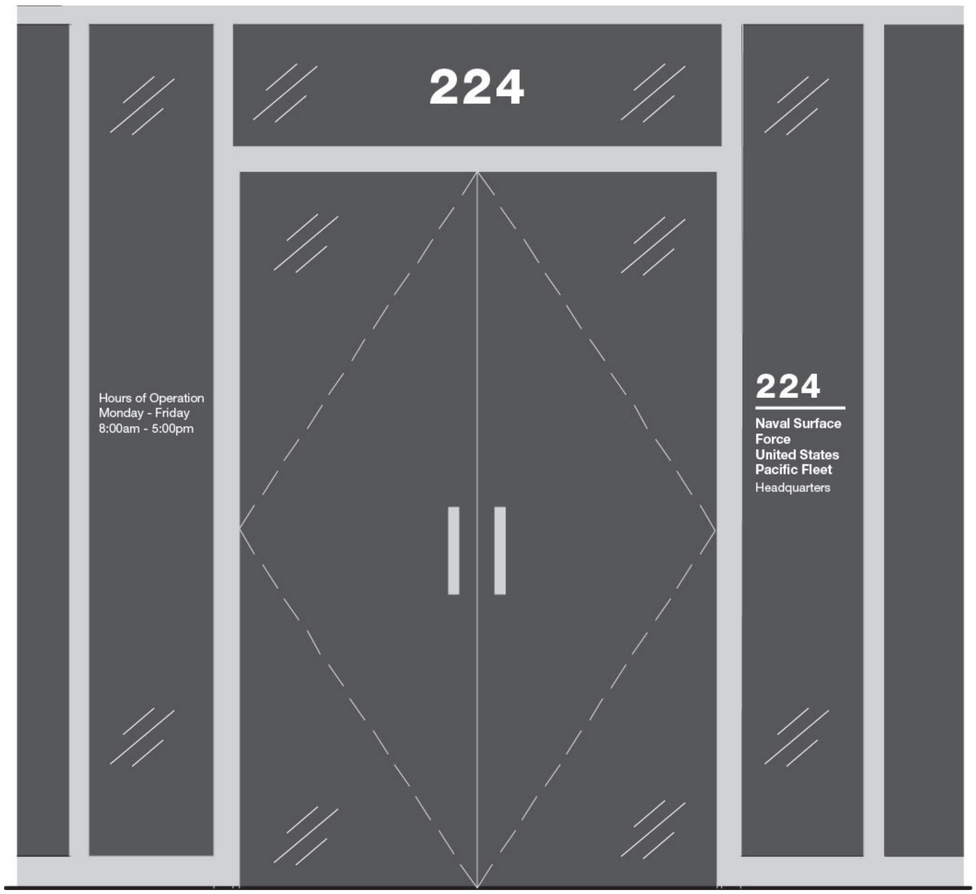
Building-mounted entry signs must be non-illuminated and must be painted aluminum with white vinyl messages. Signs must be wall-mounted where possible and attachment methods may vary depending upon building conditions. The dimensions of the signs are 1.5 feet x 1.5 feet (457 mm x 457 mm). If building numbers are used they should be located at the top of the sign. If the required message on a building entry sign is too long to fit on the standard layouts shown, reduce the size of the text as required.

Provide a dark bronze painted finish for the background of the message panels or other background color that is consistent with the installation standards. Minor deviations from these general specifications are permitted where needed to align with installation-specific standards and pre-existing sign programs. Use these standard materials and colors unless there are specific requirements established in the IPS.

3-3.3 Building Entrance Signs on Glass.

Customized solutions may be designed for buildings with glass entrances. Provide frosted or white vinyl building identification on glass entryway signs where required. Provide building numbers or the street address that are appropriately sized for the average viewing distance. As a guide, use letters 1 inch (25 mm) high per 25 feet (7.62 meters) of viewing distance and establish an installation standard based on the average door size and the average viewing distance. Include limited additional information such as tenant identification information and hours of operation where appropriate (see Figure 3-15).

Figure 3-15 Building Identification for Glass Entrances.



3-3.4 Building-Mounted Identification.

Minimize the use of building identification signs to only high-profile buildings, except where building identification numbers are used. Signs mounted on prominent buildings may include the building name, primary function, and/or building identification number when the facility needs identification from long distances. Building number signs may be used in addition to the primary facility identification sign where required.

3-3.4.1 Materials and Colors.

Individual dimensional letters applied directly to the surface of the wall are discouraged. The preferred fabrication details should include an aluminum sign panel mounted to the building with letterforms applied to the panel. Use the Helvetica Neue 85 Heavy font for typical building identification letters or numbers where required. Provide a dark bronze painted finish for the background of the message panels or other background color that is consistent with the installation standards. The color or finish of the letters should complement the predominant color of the building while providing enough contrast with the background for visibility. Use light-colored letters on dark sign panels and dark-colored letters on light sign panels. Use these standard materials and colors unless there are specific requirements established in the IPS. Minor deviations from these general specifications are permitted where needed to align with installation-specific standards and pre-existing sign programs.

3-3.4.2 Placement.

Building-mounted identification signs should be coordinated and compatible with the building's design and applied consistently across the installation. They are often most effective near the main building entrance or on a covered drop-off canopy. Signage may be required on the back or side of the building to provide better visibility and wayfinding cues for visitors or customers. The installation engineer should select the most appropriate solutions for the architectural style of the buildings and apply them consistently.

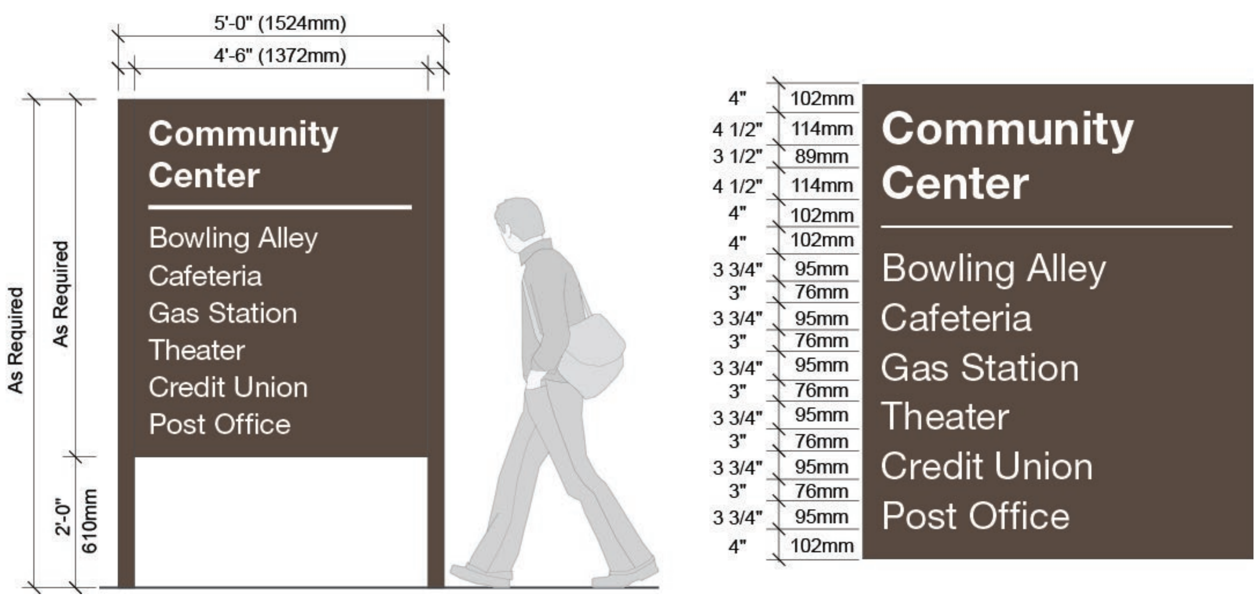
3-3.5 Commercial Signs.

Many commercial entities on military installations have standard image symbols or unique logos that may be used to provide identifiable images and/or wording that is easily recognizable to potential users. Commercial organizations, such as the base exchange, Defense Commissary Agency (DeCA) stores, and restaurants may display their registered trademark logos. The size, placement, and material composition of these signs must be consistent with installation-specific standards. The use of neon signs is prohibited.

3-3.6 Centralized Facilities Freestanding Identification Signs.

Centralized facilities signs may be designed to address multiple buildings or services that use a common roadway entrance or parking area. Set the sign to permit viewing by traffic moving in both directions. The size, placement, and material composition of these signs must be consistent with installation-specific standards. See Figure 3-16.

Figure 3-16 Centralized Facilities Freestanding Identification Signs.



3-3.6.1 Specialty Community Identification Signs.

Limited use of specialty community identification signs is permitted to identify communities, housing areas, districts, or other installation-specific specialty facilities. These signs may be customized to align with the unique architectural characteristics of each area or installation, as required. Use the general guidance and design principles provided in this UFC for these types of non-standard signage options.

3-3.7 Water Tower Signage and Graphics.

Water towers must comply with UFC 3-535-01 for marking and lighting requirements for airfield obstructions. Service logos and shields are not required for all water towers. When applied, these guidelines apply only to water towers and may not be used for other highly visible structures. The face of the water tower tank must display only the Service branch seal or logo and the approved font identification; no additional graphics or lettering will be applied (see Figure 3-17). The paint scheme for the symbol and letterforms must be consistent with the approved colors associated with the appropriate Service branch logo. The application of each logo template may vary in overall size but must maintain the composition and proportions as provided by the digital artwork. The shapes of the seals, symbols, or letterforms must not be altered in any way.

Only apply Service logos and shields to water towers with a background color for the body of the tank that is a uniform light tone consistent with installation standards. Due to the diversity of water tower tank shapes, configurations, and orientations, the following guidelines are provided to facilitate consistent and effective implementation:

- Avoid a cluttered appearance by having no more than two applications of the symbol and letterforms on one tank.
- Orient the symbol and letterforms on the side(s) of the tank that provide the best visibility for the public.
- Size the symbol and letterforms to be easily read from a reasonable distance.
- Position the symbol and letterforms in a manner that minimizes visual interference by railings or other structural elements and minimizes distortion due to any vertical curvature of the tank surface.

Figure 3-17 Water Tower Signs.

3-4 TRAFFIC CONTROL DEVICES.

All traffic control devices must conform to the requirements specified in the latest versions of the MUTCD and the SDDCTEA DoD Supplement to the MUTCD. The MUTCD defines the standards used to install and maintain all traffic control devices. Exceptions to the MUTCD must be approved by SDDCTEA. SDDCTEA executes DoD's overall transportation engineering program on behalf of the Services.

3-4.1 Fabrication and Installation.

All sign colors for traffic control devices will be in accordance with the MUTCD. Material selection and installation must consider the effects of local climatic conditions. Painting sign posts and the backs of signs is prohibited. Wood for sign faces is prohibited.

3-4.2 Access Control Point/Entry Control Facility Signs.

The required traffic control devices required for access control points and entry control facilities (ACP/ECF) are detailed in the MUTCD, the SDDCTEA DoD Supplement to the MUTCD, and SDDCTEA Pamphlet 55-15.

3-4.3 Speed Limit Signs.

Speed limit signs must display the limit established by law, ordinance, regulation, or as adopted by the authorized agency. Speed zones (other than state statutory speed limits) will only be established on the basis of an engineering study performed in accordance with traffic engineering practices. The speed limits displayed must be in multiples of 5 miles per hour (mph) (8 kilometers per hour [kph]).

3-4.4 Street Name Signs.

Provide street identification signs in accordance with the guidelines established in the MUTCD. Pictographs and logos are prohibited on street name signs. Use double-faced street name signs.

3-4.5 Reserved and Accessible Parking Signs.

Reserved and accessible parking should be kept to a minimum and assignment of reserved spaces should be established at the installation level. The use of freestanding and building-mounted signs is discouraged. Acceptable space identification methods include curb markings, pavement markings, or identifying the entire reserved area with a sign at each entrance. The requirements for reserved parking do not apply to accessible parking. The guidelines and requirements for accessible parking and signs are detailed in ABAAS and the MUTCD.

3-5 DIRECTIONAL AND WAYFINDING SIGNS.

There are two types of directional and wayfinding signs: pedestrian and vehicular. Pedestrian circulation is separate from vehicular circulation and requires its own wayfinding system. Vehicular directional and wayfinding signs are detailed in the MUTCD and paragraph 3-4 of this UFC. A cohesive signage plan is important and both sign systems must work together. See Figure 3-18.

3-5.1 General Guidelines.

Provide pedestrian directional signs at critical points where decisions are necessary for movement to a destination. It is very important for these signs to meet the information needs of visitors and other installation users. There are too many potential destinations on any military installation to list on directional signs, but effective directional signs help visitors find their destinations more easily. Directional signs, proper street identification, and effective installation maps form the basic keys to visitor orientation and effective wayfinding. Graphics and messages must appear on both sides of the sign if visible and meaningful to people moving in both directions. Separate the destinations with white rule lines. Place no more than six, and no fewer than two, destinations on pedestrian directional signs.

3-5.1.1 Materials and Colors.

Pedestrian directional signs must be non-illuminated and use a standard post-and-panel type construction. Use extruded aluminum square posts with flat aluminum graphic sign message panels that are removable for easy replacement. Sign post and panel sizes must be engineered by the sign contractor according to the wind loads and other requirements at each installation. Minor deviations from these general specifications are permitted where needed to align with installation-specific standards and pre-existing sign programs.

Provide a dark bronze painted finish for the background of the message panels and support posts. Sign message content must be white vinyl. Use these standard materials and colors unless there are specific requirements established in the IPS.

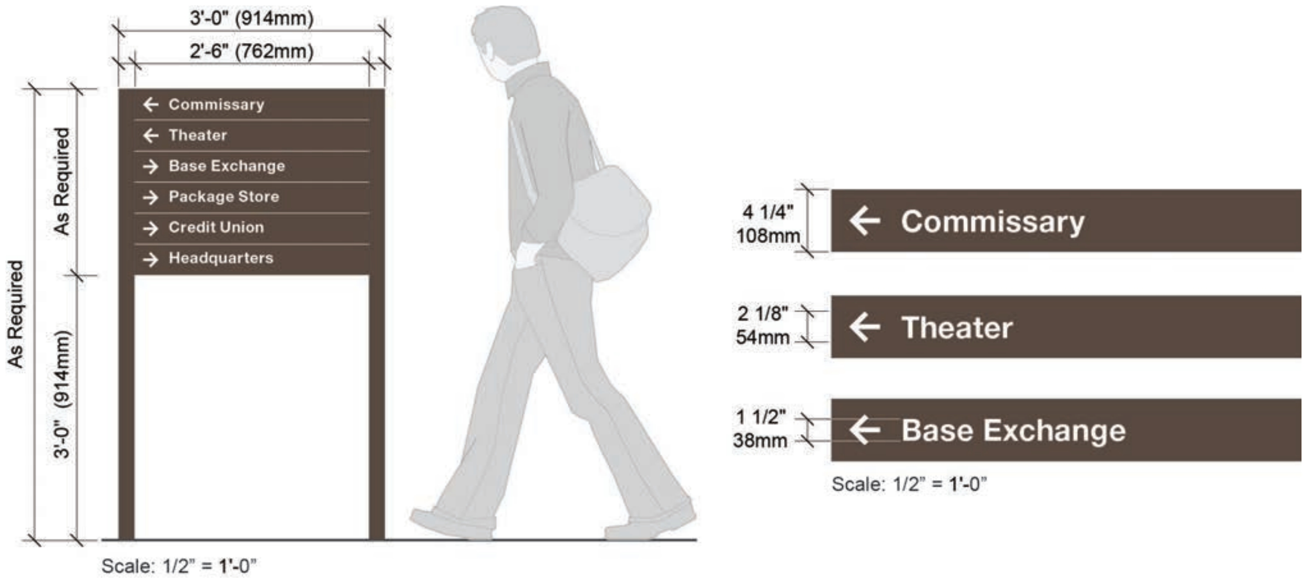
3-5.1.2 Message Limitations.

The destinations most often sought by people new to the installation should be clearly named on orientation maps and directional signs. Other major destinations should be listed in a map legend keyed to building address numbers. Area designations should be used only if they are meaningful. No more than six destinations should appear on one directional sign. If it is necessary to show more than six destinations then add a second sign, but do not use more than two directional signs in any situation.

3-5.1.3 Sign Placement and Installation Details.

Signs should be placed where they can be clearly seen by the user. Check sight lines before signs are erected. Place signs to take advantage of indirect light from existing light sources for good night visibility. A series of signs requiring pedestrian decisions should be placed far enough apart to allow enough time for the user to make the required decisions.

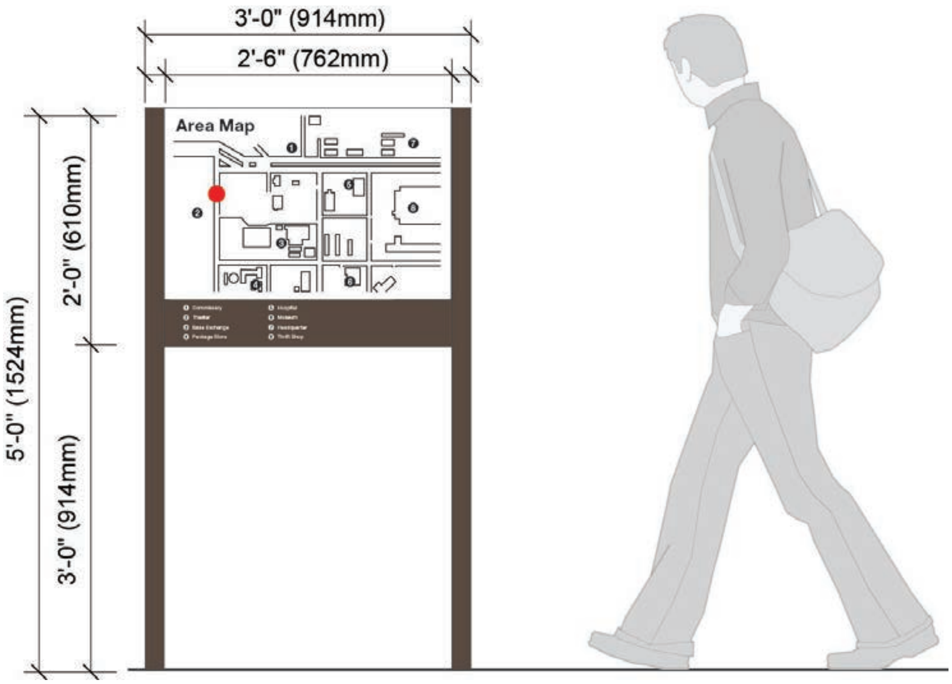
Figure 3-18 Pedestrian Directional Signs.



3-5.2 Orientation Map and Wayfinding Signs.

Most first-time visitors to a military installation receive verbal information at the entry gate, but may also need wayfinding/orientation map information. Provide installation maps at strategic locations to orient visitors and help them find destinations (see Figure 3-19).The installation map, directional signs, and building and street identification signs comprise the total wayfinding system outlined in this UFC. It is essential to use consistent nomenclature throughout the system. For example, the community center should be indicated by the same name on the map, directional signs, and the building identification sign. Design maps for clarity and ease of use. Maps created by merely reducing the installation site plan are usually too difficult to read, so the site plan must be simplified to emphasize major circulation routes and destinations. Use a halftone screen to indicate roadways. Emphasize important buildings by increasing the scale of the buildings in relation to other buildings or by adding color. Maps should be drawn from the perspective of the main entrance to aid visitor orientation and include “You Are Here” orientation information.

Figure 3-19 Orientation Map Signs.



3-6 MANDATORY AND PROHIBITORY SIGNS.

There are many different types of mandatory and prohibitory signs required for military installations that inform visitors and personnel of physical hazards and unsafe practices. These signs are required to define areas of restricted access to maintain proper levels of security. Other signs are required to address many types of specialized issues (e.g., hazardous or flammable materials, ordnance, fuel storage tanks). Utilization of these sign types should be kept to the minimum number and size required to meet safety regulations and avoid visual clutter. Refer to the design criteria and specification provided in the SDDCTEA DoD Supplement to the MUTCD for all traffic-related mandatory and prohibitory sign requirements.

3-6.1 Accessibility Pathway and Entrance Signs.

Provide signs as required by the ABAAS and to indicate the accessible routes from parking areas, public transportation stops, and public streets or sidewalks to building entrances. The signs must include the ISA and may require arrow indicators, as needed.

3-7 INFORMATIONAL AND MOTIVATIONAL SIGNS.

Informational signs may be used to address a wide variety of communication initiatives. These signs may include promotional advisories, general information, or temporary campaigns. Use signs that complement the standard morale signs and avoid visual clutter. Informational signs may be used alone or in combination with morale signs. Consider the need for message panels that can be easily updated or replaced using digital output sources like printed vinyl graphics.

The design of motivational signs may vary depending upon the installation standards and what types of signs are selected. Place signs at a prominent location on the installation, in an open area free from other signs or obstructions. Avoid haphazard placement and odd sizes. There are two types of exterior motivational signs: installation and standard. Unit morale signs should be used only inside buildings and are addressed in paragraph 4-8. The installation commander is responsible for controlling the quality, content, and placement of motivational signs. Minimize the number of motivational signs to avoid a cluttered appearance and do not use motivational signs at ACP/ECFs. Sign faces may be finished in a variety of materials, but sign structures must conform to the design requirements provided in this UFC.

3-7.1 Motivational and Morale Signs.

These signs are typically placed inside the main gate or at a central location on the installation, and may show the command shield, organizational emblems, mottoes, awards, and other elements related to installation morale. The design parameters of these signs may vary. There are no restrictions on the use of color or the character of the specific design, but these signs should be professionally designed and fabricated. Morale signs are used to support safety campaigns, fundraising drives, and special events. The design and fabrication should reflect the overall design principles outlined in this UFC. The dimensions should not exceed 4 feet x 10 feet (1219 mm x 3048 mm).

3-7.2 Electronic Message Signs.

Electronic messaging must be limited to the locations listed below:

- Primary entrance/entrances to the installation or at a central location in the community area
- Single location at the VIP entry point along the flight line
- Wing commander's office (serves as the wing commander's board)
- Electronic sortie board

When utilized at Air Force installations, an electronic message board that tracks the number of sorties flown will also serve as the base commander's message board. The size of this board depends on the total number of units being tracked. Information on the board is laid out with the flying unit designations across the top and "Goal," "Flown," "Remaining," and "Ahead/Behind" along the left side. The board should have the same layout on the opposite face (two-sided board). For initial planning purposes, anticipate a board size of 12 feet (3658 mm) long by 5 feet (1524 mm) high, supported on a 2.5 foot (762 mm) high masonry base.

Existing electronic messaging signs not in compliance with this UFC must not be grandfathered or replaced in kind and must be removed or brought into full compliance at the end of their useful life. Electronic messaging signs are limited to the locations identified above. **\2** The electronic message area, with the exception of the electronic sortie board, must be up to a maximum 10 feet (3048 mm) wide by 6 feet (1829 mm) high. Electronic message signs must be carefully located to avoid visual distraction and obstruction of vehicle and pedestrian traffic. ***/2/*** It is recommended to place the electronic message board on a masonry base to help protect the board from damage by grounds equipment and to conceal the electrical and control wiring. Electronic message sign hours of operation should be controlled by a timer so signs are turned off when vehicular traffic is minimal.

3-7.3 Exhibit Signs.

Use exhibit signs to display information relating to large-scale exhibits, such as aircraft, tanks, missiles, and specialty equipment. Place these informational signs in the vicinity of the exhibit they describe, oriented to the roadway or to the principal direction from which a visitor will approach. Informational text should appear on only one side of the sign. The materials should be selected to be compatible with the expected lifespan of the exhibit.

3-7.4 Specialty Informational Signs.

Specialty informational signs may be used to provide supplemental information regarding a building or organization, such as hours of operation or similar public information. Message information may use vinyl cut out by computer and applied with pre-spacing tape, or digitally output graphics on glass or on removable sign message panels, as required.

3-7.5 Construction Project Identification Signs.

Construction project identification signs must be utilized as temporary signs that provide information regarding construction projects with performance periods of 120 days or more. See UFGS 01 58 00 for details regarding all construction project identification signs.

CHAPTER 4 INTERIOR SIGN STANDARDS

4-1 INTERIOR SIGN DESIGN REQUIREMENTS.

This UFC is intended to provide requirements for the design of all interior signs. Design details for interior signs will vary due to many factors, such as existing installation standards, installation-specific colors, interior or architectural design details, and manufacturer-specific fabrication techniques. Interior signs must complement interior architecture and color schemes. Each interior sign system must be flexible enough to adapt to frequent personnel changes and office relocations. Coordinate room numbers and sign message text with the project team during the design phases through the completion of the project to ensure changes during the project development are addressed by the sign program.

Provide directional signs to guide visitors through a building from the entrance point to the correct floor, the correct area of a floor, the correct office, and (if appropriate) the correct desk. All interior signs must follow the requirements in this UFC for system organization, sign types, and sizes. Variations in types of hardware, materials, and colors are permitted. Design interior signs for minimum maintenance and maximum durability.

The general requirements for interior sign fabrication details include high-quality materials, workmanship, and fabrication techniques. Flexibility is included in the standard design direction provided in this UFC to allow for minor fabrication and material differences. Include extra “attic stock” or surplus signs when specifying a large project for future use and changing needs. Provide additional blank paper stock as appropriate for the size of the project for future use by the installation to print additional or replacement inserts, as required.

4-1.1 Interior Sign Types.

Interior sign types are standardized by function. Each sign type addresses specific requirements for wayfinding, codes, life safety, or other facilities management purposes. The seven main sign type categories include the following:

- Room, space, and workstation identification
- Life safety
- Interior directional
- Building directories
- Interior mandatory and prohibitory
- Interior informational and motivational
- Unit identification and morale

4-1.2 Interior Signage Objectives.

The primary objectives of interior signage programs include the following:

- Identify rooms and areas in conformance to ABAAS requirements.
- Address life safety code requirements.
- Develop a room numbering system for new facilities.
- Establish appropriate terminology for Services, departments, entrances, units, and other information required for each building. Avoid use of terminology that is likely to change (e.g., department codes).
- Provide effective directional information that guides visitors to their destinations and reduces the need for staff to help visitors.
- Establish and document new sign standards to be implemented in each facility.

4-1.3 Materials and Colors.

The fabrication methods used for interior signs may vary depending upon the manufacturer selected and existing sign systems at each installation. Interior signs should use primarily neutral colors and materials that blend with the interior finishes. Exact colors, materials, and finishes must be determined on a project-by-project basis. All interior signage colors must comply with the color contrast requirements of message content and sign backgrounds as specified in the ABAAS.

Where possible, maintain consistency with existing sign systems. Minor deviations from these general specifications are permitted where needed to align with installation-specific standards and pre-existing sign programs. Example layouts have been provided for general guidance but layout specifications will vary according to the unique message content requirements of each sign. Unacceptable fabrication techniques for interior signs include surface-applied vinyl letters or graphics that can be rubbed off or damaged and exposed paper inserts with no protective covering such as non-glare glass, clear acrylic, or other clear plastic-type product. Exterior-grade signs with durable plastic or other insert materials should be located in open areas (such as hangars or workshops), and interior grade signs should be located inside buildings, where required (e.g., offices, labs, and corridors).

4-1.4 Room Numbering.

Room numbering strategies are critical to wayfinding and facilities management. A master plan strategy of room numbering and workstation identification is required to ensure the numbers used on the architectural and interior plans will align with the wayfinding and signage objectives. This coordination will allow information in the architectural model to be extracted directly into the sign message schedule database that will be used to implement, maintain, and manage the sign program in the future.

4-1.5 Medical-Related Facilities.

The design guidance provided in this UFC is applicable for medical-related facilities as needed. Refer to UFGS 10 14 00.20 for additional information and guidance.

4-1.6 Owner Education and Maintenance Manuals.

The sign contractor must provide owner education services for any components that may require future actions by the installation. This often includes templates for replacing sign message inserts developed in specific software specified in the contract documents that will allow the facility to produce their own in-house message inserts. Maintenance or owner's manuals are required for any complex or electronic signs.

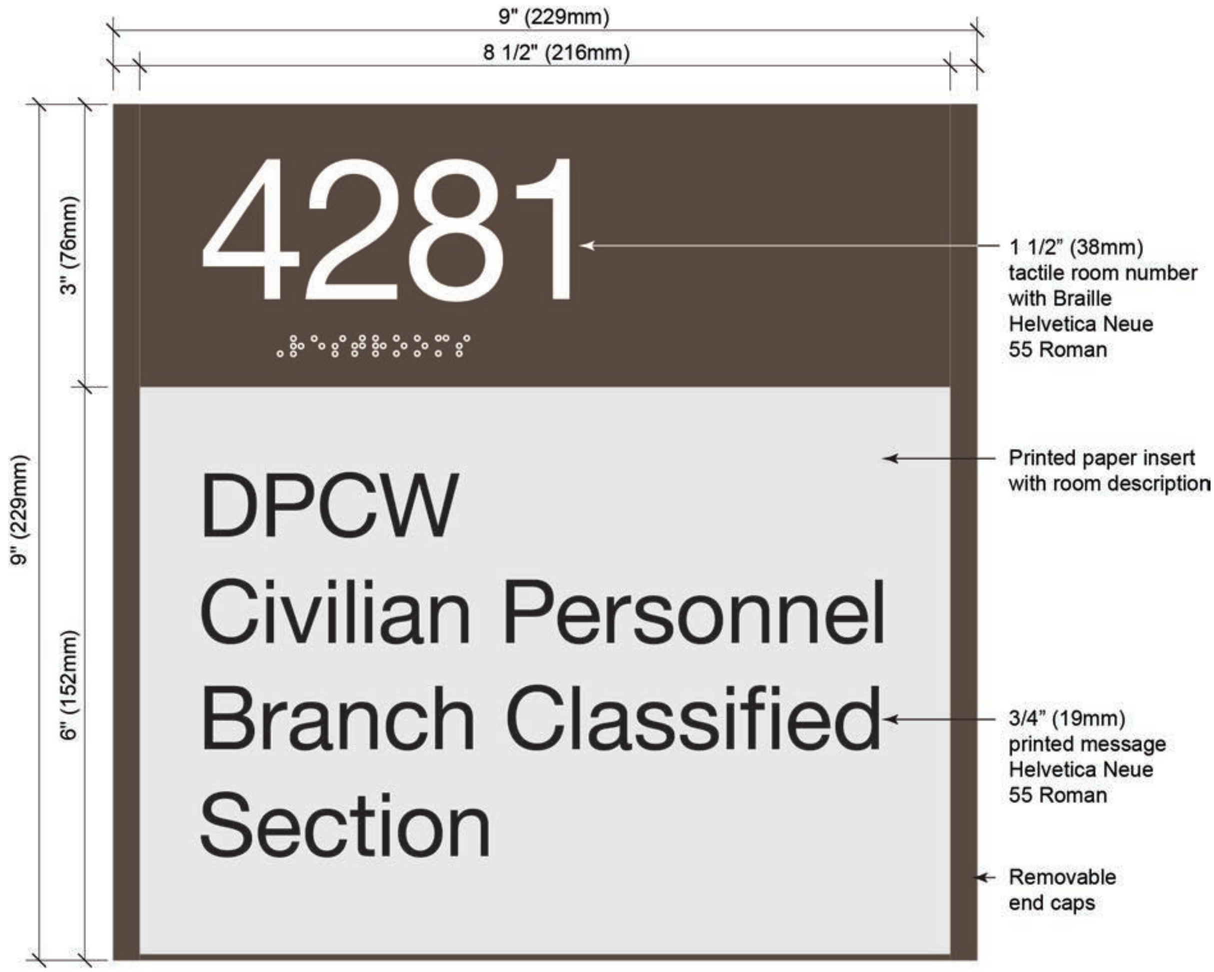
4-2 ROOM, SPACE, AND WORKSTATION IDENTIFICATION SIGNS.

Room identification signs must be included for most facility types. Provide room identification signs as required by ABAAS and other applicable code requirements. Include workstation identification and other signs needed for the core functionality of the building.

4-2.1 Room Identification Signs.

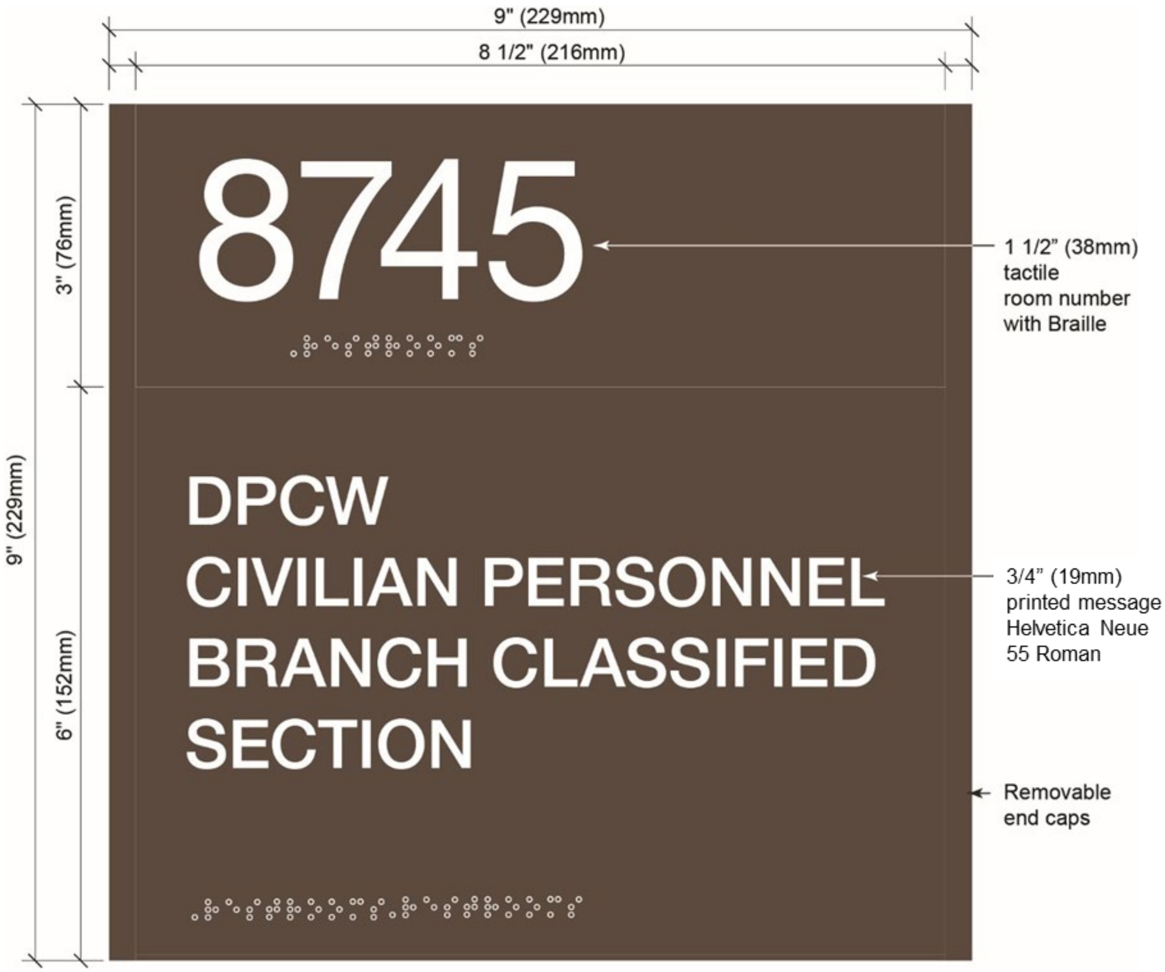
Provide room identification signs for all rooms that have an entrance door and for some entrances to spaces without a door. ABAAS requires that all permanent rooms be identified with signs that use tactile characters raised 0.03125 inch (0.8 mm) from the surface and Grade 2 Braille. Since the architectural room number is the most permanent component of the room description, it is most effective to use it as the tactile character and Braille portion of the sign. The room description, unless it is a permanent space such as a mechanical room, may be provided by a printed paper insert behind clear acrylic that can be easily and inexpensively replaced as the room function and/or occupants change (see Figures 4-1 and 4-2).

\2\ Figure 4-1 Room Identification Signs. /2/



Room Identification Sign with Paper Insert

\3\ Figure 4-2 Permanent Room Identification Signs. /3/

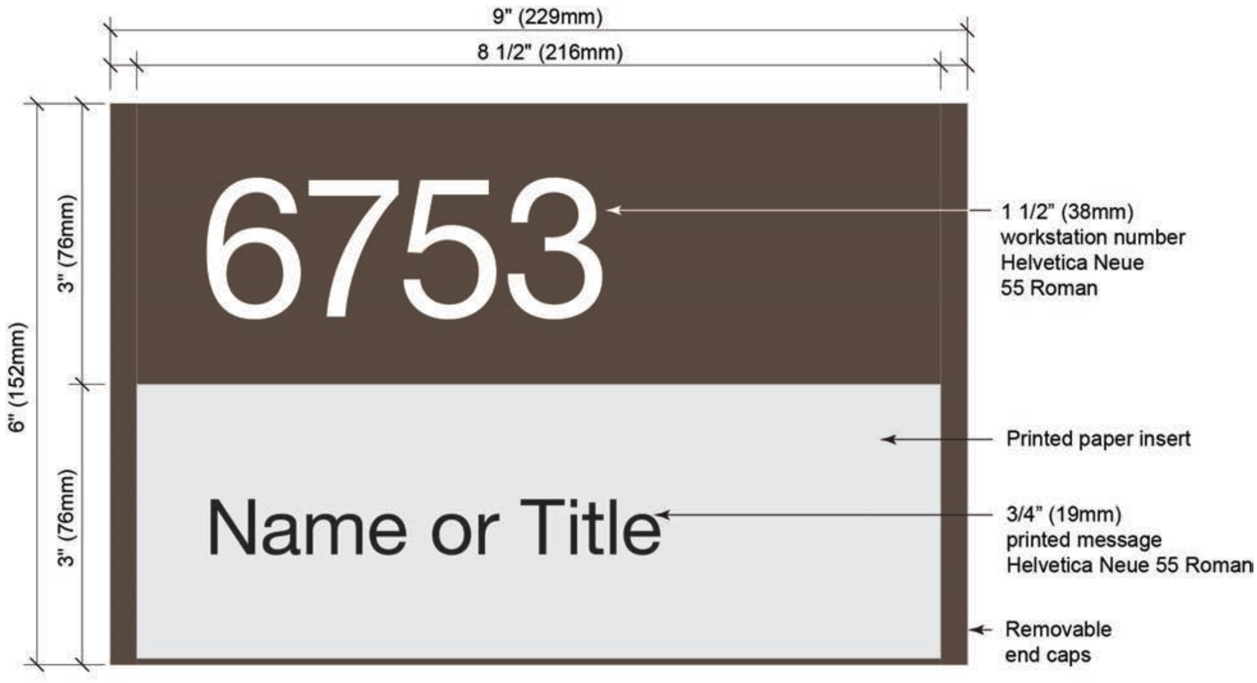


Permanent Room Identification Sign

4-2.2 Workstation Identification Signs.

Most office environments on military installations use workstations or cubical workspaces that are not considered permanent because they can be easily reconfigured (see Figure 4-3). Signs used to identify these spaces are not required to use tactile and Braille information; however, the space or identification number is still a very important component of these signs for wayfinding and facilities management. These numbers impact a wide variety of building systems, such as data connections, and should be clearly identified to assist facility management. Workstation signs are also used for occupant identification. Provide occupant message inserts that can be printed on paper or cardstock and easily replaced behind clear acrylic or plastic.

\1\ Figure 4-3 Workstation Identification Signs. /1/



Typical Workstation Sign with Number

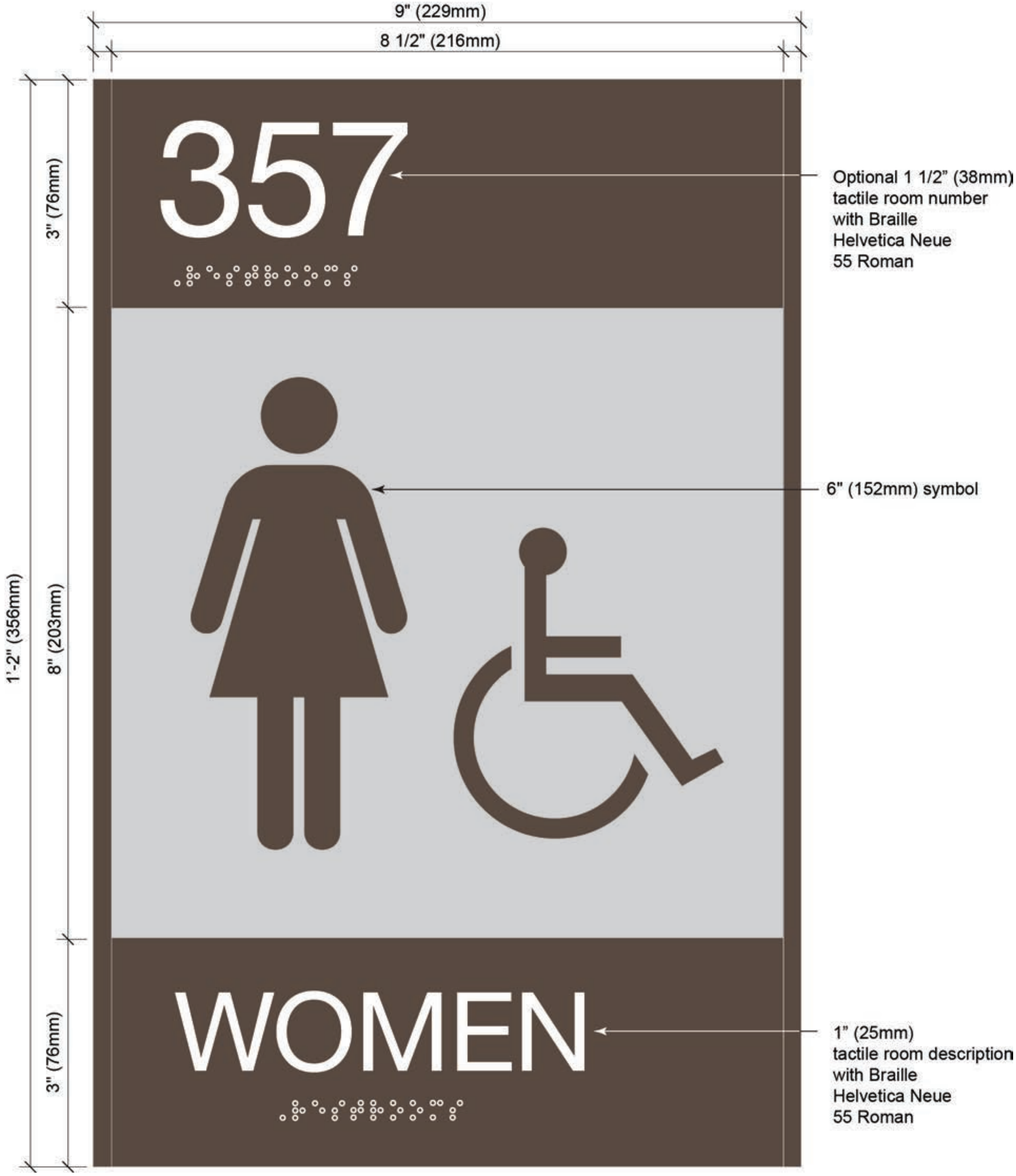
4-2.2.1 Workstation Sign Installation.

Workstation occupant identification signs should be mounted with over-the-panel hangers, mounting brackets, hook and loop (Velcro), or other similar methods, depending on the workstation furniture selected by the owner (see Figure 4-3). Mount signs on glass panels using double-faced foam tape and vinyl.

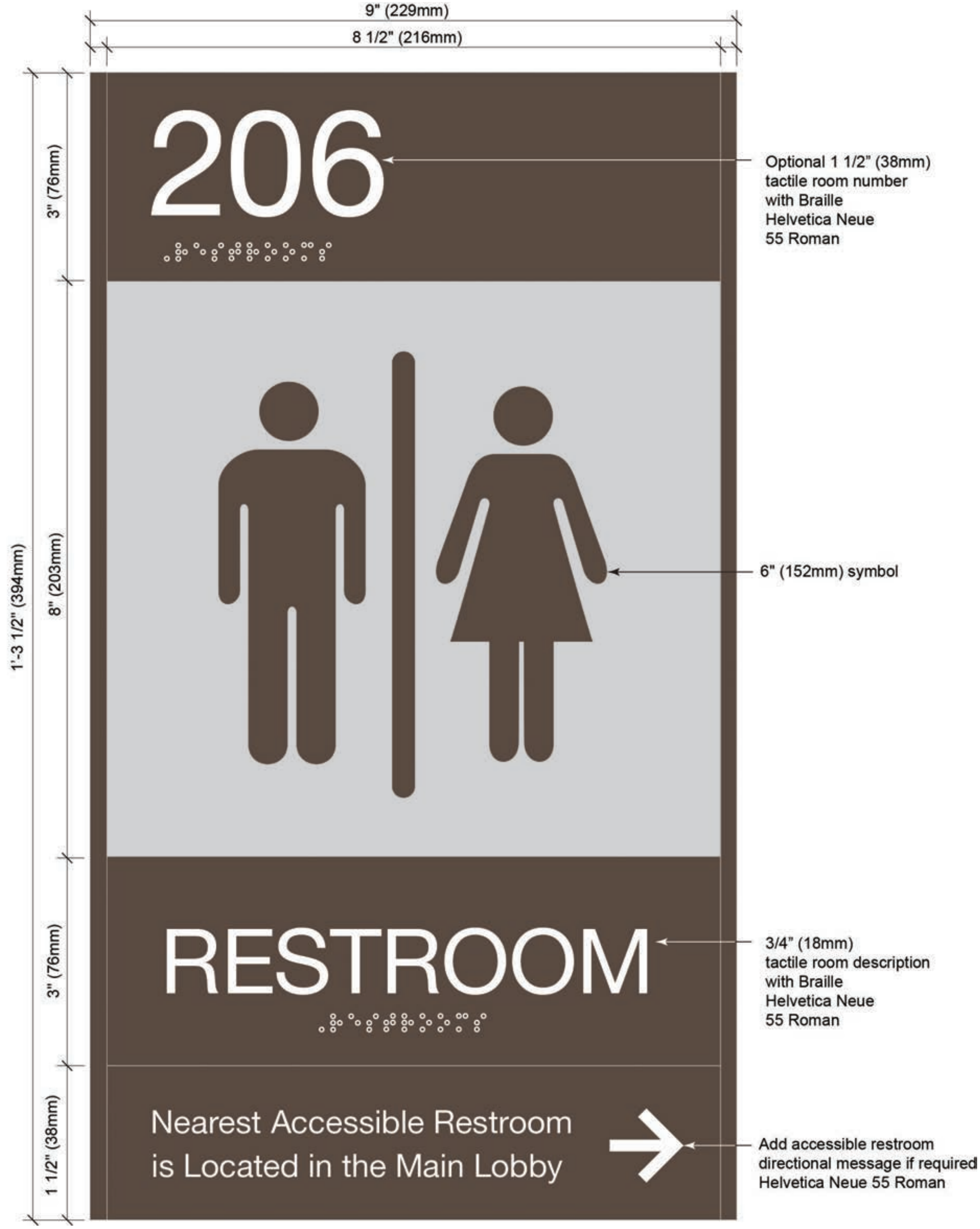
4-2.3 Restroom Identification Signs.

Refer to all current ABAAS requirements regarding restroom sign identification, use of pictograms, symbols of accessibility, finish, and contrast. See Figures 4-4 and 4-5.

\1\ Figure 4-4 Accessible Restroom Identification Signs. /1/



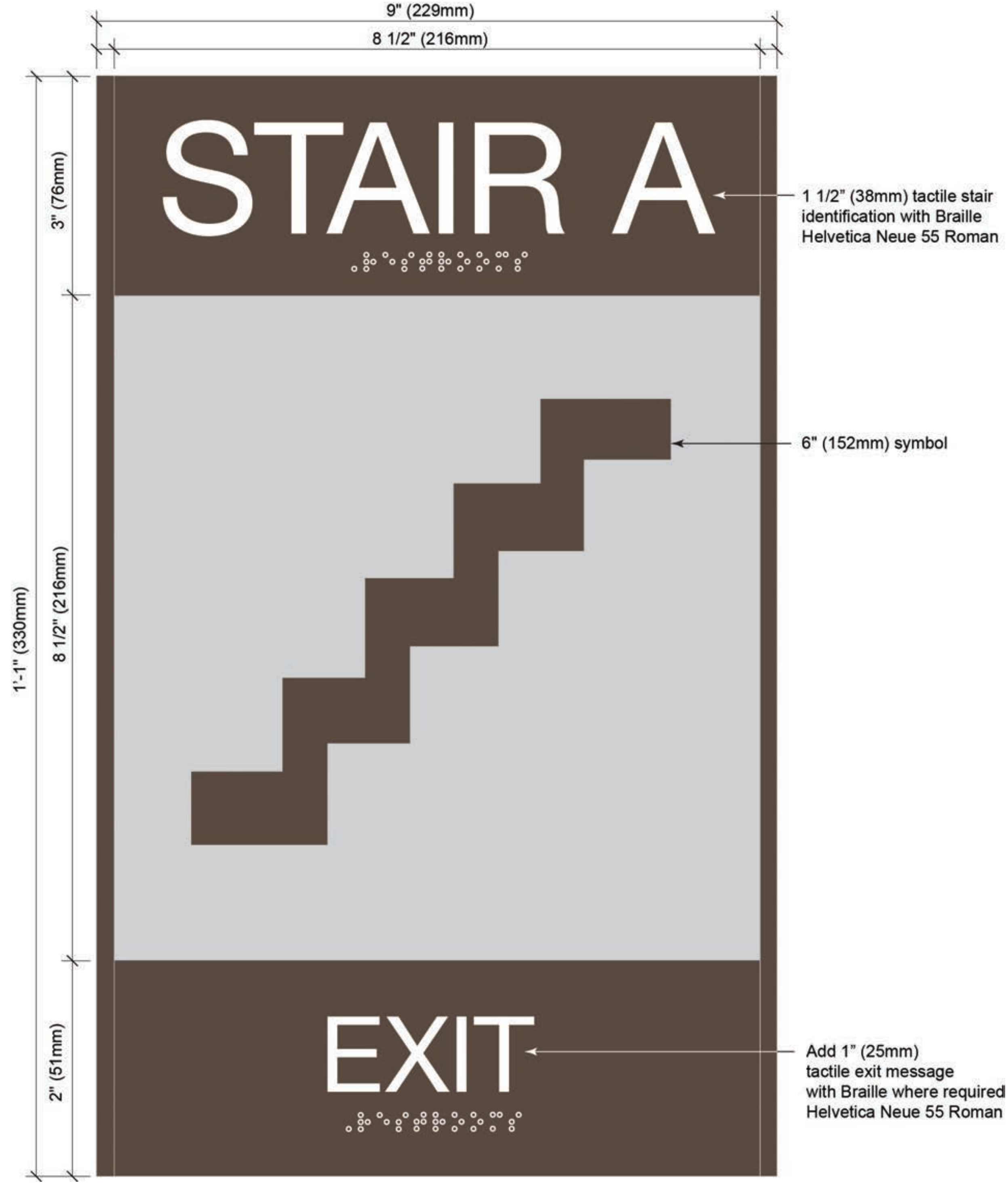
\1\ Figure 4-5 Non-Accessible Restroom Identification Signs. /1/



4-2.4 Stair Identification Signs.

Stair identification signs on the occupancy side of the entrance door are required on the wall next to the strike side of the door. Use tactile characters and Grade 2 Braille to identify each stairway entrance; also consider the need for including the architectural room number if this is beneficial for facilities management. Refer to current ABAAS requirements regarding stair sign identification, use of pictograms, symbols of accessibility, finish, and contrast. Pictograms are not required but may be used if desired for consistency with the overall sign program. The IBC requires that egress stairways be identified with a tactile sign stating “EXIT” in compliance with ICC/ANSI A117.1. Include exit information on stair identification signs to reduce visual clutter. Refer to Figure 4-6.

\1\ Figure 4-6 Stair Identification Signs. /1/



4-2.5 Typical Room and Space Identification Sign Installations.

Most room identification signs required by ABAAS must be installed adjacent to the strike side of the door. This requirement should be coordinated with the architectural and interior design team during the design development of the project. Mounting options will vary with each sign system. Refer to current ABAAS requirements regarding sign mounting height, use of pictograms, finish, and contrast. Since the signage system detailed in this UFC has built-in flexibility for modifying message inserts, most interior signs can be easily installed using a combination of clear silicone adhesive and double-sided foam tape. Another acceptable mounting method is concealed mechanical fasteners. Provide white vinyl backing of the same shape as the sign on the glass to conceal mounting tape whenever signs are installed on glass. Refer to Figures 4-7 and 4-8.

Figure 4-7 Typical Interior Sign Installations.

Typical Wall Sign Installation

Typical Door Mounted Installation

Figure 4-8 Typical Sign Installations on Glass.

Typical Glass Sign Installation

Typical Glass Installation Detail

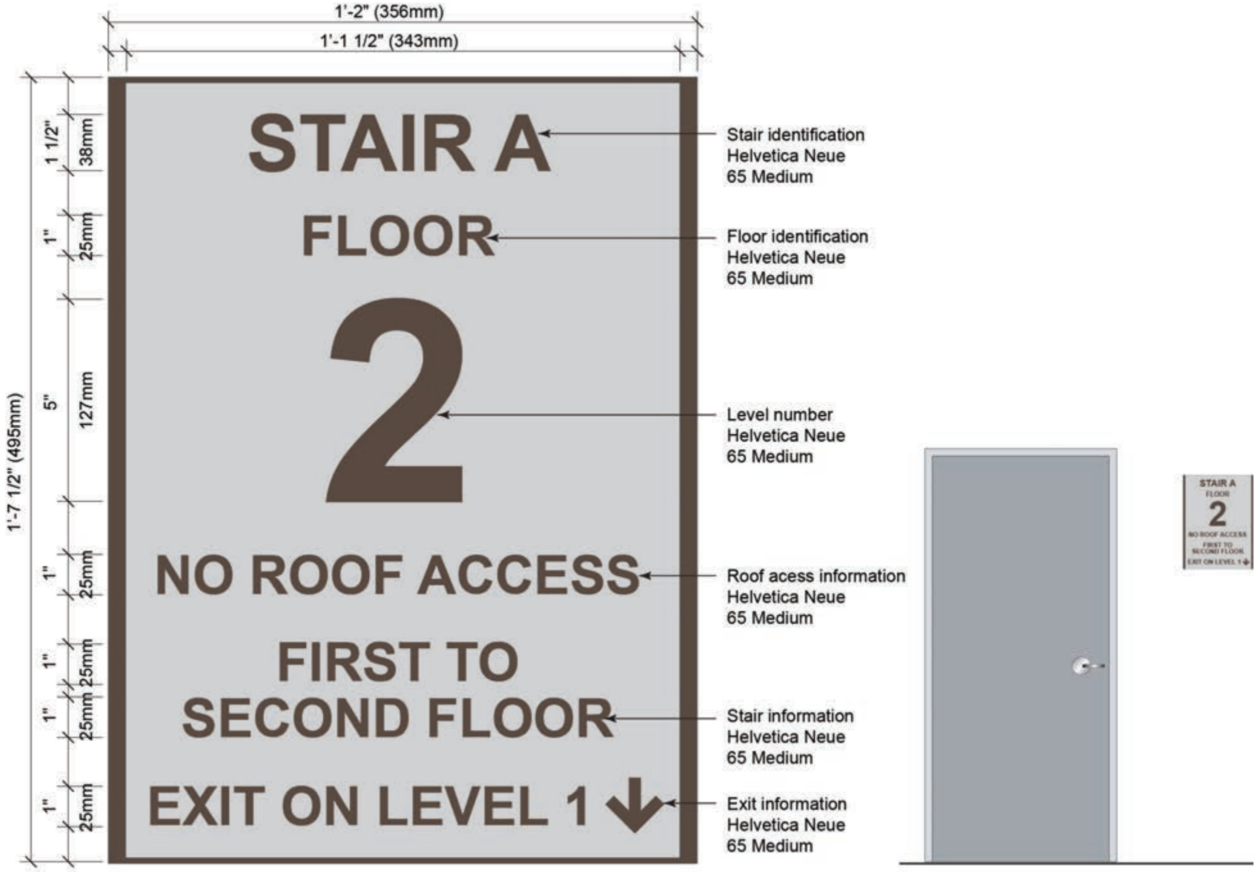
4-3 LIFE SAFETY SIGNS.

Life safety signs are required for building occupancy for every facility type. Provide life safety signs required by NFPA 101, such as exit identification, egress information, elevator information, fire extinguisher identification, and types of signs as required by the applicable life safety code requirements for each project.

4-3.1 Stairway Life Safety Signs.

Stairway life safety signs are required at each stairway landing for new enclosed stairs serving three or more stories and existing enclosed stairs serving five or more stories. Provide the required stairway identification and information at each stairway landing as required by NFPA 101. These sign messages require detailed information about building egress and also provide vital information for the fire department and other first responders. Ensure that these sign messages accurately reflect the current building conditions, such as level information, re-entry restrictions, roof access, and exiting information. Refer to Figure 4-9.

Figure 4-9 Stairway Life Safety Information.



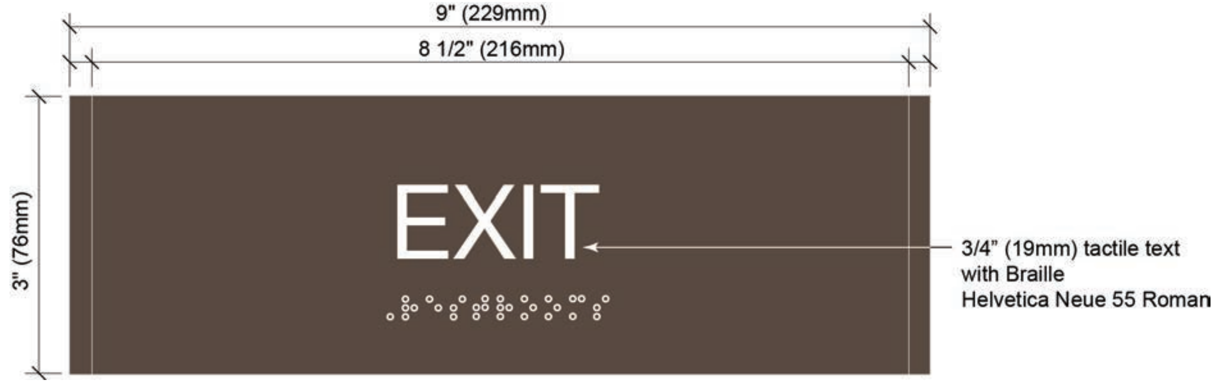
NFPA 101 Sign Message Example

NFPA 101 Sign Placement Example

4-3.2 Tactile Exit Signs.

Tactile exit signs must comply with ICC/ANSI A117.1 according to the current edition of the IBC. Provide signs at each exit door requiring an exit sign, including doors to areas of refuge. Consider including this required exit information on all stair identification signs that are egress stairways to minimize the number of signs required and also include other small exit signs where required. Refer to Figure 4-10.

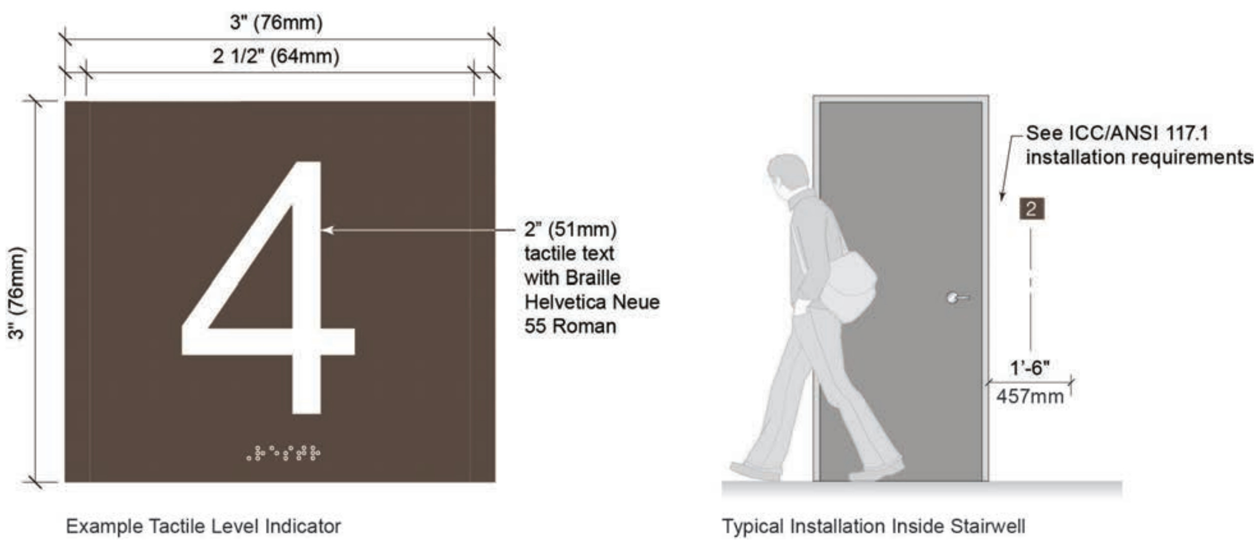
\1\ Figure 4-10 Tactile Exit Signs. /1/



4-3.3 Tactile Stairway Level Indicator Signs.

Provide small tactile level indicator signs adjacent to the door inside each stairway landing on the strike side as required by NFPA 101 (see Figure 4-11). Provide these signs at all stairway landings that do not require tactile exit signs.

\1\ Figure 4-11 Tactile Stairway Level Indicators. /1/



4-3.4 Life Safety Door-Mounted Signs.

The current edition of NFPA 101 requires a variety of door-mounted informational signs, depending upon the egress plans for each building and the door hardware. Provide signs as required to reflect information, such as key-operated locks, delayed-egress locking systems, access-controlled egress door assemblies, powered door leaf operation, and other NFPA and IBC sign requirements. Refer to Figure 4-12.

Figure 4-12 Life Safety Door Signs.

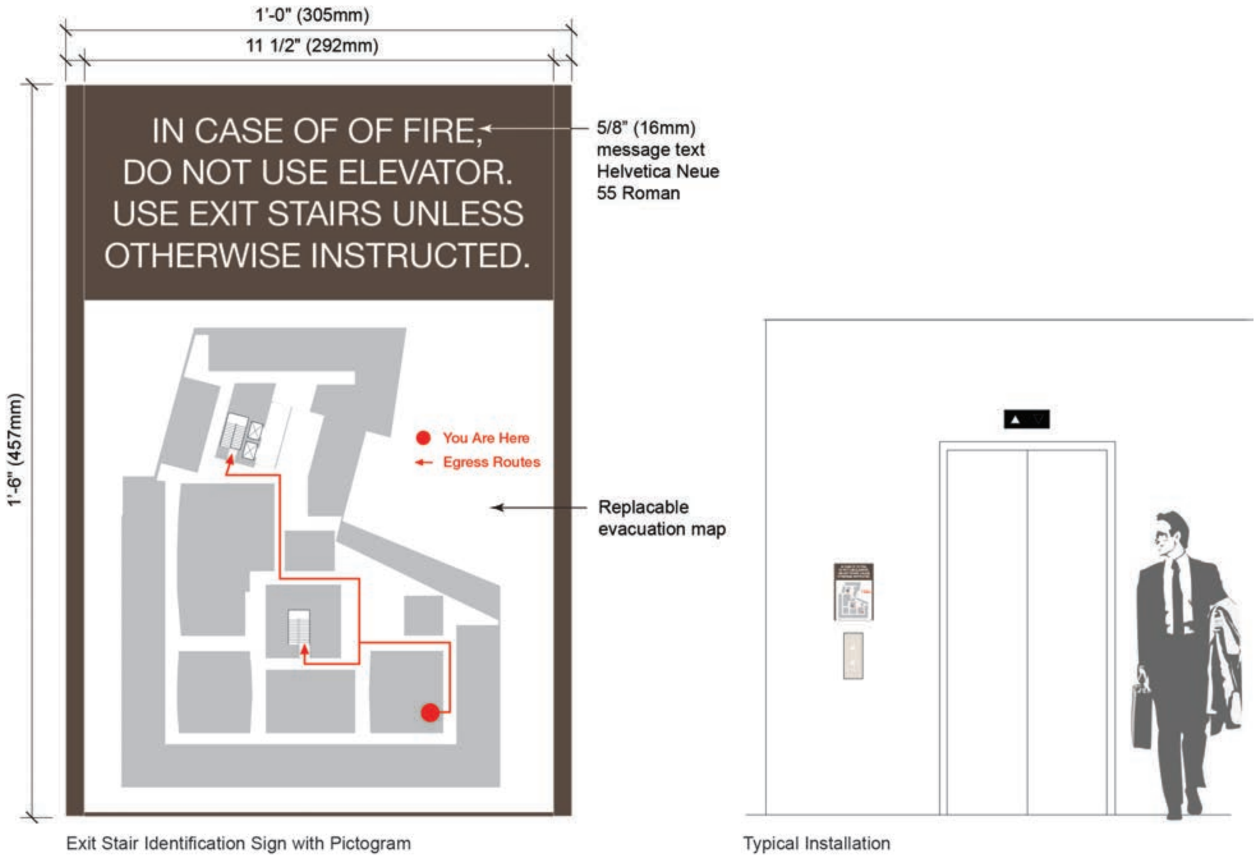
Example NFPA Life Safety Door Informational Signs

Typical Door Mounted Installation

4-3.5 Elevator Egress Signs.

Both NFPA 101 and the IBC have specific signage requirements for elevators. Elevator egress maps and artwork must be provided as part of the overall signage package. Consider the need for using replaceable map artwork that can be modified if there are future changes in the floor plan layout that may impact the provided egress information. Refer to Figure 4-13.

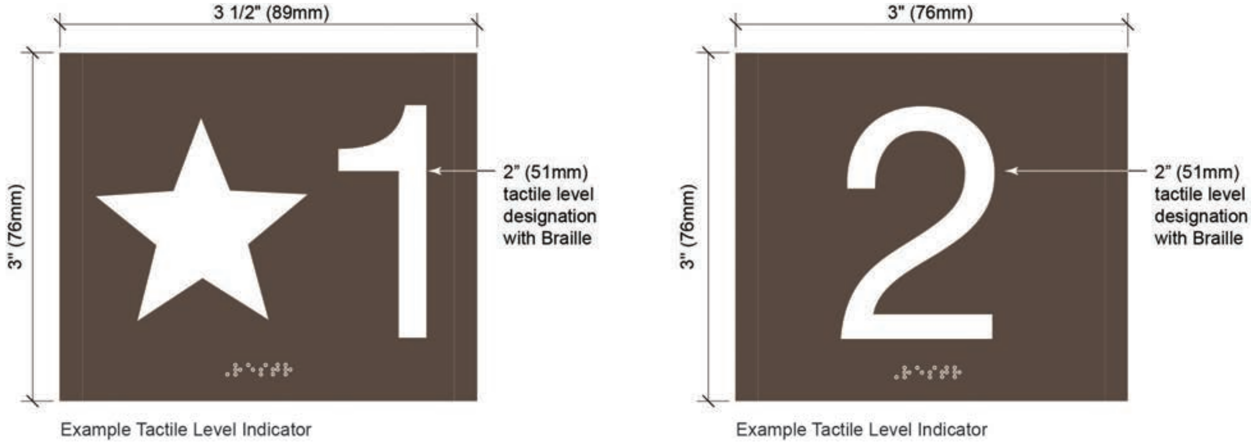
\1\ Figure 4-13 Elevator Egress Signs. /1/



4-3.6 Tactile Elevator Hoist Way Level Indicator Signs.

Tactile elevator hoist way level indicator signs are required on both elevator door jambs in compliance with the IBC (see Figure 4-14). Most tactile and Braille level indicator requirements are typically provided by the elevator contractor. Ensure that these requirements have been addressed or have them included in any new construction signage package.

\1\ Figure 4-14 Elevator Hoist Way Level Indicators. /1/



4-3.7 Additional Life Safety Signs.

There are a variety of other life safety signage requirements regarding NFPA 101 and the IBC that may also be required, such as maximum occupancy signs, two-way communication signs, area of refuge identification, and fire extinguisher identification. Some of the signs, such as fire extinguisher identification signs, are typically provided by the manufacturer of the equipment. Ensure the sign layouts, fonts, colors, and materials are consistent with the rest of the interior signage program.

4-4 INTERIOR DIRECTIONAL SIGNS.

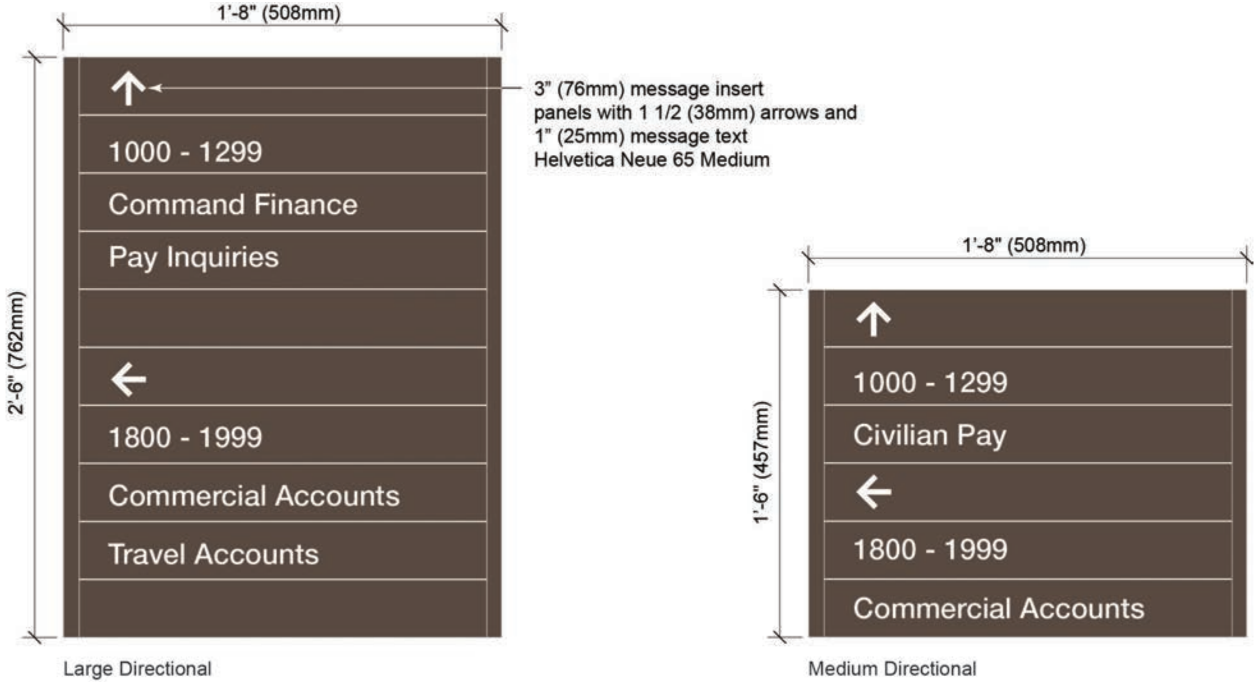
Provide directional signage that contains wayfinding information, identifies rooms or other destinations, and meets additional needs like code requirements. Coordinate the signage package with the architectural design to direct people to their destination and support facilities management activities. Implement signage standards that are designed as part of a wayfinding system integrated with other building systems and the overall project design.

Room or area identification, terminology guidelines, and room numbering strategies are also critical to the effective implementation of a signage program that facilitates wayfinding. This UFC provides guidelines for interior signs that address code requirements, size, appearance, messages, and graphic layouts. Provide strategic implementation of wayfinding signs that are integrated into the interior architecture. Implement an overall wayfinding philosophy that minimizes sign clutter by utilizing concise messages where they are needed most. Use signs of minimal size to communicate the required messages. Overloading the environment with excessive signage reduces their effectiveness. Directional signs should be located at each decision point in the path of travel, e.g., opposite elevators or stairwells.

4-4.1 Wall-Mounted Directional Signs.

Provide wall-mounted, eye-level directional signs at decision-making intersections or as required (see Figure 4-15). Wall-mounted signs are the most effective way to communicate multiple messages. Implement wall-mounted directional signs in a consistent and orderly manner to establish areas where people can look for information.

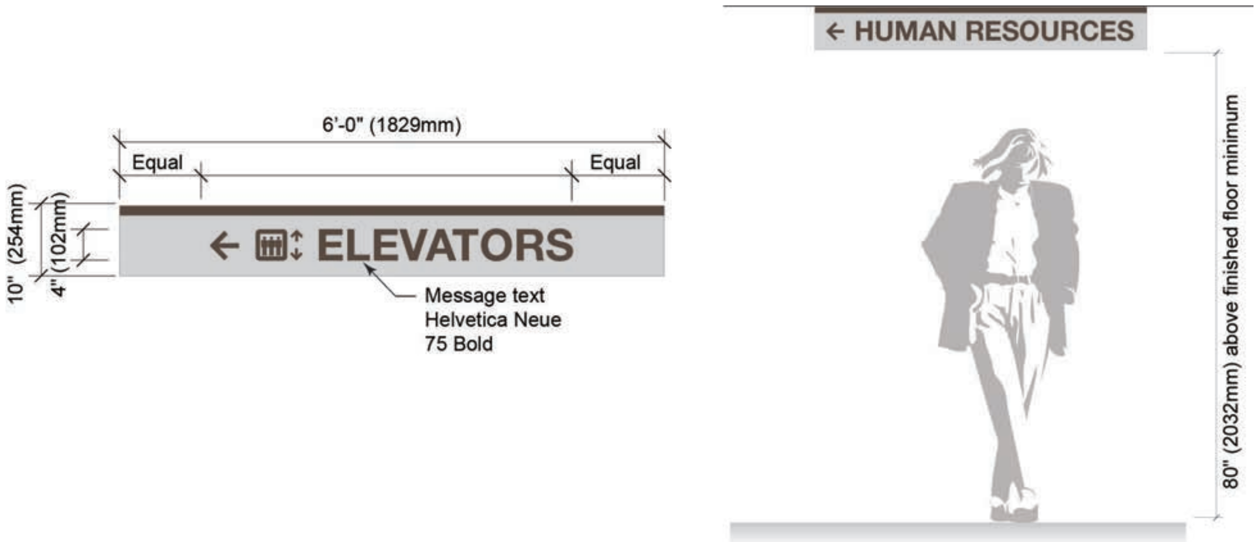
\1\ Figure 4-15 Interior Wall-Mounted Directional Signs. /1/



4-4.2 Ceiling-Mounted Directional Signs.

Ceiling-mounted directional signs may also be used where appropriate, but their use should be selective due to limitations on the quantity of sign messages and potential conflicts with the building infrastructure, e.g., lights, sprinklers, and video cameras. Refer to Figure 4-16. Ceiling-mounted directional signs may also be useful to designate the entrances to major departments or areas. These overhead signs also serve as good wayfinding aids by providing visual cues that visitors can see as they travel down long corridors.

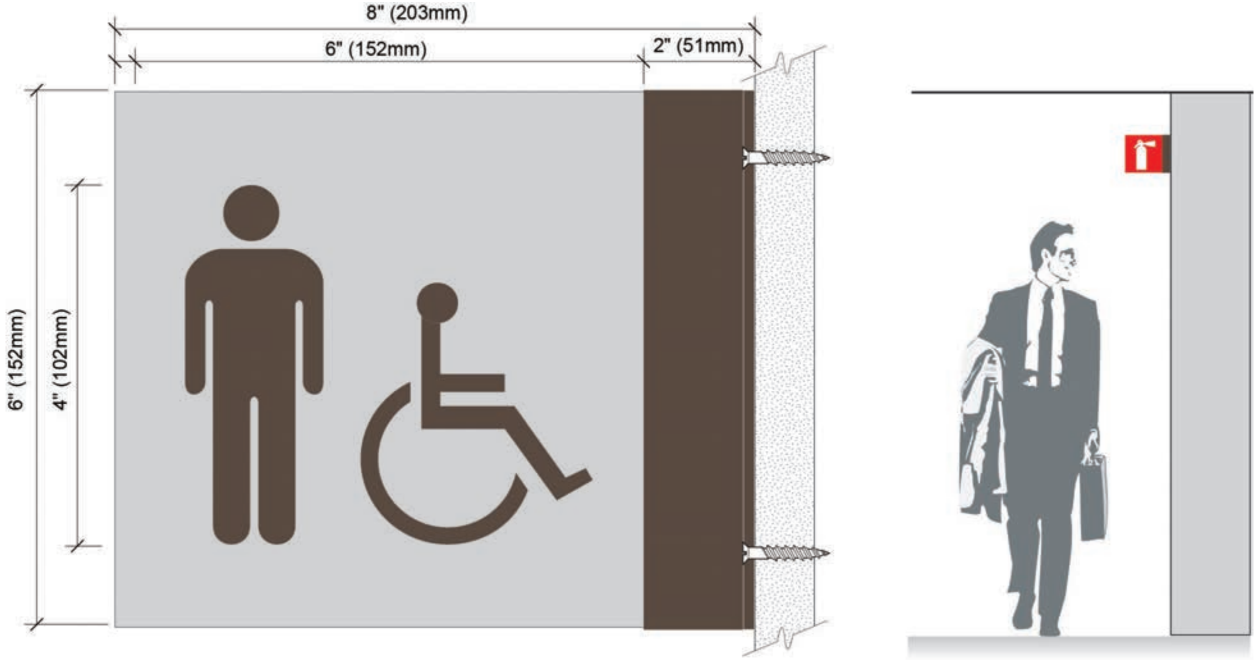
Figure 4-16 Ceiling-Mounted Directional Signs.



4-4.3 Flag-Mounted Signs.

The utilization of flag-mounted identification signs can help facilitate wayfinding by providing additional visual cues for users, especially down long corridors. These signs can help identify high-traffic rooms or amenities like conference rooms, restrooms, coffee/break rooms, and copy or print rooms. These signs are also useful to identify critical life safety items like fire extinguishers and automated external defibrillators. See Figure 4-17.

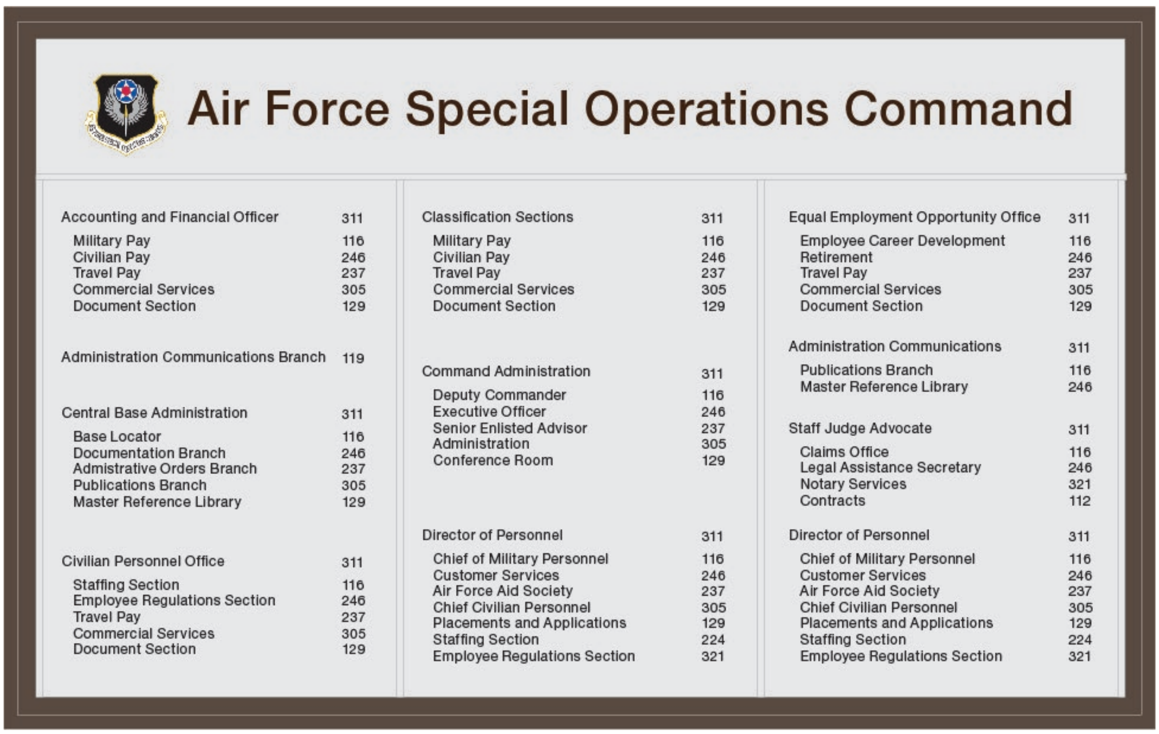
Figure 4-17 Flag-Mounted Signs.



4-5 BUILDING DIRECTORIES.

Provide building directories in major buildings to identify departments, offices, or other required information. Locate directories in the main entrance lobby where they are clearly visible to visitors as they enter the building. Most building directories have two components. The permanent header panel provides the name of the building or the major tenant organization name and/or emblem. The directory message content provides detailed information about destinations located in the building, such as the name of each tenant in the building, room numbers, and department names. Standard commercially available directories may be obtained from a wide variety of sign manufacturers. Coordinate the frame material with the architectural finishes. See Figure 4-18.

Figure 4-18 Building Directory.



4-5.1 Electronic Directories and Wayfinding Systems.

Use electronic or touch screen directories with orientation maps at strategic locations for large, high-profile facilities.

4-6 INTERIOR MANDATORY AND PROHIBITORY SIGNS.

There are many mandatory and prohibitory signs required inside military buildings. These signs may communicate messages that restrict, warn, and advise visitors and military personnel in matters of security and safety (see Figure 4-19). These signs should be designed to be flexible by using printed inserts that can be easily and inexpensively replaced as the room function or occupants change. Where needed, reinforce the meaning of the symbol with a word message for clarity. Sign messages and colors may vary but sign sizes should be consistent within a building.

Figure 4-19 Mandatory and Prohibitory Signs.

4-7 INTERIOR INFORMATIONAL AND MOTIVATIONAL SIGNS.

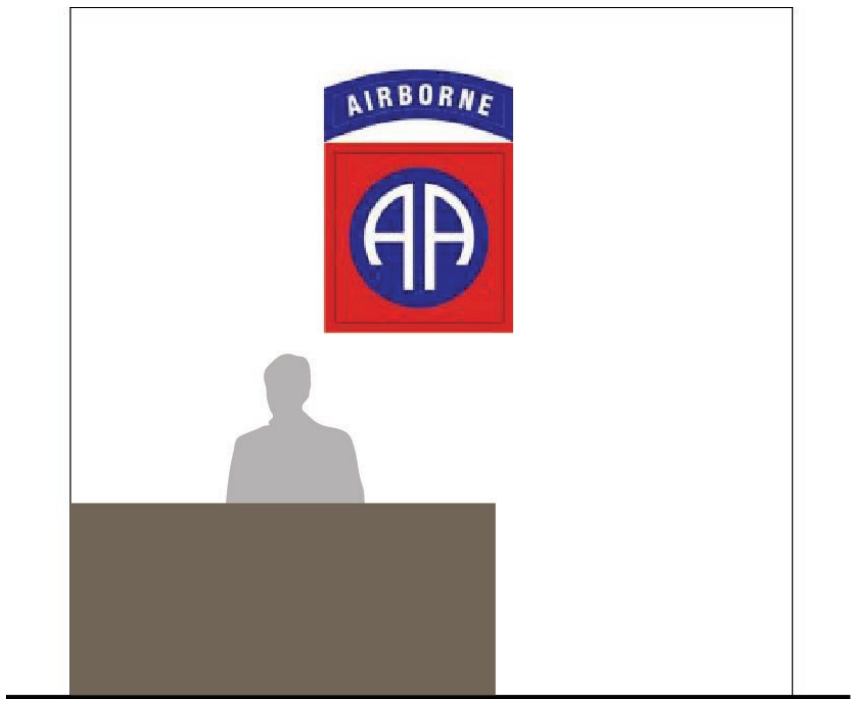
There may be a need to display informational and motivational signs on military facilities. Provide graphic information that educates visitors about the facility and the various services provided, where required. This may include orientation maps and directories. See Figure 4-20. These signs should be designed to be flexible by using printed inserts that can be easily and inexpensively replaced as the room function or occupants change. Using signs that accept standard paper sizes is most cost effective and efficient. Consider the need for both portrait and landscape versions of these signs. Provide required exterior- and interior-grade signs, depending upon the conditions where each sign will be installed.

Figure 4-20 Informational and Motivational Signs.

4-8 UNIT IDENTIFICATION AND MORALE SIGNS.

Unit identification and morale signs display organization emblems, mottoes, and awards. Refer to Figure 4-21. These signs should be placed at the principal arrival point for visitors and should be designed to easily accommodate changes in the message content as different units are deployed at each installation. If an organizational emblem is used on a unit identification sign or a building entry sign, it should not be repeated on a morale sign placed in the same area.

Figure 4-21 Unit Identification and Morale Sign.



APPENDIX A REFERENCES

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

A Policy on Geometric Design of Highways and Streets (Green Book)

Roadside Design Guide

FEDERAL HIGHWAY ADMINISTRATION

Manual on Uniform Traffic Control Devices (MUTCD), http://mutcd.fhwa.dot.gov/

Standard Alphabets for Highway Signs and Pavement Markings

Standard Highway Signs, http://mutcd.fhwa.dot.gov/ser-shs_millennium.htm

INSTITUTE OF TRANSPORTATION ENGINEERS (ITE)

Traffic Control Devices Handbook

INTERNATIONAL CODE COUNCIL (ICC)

International Building Code (IBC)

ICC/ANSI 117.1, *Accessibility Standard*

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA 101, *Life Safety Code*

SURFACE DEPLOYMENT AND DISTRIBUTION COMMAND TRANSPORTATION ENGINEERING AGENCY (SDDCTEA)

http://www.tea.army.mil/pubs/nr/DynaListDOD.asp?Cat_id=4&Sub_id=14&Topic_id=0&Cat_Name=DOD%20Programs%20for%20National%20Defense&Topic_Name=Pamphlets%2C%20Manuals%2C%20and%20Directories

DoD supplement to the MUTCD

Pamphlet 55-14, *Traffic Engineering for Better Signs and Markings*

Pamphlet 55-15, *Traffic Engineering for Better Entry Control Facilities*

Pamphlet 55-17, *Better Military Traffic Engineering*

UNIFIED FACILITIES CRITERIA

http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

UFC 2-100-01, *Installation Master Planning*

UFC 3-535-01, *Visual Air Navigation Facilities*

UNIFIED FACILTIES GUIDE SPECIFICATIONS

http://www.wbdg.org/ccb/browse_cat.php?c=3

UFGS 01 58 00, *Project Identification*

UFGS 10 14 01, *Exterior Signage*

UFGS 10 14 00.20, *Interior Signage*

UNITED STATES ACCESS BOARD

http://www.access-board.gov/guidelines-and-standards/buildings-and-sites/about-the-aba-standards/aba-standards

Architectural Barriers Act Accessibility Standard for Department of Defense Facilities (ABAAS)

APPENDIX B GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials
ABAAS	Architectural Barriers Act Accessibility Standards for Defense Department Facilities
ACP/ECF	Access Control Point/Entry Control Facility
IBC	International Building Code
ICC	International Code Council
IPS	Installation Planning Standards
ISA	International Symbol of Accessibility
ITE	Institute of Transportation Engineers
MUTCD	Manual on Uniform Traffic Control Devices
NFPA	National Fire Protection Association
SDDCTEA	Military Surface Deployment and Distribution Command Transportation Engineering Agency
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
DoD	Department of Defense
FHWA	Federal Highway Administration
PMS	Pantone Matching System
USDOT	U.S. Department of Transportation
ABA	Architectural Barriers Act
mm	millimeter

UFC 3-120-10
16 May 2018
Change 3, 22 May 2025

UNIFIED FACILITIES CRITERIA (UFC)

INTERIOR DESIGN

UNIFIED FACILITIES CRITERIA (UFC)

INTERIOR DESIGN

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\\ ... /**1**/)

Change No.	Date	Location
1	20 Apr 2021	1. Updated CAD standard information in paragraph 4-4. 2. Added reference to USACE Nomenclature document in paragraph 4-4.6. 3. Added bulleted item c, link to USACE Nomenclature document, to paragraph 5-3.1.2. 4. Added reference/link to USACE Nomenclature document in Appendix A.
2	15 Jun 2021	1. Added paragraph prohibiting the use of brand names and proprietary information; added bulleted item c; and deleted last subparagraph in paragraph 4-5.1. 2. Added reference to Pantone Color System in paragraph 4-5.1.1. 3. Deleted paragraph 4-5.1.2. 4. Deleted bulleted items d and p, requirements for manufacturer's contact information and dealer/vendor quotes in paragraph 5-4.7. 5. Deleted paragraph 5-4.9 Manufacturers Source List.
3	22 May 2025	1. Updated the language in the paragraph 1-2 to be in accordance with UFC 1-200-01. 2. Added cordless shades reference to paragraph 1-5.1. 3. Revised paragraph 3-4.1. 4. Added Paragraph 3-5 and Table 3-1 Design Stage Equivalency and removed percentages within the Design Stage paragraphs.

		5. Added references to UFC 3-520-01 and UFC 3-580-01 to paragraph 3-5.3. 6. Added cordless shades reference to paragraph 4-2.5. 7. Added reference to other Defense Agencies to section 5-1. 8. Added paragraph 5-2.3. 9. Updated Army Project references in paragraph 5-3.1.2. 10. Added paragraph 5-3.1.4. 11. Revised paragraph 5-4.6. 12. Removed first sentence of paragraph 5-4.9.1. 13. Updated Department of the Army and WBDG references in Appendix A.

This UFC is a revision to UFC 3-120-10 dated 15 June 2006 including Change 1, July 2007.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site https://wbdg.org/dod.

Hard copies of UFC printed from electronic media should be checked against the current electronic version prior to use to ensure that they are current.

AUTHORIZED BY:

LARRY D. MCCALLISTER, PHD, P.E., PMP, SES
Chief, Engineering and Construction
Directorate of Civil Works
U.S. Army Corps of Engineers

JOSEPH E. GOTT, P.E.

Chief Engineer
Naval Facilities Engineering Command

EDWIN H. OSHIBA, SES,
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection

MICHAEL McANDREW
Deputy Assistant Secretary of Defense
(Facilities Investment and Management)
Office of the Assistant Secretary of Defense
(Energy, Installations, and Environment)

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-120-10, *Interior Design*

Superseding:

- UFC 3-120-10, *Interior Design,* dated 15 June 2006, including Change 1, July 2007

Description: This UFC is a coordinated compilation of interior design requirements, and references non-government standards to the greatest extent practicable. It provides a succinct reference for interior designers to ensure that all requirements are met.

Reasons for Document:

- Defines the requirements for interior design work on military construction and renovation projects.
- Relies on a list of industry and government standards, codes and references; and
- Provides DoD sources for standards and guidance not otherwise addressed.

Impact: Cost impacts are negligible; however, design delays should decrease as all requirements for all services are now in a single, consolidated document that has been coordinated with other elements of construction and renovation projects.

Unification Issues

- Each agency has its own procurement process for Furniture, Fixture & Equipment, as directed by the Departments of the Air Force, Army and Navy; refer to Part 5.
- Army and Navy have specific Data Sheet Templates that are required for FF&E procurement; refer to Appendix D.

TABLE OF CONTENTS

FIGURES

TABLES

This Page Intentionally Left Blank

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC provides general guidance and outlines technical requirements that apply to both building-related and furniture-related interior design projects, new construction and renovation projects. The information provided in this UFC will be used by interior designers and architects that meet the interior designer qualifications and serves as the minimum interior design requirements. This UFC covers requirements for schematic design, design development and construction documents including drawings and specifications, procurement documentation and project presentations for Design-Bid-Build (DBB) and Design-Build (DB) projects.

Excellence in design is the primary goal for all projects. Reaching this goal requires a commitment by the Government and designers to a level of quality that includes the coordinated relationship of interior design with the building design, as well as the details of design that affect the users of the facilities. Quality interior design is value added to a project as it vitally improves facility operating efficiency, attractiveness, livability, functionality, life-cycle economics, and the productivity of the users. Project conditions may dictate the need for design that exceeds these minimum requirements.

1-2 APPLICABILITY.

\3 This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, with no exceptions. **/3/**

1-2.1 Funding.

1-2.1.1 Design.

Design funds are associated with the type of funding for construction. When construction is funded under the Military Construction (MILCON) program, MILCON funds are used for the SID and typically the FF&E designs. Funding of the SID and FF&E design is dependent on the project execution method (DBB or DB) and could be funded with MILCON Planning and Design (P&D) funds for DBB or MILCON construction funds for DB. Typically when a using agency identifies the requirement for furniture on DD Form 1391, this service will be provided from MILCON funds. When furniture is not listed on DD Form 1391, the FF&E design and review effort will be provided by the user with other funds. The design of FF&E for Facilities Sustainment, Restoration and Modernization (FSRM) projects is funded with Operations and Maintenance (O&M) funds. Non-Appropriated Funds (NAF) are used for the design of NAF projects. For projects whose construction is not associated with MILCON, either NAF or O&M funding could be used for the design of the FF&E package.

1-2.1.2 Construction.

Funding for the construction or renovation of a building may come from a broad range of sources. The most common sources in military programs are MILCON, NAF and O&M funds, but other funds may be used.

1-2.1.3 Furniture, Fixtures and Equipment Purchase and Installation.

FF&E is defined as movable personal property. In addition to the furniture funding, the user typically provides O&M or NAF funds to support the procurement, tracking, shipping, warehousing, installation, inspection, and other associated services.

1-3 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01 which provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and other UFCs and government criteria referenced therein.

1-4 REFERENCES.

Appendix A contains a list of references used in this document. The publication date of the code or standard is not included in this document. In general, the latest available issuance of the reference is used.

1-5 OVERVIEW OF MILITARY INTERIOR DESIGN.

Provide a Comprehensive Interior Design (CID) unless otherwise directed. A CID includes the SID and the FF&E design.

1-5.1 Structural Interior Design (SID).

The SID includes building-related design elements and components generally part of the building itself, such as walls, ceilings, floor coverings, primary window treatments (blinds, **\3** shades, drapery hardware, and cordless shades as a safety element **/3/**), signage and built-in casework. The interior designer must be involved with the programming and space planning to help achieve the user’s goals for space utilization and develop a furniture floor plan based on the project program. In addition, the interior designer must determine the desired interior finish materials based on the respective aesthetic, durability and maintenance qualities, and characteristics applicable to each space within the facility. The SID will be designed by a qualified interior designer in accordance with Chapter 2 paragraph “Interior Designer Qualifications.” See Chapter 4 for more detailed requirements for the SID.

1-5.2 Furniture, Fixtures and Equipment (FF&E) Design.

The design of the FF&E includes the layout, selection, specification and documentation of furniture, such as workstations, seating, tables, storage, filing, accessories, and artwork. The documentation facilitates furniture procurement and installation. The FF&E design is based on the furniture floor plan developed in the SID portion of the interior design. Items such as markerboards, bulletin boards and some primary window treatments may be specified in either the SID or the FF&E design. Secondary window treatments such as drapery, sheers and top treatments are typically included in the FF&E design. The FF&E will be designed by a qualified interior designer in accordance with Chapter 2 paragraph “Interior Designer Qualifications.” See Chapter 5 for more information on FF&E interior design requirements.

1-6 GLOSSARY.

Appendix E contains acronyms, abbreviations, and terms.

This Page Intentionally Left Blank

CHAPTER 2 TECHNICAL REQUIREMENTS

2-1 DESIGN REQUIREMENTS.

The interior designer must satisfy the following for each project:

a. Provide a design in accordance with agency standards.

b. Provide a design that is fully coordinated with architectural features, interior finish materials, furnishings, and building systems such as electrical (power, data, voice, audio visual and lighting), mechanical (Heating, Ventilation, & Air Conditioning (HVAC), fire protection and thermostats) and structural. Coordinate design with building maintenance and operations practices to include adequate space allowances for maintaining equipment. Comply with UFC 3-101-01.

c. Provide a flexible interior design that accommodates changing functional requirements. DoD may own or lease a building from its time of construction until the end of its useful life and its functional requirements may change.

d. Incorporate appropriate ergonomic principles in the facility and furniture design.

e. Comply with agency requirements for advanced modeling, to include 3D visualization, Building Information Modeling (BIM), facility data, quantity take-off, geospatial, etc.

   - For Army requirements, refer to USACE Minimum Model Matrix (M3) and Project Execution Plan (PxP) which outline required model uses. Refer to CAD BIM Technology Center (Contract Requirements) for more information on M3 and PxP.

   - For Navy requirements, refer to NAVFAC Building Information Management and Modeling (BIM).

   - For Air Force requirements, follow the Army standards. Refer to USACE Minimum Model Matrix (M3) and Project Execution Plan (PxP) which outline required model uses. Refer to CAD BIM Technology Center (Contract Requirements) for more information on M3 and PxP.

f. Provide a fully coordinated Comprehensive Interior Design (CID), unless otherwise directed, which includes:

   - Structural Interior Design (SID) and

   - Furniture, Fixtures and Equipment (FF&E) design.

2-2 INTERIOR DESIGNER QUALIFICATIONS.

Design and review must be performed by professional interior designers or architects with significant interior design experience. Qualification of designers is based on education, experience and examination. Interior designers or architects must have completed a program accredited by the Council for Interior Design Accreditation (CIDA) or equal accreditation program of academic training in interior design.

For contracted interior design services, the interior designer or architect must also have attained National Council for Interior Design Qualification (NCIDQ) certification or state licensure, certification or registration and must not be affiliated with a furniture dealership, vendor or manufacturer.

2-3 DESIGN CONSIDERATIONS.

Designers must consider interior design compatibility with the local environment, functional requirements, economy of construction, energy conservation, interior details, sustainable design and life cycle costs. Additionally, the interior design must be designed in harmony with the architectural character of existing facilities that are to remain, especially those that are considered historically or architecturally significant and must comply with the installation aesthetic. Design excellence must not add substantial project costs but balance the functionality, aesthetics, quality, sustainability and maintainability of facilities.

2-3.1 Cost Engineering.

Cost Engineering (CE) is an integral part of the design process. Comply with UFC 3-740-05.

2-3.2 Life-Cycle Costs.

Provide interior designs that achieve optimum life-cycle savings. Base design decisions on life-cycle cost considerations to determine an economical design for facilities. Take into account not only the initial construction costs but also the operating and maintenance costs of buildings, the associated impacts on productivity and the missions performed within the facility over their anticipated life. Conduct comparisons as needed to determine the most life-cycle cost effective materials, finishes, construction methods, furnishings and maintenance.

2-3.3 Health and Safety Criteria.

Design floor plans and specify building materials, furnishings and equipment with health and safety in mind. Designers must comply with the latest version of the International Building Code as modified by UFC 1-200-01, NFPA 101, and Occupational Safety and Health Administration (OSHA) Guidelines.

2-3.4 Interior Environmental Quality.

Designers must design an environment that is comfortable, welcoming and conducive to work or other prescribed activity. Contributing factors include proper HVAC, lighting, acoustics and furnishings. Acoustic design issues include speech privacy, sound isolation and sound masking; comply with UFC 3-450-01. Lighting, both artificial and daylight, is an important tool in shaping the ambiance of the environment; comply with UFC 3-530-01.

2-3.5 Wayfinding.

Provide methods of wayfinding throughout the facility, to include an interior signage package, and incorporating graphics, color and patterns as applicable. These design components must form a well-organized, comprehensive interior environment that guides users and visitors through the building to their destinations. Ensure that room numbering strategies used on the architectural and interior design plans align with wayfinding objectives. Comply with UFC 3-120-01.

2-3.6 Sustainable Design.

Sustainable design must comply with UFC 1-200-02. Refer to Appendix C-2.2 Best Practices for additional considerations and preferences. Interior design involves many sustainable requirements. Verify inclusion of all applicable requirements as early as possible in the design process.

2-3.7 Overseas Projects.

Overseas projects may have special interior design requirements based on availability of products and interior finish materials. Finish materials may need to be selected from products available within a certain geographical region. The RAL Colour Standard is an international color-matching system that can serve as a reference for painted and pre-finished interior finish materials. The AMS-STD-595 Colors Used in Government Procurement can also be used for this same purpose. It is recommended that special SID and FF&E requirements be identified early in the design process.

This Page Intentionally Left Blank

CHAPTER 3 INTERIOR DESIGN PROCESS

3-1 GENERAL.

A CID which includes both SID and FF&E design services, will be developed and coordinated with the building design in accordance with applicable design guides, the project delivery process, user requirements and project scope of work. A stand-alone SID or FF&E design may be required depending on project requirements. The following information outlines the interior design process using industry standard design stages and does not reflect the specific submittal phases in terms of percentages and terminology for each agency and type of project. Verify actual submittal phases required on a project-by-project basis as each agency will have its own specific requirements. The project scope of work must reflect project specific requirements.

3-2 PLANNING AND PROGRAMMING.

An interior designer should be involved during the initial programming and DD Form 1391 development and preparation, including information gathering or planning charrettes at the beginning of a project. The designer contributions during the planning and programming stage ensure that all applicable interior design issues are considered and evaluated as part of defining the project scope.

3-2.1 DD Form 1391.

The interior designer should be involved with the development of the DD Form 1391 which provides an estimated cost for furniture based on the FF&E Cost Estimating Guide or other historical project data. When furniture is required as part of a project, it must be specifically identified on the DD Form 1391. Furniture is included on the DD Form 1391 as “Equipment from other Appropriations (Non-Add)”. List the equipment as an O&M funded item, the Fiscal Year (FY) the funds are requested, and the line item cost. The FF&E budget must be verified by the O&M funding source. Any equipment included on the DD Form 1391 must be estimated separately from the furniture and added to the FF&E budget with applicable funding information.

3-3 PROJECT DELIVERY PROCESS.

The two main project delivery processes are Design-Bid-Build and Design-Build; other project delivery methods are possible.

3-3.1 Design-Bid-Build (DBB).

When the DBB project delivery process is used, the SID and FF&E design is typically developed by a single interior design source. The SID and FF&E portions of the interior design should be developed concurrently with the building design to ensure coordination with all building systems and construction documents. Provide a furniture plan for space planning and coordination with building systems when a FF&E design is not required. Coordinate the completion of the FF&E design, procurement and installation with the user’s Beneficial Occupancy Date (BOD). In some situations, a government interior designer or the contractor's interior designer performs the FF&E design instead of the Architect/Engineer (AE) interior designer who designed the SID portion of the project.

Refer to Appendix B for Table B3-1 Design-Bid-Build Project Delivery Process. The table outlines the stages the interior designer is involved during the DBB project delivery process, to include planning and programming, and design.

3-3.2 Design-Build (DB).

3-3.2.1 DB Pre-Award Development.

During the Request for Proposal (RFP) development, the interior designer will participate in the pre-design conference or design charrette to establish project requirements including interior material and finish requirements, space utilization, personnel requirements, SID and FF&E design requirements and FF&E acquisition strategy. The interior designer will develop the performance specifications for the SID and minimum furniture requirements for the FF&E design.

Refer to Appendix B for Table B3-2 Design-Build Pre-Award Project Delivery Process. The table outlines the interior design process and at what stage the designer is involved during the planning and programming efforts and DB RFP development.

3-3.2.2 DB Post Award.

The contractor's interior designer will meet with the government interior designer and user to review the DB RFP SID and FF&E design requirements and then complete the interior design.

Refer to Appendix B for Table B3-3 Design-Build Post Award Project Delivery Process. The table outlines the interior design process for DB after the construction contract has been awarded.

3-4 FURNITURE, FIXTURES AND EQUIPMENT (FF&E) ACQUISITION STRATEGY.

Verify the FF&E procurement methodology in coordination with the Government, facility design criteria and the project delivery process. Confirm what type of funds will be used to procure the FF&E package, for example, O&M or NAF funds. Coordinate the procurement method, format and schedule with the applicable contracting office for their specific requirements. Other items to consider are:

a. Include applicable purchasing fees or other known additional costs.

b. When Best Value Determinations (BVD) are performed, manufacturer's price quotes for backup and product mock-ups may be required, which may increase design fees and extend the design schedule.

c. Confirm if expiring funds can be obligated prior to the completion of the FF&E package; project coordination will be impacted.

d. Identify the project FF&E package funding source(s).

e. Confirm the project procurement office's interpretation of procurement regulations and what type of documentation is required.

3-4.1 Contractor Furnished Contractor Installed (CFCI) FF&E Package.

The contractor may procure and install the FF&E package, known as CFCI. Project coordination is minimized since the user has only one point of contact for a turnkey project. The FF&E design is prepared by the AE interior designer, the interior designer on the contractor's team, or by a government interior designer. The Government will provide separate funding for the actual purchase of the FF&E package including shipping and installation. **\3** Navy and USMC projects require BVDs as an integral part of the design and require the contractor to purchase the final approved FF&E package. /**3**/ The government interior designer must review the interior design deliverables to ensure the government procurement regulations and requirements are met.

Navy projects typically require the contractor to purchase the final approved FF&E package.

3-4.2 Government Furnished Government Installed (GFGI) FF&E Package.

The Government may procure and install the FF&E package independently of the building construction or renovation, known as GFGI. The FF&E design is prepared by an AE interior designer or by a government interior designer. The FF&E package is procured through DoD agencies or non-DoD Agencies, such as the General Services Administration (GSA), Fleet Logistics Command (FLC) and U.S. Army Engineering and Support Center Huntsville (HNC). In this case, the project delivery team must plan for extensive coordination between the building design, the FF&E design, changing construction schedules, and furniture delivery schedules. Other issues to consider in this acquisition strategy are:

a. The procurement agency may not have the technical expertise to purchase large projects or understand the need to purchase FF&E packages without deviating from the design intent. Technical evaluations may need to be performed by the AE interior designer, the contractor's interior designer, or the appropriate government interior designer.

b. Non-DoD procurement agencies may require an Interagency Agreement to procure the FF&E package.

3-4.3 Government Furnished Contractor Installed (GFCI) FF&E Package.

The Government may have the contractor install government furnished new or existing furniture as part of its scope of work, known as GFCI. This may be accomplished with either the Design-Build or Design-Bid-Build acquisition strategies. A FF&E design may be required for reconfiguration of existing furniture and for additional furniture to match existing furniture. Consider costs required for furniture inventory, storage, relocation, planning, phasing and temporary office space when planning to re-use existing furniture. The design team must research the availability of any new furniture required to match existing, and coordinate the construction schedule and new furniture delivery schedules.

3-5 DESIGN STAGES.

\3 Design stage names, percent completion, and submittal requirements vary by service. Confirm the actual submittal requirements with the appropriate service submission criteria. Based upon the scope of a specific project, submittals may be omitted or combined at the discretion of the project design team. The following table and paragraphs are intended to give a general framework for interior design development throughout the design stages. Refer to Appendix B for tables correlating interior design processes/involvement during all design stages for various acquisition strategies.

Table 3-1: Design Stage Equivalency

Design Stage	Tri-Service Submittal Equivalency		
	Air Force	Army	Navy & Marine Corps
Pre-design/ Parametric design	Schematic/Concept Design (10-15%)	Parametric Design (5-15%)	Preliminary Design (0-10%)
Schematic Design	Design Submittal (35%)	Concept Design (35%)	Schematic Design (10-15%)
Design Development	Prefinal Design Submittal (65%)	Interim Design (65%)	Design Development (35-50%)
Construction Documents	Design Submittal (95%)	Final Design (95%)	Pre-Final (100%)
Design complete	Final Design Submittal (100%)	Corrected Final (100%)	Final

/3/

3-5.1 Pre-design/Parametric Design.

During the **\3** pre-design/parametric design phase, the interior designer will participate in the pre-design conference/planning charrette to meet with representatives of the user and the buildings design team to assist with space planning, room-by-room program development, and identification of furniture, fixtures and equipment (FF&E) items. Documentation is typically provided in the form of a parametric design report, planning charrette report or design analysis. A cost estimate for planning purposes may be required. **/3/**

3-5.2 Schematic Design.

During the schematic design stage **\3\ /3/** the interior designer will meet with representatives of the user and the building design team to determine the design concept. The schematic design must be described in the design analysis as required in the project delivery process. The schematic design must meet the user's functional, physical, and aesthetic needs. **\3**

3-5.2.1 DB RFP Development

During the DB RFP project delivery process the interior designer will participate in the pre-design conference or design charrette to establish the RFP SID and FF&E design requirements. During the DB Post Award project delivery process the interior designer will participate in the pre-design conference or design charrette to verify the RFP requirements before proceeding with design development. **/3/**

3-5.3 Design Development.

Upon approval of the schematic design, the interior designer will further develop the design. The designer will participate in the floor plan development and contribute to the interior architectural detailing. The designer will select the appropriate interior finish materials, develop furniture layout and specifications. **\3** The interior designer will develop documents including adjacencies, space utilization, space planning, personnel requirements, furniture plan and FF&E item list. A cost estimate for planning purposes may be required. **/3/** Ensure architectural and engineering disciplines are coordinated with the interior design during design development through construction documents. Locations of equipment, casework, lighting, power and communication, electrical and fire protection panels, and sprinklers must be considered. \3\ /3/

3-5.4 Construction Documents.

During the pre/final stages of a project **\3\ /3/** the interior designer will complete the SID and FF&E design in sufficient detail to ensure successful execution. Coordinate specifications with the final drawings, schedules and details as well as furniture types and layouts with other disciplines. Coordinate placement of equipment such as motorized projection screens and computerized directory systems with electrical systems. **\3** Furniture that requires coordination with electrical or telecommunications systems or both including, but not limited to, systems furniture, powered high-density filing, powered conference and training tables, refer to UFC 3-520-01 Interior Electrical Systems and UFC 3-580-01 Telecommunications Interior Infrastructure Planning And Design for additional requirements. **/3/** Confirm furniture coordination with building elements such as power and communication sources, ceiling heights, column placement, lighting, wall switches, thermostats, alarm panels, and window placement. **3**\ /**3**/

3-5.5 Project Review.

When the design is performed by an AE, direct communication with the government reviewers (project manager, users, and interior designer) is required. This will avoid unnecessary submittal of plans and specifications due to misunderstandings. The reviewer's name, phone number and email address can be found on the comment sheets. The government reviewer(s) will provide comments regarding corrections or clarifications to be incorporated into contract documents at each design submittal. The interior designer will ensure that comments are incorporated into the subsequent submittal, or the reason for not incorporating the comment must be thoroughly documented in the AE's response to the comment. The Army and the Navy use a web-based government review management system called DrChecks, which will be used if indicated in the contract.

This same review process applies to projects designed by government interior designers.

3-6 CONSTRUCTION AND FF&E PACKAGE PROCUREMENT PHASES.

The interior designer or government construction representative will verify that equipment, architectural features, mechanical components and electrical devices are coordinated with the furniture plans and installed properly during building construction.

FF&E delivery and installation will be coordinated with the Government so it will be completed by the user's BOD. Note that a Construction Completion Date (CCD) may occur significantly before the user's BOD, depending on the procurement method selected. FF&E activities during this phase include procurement, tracking of orders, warehousing, delivery, assembly and installation, and verification that the FF&E received match the procurement documents, shop drawings and specifications. When FF&E design services are provided, the interior designer may be required to provide additional services in accordance with the project scope of work to include:

a. Consultation during procurement, delivery and installation of FF&E;

b. Evaluation of the FF&E submittal and assistance in reviewing deviations from the specified FF&E package to avoid installation of inferior or inappropriate FF&E items; and

c. Quality Assurance of furniture and furniture installation to include walk through and punch list.

3-7 POST OCCUPANCY.

When required by the Government, conduct a Post Occupancy Evaluation (POE) of the project approximately one year after construction completion or as directed. POE is required to determine the effectiveness of the design. This evaluation involves inspection of the completed facility by a team composed of members of the project delivery team, the facility management office, and the user. The POE is also used by the project delivery team to improve the project delivery and design process.

This Page Intentionally Left Blank

CHAPTER 4 STRUCTURAL INTERIOR DESIGN

4-1 GENERAL.

The Structural Interior Design (SID) involves the design, selection and specification of applied finishes and building interior features including, but not limited to, walls, floors, ceilings, trims, doors, windows, window treatments, built-in items and installed equipment, lighting, and signage. The SID package includes furniture floor plans, finish schedules, color boards and any supporting interior elevations, details or plans necessary to communicate the building finish design and build out. The SID provides basic space planning for anticipated FF&E design requirements in conjunction with the functional layout of the building and design issues such as life safety, privacy, acoustics, lighting, ventilation, and accessibility.

4-2 SPECIFIC MATERIAL CONSIDERATIONS.

The following paragraphs address special considerations and issues for selecting and specifying materials and finishes, however, these do not cover all finishes normally incorporated into design projects.

For Air Force projects, refer to the individual base Installation Facility Standards (IFS) for additional guidance.

4-2.1 Gypsum Board.

Select gypsum board product appropriate for application in specific situations. Considerations for fire-resistance, high traffic areas, exposure to moisture, water resistance, and radio frequency shielding must be taken into account and coordinated with the overall function of the facility. Identify areas such as backsplashes in breakrooms and tiled walls at water fountains. Refer to UFC 3-101-01 and Unified Facility Guide Specifications (UFGS) 09 29 00 for additional information concerning product selection.

4-2.2 Paint.

Paint selection and specification will be based on the UFGS 09 90 00 Paints and Coatings. Each coating category is identified in the Master Painter's Institute (MPI) "Approved Products List" as either having been performance tested or categorized for intended use. Select paints and coatings from MPI's "Detailed Performance Standards" which are paints and coatings that have been tested to specific performance standards. Do not use MPI's "Intended Use" standards, as they have not been tested against the performance standards. Refer to the Master Painters Institute (MPI) "Architectural Painting Specification Manual" for more information.

4-2.3 Carpet.

Where carpet is required, each project has specific carpet requirements in regards to performance, aesthetics, functional use and maintenance. Refer to the UFGS 09 68 00

Carpeting for guidance on selections and discussion on standards and performance. The use of a multi-colored or patterned carpet is recommended due to superior soil hiding capabilities.

4-2.4 Wallcovering.

Breathable wall coverings are required where used on the interior face of exterior walls in environments with high humidity where mold frequently occurs. Refer to Indoor Air Quality and Mold Prevention of the Building Envelope on the WBDG web page for more information. Also refer to UFGS 09 72 00 Wallcoverings.

4-2.5 Window Treatments.

Maintain uniformity of window treatments and color for primary window treatments such as blinds and roller shades which are viewed from the outside of the building. Primary window treatments may be included in the SID and the construction documents. Secondary window treatments such as drapery, sheers and top treatments are specified as required on a project-by-project basis and are usually included in the FF&E package. **\3** Consider the use of cordless shades as a safety element. **/3/**

4-2.6 Interior Signage.

Ensure that interior signage schedules and details are incorporated into the contract documents. If room names are subject to frequent change, an interchangeable message strip will be used to facilitate removal and replacement. Signage typical drawings and schedules must be coordinated with UFGS 10 14 00.20 Interior Signage. Comply with UFC 3-120-01.

4-3 DESIGN ANALYSIS.

Provide a design analysis that describes the basis of design, building-related finishes and furniture floor plan development and features as it relates to the user's requirements and building design. Include topics that relate to installation standards, life safety, aesthetics and durability

4-4 INTERIOR DESIGN DRAWINGS.

Interior design building-related drawings must indicate the placement and extents of SID materials, finishes and colors and must be sufficiently detailed to define all interior work. Refer to the A/E/C CAD Standard for information such as **\1** level/layer assignments, electronic file naming, and standard symbology **/1/**. Minimum required drawings may include, but are not limited to, the following list and those listed in UFC 3-101-01:

a. Room Finish Schedule

b. Finish Schedule and Finish Legend

c. Interior Finish Plans

d. Reflected Ceiling Plans

e. Interior Building Elevations, Sections and Details

f. Furniture Floor Plans

g. Interior Signage

4-4.1 Room Finish Schedule.

The interior designer is responsible for selection, coordination and specification of interior finish materials. Provide a detailed Room Finish Schedule keyed to the Finish Schedule and Finish Legend, to include finish materials and colors for floors, walls, and ceilings, with special features noted on a per room basis. Obtain input from the user and the government architectural and interior design representatives. The interior design drawings must be fully coordinated with UFGS.

4-4.2 Finish Schedule and Finish Legend.

Provide a Finish Schedule or Finish Legend, or a Finish Schedule and Finish Legend on the drawings, or use UFGS 09 06 00 Schedule for Finishes. Refer to paragraph 4-5.1 for additional requirements.

4-4.3 Interior Finish Plans.

Provide Interior Finish Plans that indicate floor patterns, finish and color placement, material transitions and extents of interior finishes.

4-4.4 Reflected Ceiling Plans.

Provide Reflected Ceiling Plans that show the ceiling tile layout where applicable and all light fixtures, air diffusers, grilles, registers, and other ceiling mounted items.

4-4.5 Interior Building Elevations, Sections and Details

Provide Interior Building Elevations, Sections and Details that indicate material, color and finish placement, and wall patterns. Include casework sections and details, transition details, and critical dimensions.

4-4.6 Furniture Floor Plans.

Incorporate FF&E design requirements throughout the design process. The interior designer will work directly with the user to assess their needs and develop furniture requirements for each space within the facility. Develop the Furniture Floor Plans to show that the furniture necessary for the user's functional requirements can be accommodated within the spaces and satisfy applicable life safety codes. The Furniture Floor Plans will show the appropriate size and type of furniture and include critical and required clearances. Code furniture on Furniture Floor Plans to furniture legends. **\1** For Army projects, refer to USACE Furniture Item Description for Standard FF&E

Nomenclature document. **/1/** The Furniture Floor Plans and documented user requirements serve as the basis for a fully integrated building design as well as the basis for the FF&E design. Coordinate equipment items to be included in the FF&E design with the Government.

The interior designer may not be responsible for specifying equipment, but in coordination with the architect and engineers is responsible for identifying the requirements for equipment items regarding space allocation and coordination with building systems. When the design of the FF&E package is included in the building design scope of work, the Furniture Floor Plans will be fully developed, along with the FF&E package. If the FF&E package is not included as part of the building design, ensure that the Furniture Floor Plans are clearly noted “Not in Contract.” Furniture Floor Plans must be included throughout the design delivery process. Furniture must be coordinated with locations of items such as equipment and casework, lighting, power and communication, electrical and fire protection panels, and sprinklers.

4-4.7 Interior Signage Drawings.

Provide typical sign drawings, plans and details which indicate size, type, location and signage schedule for all signs. The sign symbol on the drawings must be keyed to the signage schedule, which includes the locations, messages, symbols, and other related information. Indicate the location of every sign and directory in the facility. Incorporate building or floor directories and directional signage for larger facilities based on project requirements. The typical sign drawings and schedule, including sign locations, may be included in the specification or as an attachment to the specifications instead of on the drawings.

4-5 SPECIFICATIONS.

Design-Bid-Build and Design-Build projects have differing specification requirements. In either case, the specifications must be as concise as possible, definitive, and free of ambiguities and omissions that may result in controversy and contractor claims for additional compensation. Unified Facilities Guide Specifications provide important information on government quality standards and submittal requirements and should be used as the basis for project specifications. These specifications are available on the WBDG web page Unified Facilities Guide Specifications. UFC 1-300-02 provides guidance on the preparation of specifications.

4-5.1 Finish Schedule and Finish Legend.

\2 Per 2017 NDAA – Section 888, the use of brand names or brand-name or equivalent descriptions, or proprietary specifications or standards is prohibited in Department of Defense solicitations unless a justification for such specification is provided and approved in accordance with section 2304(f) of title 10, United States Code. **/2/**

The interior designer must provide all finish and color selections including finish code, **\2** materials, textures, patterns, and general color **/2/** for all interior finishes and specialties which will be exposed to view in the finished construction. The Government will direct which of the following methods to use.

a. The UFGS 09 06 00 Schedules for Finishes guide specification may be used to document finish and color selections. This specification has been fully integrated as a reference in all UFGSs that require a **\2\ /2/** material, color and finish reference.

b. If the UFGS 09 06 00 is not used, provide a Finish Schedule or Finish Legend, or a Finish Schedule and Finish Legend on the drawings associated with the Room Finish Schedule as per 4-4.2. **\2**

c. When proprietary information cannot be included on the drawings, additional requirements shall be set forth for the contractor to submit complete color boards for the entire project, prior to the submittal and approval of individual finish submittals. This shall be reviewed and approved by the DOR to verify overall building coordination and aesthetic. **/2/**

\2\ /2/

4-5.1.1 Federal Standard Colors.

The current AMS-STD-595 Colors Used in Government Procurement **\2** or the Pantone Color System **/2/** is to be used when required by installation specific criteria. The use of this standardized method of defining colors and finishes varies on a project-by-project basis.

\2\ /2/

4-6 SID BINDER.

SID binder or binders must display actual interior finish color samples proposed for the project. Color boards are required at various submittal phases as noted in the project scope of work. Submit SID information and samples in three ring binder with pockets on the inside of the covers. When samples are numerous or thick, use more than one binder. Each binder must have a table of contents and be labeled on the outside spine and front cover with the following information: Structural Interior Design (SID), design stage, date, design firm, project title and number, location and volume number. Include a copy of the Room Finish Schedule, UFGS 09 06 00 Schedules for Finishes or the Finish Schedule and Finish Legend, and Interior Finish Plans. Provide 8 ½ inch x 11 inch or 11 inch x 17 inch binders; large format color boards and color boards with fold outs can also be used. Coordinate the SID binder format and any specific requirements with the project scope of work. The SID binder may be electronic except for the finish boards with actual finishes. Also provide an electronic copy of the SID binder to include the finish boards to keep on file with the drawings and specifications.

4-6.1 Finish Color Boards for SID Binder.

Finish color boards must be sturdy enough to support samples. When required, use page protectors that are strong enough to keep pages from tearing out. Anchor large or heavy samples with mechanical fasteners, Velcro, or double-faced foam tape rather than rubber cement or glue. Label finish samples with the finish codes used in the contract documents. Samples that are difficult to attach, or large samples, such as ceiling tiles or flooring samples can be provided separately from the color board in a loose sleeve. Samples must be labeled with the finish code so they can be identified independently if removed from the binder. Manufacturer name and number may be included.

Provide actual samples of finishes that indicate true color, pattern and texture. Finish samples must be large enough to show a complete pattern or design where practical. Also provide a color illustration of materials or fabrics when necessary to show large overall patterns. For example, if the specified carpet has a large pattern, provide a color photocopy showing the overall pattern in addition to the carpet sample with representative colors.

4-7 LARGE SCALE PRESENTATION BOARDS.

In addition to the SID binder, large-scale finish color boards may be required for presentations. Boards must be sufficiently rigid to support heavy samples. Finish materials must be labeled to fully coordinate with the contract documents. Finish samples must represent true color, pattern, and texture. Samples must be large enough to indicate any pattern repeats where practical. Provide a label or title block identifying the design stage, project title and location, design firm, construction contract numbers, and date. Separate boards must be submitted for interior finishes. A copy of the Room Finish Schedule and Finish Schedule and Finish Legend must be attached to the back of the board or provided in a separate binder that is labeled the same as the SID binder.

4-8 PERSPECTIVE SKETCHES, VIEWS AND RENDERINGS.

Provide perspective sketches, views and renderings when required by the project scope of work.

4-9 SID DESIGN SUBMITTAL REQUIREMENTS MATRIX.

See Appendix B for Table B4-1 SID Design Submittal Requirements Matrix. The table indicates what components are typically included in each submittal. The submittal phases are representative and will vary due to the project delivery process. The project scope of work will define the SID requirements, submittals, and number of submittals on a project-by-project basis. SID submittals should run concurrent with architectural submittals.

Resubmittal of the SID binder is not required if there are no changes from the previous design submittal. Provide updated cover and spine for insertion into the previously submitted SID binder. If only minor changes are required, resubmit applicable coded samples (tape ready for application), updated binder cover and spine, corrected Room Finish Schedule, UFGS 09 06 00 Schedules for Finishes or Finish Schedule and Finish Legend, Interior Finish Plans, and Design Analysis. If major changes to the color boards are required, resubmit with color samples of all proposed interior finishes, updated binder cover and spine, corrected Room Finish Schedule, UFGS 09 06 00 Schedules for Finishes or Finish Schedule and Finish Legend, Interior Finish Plans, and Design Analysis.

This Page Intentionally Left Blank

CHAPTER 5 FURNITURE, FIXTURES AND EQUIPMENT INTERIOR DESIGN

5-1 GENERAL.

The Furniture, Fixtures and Equipment (FF&E) design includes the selection, specification, color coordination and procurement documentation of the required items necessary to meet the functional, operational, sustainability, and aesthetic needs of the facility. The FF&E package includes information required for purchasing and installing the furniture such as drawings, specifications, finishes and cost estimates. The interior designer will select and specify colors, fabrics, and furniture finishes to coordinate with the SID interior finish materials. The selection of furniture style, function and configuration will be coordinated with the user's requirements. Examples of FF&E items are workstations, seating, tables, storage, filing, accessories, and artwork. Items such as markerboards, tackboards, and presentation screens are typically included in the SID but can also be included in the FF&E design if necessary. Secondary window treatments such as draperies, sheers and top treatments are specified as required on a project-by-project basis and are included as part of the FF&E design. Criteria for furniture selection will include functional and ergonomic considerations, maintenance, durability, sustainability, comfort and cost. Also, the designer may have to consider reuse of and coordination with existing furniture.

The FF&E budget, the user's program requirements and the furniture plans will be the basis for the FF&E design. The designer will work directly with the user to assess their needs and develop a list of furniture required for each space within the facility. The FF&E package will be developed and coordinated with the building design as required by the project delivery process and the acquisition strategy. The designer will coordinate product lead times with the construction completion dates. Refer to Chapter 3 Interior Design Process.

Equipment not included in MILCON construction may or may not be included in the FF&E package, depending on the funding used. The user may provide specifications for specialized equipment. The Army and Air Force do not include equipment in their FF&E package. The Navy typically includes equipment in their FF&E packages where appropriate. **\3** For other Defense Agencies, refer to their FF&E requirements. **/3/**

For Navy projects refer to NAVFAC Collateral Equipment (FF&E) Criteria & Templates for additional information.

5-2 SOURCES OF SUPPLY FOR FF&E DESIGN.

Federal Acquisition Regulations (FAR) Part 8 directly affects the interior design process by outlining the required sources of supplies and services and their use. Of particular importance to the process of developing and procuring FF&E design is paragraph 8.002, Priorities for Use of Mandatory Government Sources.

FF&E items are typically specified through government sources of supply such as GSA Schedules, Federal Prison Industries, Inc. (UNICOR), GSA Global Supply Catalog, Ability One, or Air Force and Navy Blanket Purchase Agreements (BPA)s when applicable. Additional sources include GSA Advantage, or Air Force Non-Appropriated Funds Purchasing Office (AFNAFPO). These government sources of supply may not be available for overseas facilities; coordinate with the government project delivery team and the project scope of work.

If open market procurement of an item is necessary, the interior designer is required to prepare adequate written justification, giving reasons why the item(s) must be procured through the open market. Coordinate requirement with the appropriate purchasing office or contracting officer.

5-2.1 Air Force BPAs and Contracts.

For information on the Air Force's Systems Furniture and Modular Furniture mandatory contracts, contact the Air Force Furnishings Commodity Council at AF.FCC.Systems.Furni@us.af.mil.

Additionally, the AF mandatory BPA's for Executive case goods, seating and files are located on GSA Advantage.

5-2.2 Navy BPAs.

Consult with Navy interior designer for current NAVSUP BPA vendor list. See NAVFAC Collateral Equipment (FF&E) Criteria & Templates.**\3**

5-2.3 Other Defense Agencies.

Refer to agency specific guidance. **/3/**

5-3 FF&E DESIGN SUBMITTAL REQUIREMENTS.

The FF&E package is used for purchasing furniture for new or renovated facilities. It can also become the record and resource document for facilities management personnel to reference for repairing or replacing furniture and reordering additional items.

Information and samples are to be submitted in 8 1/2 inch x 11 inch (216 mm x 279 mm) format using three ring binders with pockets on the inside of the covers. When there are numerous pages with thick samples, use more than one binder. Fold out items must have a maximum spread of 25 1/2 inches (635 mm). Each binder must have a table of contents and be labeled on the outside spine and front cover with the following information: Furniture, Fixtures and Equipment (FF&E), design stage, date, design firm, project title and number, location and volume number. All pages in the binder will include the project name and location, project number, and design submittal phase. Binder information may be electronic except for the finish board with actual finishes. Also include an electronic copy of the binder information to include the finish board.

The requirements of the FF&E package must be coordinated with the government interior designer as well as with the contracting specialists or designated contracting official. The project scope of work must reflect project specific requirements. Comply with the following requirements unless otherwise directed.

5-3.1 Agency Specific Requirements.

5-3.1.1 Navy Projects.

Coordinate the procurement documents with the government interior designer and Collateral Equipment Manager. See NAVFAC Collateral Equipment (FF&E) Criteria & Templates for Navy information.

5-3.1.2 Army Projects.

Provide non-proprietary, project specific salient characteristics for the items specified.

a. **\3** Utilize the USACE Standard FF&E Nomenclature document. See USACE Standard FF&E Nomenclature for Army information.

b. Refer to UFGS 01 33 16.00 10 Design Data (Design After Award) for Design-Build Interior Design specific requirements.

c. HNC Purchased Furniture - All Army MILCON, Sustainment Restoration and Modernization (SRM), Initial Issue and Replacement Unaccompanied Housing (UH) FF&E procurements are centrally administered through HNC, per IMCOM (Installation Management Command) Narrative Funding Guidance.

    i. For a list of approved items for procurement through HNC, refer to HNC Centralized Furnishings Program – Ancillary Items Authorized for Procurement Matrix.

    ii. HNC Furnishings Program supports all DoD Components. Refer to the HNC Furnishings Program MRSI Website for furniture construction standards, additional information, and contacts.

d. Contractor Furnished Contractor Installed (CFCI) Furniture - Include specification UFGS 12 50 00.13 10 Furniture and Furniture Installation or a comparable specification in the contract documents. Specification to include non-proprietary, project specific, salient characteristics for furniture items. A FF&E package is required as an attachment to UFGS 12 50 00.13 10 but may not be required for other comparable specifications. When including a FF&E attachment, omit unit, extended or shipping costs on data sheets. Cost estimate should only be provided for review purposes and not included with the solicitation documents. **/3/**

5-3.1.3 Air Force Projects.

For CFCI furniture follow project CFCI requirements and provide non-proprietary, project specific salient characteristics for the items specified. **\3**

5-3.1.4 Other Defense Agencies.

Refer to agency specific guidance. **/3/**

5-4 FF&E PACKAGE COMPONENTS.

Provide the following components:

5-4.1 Design Analysis.

Provide a design analysis that describes the design objectives as they relate to the selection of furniture, finishes and colors and the furniture plan development and features and how project specific requirements are met. Include design decisions made to fully coordinate the SID and the FF&E design, including function, safety and ergonomic considerations, durability, sustainability and aesthetics.

5-4.2 Point of Contact List.

Provide a comprehensive list of Points of Contacts (POCs). This includes appropriate project team members, user contacts, interior design representatives, contractors and installers involved in the project. In addition to name, address, phone number and email, include each contact's job description.

5-4.3 Itemized Furniture Cost Estimate.

Provide an itemized cost estimate of furniture keyed to the plans and the data sheets. Organize by and include furniture item code and item name so the estimate can also be used as the item code legend. Base the estimate on applicable pricing to include GSA, Navy BPAs, and Air Force BPAs and contracts. The estimate must include percentage allowances for general contingency, shipping, inflation and installation costs, listed as separate line items. Consult with the government interior designer for any additional costs to be included. Installation and freight quotes from vendors should be used in lieu of a percentage allowance when available.

5-4.4 Item Code Legend.

Provide a consolidated list of all FF&E items in the package with the item code and name of each item. Organize item codes by product category such as workstations, seating and tables.

5-4.5 Item Installation List.

The Item Code Legend may be expanded to be used as an Item Installation List. Indicate quantity per room, model number and manufacturer of each furniture item. This provides a quick reference for managing larger furniture installations.

5-4.6 Best Value Determination (BVD).

The purpose of the BVD is to provide a contracting officer with the proper documentation to assist in determining that the FF&E package meets the FAR. A complete and well-written BVD is the first step in ensuring the FF&E package will be purchased as designed. Coordinate with the contracting officer and government interior designer on the procurement source of supply and associated BVD requirements to be incorporated into the FF&E package. Provide BVDs for orders over the current Micro-Purchase Threshold. Typically, furniture must be evaluated through market research and price comparisons. The documentation will list the types of furniture, the three or more required vendors considered for the item, the price of the three or more considered, and a brief statement why the selected furniture items are the "best value" to the Government. **\3** Typically, Army and Air Force projects do not require BVDs. For Navy projects also see NAVFAC Collateral Equipment (FF&E) Criteria & Templates for additional information. For other Defense Agencies, refer to agency specific guidance. **/3/**

5-4.7 Data Sheets.

One data sheet will be prepared for each item specified in the design. This form identifies all information required to order each individual item. The data sheet typically includes:

a. Item Code and Name

b. General Services Administration (GSA) Schedule Information:

- Federal Supply Category (FSC) Group and Part number and Special Item Number (SIN)
- GSA contract number and expiration date
- GSA contractor name, ordering address, phone number, and email or website

c. Provide BPA and contract information for applicable Air Force and Navy projects:

- BPA and contract number, and expiration date
- BPA and contractor name, address (ordering and payment), phone number, and email or website

\2\ /2/

d. Federal Stock information (if applicable)

e. Product specification information, manufacturer's item name, series, model number, dimensions and description to include minimum quality standards, construction materials and methods, configuration, features, options, warranty and any critical dimensions

f. Finish and fabric information coded to the finish color boards

g. Illustration must be close to the actual item specified or it must be noted that it is representative or similar

h. Quantity by room number and name

i. Total quantity of items

j. Unit cost

k. Total cost

l. Shipping costs

m. Special Instructions for ordering such as packaging information, mounting height information, and installation coordination notes (can be included in description)

n. Interior Design Source contact – whether it be the AE interior designer, or the government interior designer

\2\ /2/

The goal is to provide this information on one page, however, if necessary, a second page may be used for additional detailed specifications. Open market justifications and any other critical procurement information must be indicated. The Data Sheets are to be organized by product category in the binder and keyed to the Item Code Legend. Refer to Appendix D for examples of agency specific data sheets.

5-4.8 Furniture Material Boards.

The finish and fabric samples on the boards must be labeled and keyed to the item codes and names used on the Data Sheets and the Furniture Plans.

5-4.8.1 Finish Color Boards.

Provide Finish Color Boards with actual finishes and fabric samples. Color boards must be in 8 1/2 inch x 11 inch (216 mm x 279 mm) format and must be sturdy enough to support the samples. When needed, use page protectors that are strong enough to keep pages from tearing out. Large samples in protective sleeves must be labeled with the item code so they can be identified independently if removed from the binder. Samples must indicate true color, pattern, and texture. Use photographs or color photocopies of materials or fabrics to show large overall patterns in conjunction with samples to show the true colors. Samples must be large enough to show a complete pattern or design where practical. Provide a label or header identifying the design stage, project title and location, design firm, construction contract numbers, and date on each board.

5-4.8.2 Furniture Presentation Boards.

Large-scale Furniture Presentation Boards may also be required for presentations to illustrate typical products proposed for the project and their associated finishes and fabrics samples. Boards must be sufficiently rigid to support heavy samples. Samples must represent true color, pattern, and texture and must be large enough to indicate any pattern repeats where practical. Color photocopies of artwork and plants are acceptable. Provide a label or title block identifying the design stage, project title and location, design firm, construction contract numbers, and date on each board.

\2\ /2/

5-4.9 Furniture Plans.

Provide furniture plans to indicate locations of all furniture, equipment and accessories. Also provide furniture power, voice and data plans, panel plans and legends. Furniture plans must include composite and area plans; area plans must have key plans. Identify these items with an item code that is keyed to the Data Sheets and the finish color boards. Each drawing sheet shall include a legend listing all furniture item codes and names. Provide to scale as required by scope of work. Typically, furniture plans will be the same scale as the architectural drawings. Some projects may require furniture plans for individual rooms or areas to show furniture in sufficient detail for installation. Examples of this include enlarged plans for systems furniture or individual room drawings where typical room configurations are repeated throughout a project. Refer to the A/E/C CAD Standard for drawing requirements. The furniture plans will be included in both the SID drawings and in the FF&E package.

5-4.9.1 Systems Furniture.

\3\ /3/ Provide large scaled plans and elevations/isometrics (minimum 1/2 inch = 1 foot – 0 inches) (.5 mm = 305 mm showing workstation typical configurations which clearly identify major workstation components to include but not be limited to panels, storage, worksurfaces, accessories (such as monitor arms and keyboard trays), and task lighting. Include location of all power, voice and data outlets and indicate height on panels by note or symbol. Refer to UFGS 12 59 00 Systems Furniture for specifications or NAVFAC Collateral Equipment (FF&E) Criteria & Templates for Navy Performance Criteria Documents.

5-4.9.2 Artwork Placement Plans.

If the artwork locations and item codes cannot be clearly shown on the furniture plans, provide separate artwork placement plans. Ensure that mounting heights and special installation instructions are indicated on the plans and on the Data Sheets.

5-5 FF&E DESIGN SUBMITTAL REQUIREMENTS MATRIX.

Refer to Appendix B for Table B5-1 FF&E Design Submittal Requirements Matrix. The table indicates what components are typically included in each submittal. The submittal phases are representative and will vary due to the project delivery process. The project scope of work will define the FF&E package requirements, submittals, and number of submittals on a project-by-project basis.

Resubmittal of the FF&E binder is not required if there are no changes from the previous design submittal. Provide updated cover and spine for insertion into the previously submitted FF&E binder. If only minor changes are required, resubmit applicable coded samples (tape ready for application), updated binder cover and spine, and corrected FF&E components. If major changes to the color boards are required, resubmit with color samples of all proposed finishes, updated binder cover and spine, and corrected FF&E components.

APPENDIX A REFERENCES

Note: The most recent edition of referenced publication applies, unless otherwise specified.

A/E/C CAD STANDARD

\3 https://cadbimcenter.erdc.dren.mil/default.aspx?p=a&i=7&t=1 **/3/**

CAD BIM TECHNOLOGY CENTER

https://cadbimcenter.erdc.dren.mil/default.aspx?p=a&t=1&i=14

FF&E SOURCES OF SUPPLY

Ability One, https://www.abilityone.gov/

Federal Acquisition Regulations ***(FAR) PART 8****,* https://www.acquisition.gov/?q=browsefar

Federal Prison Industries, Inc. (UNICOR), https://www.unicor.gov/Shopping/viewCat_m.asp?iStore=UNI

GSA Advantage, https://www.gsaadvantage.gov

GSA Global Supply Catalog, https://www.gsaglobalsupply.gsa.gov

GSA Schedules, https://www.gsaelibrary.gsa.gov/ElibMain/ScheduleList%3bjsessionid=www.gsaelibrary.gsa.gov-881f:403294b2:c56e211b4174c7c3

MISCELLANEOUS

AMS-STD-595, *Colors Used in Government Procurement* https://ams-std-595-color.com/

Master Painters Institute (MPI), *Architectural Painting Specification Manual,* www.paintinfo.com

The RAL Colour Standard, https://www.ral-farben.de/en/

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA 101, *Life Safety Code,* https://www.nfpa.org/

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

https://www.osha.gov

\3\ /3/

UNIFIED FACILITIES CRITERIA

\3 https://www.wbdg.org/dod/ufc **/3/**

UFC 1-200-01, *DoD Building Code* (*General Building Requirements)*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 1-300-02, *Unified Facilities Guide Specifications (UFGS) Format Standard*

UFC 3-101-01, *Architecture*

UFC 3-120-01, *Design: Sign Standards*

UFC 3-450-01, *Noise and Vibration Control*

UFC 3-530-01, *Design: Interior and Exterior Lighting Systems and Controls*

\3 UFC 3-520-01, *Interior Electrical Systems*

UFC 3-580-01, *Information and Communications Technology Infrastructure Planning and Design* **/3/**

UFC 3-600-01, *Design: Fire Protection Engineering for Facilities*

UFC 3-740-05, *Handbook: Construction Cost Estimating*

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS)

\3 https://www.wbdg.org/dod/ufgs **/3/**

UNITED STATES DEPARTMENT OF THE AIR FORCE

Air Force Installation Facilities Standards (IFS), **\3** https://www.wbdg.org/airforce/ifs **/3/**

\1\ UNITED STATES DEPARTMENT OF THE ARMY /1/ \3

USACE Standard FF&E Nomenclature, https://rfpwizard.mrsi.erdc.dren.mil/MRSI/content/Furniture/furniture_home_page/Library/USACE%20Standard%20FFE%20Nomenclature_Feb%2024.pdf

HNC Centralized Furnishings Program – Ancillary Items Authorized for Procurement Matrix, https://rfpwizard.mrsi.erdc.dren.mil/MRSI/content/Furniture/furniture_home_page/Library/HNC%20Centralized%20Furnishings%20Program%20-%20Ancillary%20Buys_Feb%2024.pdf

HNC Furnishings Program, https://mrsi.erdc.dren.mil/furniture/ **/3/**

UNITED STATES DEPARTMENT OF THE NAVY

NAVFAC Building Information Management and Modeling (BIM) & Facility Electronic Operation and Maintenance Support Information (eOMSI) Program, **\3** https://www.wbdg.org/navy/bim-eomsi **/3/**

NAVFAC Collateral Equipment (FF&E) Criteria & Templates, **\3** https://www.wbdg.org/navy/ffe-criteria-templates **/3/**

WHOLE BUILDING DESIGN GUIDE, A PROGRAM OF THE NATIONAL INSTITUTE OF BUILDING SCIENCES

Whole Building Design Guide, https://www.wbdg.org

Criteria Change Request, https://cms.wbdg.org/ccrs/new?ufc=3-120-10

Indoor Air Quality and Mold Prevention of the Building Envelope http://www.wbdg.org/resources/indoor-air-quality-and-mold-prevention-building-envelope

OMB Circular A131 Value Engineering, **\3** https://whitehouse.gov/wp-content/uploads/legacy_drupal_files/omb/circulars/A131/a131-122013.pdf **/3/**

USD (AT&L) Memorandum, **\3** https://www.wbdg.org/FFC/DOD/ufc_implementation.pdf **/3/**

This Page Intentionally Left Blank

APPENDIX B TABLES

Table B3-1 Design-Bid-Build Project Delivery Process

INTERIOR DESIGN PROCESS (AE or Govt.)	DBB BUILDING DESIGN PROCESS							
	Planning and Programming Phase	Schematic Design	Design Development	Construction Documents	Construction Award	Construction	Beneficial Occupancy	Post Occupancy Evaluation
PLANNING AND PROGRAMMING								
Planning and Programming Charrette/Conference								
Generate Programming Documents								
Develop DD1391 & FF&E Cost Estimate								
DESIGN								
Pre-Design Conference/Design Charrette								
Establish SID/FF&E Requirements								
Establish/Verify FF&E Acquisition Strategy								
Structural Interior Design								

INTERIOR DESIGN PROCESS (AE or Govt.)	DBB BUILDING DESIGN PROCESS (continued)							
	Planning and Programming Phase	Schematic Design	Design Development	Construction Documents	Construction Award	Construction	Beneficial Occupancy	Post Occupancy Evaluation
FF&E Pre-Design Conference (May Complete during Pre-Design Conference/Design Charrette)						*		
FF&E Submittal						*		
Obtain Funding from Funding Source						*		
Field Verification & Review of SID Finish Submittals with Contracting Officer								
Procurement of Furniture								
Furniture Delivery and Installation								
Quality Assurance Review of FF&E								
Photography of Complete Interior								
Post Occupancy Evaluation								

*Applies to Navy Only

Table B3-2 Design-Build Pre-Award Project Delivery Process

INTERIOR DESIGN PROCESS (AE or Govt.)	DB SOLICITATION PROCESS				
	Planning and Programming Phase	Schematic Design	Design Development	Construction Documents	Construction Award
PLANNING AND PROGRAMMING					
Planning and Programming Conference					
Generate Programming Documents					
Develop DD1391 & FF&E Cost Estimate					
RFP DEVELOPMENT					
Pre-Design Conference/Design Charrette					
Establish SID/FF&E Requirements					
Establish/Verify FF&E Acquisition Strategy					
Generate SID Performance Specifications					
Generate FF&E Minimum Furniture Requirements					
Advertise and Award Design-Build Request for Proposal					

Table B3-3 Design-Build Post Award Project Delivery Process

INTERIOR DESIGN PROCESS (AE or Govt.)	**DB DESIGN AND CONSTRUCTION PROCESS**				
	Design Development	Construction Documents	Construction	Beneficial Occupancy	Post Occupancy Evaluation
Pre-Design Conference/ Design Charrette	■				
Verify SID/FF&E Requirements	■				
SID/FF&E Design	■	■			
Contractor Obtain Authorization to Procure through Govt. Sources		■	■		
Procurement of Furniture			■		
Furniture Delivery and Installation				■	
Photography of Complete Interior				■	
Post Occupancy Evaluation					■

Table B4-1 SID Design Submittal Requirements Matrix

SID COMPONENTS	Schematic Design	Design Development	Construction Documents
Design Analysis	■	■	■
Furniture Floor Plan	■	■	■
Room Finish Schedule	■	■	■
Other Drawings such as Interior Finish Plans, Elevations, Signage		■	■
Specifications		■	■
Finish Schedules and Legends, or UFGS 09 06 00 Schedules for Finishes		■	■
SID Binder		■	■
Large Scale Presentation Boards (if required)		■	■
Perspective Sketch(s) or View(s) (if required). One will be approved for the interior rendering.		■	■
Interior Color Rendering(s) (if required)			■
Hard Copy and Electronic File of Design Documents and SID Binder		■	■

Table B5-1 FF&E Design Submittal Requirements Matrix

FF&E COMPONENTS	Schematic Design	Design Development	Construction Documents	DBB - During Construction
Design Analysis				*
Point of Contact List				*
Itemized Furniture Cost Estimate				*
Item Code Legend (required) or Item Installation List (if required)				*
Best Value Determination Form - appropriate sample form for established procurement method and source of supply (if required)				*
Best Value Determination Forms for All Items (if required)				*
Data Sheet (sample form only)				
Data Sheet (all items)				*
Finish Color Boards				*
Furniture Presentation Boards (if required)				

*Applies to Navy Only

FF&E COMPONENTS (continued)	Schematic Design	Design Development	Construction Documents	DBB - During Construction
Manufacturers Source List (if required)				*
Perspective Sketch(s) or View(s) (if required). One will be approved for the interior rendering.				*
Interior Color Rendering(s) (if required)				*
Furniture Plans with Conventional and Systems Furniture				*
Artwork Placement Plans (if required)				*
System Furniture Panel Plans (if required)				*
System Furniture Power, Voice and Data Plans to include Legend				*
System Furniture Workstation Typical Plans and Elevations/Isometrics				*
Building Power, Voice and Data Plans to include Legend and Audio/Visual Information				*
Hard Copy and Electronic Files of Design Documents and Finish Color Boards				*

*Applies to Navy Only

This Page Intentionally Left Blank

APPENDIX C BEST PRACTICES

C-1 INTRODUCTION.

This appendix identifies background information, good interior design practices, and DoD preferences. The interior designer is expected to review and interpret this guidance and apply the information according to the needs of the project.

C-2 BEST PRACTICES.

C-2.1 Whole Building Design Guide.

The WBDG provides up-to-date information on integrated design of facilities. It is a valuable resource for information on sustainable design, accessibility, aesthetics, cost effective design, functional requirements, historical preservation, productivity and security. The WBDG provides access to all **\3** federal facility **/3/** criteria, standards and codes for the DoD Military Departments, National Aeronautics and Space Administration (NASA), and others. These include UFC, UFGS, Performance Technical Specifications (PTS), design manuals, and specifications. For approved government employees, it also provides access to non-government standards. Additionally, it contains information on and links to "Building Types" such as armories, aviation facilities, educational facilities, healthcare facilities, libraries, office buildings, parking facilities, and warehouses.

C-2.2 Sustainability.

Many sustainable elements are required in a project, and each project is different. Interior designers must take the initiative to influence nearly every sustainable goal of a project. The following list illustrates a few examples of how interior design is critical to good sustainable design, and complying with required criteria:

a. Integrated Design (participate early to ensure compliance with all applicable sustainable requirements)

b. Commissioning (verify the systems to be commissioned, and if they affect systems furniture or other interior elements such as lighting, under-floor HVAC (energy, ventilation, thermal comfort), and fenestrations (affects color and texture of finishes and shading))

c. Energy (Energy Star or FEMP labeled equipment, such as task lighting)

d. Interior Environmental Quality

- Ventilation/thermal comfort (see Commissioning above)

- Daylighting (location of offices/furniture, reflective surfaces, glare control, dimming controls, etc.)

- Indoor Air Quality (material off-gassing specifications, moisture control of exterior wall, entry way systems)
- Occupant Health and Wellness (part of early integrated design discussion)

e. Impact of Materials

- Recycled content (specification of materials)
- Biobased content (specification of materials)
- Storage/collection of recycled materials (layout consideration)

Refer to UFGS 01 33 29 for Third Party Certification (TPC). Verify the appropriate TPC for each individual project.

C-2.3 SID Items to Consider During Design.

1. Limit the number of similar colors for each material. This will assist the facility management office during maintenance and repairs.
2. In building renovation and addition projects, new interior finishes and colors must be compatible with existing where they occur in areas that are adjacent to occupied areas. More flexibility in selections can be exercised in areas not adjacent to existing occupied areas. Where it is necessary that existing materials be matched closely, include both a manufacturer and color reference for the contractor to prepare his bid, and the requirement to match the existing materials for the actual construction process.
3. Uniformity of window covering color and material must be maintained to the maximum extent possible within a building.
4. Solid surface material colors must not be too dark since they show water marks and scratches. Countertops at sinks must be light to medium range in color to help hide water spotting.
5. Color of ceramic and porcelain tile grout must be at a minimum a medium range color to help hide soiling.
6. Finish colors of fire extinguisher cabinets, receptacle bodies and plates, fire alarms/warning lights, emergency lighting, and other miscellaneous items must be coordinated with the building interior design. Color of equipment items on ceilings (such as speakers, smoke detectors, and grills) shall match the ceiling color.
7. Specifications must not be proprietary.
8. Provide finish and color selections that help hide soiling and are easy to maintain.

C-2.4 FF&E Items to Consider During Design.

1. Coordination is required with the contracting office to ensure that the FF&E package is procurable.

2. The interior designer is to provide a FF&E design which includes all services and information necessary for a complete and procurable package. The designer shall ensure that the FF&E design and building-related design schemes are coordinated.

3. Specify furniture from within a manufacturer's family wherever possible while ensuring aesthetic, quality and functionality are not compromised.

4. Provide furniture from manufacturer's standard product line as shown in the most recent published price list or amendment. Custom products are not recommended.

5. Specify seating upholstery that meets the following Wyzenbeek Abrasion Testing unless otherwise noted: 55,000 minimum double rubs for regular use areas and 100,000 minimum double rubs for high use areas. HNC requires the use of seating upholstery that meets 100,000 minimum double rubs.

6. Specify a topical or inherent soil retardant treatment on fabric where appropriate.

7. Furniture specified and furniture layout must allow access to building power and communication where required.

8. Coordinate furniture layout with locations of SIPRNET and NIPRNET, and other secure communications as applicable. Ensure required SIPRNET and NIPRNET separation requirements are met.

9. Furniture must not block windows or negatively impact the perimeter heating and cooling systems.

10. Furniture layout must allow for easy access to HVAC equipment for routine maintenance.

11. Existing furniture must be inventoried for reuse and incorporated into the furniture layout when applicable. Any new furniture required must be compatible with and complementary to the existing furniture.

This Page Intentionally Left Blank

APPENDIX D TEMPLATE FORMS FOR INTERIOR DESIGN SUBMITTALS

Figure D-1 Navy FF&E Data Sheet TEMPLATE

NAVAL FACILITIES ENGINEERING COMMAND			SHEET/PAGE: DATE:
PROJECT:		ITEM CODE:	
BASE/CITY/STATE:			
ITEM NAME:			
BPA CONTRACT #:	EXPIRATION DATE:		
GSA CONTRACT #:			
MANUFACTURER:	ORDERING ADDRESS:		
LOCAL REP CONTACT INFO:			
ANY VARIANCE OR MODIFICATION OF THIS SPECIFICATION WILL BE COORDINATED THROUGH THE NAVFAC INTERIOR DESIGNER NAVFAC ID CONTACT:			
PROJECT ID CONTACT:			
DESCRIPTION:	QTY:	UNIT COST:	TOTAL COST:
MODEL #: SIZE: FINISH: FABRIC: FREIGHT/SHIPPING: FOB ORIGIN (If applicable)			
TOTAL:			

ROOM LOCATIONS:		REMARKS:
QTY:	ROOM NUMBER:	

ITEM PHOTO/FINISH SAMPLES
FINISHES / FABRICS SHOWN ARE FOR GENERAL REPRESENTATION AND MAY NOT DEPICT AN EXACT COLOR MATCH.

Figure D-2 Army FF&E Data Sheet TEMPLATE - Standard

DATA SHEET

ITEM NAME: ITEM CODE:

MANUFACTURER:

CONTRACTOR:

CONTRACT #:

CONTRACT EXP:

FSC GROUP:

SIN:

PRODUCT NAME:

PRODUCT #:

DIMENSIONS:

FINISH:

FABRIC:

DESCRIPTION:

Approximate location for illustration.

ROOM LOCATION:	Room #	Room Name	Quantity
			0

TOTAL QUANTITY:	0
UNIT COST:	0
TOTAL COST:	0

Project Name
Project Number

Figure D-3 Army FF&E Data Sheet TEMPLATE - HNC

DATA SHEET

ITEM NAME: **ITEM CODE:**

MANUFACTURER:

Approximate location for illustration.

CONTRACTOR:

CONTRACT #:

CONTRACT EXP:

FSC GROUP:

SIN:

PRODUCT NAME:

PRODUCT #:

DIMENSIONS:

FINISH:

FABRIC:

DESCRIPTION:

ROOM LOCATION:	Room #	Room Name	Quantity
			0

TOTAL QUANTITY: 0

SPECIAL INSTRUCTIONS:

ALTERNATE MANUFACTURERS:

Project Name
Project Number

This Page Intentionally Left Blank

APPENDIX E GLOSSARY

AE	Architect/Engineer
A/E/C	Architecture/Engineering/Construction CAD Standard
AFCEC	Air Force Civil Engineer Center
AFCFS	Air Force Corporate Facilities Standards
AFNAFPO	Air Force Non-Appropriated Funds Purchasing Office
BIA	Bilateral Infrastructure Agreement
BPA	Blanket Purchase Agreement
BIM	Building Information Modeling
BOD	Beneficial Occupancy Date
BVD	Best Value Determination
CAD	Computer-Aided Design
CCD	Construction Completion Date
CCR	Criteria Change Request
CE	Cost Engineering
CFCI	Contractor Furnished Contractor Installed
CID	Comprehensive Interior Design
CIDA	Council for Interior Design Accreditation
DB	Design-Build
DBB	Design-Bid-Build
DD	Department of Defense Forms Management Program is administered by the Directives Division (DD) of the Executive Services Directorate
DoD	Department of Defense
FAR	Federal Acquisition Regulations
FF&E	Furniture, Fixtures and Equipment
FLC	Fleet Logistics Command

FSC	Federal Supply Category
FSRM	Facilities Sustainment, Restoration and Modernization
FY	Fiscal Year
GFCI	Government Furnished Contractor Installed
GFGI	Government Furnished Government Installed
GSA	General Services Administration
HNC	U.S. Army Engineering and Support Center Huntsville
HNFA	Host Nation Funded Construction Agreements
HVAC	Heating, Ventilation and Air-Conditioning
HQUSACE	Headquarters, U.S. Army Corps of Engineers
M3	Minimum Model Matrix
MILCON	Military Construction
MPI	Master Painter's Institute
NAF	Non-Appropriated Funds
NASA	National Aeronautics and Space Administration
NAVFAC	Naval Facilities Engineering Command
NFPA	National Fire Protection Association
NCIDQ	National Council for Interior Design Qualification
O&M	Operations and Maintenance
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
P&D	Planning and Design
POC	Point of Contact
POE	Post Occupancy Evaluation
PTS	Performance Technical Specifications

PxP	Project Execution Plan
RFP	Request for Proposal
SID	Structural Interior Design
SIN	Special Item Number
SOFA	Status of Forces Agreement
TPC	Third Party Certification
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
UNICOR	Federal Prison Industries, Inc. (also known as FPI)
U.S.	United States
VE	Value Engineering
WBDG	Whole Building Design Guide

UFC 3-130-01
03 December 2024

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC ENGINEERING

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC ENGINEERING

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes UFC 3-130-01, dated 16 January 2004.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007, and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website http://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

PETE G. PEREZ, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

S. KEITH HAMILTON, P.E., SES
Chief Engineer and Assistant Commander
Planning, Design and Construction
Naval Facilities Engineering Systems Command

THOMAS P. BROWN, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW, SES
Deputy Assistant Secretary of Defense
(Infrastructure Modernization and Resilience)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

FIGURES

This Page Intentionally Left Blank

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

The field of Arctic and Subarctic engineering, also known as cold regions engineering, covers a wide range of multidisciplinary topics and principles. Unique issues exist in the planning, design, construction, and operation of infrastructure and facilities in Arctic and Subarctic regions. Among them are permafrost, seasonal ground frost heave and thaw settlement, extreme low temperatures, high wind loads, heavy snow loads, and remote construction sites. Additionally, the implications of the rapidly changing climate in Arctic and Subarctic regions exacerbate these unique challenges.

This Unified Facilities Criteria (UFC) Arctic and Subarctic series includes five volumes that summarize relevant information and the most feasible approaches and solutions for planning, design, construction, and maintenance of infrastructure and facilities in the Arctic and Subarctic areas of the globe.

1-2 NEED FOR SPECIAL APPROACHES.

Cold regions engineering involves design and construction in locations that experience extreme, low-temperature conditions with freezing and thawing periods. In the design, construction, and maintenance of facilities such as buildings, roads, utilities, embankments, and other improvements in the Arctic and Subarctic regions, many problems are encountered that do not exist, or are not present to the same degree, in temperate regions. These problems have several causes:

- The presence of permafrost, with its potential for thaw and subsequent thaw settlement.
- The special properties of frozen soil, frozen rock, and ice
- The effects of frost action, specifically frost heave, in soil, rock, pavement, and other materials subject to intense annual freeze–thaw cycles.
- Drainage, water supply, and sewer disposal problems specific to those regions.
- The effects of solutes and the influence of salinity on frozen-soil properties
- The effects of changing climate, which present new challenges and environmental constraints.
- Other factors, such as the shortness of the above-freezing summer season, as well as the limited amount of daylight in fall and winter; environmental aspects; and difficult conditions for transportation, access, material and equipment supplies, and communications.

1-3 REISSUES AND CANCELS.

This document supersedes and cancels inactivated UFC 3-130-01, dated 16 January 2004.

1-4 PURPOSE AND SCOPE.

The Arctic and Subarctic UFC series provides technical guidance and available technical requirements for planning, design, construction, and maintenance of DoD facilities worldwide for all service elements in Arctic and Subarctic environments. These guidance and technical requirements are based on the International Building Code (IBC) and the requirements in UFC 1-200-01. The UFC 3-130 series covers many aspects of Arctic and Subarctic engineering with the specific exception pavements, which is incorporated into the UFC 3-250 and 3-260 series as discussed in paragraph 1-6.3. In addition to this volume, there are four other series volumes:

- UFC 3-130-02, *Arctic and Subarctic Site Assessment and Selection*. UFC 3-130-02 provides applicability and technical guidance for geotechnical site assessment for the Arctic and Subarctic environment conditions.
- UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*. UFC 3-130-03 includes horizontal and vertical foundations, considerations affecting foundation design, and construction and monitoring of facilities in the Arctic and Subarctic areas.
- UFC 3-130-04, *Arctic and Subarctic Buildings*. UFC 3-130-04 includes building design in the Arctic and Subarctic areas.
- UFC 3-130-05, *Arctic and Subarctic Utilities*. UFC 3-130-05 provides criteria and guidance for the design of utility systems for military facilities in Arctic and Subarctic regions.

UFC 3-130-01 serves as an introduction to the Arctic and Subarctic UFC series. It includes background information, data, and engineering considerations pertaining to the various elements of Arctic and Subarctic facility planning and design presented elsewhere in the series. Chapter 2 defines Arctic and Subarctic regions. Appendix B defines terms unique to cold regions and cold regions engineering. This volume also introduces risk assessment and resilience in terms of cold regions engineering. These are emerging topics in Arctic and Subarctic infrastructure, whose development is critical to planning sustainable projects. UFC 3-130-01 is not all inclusive. Other resources are cited to provide additional sources of information. The revision of the Arctic and Subarctic UFC series provides state-of-the-practice criteria and guidance for engineers, architects, and planners when planning, designing, and constructing DoD infrastructure in cold regions.[1]

1-5 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, for those geographic locations in Arctic and Subarctic regions worldwide.

[1] *New Construction Criteria for a Changing Arctic and Subarctic: The UFC 3-130 Series Revision Process,* Bjella et al.

1-6 GENERAL BUILDING REQUIREMENTS.

This UFC is an integrated part of the Arctic and Subarctic UFC 3-130 series. Use the other documents of this series in conjunction with this UFC to address construction aspects unique to cold regions. See Chapter 2 for the definitions of Arctic and Subarctic.

Often, conventional construction practices are acceptable in Arctic and Subarctic regions with appropriate modification to account for extreme cold temperatures, frost heaving soils, and permafrost areas. This UFC modifies and supplements the criteria found in the core UFCs. Utility provider's or Installation specific requirements must be considered.

1-6.1 Structural.

Use UFC 3-301-01 for the design and analysis of DoD buildings and other DoD structures. Also, use UFC 3-301-02 for Risk Category V structures.

1-6.2 Geotechnical.

It is essential for engineers to consider the effects of extreme low temperatures, freeze and thaw conditions, variable soil conditions, snow and ice, and drainage on soil properties such as bearing capacity and other geotechnical engineering requirements. Geotechnical investigations must be tailored to the individual projects and sites.

1-6.3 Pavements.

Comply with the UFC 3-250 and UFC 3-260 series. These series provide technical requirements and guidance for roads, pavements, and airfield design, construction, and maintenance. Note that pavements in the Arctic and Subarctic present unique challenges. Unlike the temperate pavements, it is essential for engineers to consider the effects of extreme low temperatures, freeze and thaw conditions, bearing capacity, material behavior, snow and ice, variable soil conditions and material properties, and drainage or the effects of groundwater in the pavement structure. Several cold regions textbooks include detailed information on pavements topics:

- *Cold Regions Pavement Engineering*, by Doré and Zubeck;
- *Introduction to Cold Regions Engineering*, by Freitag and McFadden;
- Permafrost Engineering Design and Construction, by Johnston; and
- *Construction in Cold Regions: A Guide for Planners, Engineers, Contractors, and Managers*, by McFadden and Bennett.

These texts include design methodologies, material selection, approaches for proper calculations of structural design, strategies for constructing new roads, recommendations for rehabilitating old or damaged surfaces, maintenance techniques, as well as case studies of problems and respective solutions.

1-7 CYBERSECURITY.

All facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-8 LEVEL OF CONSTRUCTION.

See UFC 1-200-01, paragraph 1-3.2, for the definitions of permanent construction, temporary construction, and facilities in support of military operations.

1-9 MODULAR OR NONPERMANENT FACILITIES.

Use UFC 1-201-01 for the minimum requirements for life safety and habitability-related design of nonpermanent facilities for use by DoD in support of military operations. This includes portable structures intended for use up to 3 months, 24 months, 60 months (5 years), and semipermanent facilities that can be extended to 25 years. Portable structures require specific foundation considerations for placement on the frozen ground (see UFC 3-130-03). Additionally, the effects of extreme low temperatures in the Arctic and Subarctic environment, including freeze and thaw conditions, snow drifting or snow and ice effects, and material behavior of the structures, must be determined.

1-10 PERSONNEL REQUIREMENTS.

Engineering decisions for the planning, design, construction, and maintenance of infrastructure in Arctic and Subarctic regions are based not only on applicable federal, state, and local codes but also on the expertise of engineers or practitioners with experience dealing with the unique conditions and the extreme weather of these regions. The intent of this UFC, and the Arctic and Subarctic UFC series, is to provide requirements and guidance to prevent significant missteps in the planning, design, and construction of cold regions infrastructure. Consultation with experienced engineers at the Command, District, and Installation level is required to ensure technologies and practices that are unsuitable for this environment, or a specific location, are not proposed. This UFC provides indicators of potential problem areas that may require unique engineering solutions outside the realm of those seen in temperate or standard construction practice.

The Engineer of Record or Designer of Record (DoR) must be a registered design professional, defined as an individual licensed to practice engineering in the project area; knowledgeable in the design and construction of infrastructure in Arctic and Subarctic areas; and experienced with the permafrost, frozen ground, and other geotechnical and climate conditions found in these regions. Some jurisdictions require licensure in the location of the project to obtain permits and approvals.

1-11 PLANNING.

Follow the site planning requirements as described in UFC 3-201-01. This includes environmental requirements, land-use restrictions, building setbacks, flood hazard areas, utility connections, utility offsets, vehicle circulation, buffers from natural and manmade features, and other similar requirements. Use UFC 3-201-01 prior to starting design to determine specific project requirements (such as demolition, site development, water distribution, and wastewater collection). Familiarization with the UFC 3-130 series at the planning stage is advisable to anticipate and prepare for issues of concern for structure and infrastructure development in Arctic and Subarctic areas.

1-12 APPLICABLE POLICIES AND PROGRAMS.

Comply with UFC- 3-201-01 for National Environmental Policy Act (NEPA) actions. NEPA is not unique to climate regions.

Arctic and Subarctic military facilities can either benefit or adversely impact the environment, affecting the air, water, land, local ecology, and socioeconomic environment. Despite low population density and minimal development, the fragile nature of the ecology of the Arctic and Subarctic has attracted the attention of environmental groups. Actions that may meet the criteria for a Categorical Exclusion (CX or CATEX) at other locations may not apply in the Arctic and Subarctic. Areas of particular concern in the Arctic and Subarctic include, but are not limited to, threatened and endangered species and habitat; wetlands; migratory birds; and historic, archaeological, and cultural resources for both Indigenous peoples and early settlers.

1-13 APPROVALS AND PERMITS.

During the planning, design, and construction of the project, the DoR will be responsible for obtaining all necessary permits and approvals and for complying with all applicable laws, codes, and regulations, or overseas equivalent. Regulatory authorities may be at the federal (to include Occupational Safety and Health Administration [OSHA]), state, or local level. In the United States and its territories and possessions, the government will review permits for acceptability. In locations outside the United States and its territories and possessions with Host Nation agreements, follow permit approval procedure as directed in the project scope and by the Government Project Manager. In locations outside the United States and its territories and possessions without Host Nation agreements, the government will review and approve plans for compliance. Consult with the Government Project Manager to determine the appropriate signatories for permit applications.

1-14 SAFETY CONSIDERATIONS.

1-14.1 Facility Safety.

Use UFC 1-200-01, paragraph 1-6.3.4, for facility-safety-related requirements. All DoD facilities must comply with Department of Defense Instruction DoDI 6055.01 and applicable OSHA safety and health standards.

1-14.2 Safety for Geotechnical Investigations.

Comply with UFC 3-220-01, paragraph 2-4.2.

1-14.3 General Safety for Cold Regions Operations.

Awareness of safety aspects relevant to field activities is especially important in the Arctic and Subarctic. Consider safety awareness and planning when conducting site reconnaissance or field assessment for site planning and construction, including but not limited to

- cold weather hazards such as freezing injuries, dehydration, hypothermia, frostbite;
- encountering wildlife;
- visibility;
- slip and fall hazards on snow and ice surfaces and uneven terrain;
- limited daylight during the winter months; and
- site-specific safety and health plan considering support contingencies at remote locations.

1-15 BEST PRACTICES.

Appendix A identifies background information; lessons learned; and proven best practices, methodology and approaches pertinent to engineering planning, design, and construction in Arctic and Subarctic locations. The DoR must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any UFC, the UFC takes precedence. For Best Practices guidelines not discussed in the UFCs, the DoR must submit to the Government Project Manager a list of the guidelines or requirements being used for the project with documentation sufficient for review and approval prior to completing design.

1-16 GLOSSARY.

Appendix B contains acronyms, abbreviations, and a list of terms used in this document and are specific to cold regions engineering, design, and construction.

1-17 SUPPLEMENTAL RESOURCES.

Appendix C provides supplemental resources on subjects related to Arctic and Subarctic engineering, design, and construction. These resources are valuable tools to the engineer for additional information on topics pertinent to and affiliated with cold regions engineering. It also identifies additional background information and resources for accomplishing building design and construction in Arctic and Subarctic regions.

1-18 REFERENCES.

Appendix D contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

This Page Intentionally Left Blank

CHAPTER 2 ARCTIC AND SUBARCTIC ENVIRONMENT AND CLIMATE

2-1 INTRODUCTION.

This chapter provides background information on the environment, site characteristics, and climate conditions unique to Arctic and Subarctic regions for engineering, design, construction, and maintenance of facilities and other infrastructure. The topics include permafrost and ground ice, permafrost structure and stability, geomorphic features, permafrost structure, climatic conditions (such as air-temperature distribution, design freezing index, ground temperature, snow, wind, and visibility), climate change, vegetation, wildfires, seismic condition, and freeze and thaw of soils.

For the purposes of the UFC 3-130 series, the Arctic is characterized by mean annual temperature ranges between below 32°F (0°C) for the coldest month and below 50°F (10°C) for the warmest month of the year (see Appendix B, paragraph B-3.2).[1] Generally, Arctic conditions are found north of the Arctic Circle (approximate latitude of 66°33' N). The Arctic Circle marks the latitude above which the sun does not set on the summer solstice and does not rise on the winter solstice. The Subarctic is characterized by mean annual temperature ranges between below 32°F (0°C) for the coldest month and above 50°F (10°C) for the warmest month (see Appendix B, paragraph B-3.2). Subarctic conditions are generally south of the Arctic and north of temperate forests, between latitudes 50° N and 70° N. Other cold regions, with similar temperature and ground conditions, exist in the Aleutian Islands and at high altitudes in mountainous areas of the globe and therefore warrant cold regions engineering considerations. Additional discussion of Arctic and Subarctic conditions as they pertain to each specific topic are found in the other documents of the UFC 3-130 series.

2-2 PERMAFROST AND GROUND-ICE DISTRIBUTION.

Permafrost boundaries further define the Arctic and Subarctic regions. Permafrost distribution is divided into classifications, including continuous permafrost, discontinuous permafrost, sporadic permafrost, and isolated patches. Permafrost extent provides general information on ground-ice content (Figures 2-1 and 2-2). See Appendix A, paragraph A-5, for additional information on permafrost extent and distribution under natural, undisturbed ground cover conditions in the area with a mean annual air temperature of 21°F to 30°F (−6.1°C to −1.1°C). Surface temperatures are potentially available from global observational networks or from observation stations. Actual ground-temperature measurement at the specific location provides more-accurate information of the site conditions. The existence of perennially below-freezing ground temperatures is a result of many factors other than air temperatures, including solar radiation, surface cover, snow cover, wind, soil type, soil moisture content, groundwater flow, and presence of stationary or moving surface water. Landscape changes due to

[1] The way the Arctic and its location are defined varies based on the topic of concern. Many of the common definitions are based on scientific, climatic, geologic, biologic, marine, and political considerations. Cold regions engineers define the Arctic and Subarctic regions in terms of permafrost boundaries, ice contents, ground temperatures, air temperature (freezing-degree days), snow and ice distribution, and other factors that influence design and construction.

land developments, forest fires, or stream meandering may alter permafrost conditions over many years.

Figure 2-1 Circum-Arctic Map of Permafrost and Ground-Ice Conditions

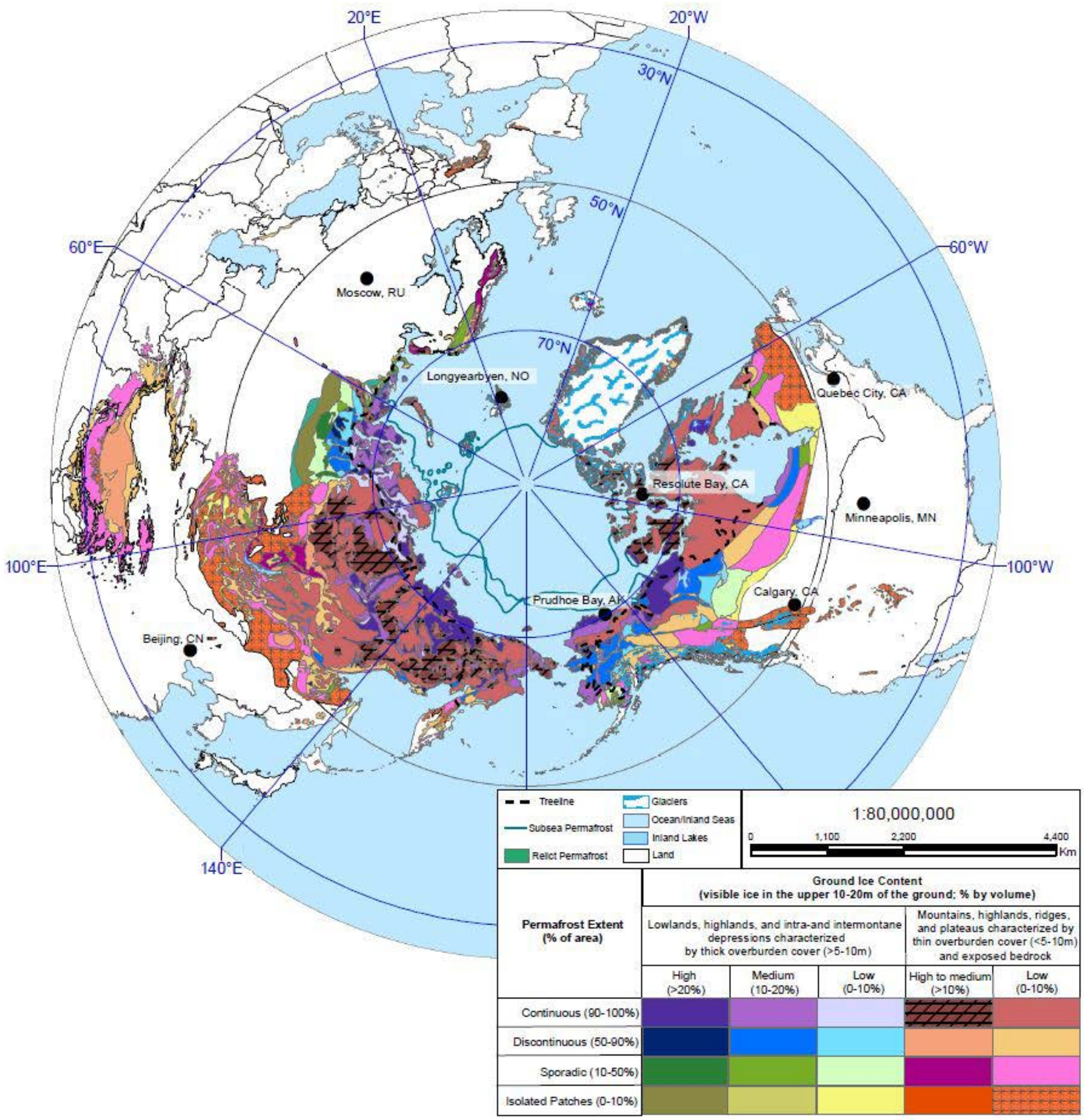
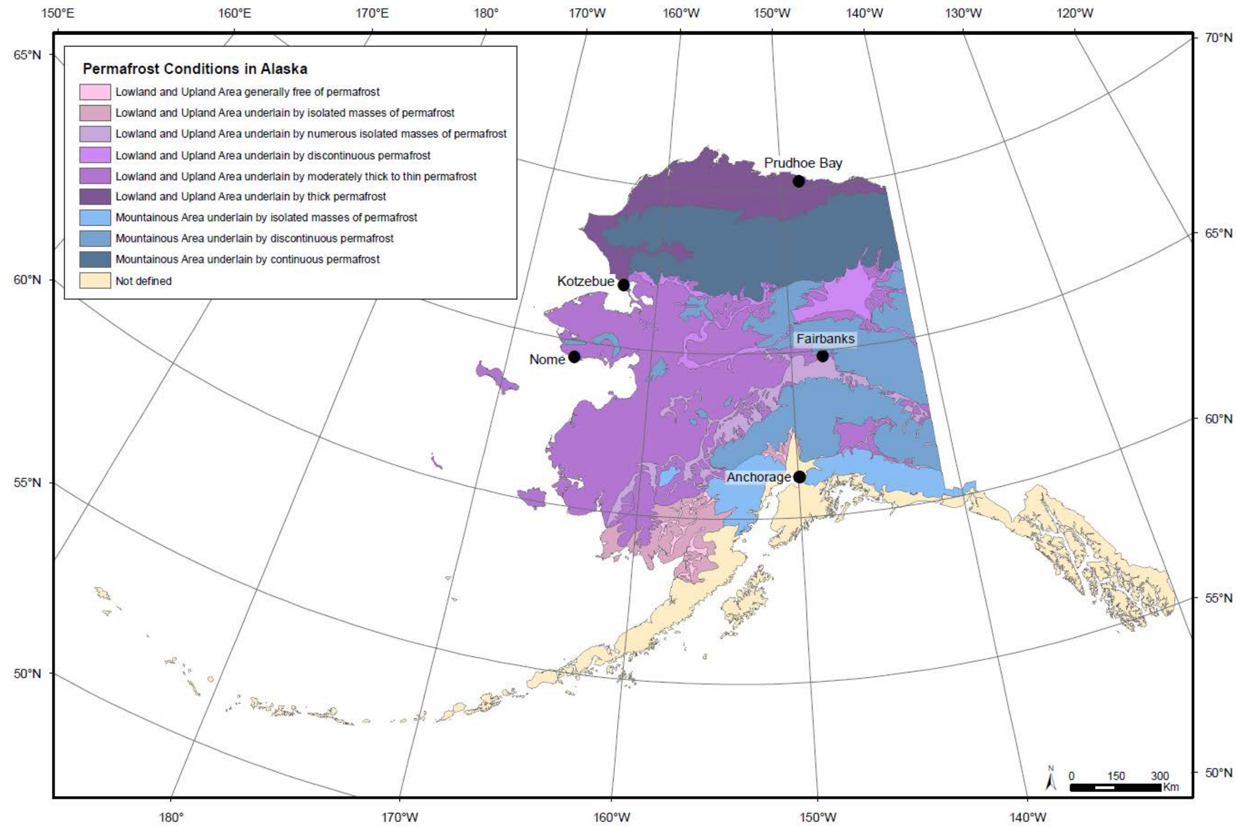


Figure 2-2 Permafrost Conditions in Alaska



2-3 GEOMORPHOLOGY AND SURFICIAL FEATURES.

Understanding the geomorphic features of the permafrost landforms is important in the design and construction of facilities in the cold regions. Thus, guidance for design and construction in Arctic and Subarctic environments requires thorough consideration of ground characteristics, climatic information, and local thermal conditions, as well as the physical, mechanical, and thermal properties of the permafrost and seasonally frozen ground. See Appendix A, paragraph A-5.1, for additional resources on this topic.

The cold regions landforms are unique geomorphic features produced from frost action, permafrost degradation, mass degenerative and other geologic processes, or cryogenic actions in the active layer and in permanently frozen ground. These features include solifluction markings, pingos, thermokarst depressions, and patterned ground. They can serve as important indicators of ground conditions, such as the likelihood of permafrost and ground ice.

2-3.1 Polygonal Ground.

Areas of intensive frost action, common in Arctic and Subarctic regions, can result in the formation of surface expressions such as polygonal-patterned ground or polygons. Polygons can range in size from several feet to hundreds of feet in diameter and generally have four to eight sides. Ice-wedge polygons are grouped into either high centered or low centered. Low-centered polygons, where water is ponded in the middle of the polygon, indicate climatic conditions conducive to maintain the environment in the frozen condition. High-centered polygons, where water is not ponded in the middle but along the margins of the polygon, indicate the overall thermal regime is creating a thawing permafrost environment. In general, the existence of polygonal features indicates a very high probability that permafrost exists.

2-3.2 Pingo.

Pingos are good indicators of permafrost as they are very rare outside continuous permafrost zones. They are formed as permafrost creates hydraulic pressure on liquid water beneath an overlying, confining layer of soil, focused on a single area, where it forms a massive ice lens and causes the ground surface to heave upward dramatically.

2-3.3 Thermokarst.

While there are several different types of thaw features, they all have similarly identifiable characteristics, as they are all the result of the same process of permafrost degradation. Thermokarst landform features include hummocks, sinkholes, ravines, caverns, tunnels, thaw lakes, and beaded drainages. Hummocks are mounds many feet in diameter and height and are the result of thaw degradation of the very ice-rich margins of the polygonal terrain. Thawing leaves the soil-rich center of the polygon at a much higher elevation, resulting in recurring mounds across the landscape. Thaw lakes are characterized as rounded or scalloped depressions with sharp or shear banks that often extend into the waterline, with impounded water as evidence of active caving along the edges. These often include trees tilted toward the center of the lake or, in the case of treeless terrain, crevices forming parallel to the edges of the bank. Beaded streams are characterized by a series of small, rounded thaw lakes connected to one another by short waterways. Each rounded thaw lake is the result of both mechanical and thermal erosion. Connecting waterways can follow the strait profile of degrading ice wedges, but this is not always the case. Further evidence of thermokarst and permafrost degradation is the occurrence of “drunken forests,” large numbers of trees at an angle to each other and the ground. Trees off axis are indicative of unstable ground, often due to permafrost in Arctic and Subarctic regions.

2-4 PERMAFROST CHARACTERISTICS.

In Arctic and Subarctic regions, the depth of frost and permafrost is related to both the temperature, duration, and intensity of winter for a given location. Cold regions textbooks provide detailed descriptions of permafrost features. The following summary of the characteristics of permafrost are merely introductory.

2-4.1 Structure.

The structure of permafrost varies and depends on the ground characteristics and local thermal conditions. Permafrost may exist as the following:

- A continuous layer with its upper surface at the bottom of the annual frost zone (active layer) (This is common in Arctic regions.)
- A continuous layer with its upper surface separated from the annual frost zone (active layer) by a residual thaw layer (If the permafrost table is progressively lowering, the subsequent effect is degradation of permafrost.)
- Frozen layers separated by layers of unfrozen material.
- Inclusions of remnants of permafrost in unfrozen ground.

2-4.2 Thickness and Depth.

The thickness of the permafrost layer increases with increasing latitude, being greater in Arctic than in Subarctic regions. The depth to the permafrost layer depends primarily on the magnitude of the air thawing index, the amount of solar radiation that reaches the surface, the surface cover conditions from the previous several years, and the water content and dry unit weight of the soil. Methods for estimating depths of freeze and thaw penetration are described in paragraph 3-5 and are thoroughly discussed in *Frozen Ground Engineering,* by Andersland and Ladanyi.

2-4.3 Factors on Permafrost Structure.

Factors and stability aspects of permafrost must be considered and are described in the following sections.

2-4.3.1 Active Layer.

The active layer refers to the portion of the permafrost soil or soil and rock column from the surface downward, which thaws each summer season to some depth. The depth of thaw is determined by the extent of the previous winter freezing, snow depth, groundwater, soil type, vegetation, slope gradient, and slope aspect. However, the complex nature of the soil thermal regime generally yields varying active layer depths of inches to feet on yearly to decadal scales.

Because the bottom of the active layer transitions to impermeable frozen soils and rock, this confining layer prevents adequate draining of the active layer's moisture, often increasing moisture content to values greater than saturation. During the winter freezing process, the top-down movement of the freeze front creates layers of segregation ice, often inches thick. This segregation ice heaves the active layer soils upwards during the winter season, with subsequent settlement in the next summer's full thawing season. With this repetitive freeze–thaw cycle, active layer soils in the natural or undisturbed state are often very loose with poor bearing capacity and drainage capability.

2-4.3.2 Soil Factors.

As a rule, the characteristics of permafrost will depend on the texture, water content, and temperatures of the soil. Relatively clean sands and gravels located in well-drained positions may not present serious engineering construction problems if they do not contain appreciable amounts of excess ice and are termed thaw stable. Conversely, permafrost consisting of fine-textured soils such as silt, silty-sands, and clays often contain excess volumes of ice in the soil matrix, in lenses, layers, wedges, and veins or other shapes and are termed thaw unstable. See paragraph 3-4 for quantifying soil factors. UFC 3-130-03, Chapter 5, presents information on the strength and other properties of frozen soils. Information on the standard system for classification of frozen soils, frost action, and the strength and thermal properties of frozen soils can be found in cold regions textbooks such as *Frozen Ground Engineering*, by Andersland and Ladanyi.

2-4.3.3 Thaw Stable.

Frozen soils are termed thaw stable if the amount of water contained within a soil matrix (as a direct result of the thawing of ice in the soil) can freely drain away without any settlement and maintain the soil strength.

2-4.3.4 Thaw Unstable.

Frozen soils are termed thaw unstable if they, on thawing, would exhibit loss of strength below normal or exhibit long-term significant settlement as a direct result of the thawing of ice in the soil. Soils that contain an excess of thaw water on melt (greater than available pore space in the material) and soils that do not exhibit particle-to-particle contact in a frozen state due to excess ice, in general, will exhibit settling on thawing.

2-4.3.5 Frost Susceptible Soil.

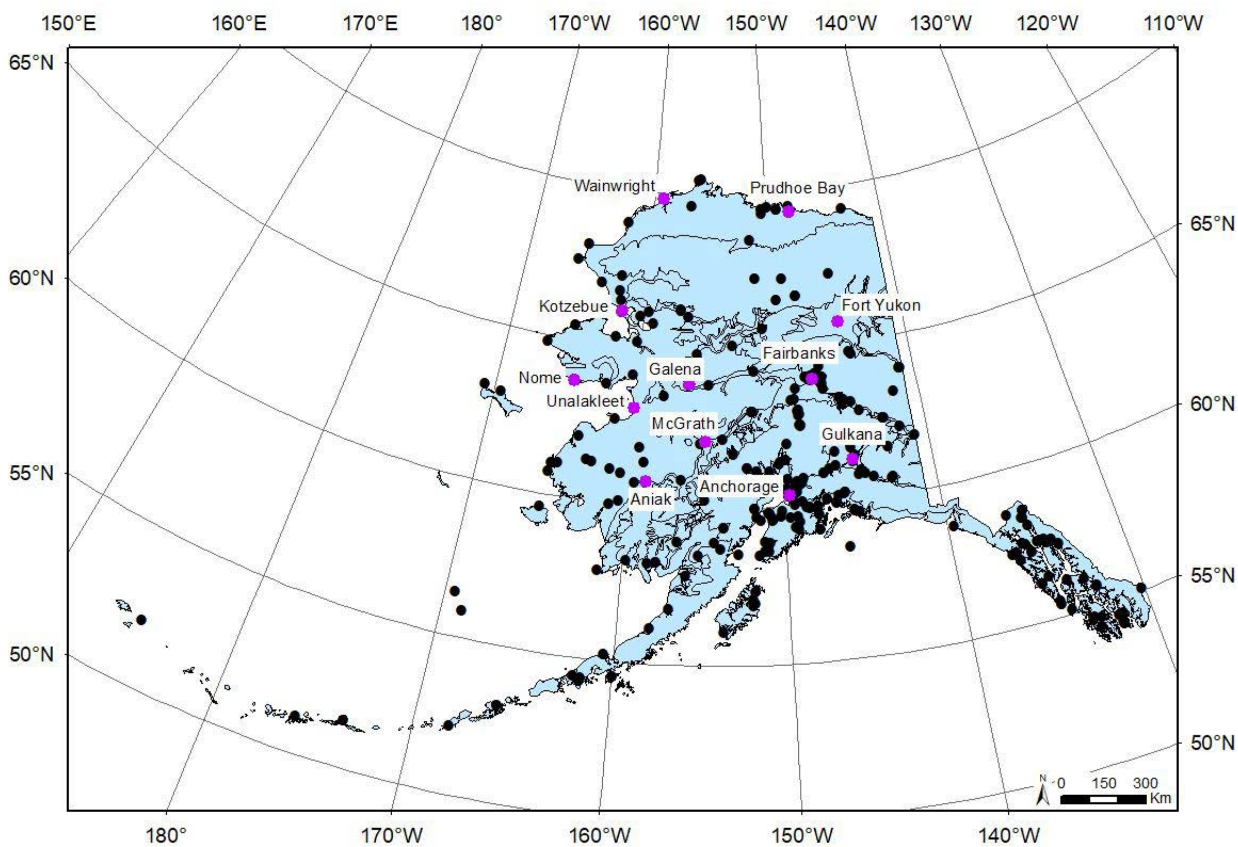
Fine-grained soils such as silty-sands, silts, and clays generally have the ability to wick and retain moisture. Soils located at and near the surface are often inundated with surface and subsurface water flow, so fine-grained soils in the vicinity of these regions will tend to have high moisture levels, with potential to exceed saturation levels. On freezing, the excess amount of soil moisture, when changed to ice, will cause the soil particles to be pushed apart, or disaggregate. The result is the ground surface and any associated structural elements within or on it can be significantly pushed upwards, or heaved. This is most common with pavement materials with poor subsurface drainage but also can occur under foundation elements and floors of structures, causing cracked floors and fractured foundation elements. These soil types are termed frost susceptible.

Structural fill material used for bearing support is considered non–frost susceptible (NFS) when the percentage of the fill material passing the 200 sieve is less than 3% to 5%. Under normal compaction requirements for typical bearing capacity, this low quantity of fines eliminates wicking of moisture and decreases the available pore space volume for water entrainment. Minimizing the entrainment of water also eliminates excess ice development on freezing, preventing disaggregation of the soil particles and frost heaving.

2-5 CLIMATIC CONDITIONS.

Refer to UFC 3-400-02 for an overview of available Engineering Weather Data (EWD) sites and instructions on how to access climate data. A Common Access Card (CAC) is required to access the 14th Weather Squadron's website https://www.climate.af.mil/. For those without a CAC see paragraph 1-6 in UFC 3-400-02 to request EWD. Also, land-based atmospheric observational data, including temperature, dew point, relative humidity, precipitation, and wind speed and direction, are collected and are available online. Ground-based observation records, including those from the Alaska observation stations (Figure 2-3), are available from the National Weather Service (NWS) website; and links to download the data are included in Appendix A, paragraph A-6.

Figure 2-3 Locations of Observation Stations in Alaska



The American National Standards Institute / American Society of Heating, Refrigerating, and Air Conditioning Engineers (ANSI/ASHRAE) Standard 169-2020 covers climate data and climatic zones (based on heating and cooling degree-days) worldwide. For engineering purposes, the general climatic conditions of the Arctic and Subarctic regions are best defined by the prevailing air temperature for the location. The Arctic and Subarctic regions have wide climatic variations; and the climatic conditions differ between the coastal areas and interior locations because of latitude, circulation patterns, and elevation. Atmospheric observations are needed to monitor and examine the climate conditions at a particular location. Definitions based on air temperature are given in Appendix B. See paragraph 2-6 for implications of the changing environments in the Arctic and Subarctic.

2-5.1 Air Temperature.

Air temperatures, which vary significantly from place to place in the Arctic and Subarctic regions, are typically collected by sensors located a few feet above the ground. Distributed air-temperature data sets (minimum, maximum, and mean temperature) for Alaska, and historical 30-year normal data are available online (see Appendix A, paragraph A-6.1, for resources).

2-5.2 Freezing Temperatures.

The patterns of the mean annual temperatures across North American and Eurasian continents are shown in Figures 2-4 and 2-5. On both the North American and Eurasian continents, the lowest mean annual temperature is about 5°F (−15°C). These maps are derived from the WorldIndex database, which is compiled from the Global Surface Summary of Day (GSOD) data. The GSOD data are available at the National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information (NCEI), website https://www.ncei.noaa.gov. The compiled data include the period of record from approximately 1980 to 2017 at various climate stations in North America and in northern Eurasia.[2] See paragraph 2-6 for implications of climate change on air temperatures.

The freezing season, defined as the period when the average daily temperature is below 32°F (0°C), also varies by location. In general, the freezing season begins as early as September in the northern latitudes (Figure 2-6). The freezing season starts when the mean daily temperature stays below freezing for three consecutive days, and it ends when the mean daily temperature begins to remain above freezing for three consecutive days. The average length of the freezing season (in terms of number of days) over the period of record can be more than two hundred days in the northern latitudes (Figures 2-7 and 2-8). Thus, the thawing season can be as late as June (Figure 2-9).

[2] "One-Dimensional Computer Models to Estimate Frost Depth," Barna et al.

Figure 2-4 Distribution of Mean Annual Air Temperature (°F) in North America, Derived over the Period of Record from the WorldIndex Database

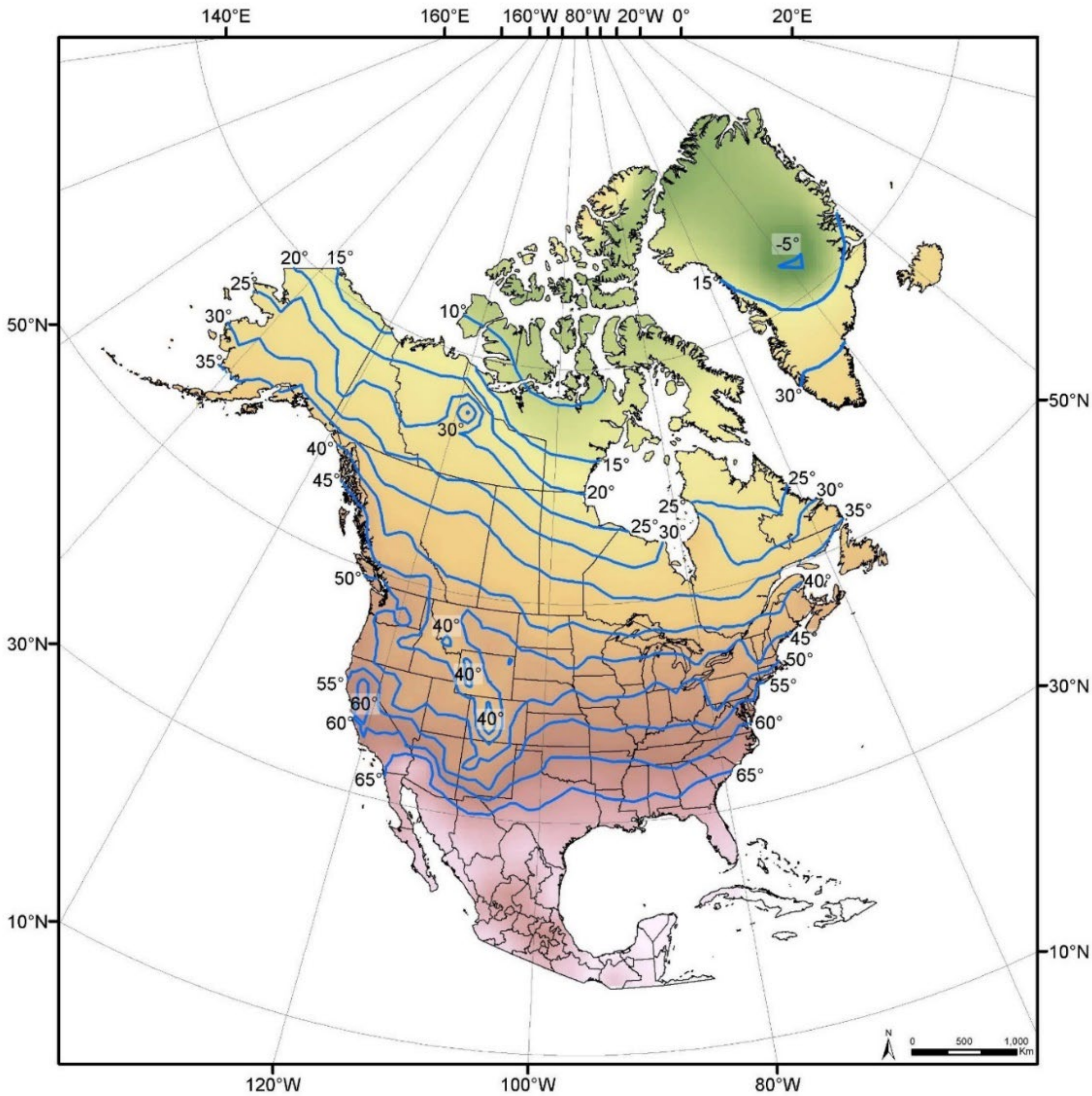


Figure 2-5 Distribution of Mean Annual Air Temperature (°F) in Northern Eurasia, Derived over the Period of Record from the WorldIndex Database

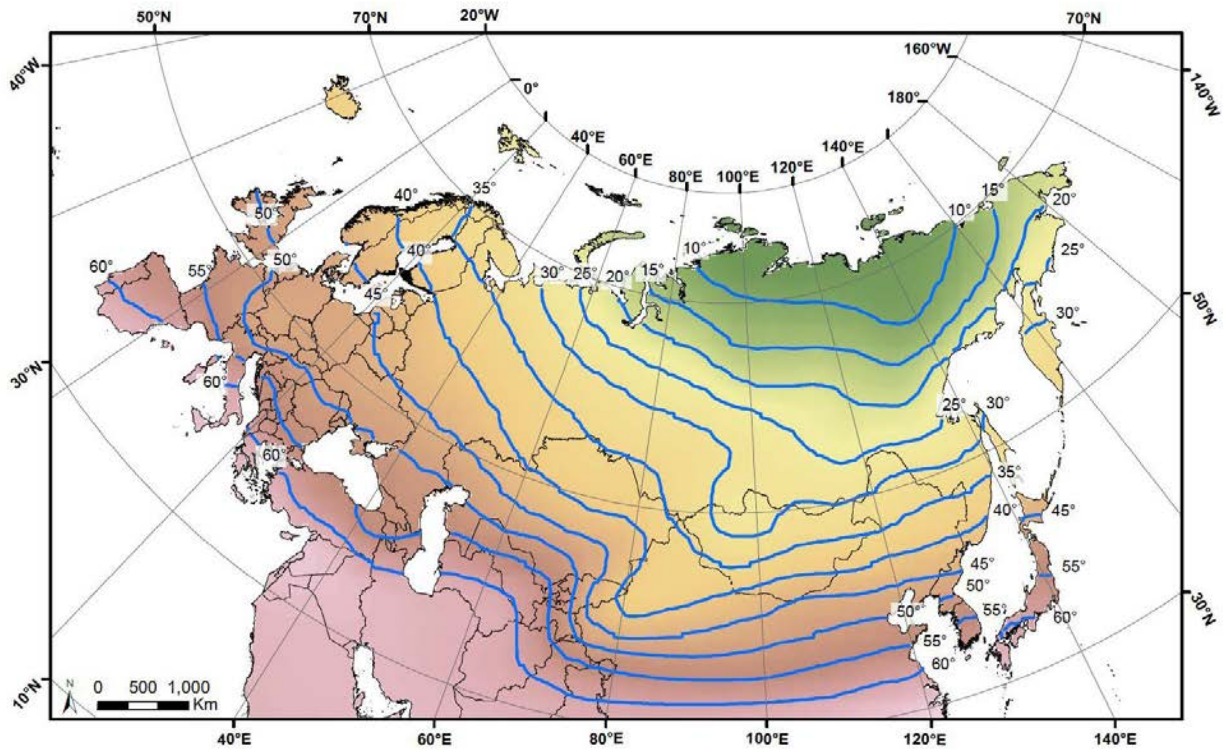


Figure 2-6 Mean Date of the Beginning of the Freezing Season, Derived over the Period of Record from the WorldIndex Database

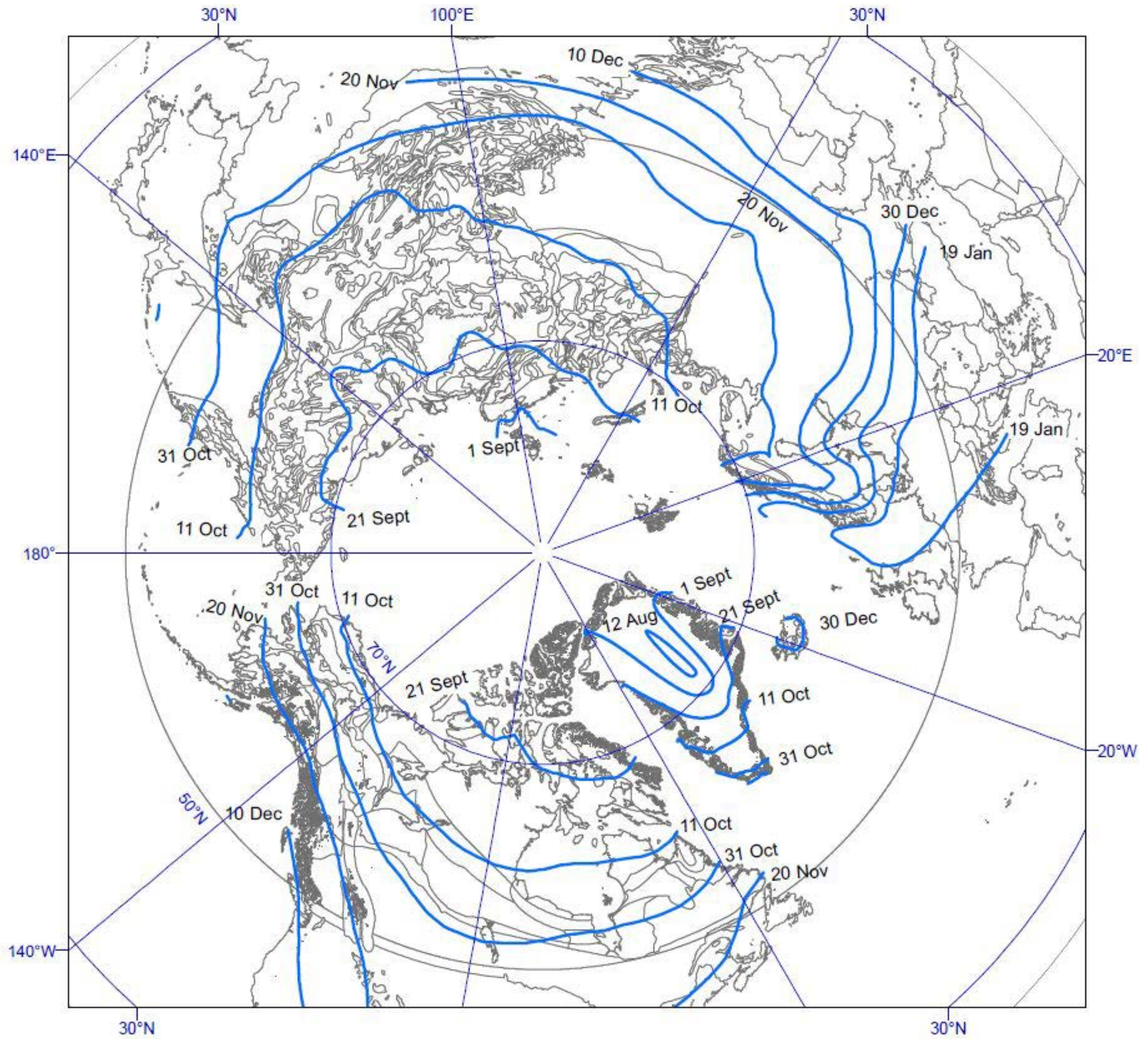


Figure 2-7 Average of the Number of Days in the Freezing Season in North America, Derived over the Period of Record from the WorldIndex Database

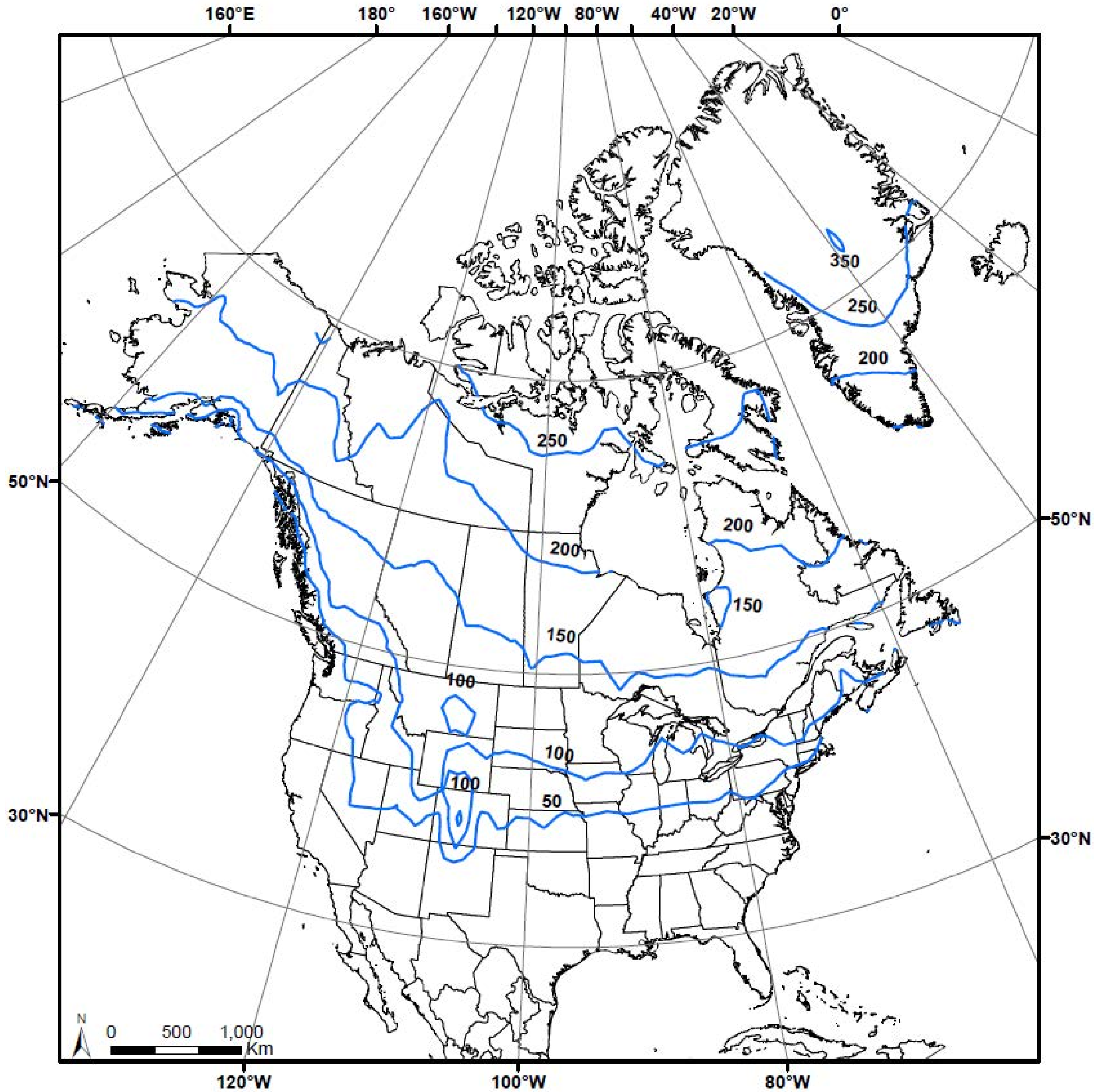


Figure 2-8 Average of the Number of Days in the Freezing Season in Northern Eurasia, Derived over the Period of Record from the WorldIndex Database

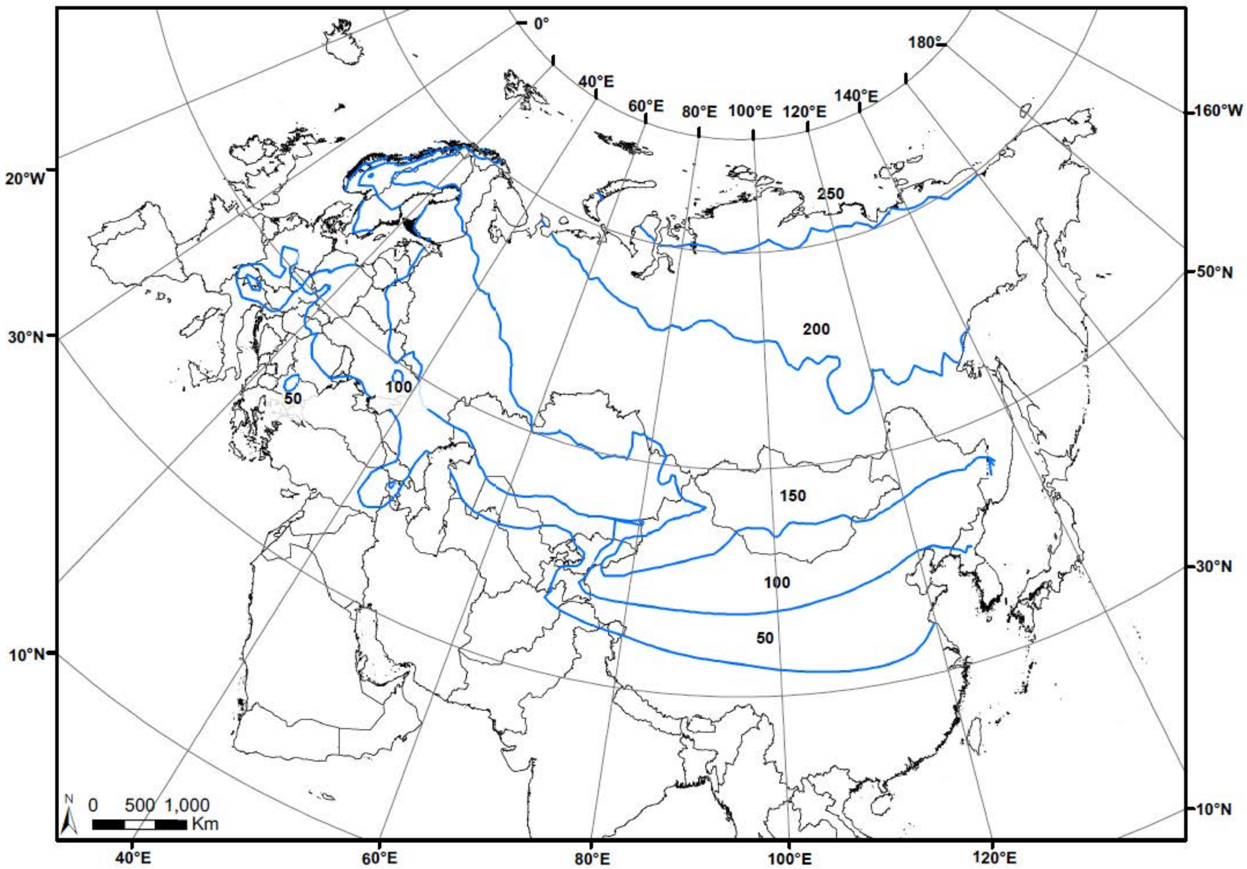
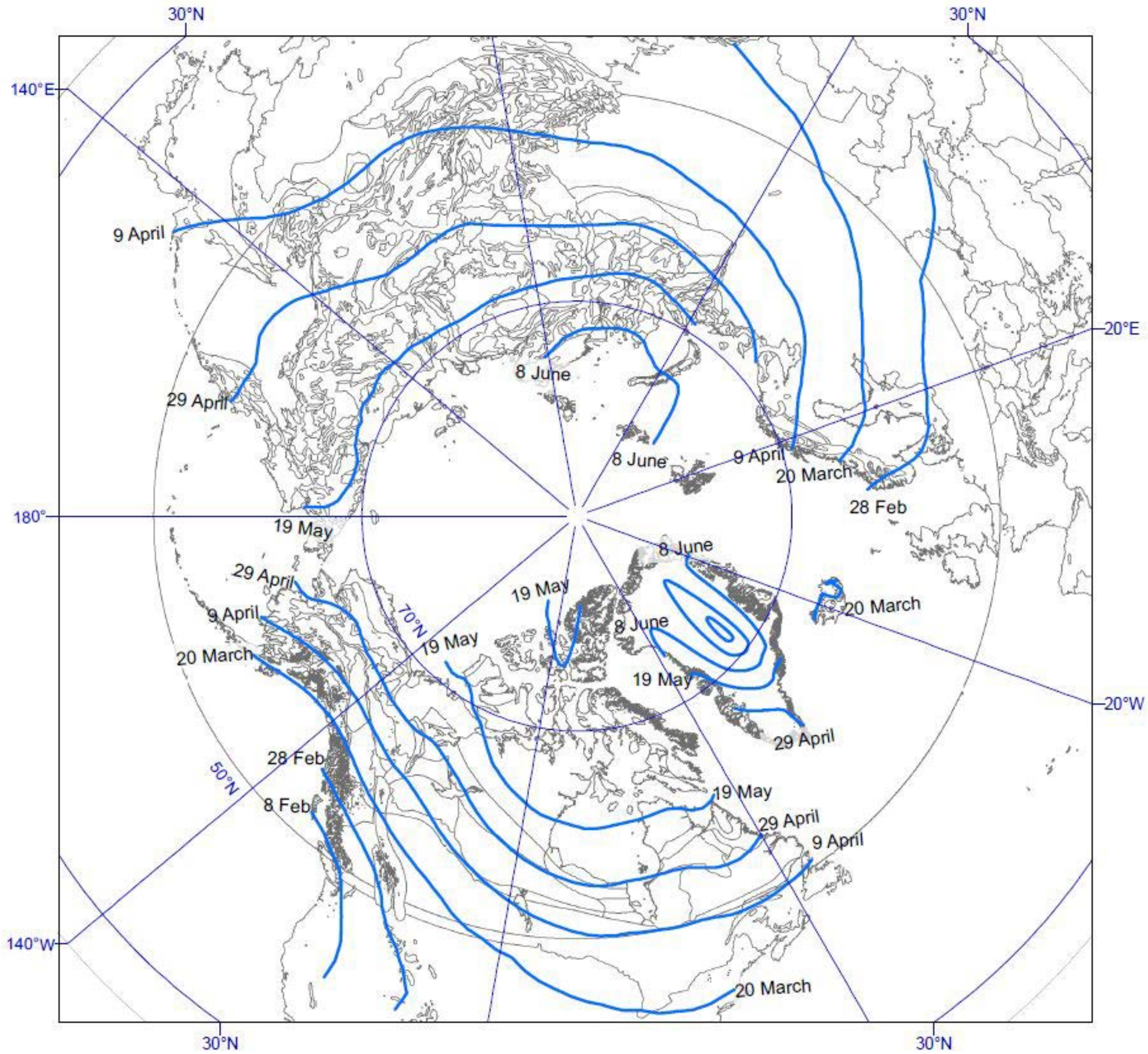


Figure 2-9 Mean Date of the Beginning of the Thawing Season, Derived over the Period of Record from the WorldIndex Database



2-5.3 Freezing Index and Design Freezing Index.

Air-temperature records for a given location are also used to quantify the intensity of temperature variation using the degree-day concept. The freezing index is computed as the sum of the number of degrees that the mean daily temperature departs from the freezing point of bulk water (32°F) during the freezing season. See *Frozen Ground Engineering*, by Andersland and Ladanyi, for graphical illustration of cumulative degree-days versus time for determining the freezing index, as well as thawing index. These indices are affected by the changing climate in the Arctic and Subarctic. See paragraph 2-6 for climate change implications.

The design freezing index is an expanded value of the freezing index and is used to account for climatic variations from year to year. The traditional method for calculating the design freezing index is to average the freezing indices of the three coldest winters in the most recent 30 years of weather records. If the weather records are less extensive, the design freezing index is calculated from the coldest winter in ten years. A more modern approach takes advantage of computers to calculate the design freezing index using the mean freezing index plus the product of 1.5 times the standard deviation of the freezing indices for the winters of record.[3] For pavement and foundation designs, comply with this approach for determining design freezing. Figure 2-10 and 2-11 show the estimated design freezing indices using the more modern approach described in "Computer Assisted Calculations of the Depth of Frost Penetration in Pavement-Soil Structures," by Cortez et al., for North America and northern Eurasia.

2-5.4 Ground Temperature.

Ground temperatures vary from one place to another. Ground temperature is a function of many factors other than air temperature. These factors include solar radiation, surface cover, snow cover, wind, soil type, soil moisture content, groundwater flow, and presence of stationary or moving surface water. The periodic fluctuation of ground-surface temperatures produces the diurnal cycle from day to day, season to season, or year to year. Measurements of subsurface temperature profiles are the most suitable to use for design. However, equations for estimating ground-temperature profiles using surface temperature or mean annual temperature data are in cold regions textbooks such as *Frozen Ground Engineering*, by Andersland and Ladanyi.

Data for ground temperatures is not always available for most locations in the Arctic and Subarctic. However, surface temperatures are available for certain locations and are accessible through global observational networks, observation stations, and from models. See Appendix A, paragraph A-6.2 for data resources. See paragraph 2-6 for climate change implications on ground temperatures.

[3] "Computer Assisted Calculations of the Depth of Frost Penetration in Pavement-Soil Structures," Cortez et al.

Figure 2-10 Design Freezing Index (°F days) in North America Derived Using the More Modern Approach Described in "Computer Assisted Calculations of the Depth of Frost Penetration in Pavement-Soil Structures," by Cortez et al., over the Period of Record from the WorldIndex Database

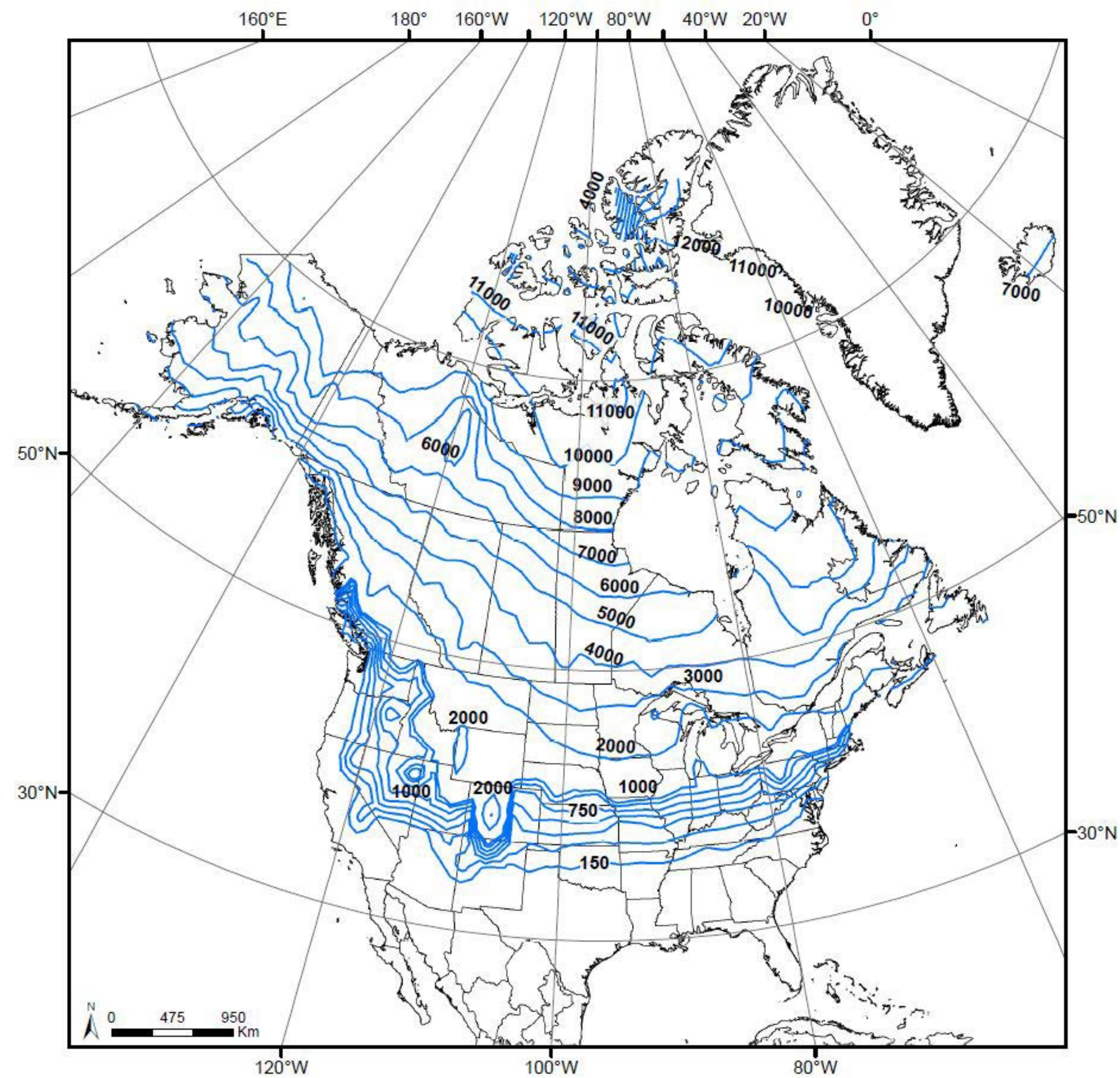
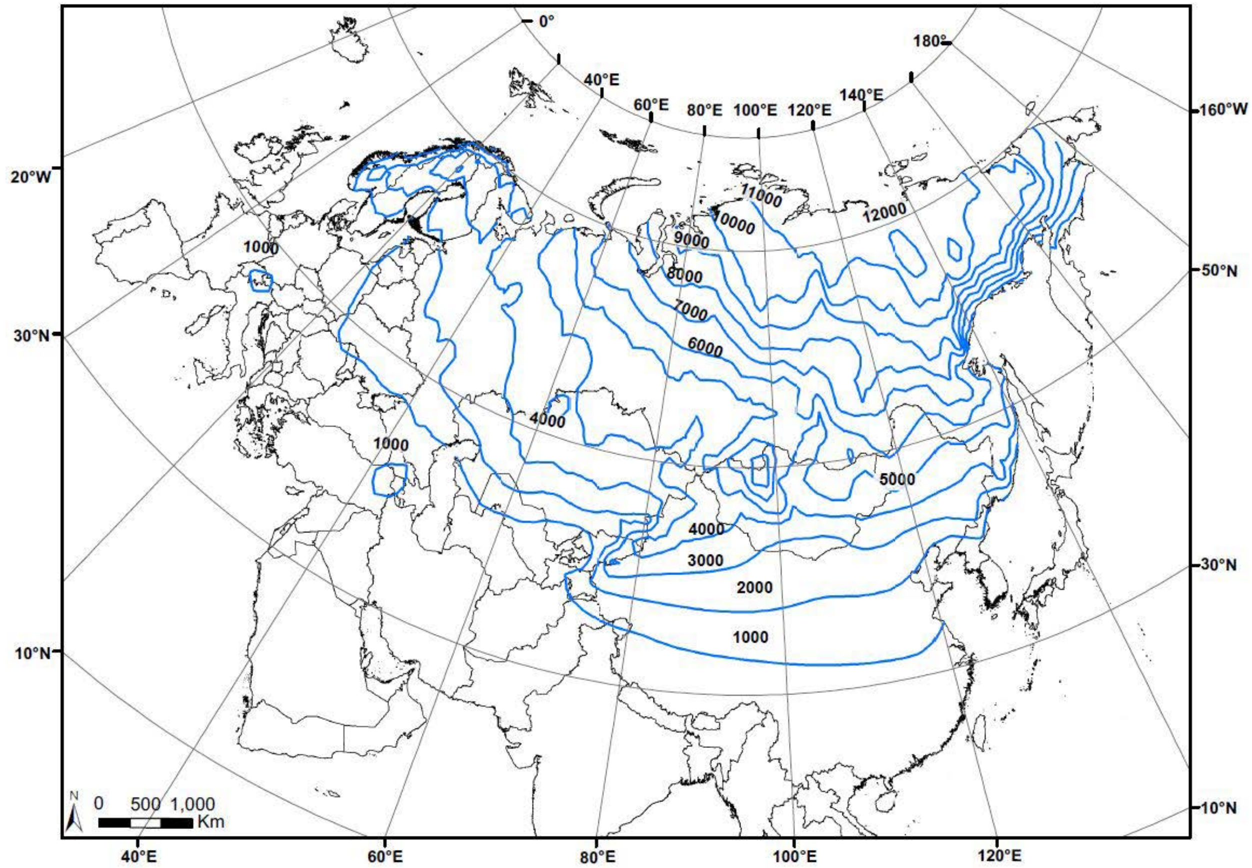


Figure 2-11 Design Freezing Index in Northern Eurasia Derived Using the More Modern Approach Described in "Computer Assisted Calculations of the Depth of Frost Penetration in Pavement-Soil Structures," by Cortez et al., over the Period of Record from the WorldIndex Database



2-5.5 Precipitation and Snow Distribution.

Precipitation and snowfall vary in the Arctic and Subarctic regions due to the complex interactions between the atmosphere, ocean, ice, and snow, as well as global and local processes and environmental changes. Winter has lower rainfall since moisture precipitates as snow. Archives of precipitation observations and other climatic products, like the Operational Climatic Data Summary (OCDS), are available from the U.S. Air Force 14th Weather Squadron for several different stations. Figure 2-12 shows mean monthly and annual precipitation values at selected stations over the observed period of record ending 2020, which are mapped in Figure 2-13. The observed period of record varies by station depending on when the station was established. For Alaska, summaries of climatological conditions such as precipitation, snowfall, and snow depth are also available from NCEI. For additional information, see Appendix A, paragraph A-6.3. Also see paragraph 2-6 for implications of the changing environments on precipitation and snow in the Arctic and Subarctic regions.

Figure 2-12 Mean Monthly and Annual Precipitation in Inches at Selected Stations from the U.S. Air Force 14th Weather Squadron Archived Data

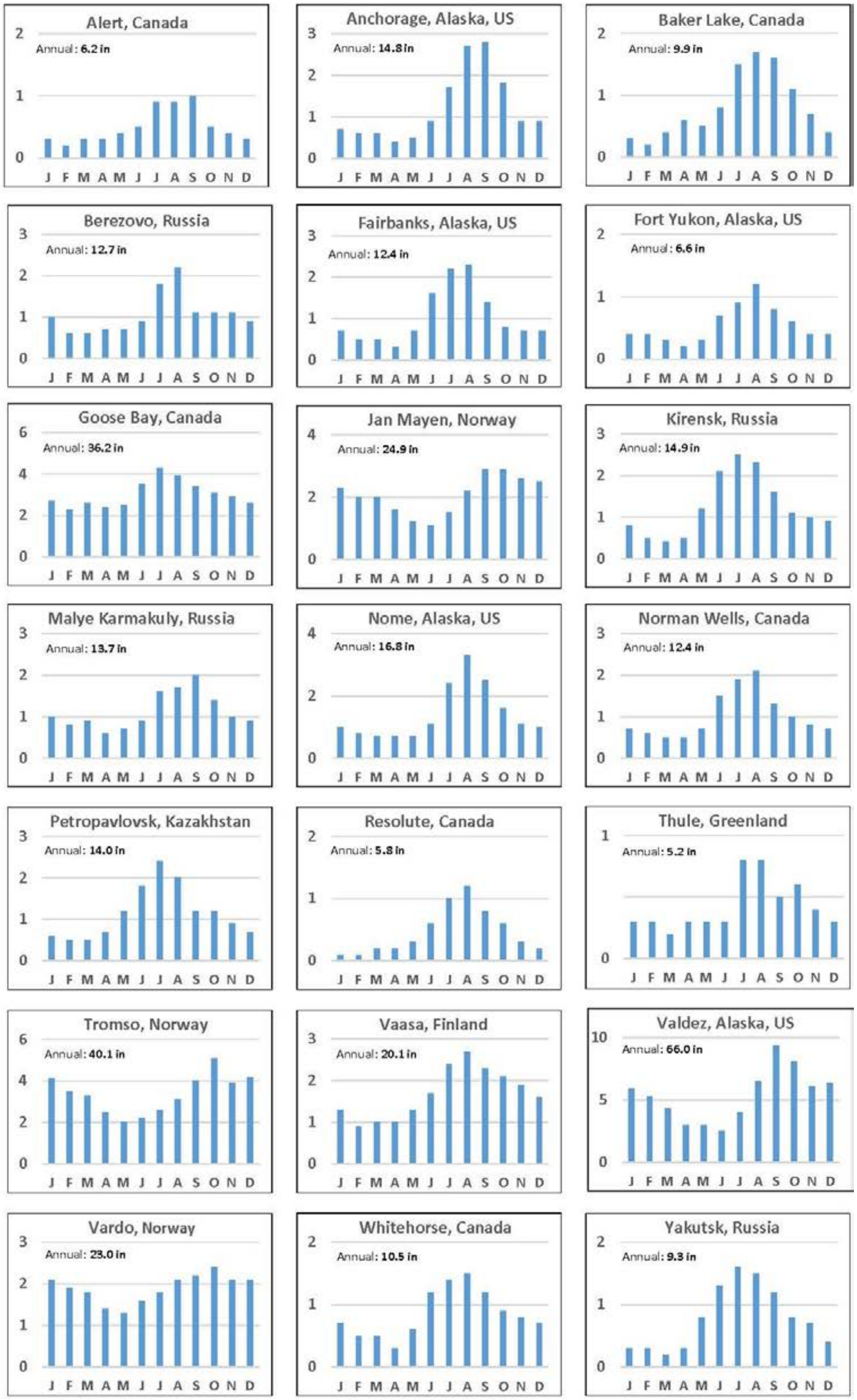
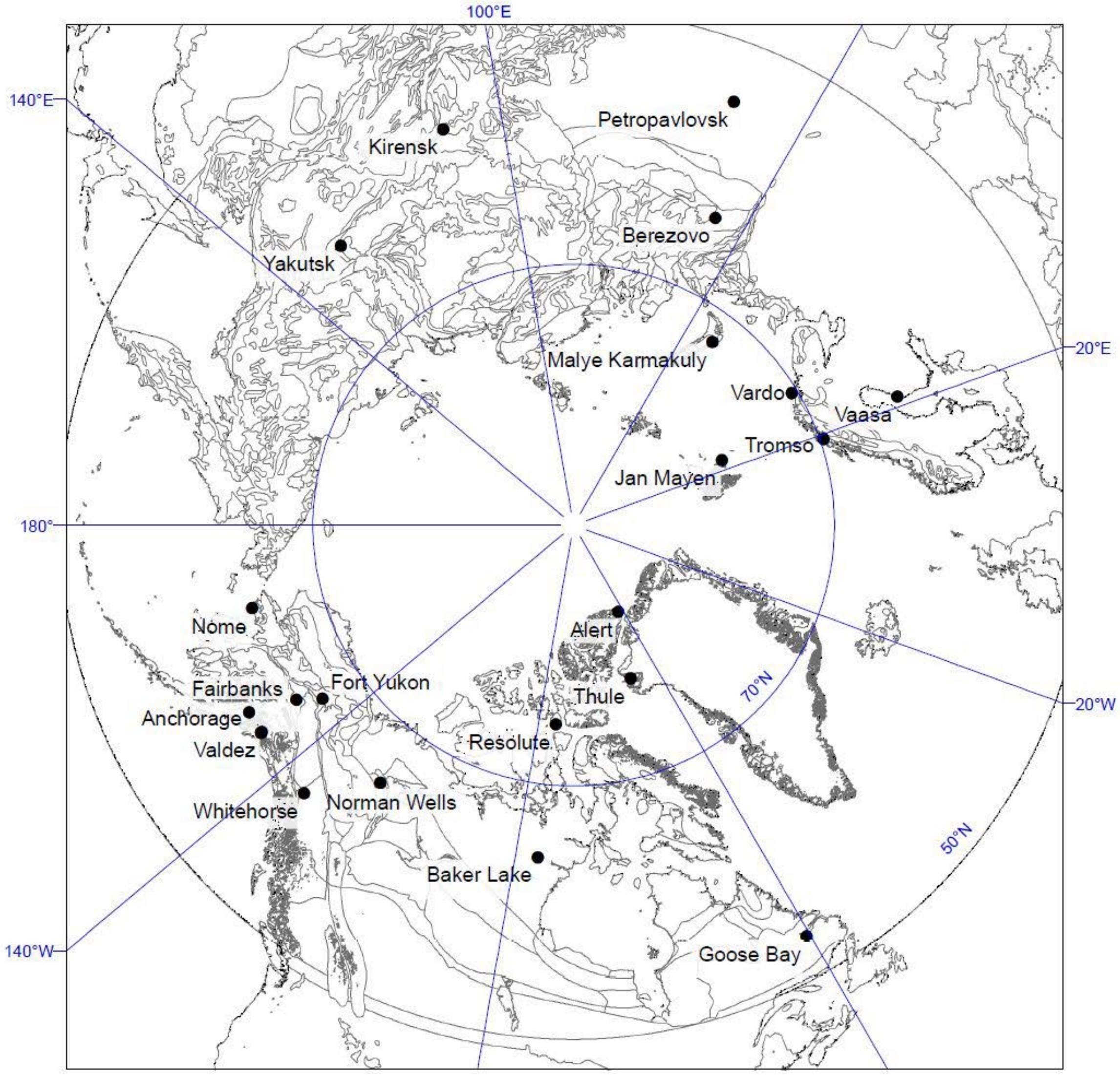


Figure 2-13 Locations of Selected Stations used in Figure 2-12



2-5.6 Snow Loads.

Comply with UFC 1-200-01, UFC 3-301-01, and UFC 3-301-02. Base snow load design on American Society of Civil Engineers (ASCE) guidance ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. Ground snow load information is available from the following sites:

- The Structural Load Data Tool (SLDT), hosted on the Whole Building Design Guide website https://www.wbdg.org/ar/tools/sldrt
- The ASCE Hazard Tool (https://asce7hazardtool.online/)
- The Structural Engineers Association of Alaska website https://seaak.net/alaska-snow-loads, which provides values in two

formats: 50 year mean recurrence interval values described in ASCE 7 and reliability-targeted values sorted by risk category

- *Site-Specific Case Studies for Determining Ground Snow Loads in the United States,* by Buska et al., which provides additional locations for site-specific case studies in both the Lower-48 states and Alaska.

Note that ground snow loads in ASCE 7 account for rain-on-snow events and include snow water equivalent (SWE) data as needed in the criteria. At locations where the ground snow load is not provided, use the best locally available criteria. With the approval of the Authority Having Jurisdiction (AHJ), completing snow load case studies may clarify and refine snow loads for site-specific conditions.

2-5.7 Snow Drift.

Wind-induced snow movement, or drifting, is a common occurrence that creates a variety of problems for Arctic and Subarctic infrastructure. Considerable drifting snow deposited adjacent to and on structures can create unanticipated extra snow overburden, potentially accelerating the settlement and deformation of these structures, leading to premature failure. The mechanics of the snow-drifting process deal with snow particles lifted by the dynamic forces of the air flow. General engineering guidance to minimize snowdrift problems is described in publications such as *Introduction to Cold Regions Engineering*, by Freitag and McFadden. An updated summary follows:

- Avoid locations in which snowdrifts form, if possible.
- Before deciding on a final site, evaluate or study snow conditions at proposed locations for at least one winter by using aerial and satellite imagery to identify drift features. Analyze historical meteorological data from the site to determine representative wind directions, speeds (and more importantly, dominant snow transport direction and amount as this may differ from prevailing wind directions).[4]
- Identify potential effects of wind-transported snow on the operation of the facility access roads, sidewalks, and parking areas.
- Consider the entire facility when evaluating snow problems.
- Select locations with the least snow transport by considering the fetch distance, winter precipitation, and wind exposure. Where possible, select sites in the snow erosion zone, 490 to 650 ft (150 to 200 m) downwind from a deposition area.
- Chapter 7 in ASCE 7, Minimum Design Loads, contains design guidance for the calculation of different snow loading conditions, including guidance for drifts, sliding, and rain on snow applied to various roofing configurations and scenarios.

[4] "Blowing Snow Transport Analysis for Estimating Drift Orientation and Severity," Haehnel.

Find design guidelines for controlling blowing and drifting snow in *Design Guidelines for the Control of Blowing and Drifting Snow*, by Tabler. Numerical methods are applicable for modeling and evaluating snowdrift conditions. Procedures and methodology from case studies of snow transport and using computational modeling of snowdrifts around a building are listed in Appendix A, paragraph A-13.

2-5.8 Ice Load and Atmospheric Icing.

Comply with UFC 3-301-01 to design ice-sensitive structures that withstand ice loading caused by freezing rain, snow, and in-cloud icing.

Structures are subject to two categories of ice loadings. The first category includes loads caused by the ice formed on lakes and rivers. Structures affected by these loads include dams, locks, bridges, pile-supported structures, wharves, docks, and all structures located immediately on the shoreline. Infrastructure and structures located adjacent to lakes and rivers, such as channel erosion controls and buildings, are also subject to ice loads. These loads tend to occur during ice ride-up events when wind pushes ice onto shore and during wintertime floods, typically caused by river ice jams. See paragraph 2-5.9 for guidance on ice loads from ice formed in lakes and rivers. The second category includes loads caused by freezing rain, snow, and in-cloud icing. This category is referred to as atmospheric icing. Structures that are sensitive to atmospheric icing include, but are not limited to, lattice structures, guyed masts, overhead lines, light suspension and cable-stayed bridges, aerial cable systems (such as for ski lifts and logging operations), open catwalks and platforms, flagpoles, and signs. ASCE 7 describes the requirements to design these types of structures to withstand atmospheric icing. Electric transmission systems and communications towers and masts are also sensitive to atmospheric icing but are not included in ASCE 7 because other national standards exist for these types of structures. See *National Electrical Safety Code* (Institute of Electrical and Electronics Engineers [IEEE C-2]), *Guidelines for Electrical Transmission Line Structural Loading* (ASCE MOP 74), and *Structural Standards for Steel Antenna Towers and Antenna Supporting Structures* (ANSI/EIA/TIA-222).

2-5.9 Ice Cover and Ice on Water Bodies.

The freezing of lakes, rivers, and coastal waters is a major factor controlling scheduling and effectiveness of field activities in the Arctic and Subarctic. Waterways used for boats or float-equipped aircraft are unusable during the freeze period from September through November. Several weeks of freezing temperatures are required before the ice becomes thick enough to support other types of vehicles. During the winter, ice surfaces, or cover, are often extremely valuable as aircraft landing areas and as smooth, obstruction-free surfaces for tractor trains and other forms of surface transportation. See paragraph 3-2 for guidance on ice-engineering-related ice hydraulics and hydrology and paragraph 3-10.3 for ice or snow roads.

2-5.9.1 Ice Thickness and Bearing Capacity.

When a load is placed on an ice cover, the ice cover deflects downwards in response. The amount of deflection is proportional to the magnitude of the load and the flexural rigidity of the ice cover. The ability of the ice cover to support a load is the bearing capacity of the ice cover. The cover deflects until the water pressure on the bottom of the ice cover increases sufficiently to balance the load. The greater the flexural rigidity of an ice cover, the less it deflects and the larger the area over which the ice cover deflects. The two basic parameters that determine flexural rigidity are the ice cover thickness and its elastic modulus (Young's modulus). In practice, elastic modulus of an ice cover is rarely measured in the field due to practical difficulties. In almost all cases, the bearing capacity is estimated based on the ice thickness, an easily measured parameter.

There are some important considerations when estimating the ice thickness needed to achieve a required bearing capacity.

- **Ice Quality.** It is important that the measured ice thickness be competent blue or black ice and that the ice excludes any unfrozen or partially frozen layers. Snow ice, also called white ice, forms when an ice layer covered with snow floods and the saturated surface snow and water layer freezes. Generally, snow ice has less strength than blue or black ice, and its presence downgrades the ice-cover bearing capacity.
- **Creep.** When a load on an ice layer remains at one location, the deflection of the ice increases with time. The additional deflection is known as creep. In effect, creep reduces the bearing capacity of the ice cover with time. For a load close to or at the maximum bearing capacity of the ice cover, creep can lead to an eventual failure and breakthrough. The occurrence of creep requires treating stationary (or long-term) loads placed on ice differently than moving loads.
- **Risk Factor.** The ratio of the load (pounds force) to the square of the ice thickness (square inches) is often referred to by the symbol *A* and is called the risk factor in using the ice cover. The level of risk increases with increasing *A* values. Operational controls are necessary to implement for managing the risk associated on ice cover with an *A* value of higher than 50. For example, closely monitored, one-of-a-kind missions can tolerate relatively high *A* values of 100 or more. On the other hand, heavily trafficked ice covers such as ice roads require *A* values much closer to 50.
- **Minimum Ice Thickness for Lighter Loads**. Generally, a minimum ice thickness of 4 in. (100 mm) is specified for pedestrians (260 lb or 120 kg), 7 in. (175 mm) for snowmobiles with riders (1,100 lb or 50 kg), and 15 in. (380 mm) for 3/4-ton 4×4 vehicles (up to 11,000 lb). When using the risk factor *A* to estimate the required ice thickness for lighter loads, the estimated ice thickness may not be adequate to support the load because

of normally occurring ice thickness variations (see below), unknown spacing between loads, and other considerations.

See Appendix A, paragraph A-12, for additional guidance on estimating bearing capacity, ice thickness with creep, ice risk, and loads.

2-5.9.2 Ice Thickness Variation.

Ice covers on the surface of a body of water increase in thickness due to the formation of new ice on the underside of the ice layer. The thickness of the ice cover and the resulting ice cover bearing capacity are determined by the climatic conditions. The primary parameters controlling ice thickness are the daily average air temperature and the snow-cover depth.

Ice thickness is also affected by Arctic warming trends due to climate change, with warmer-than-average air temperatures, fewer very cold days, river break-up happening earlier, annual precipitation increase, increase in the occurrence of freezing rain, and a shrinking snow season. Milder winters have resulted in later freeze-up dates, earlier break-up dates, or both, for lakes and water bodies.

2-5.10 Wind and Wind Chill.

Comply with UFC 1-200-01, UFC 3-301-01, and UFC 3-301-02. Identify wind loads at all DoD Installations worldwide by using the structural load data tool hosted on the Whole Building Design Guide website https://www.wbdg.org/ar/tools/sldrt. In many parts of the Arctic and Subarctic, where pressure gradients are weak and temperature inversions are common, surface winds are normally low. Where pressure gradients are more marked, however, near seacoasts and mountains, strong winds are quite common; and wind speeds can attain hurricane velocities. Consider the possibility of strong katabatic winds concentrated in valley outlets during site selection. If strong winds are possible, they may especially affect outdoor activities during the colder months. Worker efficiency decreases with lowering air temperatures, and wind significantly increases this effect. See Appendix A, paragraph A-6.4, for data and online resources.

2-5.11 Visibility and Natural Illumination.

Considerations for adverse weather conditions are necessary when conducting site assessment and surveys, particularly in remote locations. Daylight and seasonal variations affect construction. Poor visibility can disrupt operations and increase safety hazards. Visibility problems may arise from ice fog, blowing snow, and whiteout conditions. Localized fog can form over bodies of water. Ice fog is a type of fog consisting of fine ice crystals suspended in the air. Blowing winter snow can cause severe reductions in visibility, compounded by the shortage of natural daylight. Ground blizzards with winds gusting as high as 40 mph (1.6 km/h) create whiteout conditions in blowing snow. Significant drifting of the snow is likely. Whiteout conditions produce a lack of contrast between the sky and the snow surface and are dangerous and disorienting. See Appendix A, paragraph A-6.5, for hazard warnings and advisory resources.

2-6 CLIMATE CHANGE AND PROJECTIONS.

Global climate change trends are expected to accelerate in the Arctic and Subarctic regions and increase challenges for designing, building, and sustaining infrastructure. These changes are expected to affect many of the climatic factors described in paragraph 2-4. Paragraph 2-6 highlights how future projections of these climatic factors are developed and can affect the infrastructure and facilities criteria in the Arctic.

2-6.1 Overall Climate Observations and Projections.

Climate change trends will present an increasing challenge for infrastructure in Arctic and Subarctic environments with observed changes in air temperatures, ice cover, permafrost, coastal erosion, and other factors. However, translating these trends into the future requires considering climate projections developed from climate models under a range of future greenhouse-gas (GHG) emissions scenarios. These are called projections, rather than specific predictions, because they are “what-if” scenarios, where any of the future GHG emissions scenarios are possible, and actual future trends in emissions may not follow any one of them consistently over time. The future GHG emissions scenarios used in climate projections include low-, moderate-, and high-emission rates under Representative Concentration Pathways (RCPs), for example, 4.5, 6.2, and 8.5, to represent the amount of added infrared greenhouse forcing (in watts per square meter). These projections represent the most comprehensive picture of the expected changes on the climatic factors that would affect Arctic and Subarctic infrastructure.

The Scenarios Network for Alaska and Arctic Planning (SNAP) developed climate projections specifically for the Alaskan and Arctic regions that are applicable to infrastructure and building criteria. SNAP uses global climate model results from the Coupled Model Intercomparison Projects (CMIP3 and CMIP5) for twentieth-century conditions and future low-, moderate-, and high-emissions scenarios out to the year 2100. See Appendix A, paragraph A-7, for additional resources and links to the SNAP future climate projections, reports, and related studies documenting the changing Arctic environment, models, and data. The most likely or significant projected climate impacts affecting the design, building, and sustainability of Arctic and Subarctic infrastructure are summarized in the following sections.

2-6.2 Surface Air-Temperature Projections.

Surface air-temperature increases in the Arctic are projected under all GHG emissions scenarios. Even for low-emissions scenarios, models show on average 5.4°F (3°C) warming over much of Eurasia and North America, and more than 7.2°F (4°C) warming over the Arctic in 2081–2100. The high-emissions scenarios show annual increases of 14.4°F to 18°F (8°C to 10°C) in years 2081–2100 across the Arctic.

The local temperature-change projections developed by SNAP for Alaskan regions and locations assess future changes for criteria infrastructure design for each decade from 2040 to 2100. For coastal northwest Alaska, for example, it shows increasing average temperatures by 12°F (6.6°C) in winter and 8°F (4.4°C) in summer by 2050 in the low-emission scenario and 15°F (8.3°C) in winter and 10°F (5.5°C) in summer in the high-emission scenario.

2-6.3 Projections on Permafrost Warming and Thawing.

Increasing air temperatures, both observed and projected, invariably result in warming and thawing permafrost, whose strength and stability are dramatically reduced by warming. The projections of the observed circumpolar degradation of permafrost across North America and Eurasia concluded that nearly 70% of current infrastructure will have damages associated with high thaw potential by 2050.

2-6.4 Precipitation Projections.

Climate projections in all scenarios are highly consistent in showing increasing precipitation in the Arctic and northern latitudes due to higher air temperatures and a northward moisture transport due to a warmer climate. The projected increase for annual precipitation for Alaska is estimated from +10% for low scenarios to +30% for high scenarios. In Fairbanks, for example, the monthly maximum precipitation expected, with a 50-year return period, would increase from 7 in. (175 mm, historical average) to about 10 in. (250 mm) with projected climate change over 2020–2099.

2-6.5 Snow, Rain, and Ice Events.

Future projections of snowfall and snow cover are more variable and uncertain. As greater moisture becomes available for snowfall, and with the increase in mixed precipitation, the SWE would increase. However, increased temperatures also mean a shorter duration of snow cover and an increase in the fraction of rain in storm events, both for “shoulder seasons” (spring and fall) and for winter rain events.

These winter rain events are expected to result in more frequent freezing rain and icing events that impact roadways and damage trees and power lines in regions not previously affected. The increase in SWE and winter rain events may also increase the total weight of snow loads on roofs, compared to historically dry snow. Because ground snow load measurements consider rain-on-snow events, the expected increase in SWE is included in the updated ground snow load criteria.

2-6.6 Sea Ice Cover.

Climate warming dramatically decreases the safety of operating on Arctic Ocean sea ice. The sea ice extent (the area covered by 15% ice concentration) has declined significantly from 1979 to 2021, decreasing by 2.6% per decade for the March maximum extent and decreasing 13.0% per decade for the September minimum extent. In future projections, the Arctic sea ice area steadily decreases significantly by 2050. The Arctic Ocean is likely to be ice-free in summer (less than 0.4 million square miles) at least once before 2050 under all assessed scenarios and consistently ice-free in September by 2050 under the moderate- and high-GHG emissions scenarios.

2-6.7 Coastal Erosion.

The projections of sea level rise, permafrost thawing (paragraph 2-6.3), and sea ice reduction (paragraph 2-6.6) all contribute to an acceleration of coastal erosion rates in the Arctic. The reduction in ice cover along coastlines, specifically during spring and fall, leaves coasts susceptible to greater storm-driven wave activity that can significantly damage coastal infrastructure in addition to eroding the thawing ground.

2-6.8 River Discharge.

The increases in precipitation (paragraph 2-6.4) also appear to be driving an overall increasing trend in river discharge across the Arctic. While there is significant year-to-year variability in the amount of discharge, there are many natural terrestrial effects and water management activities that will affect local river discharge.

2-7 STABILITY AND PERMAFROST DEGRADATION.

Increasing air temperatures and additional frequency of heat waves as discussed in paragraph 2-6 pose risks for irregular thermal thawing of landforms, creating uneven subsidence and thawing of ice-rich permafrost. The degradation processes include inflow of heat energy into the ground, reduction in soil strength or bearing capacity, water migration, and progressive settlement soils containing excess ice. Issues associated with permafrost degradation due to collapse of soil structure include slope instability; coastline and riverbank erosion; and damage to foundations, roads, railways, retaining embankments, and utilities. Consider such potential effects during design. See Appendix A, paragraph A-8, for additional resources.

2-8 VEGETATION AND WILDFIRES.

The three major types of vegetative cover in Arctic and Subarctic areas are tundra, muskeg, and forest. Vegetation types with shallow root systems that occur in wet or poorly drained areas will often occur over shallow depths of permafrost. North American examples of shallow-rooted vegetation commonly overlaying permafrost are black spruce and larch. Ground layers consisting of sphagnum moss (North America) and other thick, spongy insulating ground layers are also high-probability indicators of permafrost. Vegetation types with deeper root systems and requiring better drained soils will occur in areas with deeper occurrences of permafrost, if present. Generally, deciduous tree cover indicates a low probability of shallow permafrost occurrence. Vegetation profiles are useful as indicators of potential permafrost occurrence but should be interpreted in concurrence with other indicators. It is reasonable to assume that areas of homogenous vegetation share similarly homogenous conditions across the same area. UFC 3-130-02 provides further guidance on vegetation for site assessment.

Wildfires or forest fires affect vegetation, promote permafrost thawing, and may alter permafrost conditions over many years. In the Alaskan interior, summer is typically the driest and warmest season and, as such, is prone to wildfires. Appendix A, paragraph

A-9 contains information on fire-weather conditions and fire impact on vegetation and soil in the Arctic.

2-9 WETLANDS.

Wetlands are common in the Arctic and Subarctic environments. Approximately 40% of the State of Alaska is considered wetlands (Alaska Department of Environmental Conservation, Division of Water website https://www.fws.gov/wetlands/Documents/Status-of-Alaska-Wetlands.pdf, and Hall et al. 1994). Some of these wetland types are bottomland forests, bogs, wet meadows, potholes, and wet tundra. In the winter months, these areas are frozen and covered with snow and ice. Executive Order 11990 directs all Federal agencies to avoid wetlands development wherever there is a practicable alternative. Also, see UFC 3-201-01 for basic site development, design, and planning requirements and for specific issues such as wetlands, flood hazards, and tidal zones.

2-10 SEISMIC.

Comply with UFC 1-200-01, UFC 3-301-01, and UFC 3-301-02. Assess location-specific seismic parameters using the structural load data tool hosted on the Whole Building Design Guide (WBDG) website https://www.wbdg.org/ar/tools/sldrt.

2-10.1 Seismic Loading.

Design codes for the dynamic loads imposed by earthquakes are applicable to frozen soil conditions; however, the presence of permafrost can significantly alter the ground-motion characteristics. Stress-wave velocities are much higher and damping is lower in frozen soils. Propagation of stress waves through permafrost is faster and of a higher intensity than for nonfrozen soils. The average response in spectra vary depending on the depth of permafrost, local soil conditions (unfrozen soils above the frozen layer), and the interaction between distributed blocks of isolated frozen soil. See Appendix A, paragraph A-10, for additional literature on how these affect ground motion in Arctic and Subarctic areas. Site exploration must include a seismic survey to quantify spectral values for seismic parameters because the stratigraphy and geotechnical properties of soil profiles affect seismic responses.

2-10.2 Design.

Infrastructure in the Arctic and Subarctic includes seismic design by considering the probability, severity, frequency, and potential damage of seismic ground shaking or tsunamis, in addition to designing for dead, live, snow, and wind structural loads. The U.S. Geological Survey (USGS) Earthquake Hazards Program website posts and archives seismic activities worldwide. The University of Fairbanks (UAF), Alaska Earthquake Center, posts earthquake activities in Alaska. Alaska is a seismically active region with frequent earthquakes. Ground motion can be characterized as moderate to high, depending on location and proximity to faulting. See Appendix A, paragraph A-10, for additional resources.

The National Institute of Building Sciences Building Seismic Safety Council, along with the U.S. Department of Homeland Security, Federal Emergency Management Agency (FEMA), publishes *An Introduction to the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures* (FEMA P-749), highlighting earthquake effects and design requirements. FEMA P-749 also provides a seismic design category map for Alaska.

2-11 GEOSPATIAL DATA.

Geospatial data are valuable for site planning, reconnaissance, and initial site characterization of ground conditions. Geospatial data sets including the digital elevation model (DEM), digital surface model (DSM), soils, and other terrain features in Arctic regions are available. See Appendix A, paragraph A-11, for other resources.

CHAPTER 3 ENGINEERING FACTORS AFFECTING DESIGN AND CONSTRUCTION

3-1 INTRODUCTION.

This chapter introduces specific requirements for planning, design, and construction procedures for Arctic and Subarctic regions and identifies issues associated with the extreme cold region conditions. Full discussions of these topics are found in the other volumes of the UFC 3-130 series.

3-2 ICE ENGINEERING.

Water infrastructure in cold regions, such as piers, bridges, dams, and riprap, are included in the field of ice engineering. Resources for various ice engineering topics to consider in the design and construction of water infrastructure are available in Appendix A, including practical recommendations for modeling ice-jam floods. Additional considerations, such as freezing of lakes and streams, ice and snow in hydrology, and ice and snow in hydraulics, are discussed in *Introduction to Cold Regions Engineering*, by Freitag and McFadden. Climate change may affect river ice, including ice-jam floods.

3-3 HYDROLOGY: SNOW AND SNOWMELT.

In general, hydrology in Arctic and Subarctic environments is highly dynamic, is seasonally and climatically dependent, and varies greatly in extent for both surface and subsurface conditions across the regions. The important characteristics for hydrology in Arctic and Subarctic environments include considerations with surface energy balance, snow process, snow insulation, snowmelt, infiltration, soil temperature, soil moisture, permafrost, active layers, and other aspects. Surface hydrology is influenced by permafrost depth (the active layer) and snow loading as well as the potential retention of winter or late-season rain events. Also, permafrost greatly influences subsurface hydrology (groundwater), causing reduced ground permeability, which in turn affects the distribution and movement of subsurface water.

Snow hydrology and estimating snowmelt runoff produced by a watershed over a specified time are important factors to consider for groundwater flow and drainage design. There are three basic components required to estimate snowmelt runoff. The first is the spatial distribution of the SWE throughout the watershed at the start of the snowmelt period. SWE is the depth of water produced by melting the entire depth of snow over a unit area of the watershed. The second is a snowmelt model that estimates properties of the snowpack (temperature and liquid-water saturation) and the heat transfer into the snowpack from the atmosphere and calculates the amount of the liquid water that reaches the soil surface over the specified time period. The third is a routing model to determine the time for watershed channels to transport surface water to a point of interest, generally the watershed outlet. See Appendix A for more resources and best practices on SWE measurements and snowmelt estimation.

3-3.1 Aufeis.

Aufeis is a phenomenon in which liquid water (stream or ground source) overflows and refreezes on a frozen surface or near-surface confines and atop existing terrain or ice pack. Aufeis is considered an infrastructure geohazard. It affects infrastructure by accumulating on road surfaces; eroding stream channels; contributing to ground uplift; subsidence due to ice accumulation; and thaw and frost sorting ground materials, which leads to unstable soil conditions. Aufeis generally forms in the same areas annually or can form randomly one season and never appear again in the same location. Changes in climatic, geological, or hydrological conditions can cause abrupt variance in occurrence and severity of aufeis formation. In general, the formation is controlled by local or regional surface topography, groundwater, climate, soil conditions, and permafrost presence and distribution. Practical mitigation options include removing the ice buildup by ripping with heavy equipment, installing ice fences, and installing ice storage areas or interceptor systems to divert water flow. See Appendix A for more resources on best practices.

3-3.2 Avalanche.

Mountainous terrain has the potential to pose avalanche hazards. Avalanches are the result of high-altitude structural failure of snowpack and the resulting movement of snow, ice, and debris from higher to lower altitude. Avalanche hazards include the mechanical hazards of large amounts of moving material, as well as air blast and shockwave hazards.

3-4 FROZEN GROUND ENGINEERING.

Frozen ground engineering factors affecting design and construction of facilities in Arctic and Subarctic environments are briefly introduced below. Comply with the more-detailed requirements in UFC 3-130-03 and UFC 3-130-05. Discussions of fundamental concepts and advances in the field of frozen ground engineering are available in various textbooks such as *Frozen Ground Engineering*, by Andersland and Ladanyi, and *Introduction to Cold Regions Engineering*, by Freitag and McFadden.

3-4.1 Physical Properties and Soil Factors.

As a rule, the engineering characteristics of permafrost depend on the texture, water content, salinity, and temperature of the soil. Clean sands and gravels located in well-drained areas may not present serious engineering construction problems if they do not contain appreciable amounts of excess ice. Conversely, permafrost consisting of fine-textured soils, such as silt, often contains large formations of ice lenses, wedges, veins, or other shapes. Cold regions textbooks such as *Frozen Ground Engineering*, by Andersland and Ladanyi, contain information on the standard system for classification of frozen soils, frost action, and the strength and thermal properties of frozen soils. Investigate and evaluate frozen soil index properties (for example, soil type, moisture content, ice content, and density) in accordance with accepted engineering practices, including the following:

- ASTM D4083, *Standard Practice for Description of Frozen Soils (Visual-Manual Procedure)*
- ASTM D2216, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soils and Rock by Mass*
- ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes*
- ASTM D7015/D7015M, *Standard Practice for Obtaining Intact Block (Cubical and Cylindrical) Samples of Soils*
- ASTM D7099, *Standard Terminology Relating to Frozen Soil and Rock*

ASTM publishes symposia and technical papers on the latest information on frozen soil properties and measurements of soil indices. Since frozen saline soils are widely distributed, particularly along the Arctic coast, consider the special engineering properties of these soils. See Appendix A for an additional list of information.

3-4.2 Heat Flow at the Ground Surface.

Permafrost remains stable if its natural cover of trees and other vegetation remain intact or undisturbed and if the mean annual temperature of that location is maintained. However, one of the most important things to consider in any civil engineering work in the Arctic and Subarctic is the effect of a change in surface condition on the thermal regime in the ground. Transfer of heat at the air–ground interface depends on such time-varying factors as the thermal properties of the soil, the albedo (reflectivity) and insulating properties of the ground cover at the surface, the amount of solar radiation reaching the surface, the wind structure and velocity above the surface and the surface roughness, the air temperature and humidity as a function of height above the surface, precipitation, snow cover, and evapotranspiration from vegetation. Heat flow toward the ground surface from the soil below is also a factor. Alteration by stripping away, compressing, or otherwise changing the existing vegetative ground cover, erecting structures, or constructing pavements, pipelines, or other features alters the thermal balance in the ground, changing the depth of annual freeze and thaw and, in permafrost areas, alters the depth of the permafrost table. Cold regions textbooks discuss permafrost degradation or aggradation due to ground-surface alteration in more detail, specifically *Frozen Ground Engineering*, by Anderson and Ladanyi (see Appendix D).

3-4.3 Mechanical Properties.

The mechanical properties of frozen soils are influenced by soil temperature, water content, density, applied load, and specimen orientation. See Appendix A for additional resources on mechanical properties. While certain data sets of soil mechanical properties are available, experienced field geotechnical engineers and technicians must identify and conduct the required tests for site-specific soil and loading conditions.

3-4.3.1 ASTM Standards.

Use the following ASTM standards that are specific to frozen soil material properties:

- ASTM D5520, *Standard Test Method for Laboratory Determination of Creep Properties of Frozen Soil Samples by Uniaxial Compression*
- ASTM D5780, *Standard Test Method for Individual Piles in Permafrost Under Static Axial Compressive Load*
- ASTM D5918, *Standard Test Method for Frost Heave and Thaw Weaking Susceptibility of Soils*
- ASTM D6035, *Standard Test Method for Determining the Effect of Freeze–Thaw on Hydraulic Conductivity of Compacted or Intact Soil Specimens Using a Flexible Wall Permeameter*
- ASTM D7300, *Standard Test Method for Laboratory Determination of Strength Properties of Frozen Soil at a Constant Rate of Strain*

3-4.3.2 Other Standards.

Aside from ASTM standards, the following are other commonly used, nonstandardized frozen soil test methods:

- Thaw-consolidation test
- Compressibility of thawing soils
- Shear stress test
- Triaxial compression test
- Pile pullout test for field measurement

See Appendix A for additional resources and sources of experimental data for soil properties for ice-soils.

3-5 CALCULATION OF DEPTH OF FREEZE AND THAW IN SOIL.

It is essential to understand the thermal properties that influence soil heating and cooling in cold region design and construction. The parameters include thermal conductivity, heat capacity, latent heat, thermal diffusivity, and thermal expansion and contraction as described in detail in cold regions engineering textbooks (see list in Appendix A). Heat transfer and the depths to which soils freeze and thaw are particularly important when designing structures, utilities, and pavements in areas of seasonal frost and permafrost. Methods for calculating such depths are based on heat-transfer principles and are presented in cold regions textbooks such as *Frozen Ground Engineering*, by Andersland and Ladanyi, and *Cold Region Structural Engineering*, by Erranti and Lee. The methods include one-dimensional linear, multiple-plane, and two-dimensional radial heat flow. Use UFC 3-130-03, Chapter 6, for numerical modeling of ground thermal response.

3-5.1 One-Dimensional Linear Heat Flow.

The modified Berggren equation is a mathematical construction over Fourier's Law for one-dimensional heat conduction through a homogeneous soil. The solution to the modified Berggren equation requires numerical methods. Use the modified Berggren equation for (1) calculating the depth of frost penetration in Subarctic and seasonal frost regions where the ground freezes during winter and thaws during spring and (2) for calculating the depth of seasonal thaw penetration (active layer thickness) in permafrost areas.[1] See Appendix A, paragraph A-16, for a list of one-dimensional models used in cold regions.

3-5.2 Multiple-Plane and Two-Dimensional Radial Heat Flow

Thermal problems dealing with multiple planes and radial heat flow are common for foundation and utilities design. Comply with UFC-3-130-03 for foundation design, including pile foundations, in permafrost and UFC-3-130-05 to design and construct utility supply lines including water and sewage transport in permafrost and seasonal frost areas.

See *Frozen Ground Engineering*, by Andersland and Ladanyi, and *Cold Region Structural Engineering,* by Erranti and Lee, for steady-state heat-flow equations to quantify thermal resistance and temperature conditions for multiple layers and cylindrical or spherical heat flow. The steady-state solutions include heat flow

- through several layers of different thicknesses and material conductivity, such as floor systems or a concrete pad over soil, soil layers with insulation, pavements, buried insulated utilities, and other scenarios;
- for effective thickness with a cylindrical cross section;
- of two infinite areas, with one heated and one cooled, for estimating the radial geothermal gradient between them such as temperature gradients near shores, beneath rivers, and around heated or cooled structures.

Note that these solutions can over- or underestimate results due to the variability of surface temperature or surface cover, the effects of phase change, moisture (in the frozen and thawed soil), and salinity.

3-6 SITE SELECTION AND GEOTECHNICAL INVESTIGATIONS.

Comply with UFC 3-201-01, Chapter 2, for planning and conducting geotechnical investigations during the various stages of development for civil and military projects.

Geotechnical investigations must be tailored to the individual projects. Comply with UFC 3-130-02 for site selection and development procedures specific to cold regions. The requirements and information for site selection and geotechnical assessment described in UFC 3-130-02 are unique to the Arctic and Subarctic regions. Moreover, all designs

[1] *Frozen Ground Engineering*, Andersland and Ladanyi.

for construction in Arctic and Subarctic regions are preceded by thorough site or route investigations to obtain any existing information on the proposed location and to identify new field data requirements on surface and subsurface features, drainage, permafrost, and other conditions. The importance of thorough site investigations before construction cannot be overemphasized. Sites with non-frost-susceptible subsurface conditions or foundations are much easier to develop for than those having frost-susceptible materials or permafrost. Soil investigations (sampling, testing, and evaluation) must be in accordance with UFC 3-220-01, UFC 3-250-01, and UFC 3-260-02 as discussed in UFC 3-201-01, paragraph 2-4.1. Comply with UFC 3-130-02 for site selection and geotechnical investigations, specifically on frozen and permafrost soils. Also see Appendix A, paragraph A-17, for other guidance and other standard practices.

3-6.1 Site Selection.

Arctic and Subarctic site selection and development is much more complex than in temperate regions because of the remoteness of the locations, the large distances sometimes involved, the limited support facilities, and the seasonal and environmental constraints on field activities. Over large areas of the Arctic and Subarctic, specific terrain or local climatic information is limited. The use of existing geospatial and remote-sensing data sets is beneficial. Access to proposed site or route locations is difficult and expensive, may require careful seasonal scheduling, and may involve severe restraints on sizes and weights of survey equipment that can be brought in. Field working conditions are difficult, considering that very low temperatures persist for several months of the year. Costs of site selection and development studies are high, but do not allow these costs to justify inadequate investigations.

3-6.2 Soil Sampling.

Sampling for frozen ground requires greater attention to avoid thermal disturbance. Select suitable sampling techniques and equipment based on project-specific needs and as determined by an experienced field engineer. Obtain samples that represent the subsurface conditions. Special care is required to maintain samples in their frozen state in the field, in transit, and in storage. Take specific care when machining samples, particularly for mechanical tests. For more information on field sampling, as well as sample handling of frozen soils, field testing, and instrumentations in frozen ground, see *Frozen Ground Engineering*, by Andersland and Ladanyi.

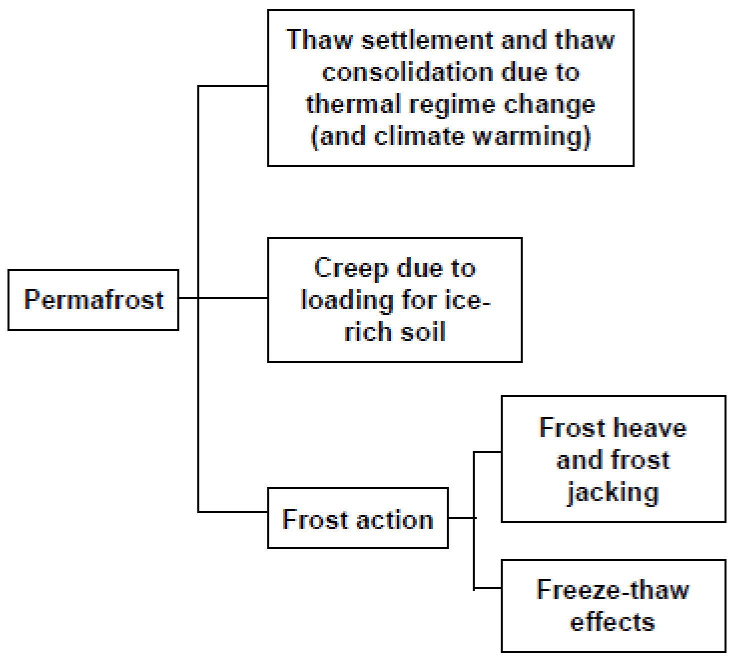
3-6.3 Geophysical Methods.

The use of geophysical methods to characterize the permafrost and ground ice has increased in recent decades. Because physical properties depend on freezing of interstitial water in soils and rocks, successful delineation of permafrost requires supplementary information (such as core data) and knowledge of geophysics methods for frozen ground. Find further information on using geophysics in frozen ground in *Frozen Ground Engineering*, by Andersland and Ladanyi, and *Improving Design Methodologies and Assessment Tools for Building on Permafrost in a Warming Climate*, by Bjella et al.

3-7 FOUNDATIONS FOR STRUCTURES.

Planning, design, and construction of Arctic and Subarctic foundations requires a thorough consideration of ground characteristics as well as the physical, mechanical, and thermal properties of the foundation soil (Figure 3-1). Permafrost and frozen soils respond to foundation loads differently than normal, unfrozen soils, requiring the appropriate type of foundation to address those differences. Comply with UFC 3-130-03 and references therein for requirements of foundation planning, design and construction in cold regions.

Figure 3-1 Consideration Factors for Foundation Design



3-7.1 Considerations.

The major principles to consider for foundation design are bearing capacity and settlement. Because foundation soils vary, the following are additional factors to consider:

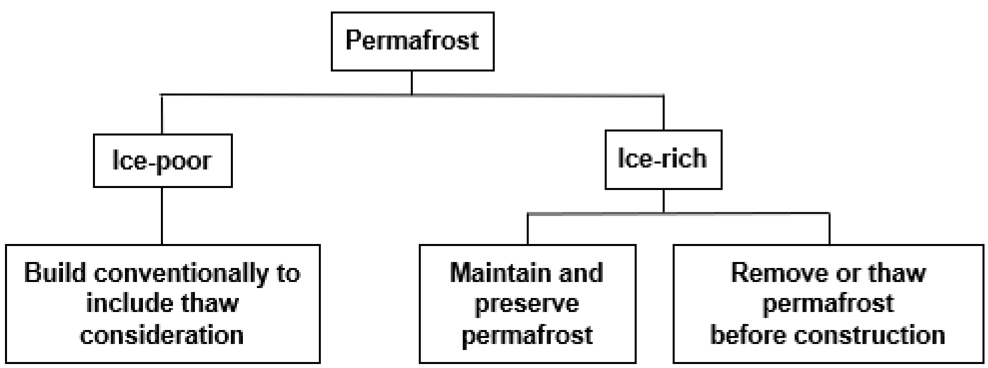
- Thaw settlement and thaw consolidation associated with thermal changes—When thaw settlement occurs, the volume of the soil structure decreases due to melting ground ice or permafrost and the subsequent draining of meltwater, causing ground settlement and creating uneven ground. Thaw consolidation occurs when frozen soil thaws but meltwater is trapped and soil remains undrained, reducing soil strength.
- Long-term strength and creep—The presence of ice causes frozen soil to take on stress-strain behavior characteristics like ice. The strength and deformation of frozen soils depend on loading, temperature, and time.

Therefore, frozen soil subjected to load responds with an instantaneous deformation and a time-dependent deformation. Determine allowable loads by conducting laboratory creep tests (such as ASTM D5520).

- Frost action—Frost action is the process of alternate freezing and thawing of moisture in soil, rock, and other materials and evaluating the resulting effects on materials and on structures placed on, or in, the ground. The process can involve frost heave, frost jacking, and other freeze–thaw effects. Frost heave is an upward ground movement due to ice formation in the underlying soil. Frost jacking is a cumulative upward displacement of objects embedded in the ground, caused by frost action. Freeze–thaw effects not only cause displacement but also change the hydraulic and strength properties of the thawed soil.

The principles for foundation design in permafrost are divided into two categories: ice-poor permafrost and ice-rich permafrost (Figure 3-2).

Figure 3-2 General Approach for Foundation Design



3-7.2 Foundation Design for Permafrost Under Ice-Poor Conditions.

Conditions under ice-poor permafrost are not adversely affected by thaw as they contain little or no ground ice. Materials within this permafrost are clean, granular soils or rocks. Consider the following principles for foundation design in permafrost areas with ice-poor conditions:

- Place foundation below the active layer with protection as needed against uplift acting in adfreezing shear and against frost overturning or sliding produced by frost thrust.
- Design with proper drainage to continue to remove water prior to freezing.
- Support the structure on a compacted, non-frost-susceptible fill capable of limiting freeze and thaw effects.
- Use normal temperate zone approaches if the foundation-supporting conditions will not be adversely affected by thaw.

3-7.3 Foundation Design for Permafrost Under Ice-Rich Conditions.

Ice-rich permafrost conditions are usually fine-grained soils or rocks with significant ground ice, which are adversely affected by thaw. These materials are found in continuous and discontinuous permafrost zones. Consider the following principles for foundation design in permafrost areas with ice-rich conditions:

- Maintain the existing thermal regime.
- Modify the foundation conditions prior to construction.
- In the design and construction, identify and account for the thermal regime changes.

Further, consider this additional guidance:

- Support the structure on a compacted, non-frost-susceptible fill capable of limiting freeze and thaw effects.
- Use thermal insulation, foundation loading, foundation soil replacement, heat to thaw ice-rich soil or removal of heat by freezing the soil, or combinations of these.

3-8 BUILDING DESIGN PRACTICES.

Specialized cold regions building design criteria and guidance are discussed in UFC 3-130-04*,* and design criteria and guidance pertinent to foundations are presented in UFC 3-130-03. General considerations include building type or use, building materials, doors, entrances, roofs, windows, sliding snow and falling ice, wind, snowmelt, icing, drifting of snow, and many other aspects of building design for Arctic and Subarctic environments. Consider requirements as part of a system of interrelated elements under broad design, construction, operation, and maintenance of facilities. Give special attention to foundations, exposure, and adaptation to the extreme environmental conditions.

3-9 UTILITIES.

Use UFC 3-130-05 for criteria and guidance for utilities in the Arctic and Subarctic. Connections of utilities to buildings are discussed in UFC 3-130-04. Utilities include water, wastewater, utilidors, fire protection, electrical, and communication systems. Many elements of these systems, such as electric generators and water-treatment mechanical equipment, are standard items that require no modifications for use in the Arctic and Subarctic if they are appropriately protected from extreme temperatures, snow, and ice and if back-up systems or power are provided as necessary. However, other items require special approaches. For example, protect water distribution pipes in the Arctic from freezing to maintain flow, prevent bursting, and withstand differential thaw settlement or frost heave. Design wastewater treatment facilities to resist frost heave or thaw; settlement damage to pipes, tanks, and other structural elements; and adverse effects of low temperatures on treatment processes. Achieve acceptable grounding conditions by finding areas where soils are less likely to freeze, by installing ground rods or piles in warmer soils, or both; UFC 3-130-05, paragraph 11-2, discusses this further.

3-10 HORIZONTAL INFRASTRUCTURE (AIRFIELD PAVEMENTS AND ROADS).

3-10.1 Airfields and Roadways.

Comply with the cold regions requirements for road, pavement, and airfield design in UFC 3-250 and UFC 3-260 series as listed in the references. In addition, several cold regions textbooks present detailed information on pavement-specific topics

- *Cold Regions Pavement Engineering*, Doré and Zubeck;
- *Introduction to Cold Regions Engineering*, Freitag and McFadden;
- *Permafrost Engineering Design and Constructio*n, Johnston; and
- *Construction in Cold Regions: A Guide for Planners, Engineers, Contractors, and Managers*, McFadden and Bennett.

Several factors affect roadway and airfield surface performance in cold regions. Factors include loading, surface characteristics, subsurface drainage, freeze and thaw, subgrade properties, resilient modulus, moisture change, icing, snow and ice removal, and many others. Consider the following detrimental effects when designing airfield pavements and roads in the Arctic and Subarctic:

- Seasonal frost heave and settlement, commonly differential
- Reduced bearing capacity during and after thaw
- Pavement pumping (the ejection of water and base and subgrade material through joints and cracks or at the pavement edge under traffic loading)
- Pavement cracking
- Deterioration of pavement surfacing
- Progressive increase of pavement roughness
- Loss of compaction
- Restriction of subsurface drainage by frozen ground
- Wintertime surface drainage problems
- Snow removal and icing problems
- Degradation settlement from thawing of permafrost, commonly differential
- Adverse surface drainage effects from permafrost degradation

All but the last two effects are observed to some extent in temperate zone frost areas. The most difficult conditions are in areas near the boundary between permafrost and unfrozen soils. Here the depth of seasonal freezing is at a maximum and permafrost, where present, is the least thermally stable. The detrimental effects of seasonal frost action on pavements are discussed in cold regions textbooks, particularly in *Cold Regions Pavement Engineering*, by Doré and Zubeck. In permafrost regions, the change of ground-surface conditions caused by construction can initiate permafrost degradation and invariably create differential settlement.

3-10.2 Unsurfaced Airfields and Roadways.

Unsurfaced roads and airfields have unbound, aggregate surfaces as an uppermost layer, meaning there is no asphalt or cement layer as a wearing surface. The typical material used for an aggregate wearing surface is compacted gravel with a specified gradation. Guidance for basic design elements, construction, and maintenance of gravel roads is listed in the Federal Highway Administration (FHWA-OTS-15-002). The Alaska Department of Transportation also provides guidance for gravel roads design and maintenance. Army and Air Force only, use UFC 3-250-09FA cold regions requirements for designing unsurfaced roadways and unsurfaced airfields.

3-10.3 Winter—Ice, and Snow Roads.

In very cold and remote areas, winter roads constructed using snow and ice, or both, are viable. Snow roads are built with compacted snow. Ice-capped snow roads use water to produce a bond between snow particles, adding stability to the road.[2] Design, construction, and maintenance techniques for ice and snow roads are described in *Introduction to Cold Regions Engineering*, by Freitag and McFadden, *Permafrost Engineering Design and Construction*, by Johnston; and *Construction in Cold Regions: A Guide for Planners, Engineers, Contractors, and Managers,* by McFadden and Bennett. Ice and snow roads are viable only when sufficient ice thickness forms on the surface of a body of water to carry the vehicle loading or enough snow cover and sufficiently frozen layers exists in the ground. Snow roads (compacted snow) are common in the high Arctic and at McMurdo Station in Antarctica. See Appendix A, paragraph A-18, for snow roads best practices and procedures used by other agencies.

3-10.4 Ice and Snow Runways.

Ice and snow runways are successfully constructed in cold regions. Snow runway design is based on strength properties and bearing capacity similar to that of conventional roads and runways. The design for an ice runway is like a snow runway, except the stress loading characteristics are based on the flexural strength of the ice rather than the shear resistance of a snow layer. The complex nature of snow and ice mechanics presents unique challenges to constructing snow and ice runways. Detailed information on the design and construction methods of a first-of-its-kind snow runway capable of supporting a wheeled aircraft as heavy as a C-17 is documented in *A Snow*

[2] "Winter Roads in Manitoba," Kuryk.

Runway for Supporting Wheeled Aircraft: Phoenix Airfield, McMurdo, Antarctica, by Haehnel et al. Guidance for snow and ice runways, specifically for Antarctica, is in FC 3-260-06F, *Air Force Design, Construction, Maintenance, and Evaluation of Snow and Ice Airfields in Antarctica*. See APPENIDX A, paragraph A-18, for other methodology on the design and construction for snow and ice runways.

3-11 DRAINAGE AND GROUNDWATER.

Although annual precipitation intensity rates are relatively light in much of the Arctic and Subarctic, except in coastal regions, control of surface and subsurface water movement around structures is necessary to prevent icings, erosion, and permafrost degradation. Sources of surface water include snowmelt (see paragraph 3-3), rain, groundwater seepage, and flooding. Also, sources of groundwater may include melting subsurface permafrost ice. In this context, icing is a sheetlike mass of layered ice formed on the ground surface by freezing of successive flows of water that seep from the ground. UFC 3-130-03 provides criteria and guidance for surface drainage design and to control icing in Arctic and Subarctic regions. UFC 3-130-03 presents criteria and guidance for drainage around structures, including brief guidance for seepage control.

3-11.1 Surface Water.

A frequent cause of damaging floods in cold regions is the temporary damming of rivers by ice jams formed by melting winter snowpack along river and tributary areas. The following are two examples of guidance for flood design:

- FEMA developed the *Design Guide for Improving Critical Facility Safety from Flooding and High Winds* (FEMA 543), which includes recommendations incorporating hazard mitigation measures into all stages, and at all levels, of critical facility planning and design for new construction, reconstruction, and rehabilitation of existing facilities.
- The Department of Commerce, Community and Economic Development, which is a department within the state of Alaska, provides *The Floodplain Management in Alaska Quick Guide*.

The frozen condition of the ground during much of year makes it necessary to assume that the rate of infiltration in the Arctic, for surface drainage design, is zero. Construct relatively deep and narrow surface channels to direct and carry away surface water to reduce the channel surface area and minimize heat loss that leads to ice formation and reduces flow capacity. Preferably, line the channels to prevent excess infiltration into the soil and prevent permafrost degradation. Oversize culverts to account for ice. Flowing surface water in channels can be a significant cause of permafrost thawing. In Subarctic regions, such channels, once formed, may continue to thaw and deepen year after year. Avoid drainage ditches that cut into ice-rich permafrost.

3-11.2 Groundwater Seepage.

Icings generally occur in upland areas where seeps or springs provide a continuous source of groundwater to the surface during winter. Icings are undesirable near buildings, roadways, culverts, or other structures as they are a serious problem when they interfere with road travel or drainage. Control of icings can be surprisingly difficult to achieve. Icing impacts can sometimes be circumvented if the flow can be redirected to locations where it does no harm. Include a steam pipe in culverts susceptible to icing to allow culvert thawing when necessary.

3-11.3 Groundwater.

Control groundwater flow where possible to prevent erosion, or permafrost degradation, and differential settlement. In practice, there are few options for controlling groundwater. Some control over the direction of summer drainage flow in the active layer is possible by modifying surface conditions to selectively control depth of thaw. Modifying downstream water levels can influence the flowrate of groundwater. Injecting water into the ground, such as from leaking water, sewer, or steam pipes, can seriously degrade permafrost and must be avoided. When wells drilled through permafrost encounter water under artesian pressure, great care is necessary to stabilize the unstable soil around the casing to avoid losing control of the well.

3-12 EARTHWORK: EXCAVATION, GRADING, AND FILL.

Conduct a site assessment before performing any earthwork and excavation activities to characterize ground conditions and identify the appropriate methods for excavation. Comply with requirements for site assessment in UFC-3-130-02.

3-12.1 Excavation.

Techniques used for excavation of frozen soils depend on the time of the year and ground conditions. Mechanical methods to fracture, break, and rip frozen materials include excavating by machine and cutting equipment, hydraulic dredging, drilling, and controlled explosive loading or blasting. Other approaches, such as thawing frozen ground, are applicable under certain conditions. Methods for thawing frozen ground include solar thawing, steam injection, water injection, and electric heating. Detailed discussion on excavation techniques and other related factors are described in various cold regions textbooks (see Appendix D).

3-12.2 Earthwork and Fill Placement.

Earthwork of frozen soil is feasible, but significant care and effort are required. Earthwork and placement of fill material can be extremely challenging if conducted during freezing temperatures. Relative compaction varies depending on temperatures, soil type, and ice contents. See cold regions textbooks such as *Introduction to Cold Regions Engineering*, by Freitag and McFadden, *Frozen Ground Engineering*, by Andersland and Ladanyi, *Construction in Cold Regions: A Guide for Planners, Engineers, Contractors, and Managers*, by McFadden and Bennett, and *Permafrost*

Engineering Design and Construction, by Johnston, for detailed information and guidance, including handling on earthwork, placement, and compaction of frozen materials. Use required tests and standards, including ASTM D4253, for determining the minimum thawed dry density of a material.

In general, the placement of frozen materials is prohibited unless the materials can be satisfactorily compacted and maintained in a frozen state for the life of the structure.[3] If material contains a significant amount of ground ice, instability due to thaw settlement will result from melting. Frost heaving can be an issue if the fill materials used are frost susceptible. Whenever possible, use non-frost-susceptible soils for fill materials. The magnitude of frost heave and subsequent thaw weakening is determined by the frost susceptibility of the soils. The frost design classification of soils provides an approximation of frost susceptibility. However, when accurate measurements are needed, ASTM D5918 provides the procedures to determine the frost-heave and thaw-weakening susceptibility of soils.

3-13 EROSION CONTROL.

Adapting to coastal erosion and bank erosion resulting from increased disturbances in hydrological cycles is an evolving field in higher-latitude areas. No specific design guidelines are currently available; however, base erosion-control designs on a solid understanding of the erosion processes involved (fluvial versus terrestrial), the mechanisms of the permafrost environment, and other applicable environment factors. Special consideration of sea ice and sea ice dynamics is necessary for coastal design. Attention to unique issues, such as river overflow during the breakup period and of formation of strudel scour for structures near rivers, is a must. Published erosion-control approaches are listed in Appendix A, paragraph A-19.

3-14 EMBANKMENTS.

Deformation such as settlements and lateral spreading of materials are common embankment failures in cold regions. Settlement of embankments in permafrost regions are attributed to thaw settlement, creep, and freeze–thaw cycling. Consider engineering measures during design to protect the permafrost underneath the embankment. Analysis such as numerical modeling is a viable approach to analyze the embankment deformation for heat transfer, creep, soil compression, and thaw consolidation. Other embankment design techniques are described in Appendix A, paragraph A-20.

3-15 GROUND AND SLOPE STABILITY.

Use general requirements for slope stability in UFC 3-220-01, paragraph 2-4.10. Ice-rich permafrost slopes can create significant creep deformation. Find analyses and design considerations for slopes in thawing permafrost and in frozen soils as well as slope stabilization methods in *Frozen Ground Engineering*, by Andersland and Ladanyi. Comply with UFC-3-130-03 to mitigate slope failures and stability of slopes during thaw.

---

[3] *Permafrost Engineering Design and Construction*, Johnston.

3-16 CONSTRUCTION MANAGEMENT AND PRACTICES.

Designs, cost estimates, and construction management and procedures in the Arctic and Subarctic regions differ from those in temperate regions because of deep seasonal frost, permafrost, and extreme climate. The environment and short construction season critically affect field operation schedules. Remote, isolated construction sites served by long and difficult supply lines mean that mistakes in planning are time-consuming and costly. A highly competent management team, with decentralized authority and centralized support, must carefully plan and organize field activities and conduct an intensive field inspection effort.

3-16.1 Methods of Transportation.

3-16.1.1 Air.

Air transport is a principal mode of transport to Arctic and Subarctic field sites. If a landing strip does not exist near the site, use helicopters or float-, ski- or wheel-equipped small planes in initial project stages, depending on available surface conditions. In winter, heavy wheel-equipped planes can use ice landing surfaces. Constructing a serviceable conventional runway facilitates regular heavy plane operations.

3-16.1.2 Water.

A suitable road or waterway, or an expedient access road, allows delivery of construction materials and equipment to the construction site. However, rivers and the Arctic coastal waters have only limited ice-free periods for water transport. Sometimes a north-flowing river may be open for upstream navigation before its mouth becomes sufficiently ice-free in the breakup period that permits entrance from the sea.

3-16.1.3 Ground.

Low-ground-pressure tractor trains can transport personnel, materials, and equipment over frozen, snow-covered terrain in winter. Frozen lakes and rivers are frequently used very effectively for such transportation. Wheeled, tracked, or sled equipment can use ice bridges to cross rivers and lakes. Stockpile materials at convenient locations during the summer for surface transport in winter. For protection of the terrain, operations on the natural tundra surface in summer are prohibited in Alaska. Vehicles with low-ground-pressure rubber tires (1 to 2 lb/in^2 [7 to 14 kPa]) are an exception. In some areas, such as nature preserves, other restrictions or permit requirements may apply.

3-16.2 Construction Equipment.

Heavy equipment is essential in Arctic and Subarctic construction. Winterize all motorized equipment, including insulated cabs and facilities, fire-retardant engine shrouds, and heaters to protect personnel from severe cold, wind, and snow. Removable cleats on tracked vehicles (such as grousers) or other special traction devices and winches are frequently necessary. Preventive maintenance plays a key role in equipment operation. Maintain a strict lubrication schedule on all equipment. Equipment operators must adhere to freezing-weather preoperation, starting, warm-up, and operating procedures. Unused “cold-soaked” hydraulic systems are especially vulnerable to failure on start-up at about 30°F (−1.1°C) or lower. Tires in extremely low temperatures become brittle and are easily punctured. Metal parts are vulnerable to brittleness at temperatures around 40°F (4.4°C) or lower and can lead to potential safety and operation problem. Inspect all equipment regularly to locate cracks and breaks. Repair all cracks when first observed by preheating before welding and replacing broken parts. Additional information on the effects of cold on equipment performance are described in *Construction in Cold Regions: A Guide for Planners, Engineers, Contractors, and Managers*, by McFadden and Bennett.

3-16.3 Cold and the Worker.

The efficiency of labor on construction projects in the Arctic and Subarctic varies with the experience, attitude, and morale of the workers, as well as working conditions. Cold and darkness during the winter months create safety and operational problems that directly limit productivity. The degree of worker climate acclimation and their cold adaptability is important across all classes of labor and directly affect productivity.

3-16.4 Construction Operations.

The special conditions that prevail in the Arctic and Subarctic impact all aspects of construction, such as excavating frozen soil or frozen rock; placing embankments, backfill, or concrete; and protecting the work. The following are examples of factors that require careful consideration:

- Difficulty of excavating frozen materials
- Difficulty of handling wet, thawed material in summer
- Adherence of ice-filled frozen materials to equipment at low temperatures
- Direct effects of low temperatures on equipment, including brittle fracture of metal
- Shortness of the above-freezing summer season
- Shortness of daylight hours in fall and winter
- Difficulty of achieving satisfactory fills and backfills when temperatures are below freezing
- Problem of placing concrete and achieving adequate strength gain without thaw of underlying permafrost
- Problems protecting work from cold, heat, drying, dust, wind, and precipitation
- Enclosure of work to maintain worker efficiency
- Fire safety and fire protection

3-16.5 Placing Concrete.

Whenever possible, conduct concrete placement work during above-freezing temperatures. Refer to UFC 3-301-01, paragraph 2-7, for requirements.

A combination of several techniques and methods are used to prevent damage to concrete placement during freezing conditions. These techniques include enclosures or tents, insulation, heating of materials, additives, and others that are described in various cold regions textbooks (see Appendix D). Refer and conform to the American Concrete Institute (ACI) *Guide to Cold Weather Concreting* (ACI 306R-16) for recommendations, test methods, mixing, placing, and preparation for cold weather concreting.

3-17 MAINTENANCE AND MONITORING CONSIDERATIONS.

Once facilities or structures are in use, maintenance and monitoring are important given the extreme temperatures and change in thermal properties that impact a facility's life cycle in the Arctic and Subarctic environments. Maintenance includes a collection of actions as well as monitoring to ensure the continued function and sustained service of facilities or structures. There are two aspects to monitoring infrastructure in cold regions: (1) monitoring ground conditions around a building and (2) monitoring the intrinsic aspects of the structure itself. Monitoring is the process of measuring to assess whether facilities or structures are performing as intended. Monitoring can include, but is not limited to, qualitative (like visual observation) assessments and quantitative measurements (such as using sensors).

For foundations and utilities, the most important factor influencing the performance in permafrost is the ground thermal regime.[4] In addition, accumulated snow and ice build-up adjacent to foundations and utilities can disrupt airflow, drainage, or surface flow. Monitoring results can identify performance failures due to factors influencing the distribution or existence of permafrost, the properties and behavior of frozen soil, or freezing and thawing effects. Regular inspection and monitoring programs are essential to ensure that the ground thermal regime is stable and identifies any concerns that affect structures. Note the following signs:

- Subsidence of fills
- Sloughing of natural and manufactured slopes
- Settlement of foundations
- Differential movement of structures
- Ponding of water
- Cracking of the ground and water flowing from under the fill
- Other indications of potential thawing, frost action, or drainage problems

[4] *Permafrost Engineering Design and Construction*, Johnston.

Soil temperature measurements conducted at critical locations beneath a structure (load-bearing points, heating-source proximity, and building geometry) measure the performance of subgrade foundation soils. Consider an early warning detection system consisting of temperature sensors installed at various locations to provide managers and engineers advance knowledge of changing conditions that risk foundation damage as discussed in *Improving Design Methodologies and Assessment Tools for Building on Permafrost in a Warming Climate*, by Bjella et al. More importantly, identify the limiting performance tolerances for which monitoring is being performed. This includes tolerance criteria such as allowable total and differential settlement for structures, limiting stress and strain criteria during pile driving, and minimum acceptable embankment fill compaction. The intent is to identify possible approaching adverse performance conditions and prepare options for engineering mitigation.

CHAPTER 4 RISK AND RESILIENCE CONSIDERATIONS

4-1 INTRODUCTION.

Currently, there is no standard or approach for risk assessment explicitly for Arctic and Subarctic conditions. The harsh Arctic and Subarctic conditions contain inherently significant risks to engineering and construction. The risks are heightened due to natural disasters and climate change. In Arctic and Subarctic regions, resilience is an increasingly important factor in developing and maintaining infrastructure against both the intrinsically extreme environmental conditions and potential climate change impacts. Some overarching updates on risk and resilience directives are available in the following:

- *Army Climate Resilience Handbook*, by Pinson et al., provides methodology and processes to assess climate hazards and incorporate risk into existing Installation Master Plans.
- *Air Force Civil Engineer Severe Weather/Climate Hazard Screening and Risk Assessment Playbook*, by the U.S. Air Force, provides a framework for screening and assessing severe weather, climate hazards, and their associated current and future risks.

Updates to the DoD Installation adaptation and resilience planning handbook and resources on resilience planning are available in the Whole Building Design Guide website.

4-2 RISK ASSESSMENT AND DESIGN FOR RELIABILITY.

Risk assessment is an analysis of a project that identifies and quantifies specific risks according to a hazard probability of impact, while design for reliability refers to the performance of a system within a given environment for the expected life cycle and the likelihood of success or failure in the operation when the system is subjected to hazards. The fundamental guidance for risk assessment is highlighted in the following UFCs:

- UFC 1-200-02 addresses climate change risk consideration and requirements.
- UFC 2-100-01 includes potential risks associated with climate change and formulates potential solutions. Paragraph 2-2.17 has risk-related planning and climate resilience that include processes for an Installation Climate Resilience Plan (ICRP).
- UFC 3-201-01, Chapter 2, includes flood-hazard-related risks.
- UFC 3-220-01 includes geotechnical-related risks.
- UFC 3-301-01 covers risk categories of building types.

Best practices and other guidance on risk assessments used by various agencies are available and listed in Appendix A, paragraph A-21.

4-3 RISK IN THE ARCTIC AND SUBARCTIC.

The general hazards that incur risk in Arctic and Subarctic areas include, but are not limited to, changes in earthquake frequency, precipitation patterns, higher temperatures and more frequent heat waves, potential flooding, wildfires, and thawing of permafrost. Higher temperatures and more heat waves pose risks for irregular thermal thawing of landforms, creating uneven thawing of ice-rich permafrost or permafrost degradation. Other risks include an increased thawing active layer, potentially destructive collapse of slopes because of thawing of near-surface permafrost, and thaw slumping. All of these affect the ground stability and induce changes in the soil's mechanical behavior, such as bearing capacity for the support of infrastructure, which must be evaluated and considered. Apply appropriate risk methodology by using the literature to quantify factors such as thermal stability, thaw sensitivity, and stability of the permafrost landscape, as well as other factors affecting ground instability due to climate change.

4-3.1 Methods.

4-3.1.1 Risk Methodology.

Apply appropriate risk assessment methods to identify various risk factors for design and construction in cold regions. There are two types of risk assessment methods applicable for cold regions (and see Appendix A for more details):

- Qualitative evaluation is based on experienced experts' judgment and evaluation of on-site risks. This method is simple, subjective, and develops a risk index value.
- Quantitative evaluation typically uses methods that analyze the interactions between various factors and quantifies the degree of influence of these factors on the stability and safety of infrastructure for predicting and evaluating the risks to infrastructure.

4-3.1.2 Design for Reliability.

The traditional steps in the design for reliability theory include (1) outline performance objectives, (2) select the mathematical formulation of limit state function or define random variables affecting the limit states of the problem and their probabilistic distributions, (3) create a structural model and conduct analysis to evaluate the limit state functions, and (4) compute the probability of failure and reliability index. See Appendix A for additional information and find examples that are appropriate to use for the project.

4-3.2 Risk Factors Associated with Permafrost.

4-3.2.1 Thermal Stability.

The risk to thermal stability includes factors such as the characteristics of permafrost and its phase changes (such as annual mean ground temperature and radiation balance), the thermal disturbance caused by engineering activities and construction, and the damages due to deformation. Thermal stability analysis includes a comprehensive consideration of climate factors, surface conditions, soil conditions, topography and geomorphology, engineering disturbance, and other influencing factors.

4-3.2.2 Thermal Thaw Sensitivity.

The factors influencing the permafrost thermal thaw sensitivity include the annual mean ground temperature, the permafrost table temperature, the freezing and thawing process, the seasonal thawing depth, and characteristics of ice content in the frozen soil.

4-4 RESILIENCE.

UFC 2-100-01 provides guidance that includes processes for the ICRP. Currently, there is no guidance or approach explicitly for Arctic and Subarctic conditions for assessing the vulnerability or resilience of engineering infrastructure. However, best practices are available that are applicable to military projects in cold regions environments and are listed in Appendix A, paragraph A-22. Incorporating resilience techniques into the design and construction of facilities in the Arctic and Subarctic environment is site or Installation focused and project specific.

This Page Intentionally Left Blank

APPENDIX A BEST PRACTICES

A-1 INTRODUCTION.

The Best Practices Appendix is guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned but may not be the only solution to meet the requirement. It identifies additional background information and practices for accomplishing infrastructure planning, design, and construction in the Arctic and Subarctic. The DoR must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any UFC, the UFC takes precedence. For Best Practices guidelines not discussed in a UFC, the DoR must submit to the Government Project Manager a list of the guidelines or requirements being used for the project with documentation sufficient for review and approval prior to completing the design.

A-2 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide (WBDG) provides additional information and discussion on practice and facility design, including a holistic approach to integrated design of facilities. The WBDG provides access to all Construction Criteria Base criteria, standards and codes for the DoD Military Departments, and other agencies. These standards include UFC, UFGS, Performance Technical Specifications, design manuals, and specifications. For approved government employees, it also provides access to nongovernment standards.

Installation Facilities Standards are also available on the WBDG website https://www.wbdg.org/airforce/ifs. Installation Facilities Standards provide guidance on

- Installation elements (such as streets, open and spaces),
- site develop (such as utilities, parking areas, stormwater management, sidewalks, bikeways and trails, landscaping, site furnishings, signage, and exterior lighting),
- and facilities design (both interior and exterior elements).

A-3 ENGINEERING RESOURCES.

The Colleges of Engineering at both the University of Alaska Anchorage and UAF offer fundamental courses in Arctic Engineering that address cold regions engineering problems and current solutions. These courses are approved and required by the State of Alaska Board of Registration for Architects, Engineers, and Land Surveyors. Their websites are given in Appendix C.

A-4 COLD REGIONS PUBLICATIONS.

There are several online sources for cold regions publications and databases. The ASCE Cold Regions Engineering Division, formerly the Technical Council on Cold Regions Engineering, sponsors conferences, publishes reports on the effects of cold regions environments on engineering design and on construction and operations, and publishes the *Journal of Cold Regions Engineering* (https://ascelibrary.org/journal/jcrgei). Another source of Arctic and Subarctic papers is the *Cold Regions Science and Technology* journal (https://www.journals.elsevier.com/cold-regions-science-and-technology). The Cold Regions Research and Engineering Laboratory (CRREL) library maintains an extensive collection of cold regions scientific and technical literature on the U.S. Army Engineer Research and Development Center (ERDC) Library Resources website https://www.erdc.usace.army.mil/Library/. In addition, the International Permafrost Association (IPA) disseminates from national and international members information pertinent to cold regions science and engineering. The IPA has a network of permafrost data sets and publications, including conference proceedings.

A-5 PERMAFROST AND GROUND ICE.

A-5.1 Distribution and Features.

The IPA defines Arctic and Subarctic limits in accordance with permafrost distribution and then divides these regions into classifications based on geographic continuity within the landscape (IPA website https://www.permafrost.org/what-is-permafrost/). Permafrost extent is also classified by ground-ice content (Figure 2-1 and 2-2). Data to derive these maps is available from the National Snow and Ice Data Center (NSIDC) (search for “frozen ground” at https://nsidc.org/). A permafrost map for Alaska is available from “Permafrost Characteristics of Alaska,” by Jorgenson et al.

Estimations of permafrost distribution are modeled across the northern hemisphere in “Northern Hemisphere Permafrost Map Based on TTOP Modelling for 2000–2016 at 1 km^2 Scale,” by Obu et al., and throughout Alaska in “Distribution of Near-Surface Permafrost in Alaska: Estimates of Present and Future Conditions,” by Pastick et al., and in “Permafrost of Northern Alaska,” by Kanevskiy et al. These papers discuss factors affecting permafrost existence and distribution.

A-5.2 Resources.

Several textbooks and papers discuss the different types of landforms and the cryostructures, or frozen ground structures, present in cold regions. These include *Cold Climate Landforms*, by Evans, *The Periglacial Environment*, by French, and “Permafrost of Northern Alaska,” by Kanevskiy et al.

Cold Region Structural Engineering, by Erranti and Lee, *Construction in Cold Regions: A Guide for Planners, Engineers, Contractors, and Managers*, by McFadden and

Bennett, and *Frozen in Time: Permafrost and Engineering Problems*, by Muller, discuss the associated challenges for engineering and design that ground ice presents.

A-5.3 Databases.

Archived data of permafrost conditions from the global network of permafrost observatories are available from IPA (https://www.permafrost.org/data/). The IPA website provides global and regional data sources, including active layer information and permafrost temperature and distribution.

A-6 CLIMATE DATA SOURCES.

Ground-based observation records are available from NOAA NCEI (https://www.ncei.noaa.gov/products/land-based-station). Numerous Alaska observation stations (Figure 2-3) are listed by NWS (https://www.weather.gov/aawu/stnlist).

Several global observational networks are searchable on the internet. Historical weather, climate data, and related information for numerous locations across Canada are available at Government of Canada, Historical Climate Data (https://climate.weather.gc.ca/). The Danish Cooperation for Environment in the Arctic publishes temperature and wind conditions for Arctic Sea ice and the Greenland ice sheet at the Polar Portal website http://polarportal.dk/en/greenland/. The “Frozen Ground” link at this website provides ground-temperature profiles at two southern sites, Sisimiut and Kangerlussuaq, and the colder northern site of Ilulissat.

Databases with compiled climate data exist. For example, the WorldIndex database provides global climate data and is used in the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) software.[1] The climate data compiled in the WorldIndex database is obtained from NOAA through NCEI (https://www.ncei.noaa.gov/). The PCASE database includes the station name, coordinates, number of years of data used to calculate the average air temperature, number of years of data used to calculate the freezing index, yearly average temperature, and other climatic trends or information used for designing and evaluating pavements on military Installations.

A-6.1 Air Temperature.

Distributed air-temperature data sets (minimum, maximum, and mean temperature) for Alaska for the period 1981–2010 and historical 30-year normal data are available online from Parameter-Elevation Regressions on Independent Slopes Model (PRISM). These downloadable data are produced by the Spatial Climate Analysis Service, Oregon State University (https://prism.oregonstate.edu/projects/public/alaska/grids/). The current set of 30-year normal data covering the period 1991–2020 is available at “NCEI U.S. Climate Normals Quick Access” (https://www.ncei.noaa.gov/access/us-climate-normals/).

[1] “One-Dimensional Computer Models to Estimate Frost Depth,” Barna et al.

A-6.2 Ground Temperatures.

Surface temperatures are available for certain locations and are accessible through global observational networks and observation stations.[2] In Alaska, the Department of the Interior developed a permafrost monitoring network on federal lands in northern Alaska as part of the Global Terrestrial Network for Permafrost. These data sets are also from IPA (https://www.permafrost.org/data/). Simulated ground temperatures near the surface from numerical modeling are available for Alaska[3] and the northern hemisphere.[4]

A-6.3 Precipitation and Snow Distribution.

Precipitation and snowfall vary in the Arctic and Subarctic regions due to the complex interactions between the atmosphere, ocean, ice, and snow, as well as global and local processes and environmental changes.[5] There are a variety of papers focused on satellite-based characterization of snowfall in the Arctic over both land and ice surfaces such as

- “Arctic Snowfall from CloudSat Observations and Reanalyses,” by Edel et al.;
- “Status of High-Latitude Precipitation Estimates from Observations and Reanalyses,” by Behrangi et al.; and
- “Intercomparison of Precipitation Estimates Over the Arctic Ocean and its Peripheral Seas from Reanalyses,” by Boisvert et al.

For example, “Arctic Snowfall from CloudSat Observations and Reanalyses,” by Edel et al., examined the frequency and phase of precipitation as well as the snowfall rates from CloudSat (a polar orbiting satellite) over the 2007–2010 period. They indicated that the mean surface snowfall rates are particularly high on the Alaska Range (approx. 40 in. [1,000 mm] per year) and extremely high over the southeastern coast of Greenland (ranging from 80 in. [2,000 mm] to 160 in. [4,000 mm] per year).

Summaries of climatological conditions such as precipitation, snowfall, and snow depth for Alaska are also available from NOAA NCEI (https://www.ncei.noaa.gov/). NCEI also provides data sets on the “Global Precipitation Climatology Project (GPCP) Clearinghouse” website https://www.ncei.noaa.gov/products/global-precipitation-climatology-project. The GPCP data sets include monthly and daily precipitation data

[2] “Thermal State of Permafrost in North America: A Contribution to the International Polar Year,” Smith et al.
[3] “Numerical Modeling of Permafrost Dynamics in Alaska Using a High Spatial Resolution Data Set,” Jafarov et al.; *Permafrost Characteristics of Alaska*, Marchenko et al.
[4] “Northern Hemisphere Permafrost Map Based on TTOP Modelling for 2000–2016 at 1 km^2 Scale,” Obu et al.; “A Ground Temperature Map of the North Atlantic Permafrost Region Based on Remote Sensing and Reanalysis Data,” Westermann et al.
[5] “Arctic Snowfall from CloudSat Observations and Reanalyses,” Edel et al.; “Winter Northern Hemisphere Weather Patterns Remember Summer Arctic Sea-Ice Extent,” Francis et al.; “Processes and Impacts of Arctic Amplification: A Research Synthesis,” Serreze and Barry.

derived from surface and satellite measurements for 1979–present (1997–present for daily). Also, the NWS's National Operational Hydrologic Remote Sensing Center produces real-time snow-cover-extent maps for the U.S. and the rest of the Northern Hemisphere. The satellite observations are available on NOAA "U.S. and Northern Hemisphere Snow Cover" (https://www.nohrsc.noaa.gov/nh_snowcover/).

A-6.4 Wind and Wind Chill.

The relationship between human temperature tolerance and wind factors are found in literature such as "A New Approach to an Accurate Wind Chill Factor," by Bluestein and Zecher, and "The New Wind Chill Equivalent Temperature Chart," by Osczevski and Bluestein. A wind-chill chart and wind-chill calculator are both available online through NOAA NWS (https://www.weather.gov/safety/cold-wind-chill-chart).

A-6.5 Visibility.

Weather-related hazard warnings and advisories (such as storm, wind, and so on) are available online. For example, alerts for Alaska are available from the "NWS Forecast Office: Anchorage, AK" website https://www.weather.gov/afc/ and for Canada from the Government of Canada "Alerts" website https://weather.gc.ca/mainmenu/alert_menu_e.html. Information on blizzards is available at the NWS "What is a Ground Blizzard?" website https://www.weather.gov/safety/winter-ground-blizzard.

A-7 CLIMATE CHANGE AND PROJECTIONS.

Recurring official reports from the Intergovernmental Panel on Climate Change (IPCC) such as "Climate Change 2021: The Physical Science Basis," by Masson-Delmotte et al., and from NOAA such as *Arctic Report Card 2022*, by Druckenmiller et al., document the changing Arctic environment. The SNAP program at UAF developed climate projections and uses global climate model results from CMIP3 and CMIP5 for twentieth-century conditions and future low-, moderate-, and high-emissions scenarios out to the year 2100.[6] The SNAP future climate projections can be found at the SNAP website https://uaf-snap.org. The IPCC, NOAA reports, and related studies estimate the most likely or significant projected climate impacts affecting the design, building, and sustainability of Arctic and Subarctic infrastructure as described below:

- Projections on permafrost warming and thawing: "Impacts of Permafrost Degradation on Infrastructure," by Hjort et al., summarizes the observed circumpolar degradation of permafrost and the associated damages to infrastructure across North America and Eurasia. They concluded that nearly 70% of current infrastructure in the permafrost domain is in areas with high thaw potential of near-surface permafrost by 2050. Data related to projected permafrost temperature for Alaska is available from the Arctic Environmental and Engineering Data + Design Support System website

[6] "Downscaling of Climate Model Output for Alaskan Stakeholders," Walsh et al.

https://arcticeds.org/physiography/permafrost/ or at the SNAP website https://uaf-snap.org.

- Precipitation projections: Under the SNAP projections, Fresco et al., in *Future Projections of Precipitation for Alaska Infrastructure: Final Report,* developed future projections of the maximum precipitation (as both snow or rain) in 1-hour, 1-day, and 1-month periods, expected over return periods of 2 years to 50 years. In nearly all future model projections from 2020 to 2099, the projections are consistently towards an increasing maximum precipitation across Alaska.

- Sea ice cover: The extent of multiyear sea ice, which is older than 1 year and generally thicker and more stable for on-ice operations, has also decreased from 2.7 million square miles to only 0.6 million square miles (7.0–1.5 million km^2), and sea ice older than 4 years has nearly disappeared.[7]

A-8 PERMAFROST DEGRADATION.

Higher temperature and more heat waves pose risks for irregular thermal thawing of landforms, creating uneven subsidence and thawing of ice-rich permafrost.[8] These changes in the thermal regime produce dynamic responses to changes in soil moisture, collapse of soil structure, vegetation change, or land surface response to thawing permafrost. "Synthesis of Physical Processes of Permafrost Degradation and Geophysical and Geomechanical Properties of Permafrost," by Liew et al., describes the physical processes of permafrost degradation and its effects on physical and mechanical properties.

A-9 VEGETATION AND WILDFIRES.

The literature such as "A Raster Version of the Circumpolar Arctic Vegetation Map (CAVM)," by Raynolds et al., "Evidence for Widespread Wildfires and Their Environmental Impact in the Late Cretaceous Canadian Arctic," by Synnott et al., and "The Circumpolar Arctic Vegetation Map," by Walker et al., provides more current information on vegetation.

Wildfires or forest fires affect vegetation, promote permafrost thawing, and may alter permafrost conditions over many years.[9] In the Alaskan interior, summer is typically the driest and warmest season and, as such, is prone to wildfires. Studies and research on fire-weather conditions and fire impact on vegetation and soil currently under development include "Impacts of Wildfire and Landscape Factors on Organic Soil Properties in Arctic Tussock Tundra," by He et al., "Estimates of Temporal-Spatial Variability of Wildfire Danger Across the Pan-Arctic and Extra-Tropics," by Justino et al., "Circumpolar Spatio-Temporal Patterns and Contributing Climatic Factors of Wildfire Activity in the Arctic Tundra from 2001 to 2015," by Masrur et al., and "Evidence for

[7] "Sea Ice," Meier et al.
[8] "Arctic Landscapes in Transition: Responses to Thawing Permafrost," Rowland et al.
[9] "Divergent Shrub-Cover Responses Driven by Climate, Wildfire, and Permafrost Interactions in Arctic Tundra Ecosystems," Chen et al.

Widespread Wildfires and Their Environmental Impact in the Late Cretaceous Canadian Arctic," by Synnott et al.

A-10 SEISMIC.

Studies and discussions on ground-motion characteristics and stress-wave velocities in frozen soils are available in the literature. Because the average response spectra vary depending on depth of permafrost,[10] local soil conditions (unfrozen soils above the frozen layer), and the interaction between distributed blocks of isolated frozen soil,[11] consider these effects on ground motion in Arctic and Subarctic areas.

Posts and archives of seismic activities worldwide are available on the USGS, Earthquake Hazards Program website. The International Federation of Digital Seismograph Networks (https://www.fdsn.org/networks/detail/DK/) provides similar global data, including Arctic regions. The UAF Alaska Earthquake Center posts earthquake activities in Alaska on their website https://earthquake.alaska.edu/earthquakes.

The National Institute of Building Sciences Building Seismic Safety Council, working for FEMA, published FEMA P-749, which provides an introduction to recommended seismic provisions for new buildings and other structures. FEMA P-749, Chapter 5, describes the seismic design category map for Alaska.

A-11 GEOSPATIAL DATA RESOURCES.

The following are some sources of geospatial data:

- "Arctic DEM Explorer" (https://livingatlas2.arcgis.com/arcticdemexplorer/) automatically produces a high-resolution, high quality DSM of the Arctic by using optical stereo imagery, high-performance computing, and open-source photogrammetry software and allows users to export a particular area of interest.
- NSIDC "Data" (https://nsidc.org/data) is a repository of geographic information systems (GIS) data on snow, ice, and frozen ground.
- Arctic Research Consortium of the United States (https://www.arcus.org/gis/maps-data/metadata) publishes geospatial data on their website.
- Find satellite and remotely sensed data at the Land Processes Distributed Active Archive Center (https://lpdaac.usgs.gov/), a National Aeronautics

[10] "Numerical Analysis of Permafrost Effects on the Seismic Site Response," by Yang et al.
[11] "Seismic Behavior of Buried Energy Pipelines in Northern Permafrost Regions," "Experimental and Analytical Study of Seismic Site Response of Discontinuous Permafrost," "Vulnerability of Buried Energy Pipelines Subject to Earthquake-Triggered Transverse Landslides in Permafrost Thawing Slopes," Dadfar et al.

and Space Administration (NASA)/USGS website. Products include multispectral and hyperspectral imagery for mapping land cover.

Additional sources for topographic maps are commercially available. Sources also include state or federal agencies or other topographic service agencies such as NASA Earth Observations (https://neo.gsfc.nasa.gov). DEM data sets for Alaska, including a 5 m resolution, are available online from the USGS Science Data Catalog (https://data.usgs.gov/datacatalog/data/USGS:e250fffe-ed32-4627-a3e6-9474b6dc6f0b). Other DEM data, such as for Greenland, is available from NSIDC (http://nsidc.org).

A-12 ICE ENGINEERING.

Resources for ice engineering topics are available in EM 1110-2-1612. EM 1110-2-1612 covers information and equations on the following topics:

- Ice processes and properties
- Ice control structures for both nonstructural and structural ice control
- Hydraulic computation and modeling of ice-covered rivers
- Analyses of ice-affected stages and flooding
- Ice forces on structures
- Sediment transport
- Bearing capacity of floating ice sheets, including ice blocks, short-term loads, moving loads, and long-term loads
- Model tests in ice
- Ice jams and mitigation measures
- Winter navigation on inland waterways, river ice management, river ice problem identification, ice forecasting, ice-related hydrometeorological data collection and monitoring, and ice control
- Control of icing on hydraulic structures

In “Modelling of Ice Jam Floods Under Past and Future Climates: A Review,” Rokaya et al. provide practical recommendations for modeling ice-jam floods.

The relationship between bearing capacity and ice thickness is described in EM 1110-2-1612. Arctic warming trends associated with climate change are increasing fall and winter air temperatures, causing fewer very cold days, river breakup to happen earlier, annual precipitation increase, an increase in the occurrence of freezing rain, and a shrinking snow season.[12] Milder winters have resulted in later freeze-up dates, earlier breakup dates, or both, for lakes in the northern United States and Canada.[13]

A-13 SNOWDRIFTS.

Procedures and methodology from case studies in Greenland and Antarctica for analyses of snow transport are found in

- South Pole Station Snowdrift Simulations, by Allen et al.;
- Snow Drift Management: Summit Station Greenland, by Haehnel and Bigl;
- Antarctic Camps Snow Drift Management Handbook, by Haehnel and Weatherly;
- "Blowing Snow Transport Analysis for Estimating Drift Orientation and Severity," by Haehnel;
- "Spatial Snowdrift Modelling for an Open Natural Terrain Using a Physically Based Linear Particle Distribution Equation," by Ohara et al.; and
- "Diagnosing Changes in Glacier Hydrology from Physical Principles Using a Hydrological Model with Snow Redistribution, Sublimation, Firnification and Energy Balance Ablation Algorithms," by Pradhananga and Pomeroy.

Computational methods, such as two-phase computational fluid dynamics modeling of snowdrift around a building, are available to use for estimating the increased rate of drift accumulation on structures in *South Pole Station Snowdrift Simulations*, by Allen et al., and "CFD Modeling of Snowdrift Around a Building: An Overview of Models and Evaluation of a New Approach," by Tominaga et al.

A-14 SNOW HYDROLOGY AND SNOWMELT.

An overview on the distinct aspects of Arctic hydrology, snow, and permafrost hydrology can be found in "Arctic Terrestrial Hydrology: A Synthesis of Processes, Regional Effects, and Research Challenges," by Bring et al., "A Review of Hydrological Models Applied in the Permafrost-Dominated Arctic Region," by Bui et al., and "Progress in Permafrost Hydrology in the New Millennium," by Woo et al. Surface hydrology is influenced by permafrost depth (active layer), snow loading, and the potential retention of winter or late-season rain events.[14] Refer to "A Review of Hydrological Models Applied in the Permafrost-Dominated Arctic Region," by Bui et al., for a comprehensive review and comparison of various hydrological models for limitations, suitability, and functionality.

---

[12] "Alaska Terrestrial and Marine Climate Trends, 1957–2021," Ballinger et al.
[13] "Historical Trends in Lake and River Ice Cover in the Northern Hemisphere," Magnuson et al.
[14] "Hydrological Response of a High-Arctic Catchment to Changing Climate Over the Past 35 years: A Case Study of Bayelva Watershed, Svalbard," Nowak and Hodson.

Snow hydrology and snowmelt with a hydrologic routing model is available at USACE Hydrologic Engineering Center–Hydrologic Modeling System (HEC-HMS) (https://www.hec.usace.army.mil/software/hec-hms/). The U.S. Army guidance on snowmelt estimation is found in EM 1110-2-1406.

The formation of aufies is controlled by local or regional surface topography, groundwater, climate, soil conditions, and permafrost presence and distribution.[15] Aufeis plagues infrastructure, including accumulation on road surfaces;[16] erosion of stream channels; [17] ground uplift and subsidence due to ice accumulation and thaw; and frost sorting of ground materials, leading to unstable conditions. The fundamental characteristics are available in the textbooks, and practical mitigation options to reduce icing are presented in "Denali Park Access Road Icing Problems and Mitigation Options," by Vinson and Lofgren, and "Observations of Arctic Snow and Sea Ice Cover from CALIOP Lidar Measurements," by Lu et al.

A-14.1 SWE Spatial Distribution.

Estimate the SWE spatial distribution in watersheds of interest using ground-based measurements or gridded estimates of SWE.

A-14.1.1 Ground-Based Measurements of SWE.

Ground-based measurements of SWE are typically made using a snow sampler. It is a hollow rod that is driven through the snowpack from top to bottom to extract a representative sample of snow. The filled snow sampler is then weighed to determine the SWE, Figure A-1.[18] The measurements are generally made at up to 10 separate locations along a line and averaged to account for variations in the snowpack depth and density. This is known as a snow course or snow survey. Samples are also retrieved and melted to determine SWE. In many cases, only the snow depth is measured, generally using a ruler or other measuring tool. Use the procedure in "Estimating Snow Water Equivalent Using Snow Depth Data and Climate Classes," by Sturm et al., to convert snow depth measurements to SWE if required.

[15] "The Distribution and Dynamics of Aufeis in Permafrost Regions," Ensom et al.
[16] "Denali Park Access Road Icing Problems and Mitigation Options," Vinson and Lofgren.
[17] *Aufeis Formation in Jarvis Creek and Flood Mitigation,* Daly et al.; "Aufeis Formation and Remediation," Zufelt and Daly.
[18] *Snow-Survey Sampling Guide*, U.S. Department of Agriculture (USDA).

Figure A-1 Weighing a Snow Sample in the Field to Measure SWE

A-14.1.2 Sources of Ground-Based Measurements of SWE.

The Global Historical Climatology Network is a worldwide database of daily weather data from over 107,000 surface stations compiled by NOAA's NCEI and available at "Global Historical Climatology Network Daily" (https://www.ncei.noaa.gov/products/land-based-station/global-historical-climatology-network-daily). The depth of snow on the ground is one of five core elements reported. More than 15,000 of these stations also report the water equivalent of the snow on the ground as the depth of the melted snow. The Global Historical Climatology Network includes data from four networks that provide snow information: CoCoRaHS, COOP, SNOTEL, and WBAN networks.

- CoCoRaHS—The Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) (https://www.cocorahs.org/) started in 1998. The network is sponsored by NOAA and the National Science Foundation and includes locations in all 50 states. Canada locations were added in 2012. Observers use a snow ruler to measure the snow depth on the ground and record the average depth to the nearest 0.5 inch. Reporting the water equivalent of total snow on the ground is optional.

- COOP—The NWS's Cooperative Observers Program (COOP) (https://www.weather.gov/coop/Overview) records daily United States observations. Snow depths are recorded in whole inches, and the water content of the snow on the ground is reported to the nearest 0.1 in. (2.5 mm).

- SNOTEL—The USDA Natural Resources Conservation Service Snowpack Telemetry (SNOTEL) network comprises over 865 automated sites at remote, high elevations in the western U.S. states, including Alaska. Data is available at the National Weather and Climate Center (https://wcc.sc.egov.usda.gov/nwcc/rgrpt?report=swe). Site instrumentation includes a sonic snow depth sensor and a snow pillow instrumented with a pressure transducer. The snow depth sensor has 0.5 in. resolution. The snow water equivalent is calculated from the snow pillow measurements with a 0.1 in. resolution up to 250 in. (6.35 m) of water as a maximum limit.

- WBAN—Weather Bureau Army Navy (WBAN) network consists of over 430 stations in the U.S. and over 83 stations outside the U.S. Snow depth is reported in whole inches whenever there is more than a trace of snow on the ground. The water equivalent of snow on the ground is reported with a 0.1 in. (2.5 mm) resolution at designated stations at 1800 UTC if the average snow depth is at least 2 in. (50 mm).

A-14.1.3 Gridded Estimates of SWE.

Gridded estimates of SWE are produced using observations and models. Typically, the models ingest surface observations, satellite data, and other data sources to determine the snowpack state at each model time step. In choosing a gridded snow product, it is important to ensure that the model spatial resolution, time step, time period, and level of accuracy are appropriate for the project. Typically, gridded snow products are distributed as large digital files that require special knowledge to process. There are many gridded snow products available. Listed below are three useful gridded snow products for snow hydrology:

- SNODAS—The NWS National Operational Hydrologic Remote Sensing Center (NOHRSC) provides a near-real-time 1 km^2 spatially distributed estimate of SWE and other snow properties across the continental United States through its SNODAS (Snow Data Assimilation System) data set available from NOHRSC (https://www.nohrsc.noaa.gov/). SNODAS data cover 2003 to the present. SNODAS integrates combined downscaled forcing data, an energy balance snow model, and assimilated observations in the SNODAS daily gridded SWE product to arrive at the best estimate of the snow characteristics over the United States and to minimize error associated with any individual method.

- University of Arizona SWE—The University of Arizona developed a 4 km gridded daily SWE data set covering 1982 to 2017 for the continental U.S. as presented in *Daily 4 km Gridded SWE and Snow Depth from Assimilated In-Situ and Modeled Data Over the Conterminous U.S. Version 1*, by Broxton et al. This data set interpolates SWE and snow depth from SNOTEL, the NWS COOP network sites, and other precipitation and temperature data.

- MERRA-2—The Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2), is available from NASA's Global Modeling and Assimilation Office, Modern-Era Retrospective Analysis for Research

Applications, Version 2 (https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/). The MERRA-2 data set begins in 1980, offers worldwide coverage, provides estimates several times a day, and has a spatial resolution of ½° latitude by ⅝° longitude. MERRA-2 includes many parameters, including snow data.

A-14.1.4 Snow Mapping.

Snow mapping describes the process of analyzing ground-based measurements of snow, gridded snow products, satellite imagery, or other data to produce spatial distribution maps of the SWE for the watersheds of interest at the start of the snowmelt period. In general, GIS techniques are used to produce the maps. Required information includes base maps, a DEM, watershed boundaries, stream-channel layout, and land cover data. There are several considerations:

- Variation of SWE with elevation—In areas with significant elevation range, the snowpack depth is likely to increase as the elevation increases. Interpolation schemes using point measurements of SWE or other snow properties must take the relationship between elevation and snow depth into account.

- Variation of SWE with land cover—In areas with abrupt changes in land cover, such as forested "tree islands" found in prairies, snow conditions found in the tree islands are not representative of the general land cover found in the standard areas. Point measurements of SWE in these types of locations can produce erroneous results if used in interpolation schemes. (See *Wintertime Snow and Precipitation Conditions in the Willow Creek Watershed Above Ririe Dam, Idaho,* by Giovando et al., for an example.)

- Areas with no significant elevation range—It is difficult to produce accurate snow maps for large watersheds with no significant elevation range. In these areas, the snow spatial distribution is strongly influenced by wind, storm tracks, and other processes that are difficult to capture by interpolation. In these areas, gridded snow products produce better results than ground-based measurements.

- Determination of snow-covered area (SCA)—It is difficult when using an interpolation scheme to accurately estimate the spatial limits of the SCA in a watershed. In these cases, additional information provided by the MOD10A1 Cloud-Gap-Filled Snow-Covered Area (referred to as CGF-SCA) product is useful. CGF-SCA is a gridded, global, fractional SCA product based on satellite imagery that provides cloud-free daily estimates of snow-covered area.[19] It is produced daily by the NSIDC (https://nsidc.org/data/MOD10A1F/versions/61).

A-14.2 Snowmelt Modeling and Flow Routing.

As mentioned in paragraph A-14, USACE HEC-HMS (https://www.hec.usace.army.mil/software/hec-hms/) combines snowmelt models and a

[19] "MODIS Snow and Sea Ice Products," Hall et al.

variety of loss method, transform methods, baseflow estimation methods, and routing schemes to estimate snowmelt runoff. The model is GIS based and has extensive capabilities for performing many types of hydrologic analysis. A brief description of its snowmelt capabilities follows. For more information, see the HEC-HMS manuals available online.

- HEC-HMS has two spatial modes for snowmelt modeling. Snowmelt is estimated on a gridded or an elevation-band basis. The gridded approach divides the watershed into grids that are of constant size but can change to match project conditions. The snowmelt is estimated separately for each grid cell. Separate meteorological conditions driving the snowmelt are required for each grid cell. The gridded approach is appropriate for watersheds with significant elevation ranges or watersheds with significant spatial variations of weather during snowmelt events. The elevation-band approach divides the watershed into several bands, with each band covering a specific range of elevation. Snowmelt is estimated separately for each band. HEC-HMS estimates the temperature for each band based on an observed temperature at a known elevation and a known lapse rate of air temperature with elevation. The elevation-band approach is appropriate for mountainous watersheds.

- A temperature index (TI) snowmelt model is available in HEC-HMS. The TI model is empirically based and requires only air temperature to drive the basic melt calculation. The TI model is based on a linear relationship between snowmelt and air temperature.[20] This method was widely used by federal, state, and local agencies, as well as private engineering firms. For best results, it is important to calibrate the relationship between snowmelt and air temperature for each location where the model is applied.

A-15 FROZEN GROUND.

A-15.1 Engineering Properties.

Methods to quantify soil indexes are available in EM 1110-2-1906, which describes testing procedures for determining soil properties. ASTM standards and technical papers also provide additional information on frozen soil testing and properties.

Since frozen saline soils are widely distributed, particularly along the Arctic coast, the unique engineering properties of these soils must be considered.[21] Further discussion can be found in

- *Frozen Ground Engineering*, by Andersland and Ladanyi;

- “Strength Characteristics of Frozen Saline Soils,” by Aksenov et al.;

---

[20] *Snow Hydrology*, U.S. Army, North Pacific Division.
[21] “Frozen Saline Soils of the Arctic Coast: Their Distribution and Engineering Properties,” Brouchkov.

- "Long-Term Pile Load Testing System Performance in Saline and Ice-Rich Permafrost," by Biggar et al.;
- "Frozen Saline Soils of the Arctic Coast: Their Distribution and Engineering Properties," by Brouchkov;
- "Design of Vertical and Laterally Loaded Piles in Saline Permafrost," by Nixon and Neukirchner; and
- "Strength of Frozen Saline Soils," by Hivon and Sego.

A-15.2 Mechanical Properties.

Aside from ASTM standards, other common, nonstandardized frozen-soil test methods used are found in "Practice of Testing Frozen Soils," by Oestgaard and Zubeck, and in "Triaxial Testing of Frozen Soils—State of the Art," by Kornfield and Zubeck. The mechanical properties of frozen soils are available in various textbooks and literature such as *Frozen Ground Engineering*, by Andersland and Ladanyi, "Mechanical Properties of Naturally Frozen Ice-Rich Silty Soils," by Ge et al., and "Sampling, Machining and Testing of Naturally Frozen Soils," by Zubeck and Yang. Additional experimental data for soil properties for ice soils are available in literature (for example, "Sampling, Machining and Testing of Naturally Frozen Soils," by Ge et al., and "Experimental Study on Influences of Water Content and Temperature on Mechanical Properties of Ice-Rich Frozen Soil," by Huo et al.).

A-16 MODELS FOR ESTIMATION OF FREEZE AND THAW IN SOIL.

ModBerg, a one-dimensional linear model, may be used to calculate the depth of frost penetration in pavement structures or in soils.[22] Also, a method called FROST Modeler is available for estimating frost depth.[23] Both the ModBerg and FROST are available within PCASE (https://transportation.erdc.dren.mil/pcase/).

A-17 SITE SELECTION AND GEOTECHNICAL INVESTIGATIONS.

Standards and methods for site selection and geotechnical investigations are available. EM 1110-1-1804 is a guide for planning and conducting geotechnical investigations during the various stages of development for civil and military projects. EM 1110-2-1906 is for general guidance on sampling and storage of soil samples collected in the field.

For frozen soils, special care is required to maintain samples in their frozen state in the field, as well as in transit and storage. "Sampling, Machining and Testing of Naturally Frozen Soils," by Still et al., discusses maintaining samples in their frozen state and

---

[22] "Computer Assisted Calculations of the Depth of Frost Penetration in Pavement-Soil Structures," Cortez et al.; "One-Dimensional Computer Models to Estimate Frost Depth," Barna et al.

[23] *Pavement-Transportation Computer Assisted Structural Engineering (PCASE) Implementation of the Modified Berggren (ModBerg) Equation for Computing the Frost Penetration Depth Within Pavement Structures*, Bianchini and Gonzalez.

machining frozen samples. An introduction to geophysical exploration for engineering, geological, and environmental can be found in EM 1110-1-1802.

A-18 SNOW AND ICE ROADS.

Snow roads (compacted snow) are common in cold regions. The complex nature of snow and ice mechanics presents unique challenges to constructing snow and ice runways. In "Review of Ice and Snow Runway Pavements," White and McCallum reviewed the methodology on the design and construction for snow and ice runways. In *McMurdo Snow Roads and Transportation: Final Program Summary* and in *Snow-Road Construction and Maintenance*, Shoop et al. provide examples of standard operation procedures and guidance for constructing, maintaining, or repairing snow roads at McMurdo Station, Antarctica. Procedures for ice road construction and a winter road operations handbook are available for northern regions in *Field Handbook Version of the Winter Roads Manual*, from the Ministry of Highways and Infrastructure, and *Overview of Ice Roads in Canada: Design, Usage and Climate Change Adaptation*, by Barrette. Additionally, "Design Considerations for the Use of Ice as a Construction Platform," by Hicks and Fayek, has practical design guidance and ice-loading criteria for short-term (less than 3 minutes) and long-term loading.

A-19 EROSION CONTROL.

Erosion-control approaches are published by the U.S. Arctic Research Commission Permafrost Task Force, in *Climate Change, Permafrost, and Impacts on Civil Infrastructure*, and in

- *Responses to Coastal Erosion in Alaska in a Changing Climate: A Guide for Coastal Residents, Business and Resource Managers, Engineers, and Builders*, by Smith and Hendee;
- "Mapping Sea Ice Overflood Using Remote Sensing: Alaskan Beaufort Sea," by Dickins et al.; and
- "Riverbank Erosion in Cold Environments: Review and Outlook," by Chassiot et al.

A-20 EMBANKMENTS.

Air convection embankments (ACEs) were used successfully for road embankments in Russia[24] and in several other countries, such as the United States, Canada, and Greenland. The ACE design concept is a mitigation approach to prevent permafrost degradation under transportation infrastructure.[25] Traditional ACEs use a highly porous,

[24] Roads and Airfields in Cold Regions: A State of the Practice Report, Vinson et al.
[25] "Modeling the Performance of an Air Convection Embankment (ACE) with Thermal Berm over Ice-Rich Permafrost, Lost Chicken Creek, Alaska," Darrow and Jensen.

poorly graded granular material to construct the main portion of the embankment.[26] The design results in a passive cooling or a natural convection system in a porous embankment with sufficient air permeability. Others have used a modified ACE with ventilation pipes installed in the embankment.[27] Canada applied and assessed methods, guidelines for thermal analysis, and mitigation design techniques for thermal stabilization of embankments built on thaw-sensitive permafrost.[28] Settlement of embankments in permafrost regions are attributed to thaw settlement, creep, and freeze–thaw cycling.[29] Analysis and numerical models are viable approaches to analyze the embankment deformation for heat transfer, creep, soil compression, and thaw consolidation.[30]

A-21 RISK METHODOLOGY.

A-21.1 USACE Risk Management Center.

The USACE Risk Management Center (https://www.rmc.usace.army.mil/) provides resources on risk assessments for various civil works projects, including best practices, software and tools, hazardous substance release, human and ecological effects, and remedial action (EM 200-1-4).

A-21.2 International Organization for Standardization.

Other guidance for risk management is published by the International Organization for Standardization (ISO):

- ISO 31000, *Risk Management—Guidelines*
- ISO/IEC 31010, *Risk Management—Risk Assessment Techniques.*

[26] "Convective Cooling in Open Rock Embankments," "Passively Cooled Railway Embankments for Use in Permafrost Areas," Goering; "Design of Passive Permafrost Cooling System for an Interior Alaska Roadway," Goering and Saboundjian.
[27] "Optimization in the Use of Air Convection Embankments for the Protection of Underlying Permafrost," Jørgensen and Ingeman-Nielsen.
[28] *Thermal Stabilization of Embankments Built on Thaw-Sensitive Permafrost*, Kong and Doré.
[29] "Large-Scale Direct Shear Testing of Compacted Frozen Soil Under Freezing and Thawing Conditions," De Guzman et al.; "Structural Stability of Highway Embankments in the Arctic Corridor," De Guzman; "Optimization in the Use of Air Convection Embankments for the Protection of Underlying Permafrost," Jørgensen and Ingeman-Nielsen; "In-Situ Monitoring of Settlement at Different Layers Under Embankments in Permafrost Regions on the Qinghai–Tibet Plateau," Yu et al.
[30] "Investigation of Embankment Deformation Mechanisms in Permafrost Regions," Ming et al.

A-21.3 Methods Used in Cold Regions.

There are two types of risk assessment methods applicable for cold regions:[31]

- Qualitative evaluation methods are simple, subjective, and develop a risk index value. An example of this can be found in “Qualitative Risk Assessment and Strategies for Infrastructure on Permafrost in the French Alps,” by Duvillard et al., which discusses the risk induced by permafrost warming and thawing on the stability of infrastructure built in mountainous areas.
- Quantitative methods include finite element analysis, the analytic hierarchy process, sensitivity analysis, Monte Carlo simulation, artificial neural networks, the catastrophe progression method, and others. Use a sensitivity analysis method to derive a specific risk value for various influencing factors of engineering risks, followed by an analytic hierarchy process and comprehensive evaluation method to analyze the weight of each influencing factor.[32] Various textbooks provide guidance for using a finite element method for a comprehensive risk assessment to simulate and predict the stability and failure probability.

A-21.4 Design for Reliability.

ISO provides general standards of reliability for structures (ISO 13822 and ISO 2394). There are also various methods used for design reliability. Examples of using Monte Carlo simulations include

- “A Probability-Based Reliability Assessment Approach of Seismic Base-Isolated Bridges in Cold Regions,” by Nassar et al., for evaluating bridge structures regarding earthquake response in cold regions;
- “Reliability-Based Assessment of Deteriorating Performance to Asphalt Pavement Under Freeze–Thaw Cycles in Cold Regions,” by Si et al., for asphalt pavement deterioration under freeze–thaw cycles in cold regions; and
- “Quantitative Risk and Optimal Design Approaches in the Snow Avalanche Field: Review and Extensions,” by Eckert et al., on optimal infrastructure design with risk frameworks for snow avalanches.

[31] “Engineering Risk Analysis in Cold Regions: State of the Art and Perspectives,” Yu et al.
[32] Ibid.

A-22 RESILIENCE.

A-22.1 Assessments.

Best practices for resilience assessments can be found in the following:

- *USACE Guide to Resilience Practices* as described in EP 1100-1-5
- ASCE *Hazard-Resilient Infrastructure: Analysis and Design* (Ayyub)
- ASCE *Climate-Resilient Infrastructure: Adaptive Design and Risk Management* (Ayyub)

A-22.2 Resources.

Academic papers on general resilience concepts include

- "Practical Resilience Metrics or Planning, Design, and Decision Making," by Ayyub;
- Adapting Infrastructure and Civil Engineering Practice to a Changing Climate, by Olsen; and
- "A Novel Framework for Risk Assessment and Resilience of Critical Infrastructure Towards Climate Change," Kumar et al.,

"Resilience and Vulnerability of Permafrost to Climate Change," by Jorgenson et al., focuses on cold regions environments; "Reliability-Based Assessment of Deteriorating Performance to Asphalt Pavement Under Freeze–Thaw Cycles in Cold Regions," by Si et al., on transportation systems; and "Best Practices for HVAC, Plumbing, and Heat Supply in Arctic Climates," by Winfield et al., on utilities. Preliminary guides on thermal resilience for buildings, with general recommendations for the building envelopes and foundations, as well as best practices for HVAC, plumbing, and heat supply in Arctic conditions, are presented in *Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates,* by Zhivov, and in "Best Practices for HVAC, Plumbing, and Heat Supply in Arctic Climates," by Winfield et al. At a geological scale, in "Resilience and Vulnerability of Permafrost to Climate Change," Jorgenson et al. (2010) assessed the interdependent factors of air temperatures and ecological variables affecting the resilience or vulnerability of permafrost stability due to climate change.

This Page Intentionally Left Blank

APPENDIX B GLOSSARY

B-1 INTRODUCTION.

The following acronyms and terms used in this document and are specific to cold regions engineering, design, and construction. ASTM D7099 also provides an excellent reference for these and additional terms.

Additionally, a glossary of permafrost and other terms related to ground ice are available in the Glossary of Permafrost and Related Ground-Ice Terms from IPA (https://www.permafrost.org/publication/glossary-of-permafrost-and-related-ground-ice-terms/).

B-2 ACRONYMS.

ACE	Air convection embankments
ACI	American Concrete Institute
AFCEC	Air Force Civil Engineer Center
AHJ	Authority Having Jurisdiction
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BIA	Bilateral Infrastructure Agreement
CGF	Cloud-Gap-Filled
CAC	Common Access Card
CATEX	Categorical Exclusion
CCR	Criteria Change Request
CIMP	Coupled Model Intercomparison Projects
CoCoRaHS	The Community Collaborative Rain, Hail, and Snow Network
COOP	Cooperative Observer Program
CRREL	Cold Regions Research and Engineering Laboratory

CX	Categorical Exclusion
°C	Degrees Celsius
°F	Degrees Fahrenheit
DEM	Digital elevation model
DoDI	Department of Defense Instructions
DoR	Designer of Record
DSM	Digital surface model
ERDC	Engineer Research and Development Center
EWD	Engineering Weather Data
FEMA	Federal Emergency Management Agency
ft	Feet
GHG	Greenhouse gas
GIS	Geographic information system
GPCP	Global Precipitation Climatology Project
GSOD	Global Surface Summary of Day
h	Hours
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling System
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
IBC	International Building Code
ICRP	Installation Climate Resilience Plan
in.	Inches
$in.^2$	Square inches
IPA	International Permafrost Association
IPCC	Intergovernmental Panel on Climate Change

ISO	International Organization for Standardization
kg	Kilograms
km	Kilometers
kPa	Kilopascal
km^2	Square kilometers
lb	Pounds
m	Meters
MERRA-2	Modern-Era Retrospective Analysis for Research and Applications, Ver. 2
mm	Millimeters
mph	Miles per hour
NAVFAC	Naval Facilities Engineering Command
NCEI	National Centers for Environmental Information
NEPA	National Environmental Policy Act
NFS	Non–frost susceptible
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NSIDC	National Snow and Ice Data Center
NWS	National Weather Service
OCDS	Operational Climatic Data Summary
OSHA	Occupational Safety and Health Administration
PCASE	Pavement-Transportation Computer Assisted Structural Engineering
PRISM	Parameter-Elevation Regressions on Independent Slopes Model
RCP	Representative Concentration Pathway
SCA	Snow-covered area
SLDT	Structural Load Data Tool

SNAP	Scenarios Network for Alaska and Arctic Planning
SNODAS	Snow Data Assimilation System
SNOTEL	Snowpack Telemetry
SOFA	Status of Forces Agreements
SWE	Snow water equivalent
TI	Temperature index
UFC	Unified Facilities Criteria
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UAF	University of Alaska Fairbanks
WBAN	Weather Bureau Army Navy

B-3 DEFINITION OF TERMS.

B-3.1 General.

Installation: With a capital "I," this refers to any DOD post, base, station, camp, fort, ranges or training areas.

B-3.2 Regions.

Arctic: The northern region in which the mean temperature for the warmest month is less than 50°F (10°C) and the mean annual temperature is below 32°F (0°C). In general, Arctic land areas coincide with the tundra region north of the limit of trees.

Subarctic: The region adjacent to the Arctic in which the mean temperature for the coldest month is below 32°F (0°C), the mean temperature for the warmest month is above 50°F (10°C), and there are less than four months having a mean temperature above 50°F (10°C). In general, Subarctic land areas coincide with the circumpolar belt of dominant coniferous forest.

Seasonal frost: Those areas of the earth having significant ground freezing during the winter but without development of permafrost. In seasonal frost areas, seasonal temperatures cause frost that affects earth materials and keep these frozen during only the winter; the occurrence of ground temperatures below 0°C appear only part of the year.

B-3.3 Soil and Frost Terms.

For common cold regions' soil terminology, see ASTM D7099, *Standard Terminology Relating to Frozen Soil and Rock*.

Active layer: The top layer of ground subject to annual freezing and thawing with a permafrost layer below.

Aggradation: Progressive increase in the thickness of permafrost, taking place over a period of years due to a change in climate or terrain conditions.

Annual frost zone: The top layer of ground subject to annual freezing and thawing. In Arctic and Subarctic regions where annual freezing penetrates to the permafrost table, the active layer, suprapermafrost, and the annual frost zone are identical.

Closed system: A condition in which no source of free water is available during the freezing process beyond that originally contained in the voids of soil.

Creep: Extremely slow, continuous strain deformation of materials under stress, at rates so slow as to usually be imperceptible except by observations of high precision or of extended duration.

Degradation: Progressive lowering of the permafrost table, occurring over a period of years.

Excess ice: Ice in the ground that exceeds the total volume of the pores that the ground would have under natural unfrozen conditions.

Free water: That portion of the pore water that is free to move between interconnected pores under the influence of gravity.

Freeze–thaw cycle: A freezing followed by thawing of a material over time.

Freezing (of ground): The changing of phase from water to ice in soil or rock.

Freezing front: The advancing boundary between frozen (or partially frozen) and unfrozen ground.

Freezing point: The temperature at which a pure liquid solidifies under atmospheric pressure; the temperature at which a ground material starts to freeze.

Freezing-point depression: The number of degrees by which the freezing point of an earth material is depressed below 0°C (32°F).

Freezing pressure: The positive pressure developed at ice–water interfaces in a soil as it freezes.

Frost action: A general term for the alternate freezing and thawing of moisture in materials, such as soil. It also covers the effects on these materials and on structures of which they are a part of or with which they are in contact. The term “frost” is often used to refer to frost action in general.

Frost boil: The breaking of a limited section of a highway or airfield pavement under traffic and ejection of soft, semiliquid subgrade soil. This is caused by the melting of the segregated ice formed by frost action. May also occur on unpaved ground surfaces, resulting in a small soil mound.

Frost creep: The ratchet-like downslope movement of particles because of frost heaving and subsequent ground settling on thawing. The heaving is normal to the slope and the settling more vertical.

Frost heave: The upward or outward movement of a ground surface (or objects on or in the ground) due to ice formation in the underlying soil. As the freeze front progresses downward, moisture migrates to the front, producing accelerated expansion and heaving.

Frost penetration: The movement of the freezing front into the ground during freezing.

Frost slough: A shallow slide that occurs when the stability of frost-loosened and moisture-saturated fine-grained soils on slopes is reduced during thaw.

Frost-stable ground: Soil or rock in which little or no segregated ice forms during seasonal freezing.

Frost-susceptible soil: Soil that will experience significant ice segregation when the requisite moisture and freezing conditions are present.

Frozen fringe: The zone in a freezing, frost-susceptible soil between the warmest isotherm at which ice exists in pores and the isotherm at which the warmest ice lens is growing.

Frost table: The surface, usually irregular, that represents the level, at any time in spring and summer, to which thawing of seasonal frozen ground has penetrated.

Frost thrust: A force due to frost action.

Frozen zone: A range of depth within which the soil is frozen.

Ground ice: A body of soil-free ice within frozen ground, including ice in pores, cavities, voids, or other openings in soil or rock, including massive ice; a general term referring to all types of ice in freezing and frozen ground.

Ground settlement: The downward movement of the ground, lowering the ground surface, resulting from the melting of ground ice more than that contained in pore fillings.

Hard-frozen ground: Frozen soil or rock which is firmly cemented by ice.

Heat capacity: The amount of heat required to raise the temperature of a unit mass of a substance by one degree. It is commonly expressed in Joules per kilogram per degree Kelvin.

Heterogeneously frozen soil: A soil with part of its water frozen as macroscopic ice occupying space more than the original voids in the soil.

Homogeneously frozen soil: A soil in which water is frozen within the material voids without macroscopic segregation of ice.

Ice lens: A lens-shaped body of ice ranging in thickness from hairline to 0.3 m. Ice layers more than 0.3 m in thickness are better termed massive ice beds.

Ice lenses: Lenticular formations of ice in soil occurring parallel to each other, normal to the direction of heat loss, and commonly in repeated layers.

Ice-rich permafrost: Perennially frozen ground that contains ice more than that required to fill pore spaces.

Intrusive ice: Ice formed from water intruded or injected under pressure into soils and rocks.

Ice segregation: The growth of ice within soil more than the amount produced by in-place conversion of the original void moisture to ice. Ice segregation occurs most often as distinct lenses, layers, veins, and masses, commonly, but not always, oriented normal to the direction of heat loss.

Ice wedge: A wedge-shaped ice mass, usually with its apex pointing downwards, in permafrost. Usually associated with fissures on trough-type polygons.

Ice wedge polygon: Any polygon surrounded by troughs underlain by ice wedges.

Latent heat of fusion: The amount of heat required to melt all the ice (or freeze all the pore water) in a unit mass of soil or rock.

Non-frost-susceptible materials: Cohesionless materials such as crushed rock, gravel, sand, slag, and cinders in which there is no significant ice segregation under normal freezing conditions.

Normal period: The time of the year when there is no alteration in strength of foundation materials because of frost action. In seasonal frost areas, it extends from mid- or late spring to mid- or late fall.

Open system: A condition where more free water than originally contained in the voids of the soil is available to move within the soil and to form segregated ice in frost-susceptible soil.

Percent heave: The ratio, expressed as a percentage, of the amount of heave to the depth of frozen soil.

Permafrost: Perennially frozen ground. A thermal condition in soil or rock where temperatures below 32°F persist over at least two consecutive winters and the intervening summer; moisture in the form of water and ground ice may or may not be present.

Permafrost base: The lower boundary surface of permafrost, above which temperatures are below 32°F, and below which temperatures are above 32°F.

Permafrost, continuous: Permafrost occurring everywhere beneath the exposed land surface throughout a geographic region, except for widely scattered locations.

Permafrost, discontinuous: Permafrost occurring in some areas beneath the ground surface throughout a geographic region where other areas are free of permafrost.

Permafrost table: An irregular surface within the ground that represents the upper boundary surface of permafrost.

Residual thaw layer: A layer of thawed or unfrozen ground between the permafrost and the annual frost zone. This layer does not exist where annual frost (active layer) extends to permafrost.

Seasonally active permafrost: The uppermost layer of the permafrost that undergoes seasonal phase changes due to the lowered thawing temperature and freezing-point depression of its pore water.

Segregated ice: Ice formed by the migration of pore water to the freezing plane, where it forms into discreet lenses, layers, or seams, ranging in thickness from hairline to greater than 10 m (32 ft). The ice is formed by ice segregation.

Snowdrift: An accumulation of wind-blown snow, often much thicker than the surrounding snow cover.

Snowline: The boundary of a highland region in which snow never melts.

Snowmelt: Melting of the snow cover; the period during which the melting of the snow cover occurs at the end of winter.

Solifluction: The perceptible, slow downslope flow of saturated unfrozen soil over a base of impervious or frozen material. Movement takes place primarily when melting of segregated ice or infiltration of surface runoff concentrates excess water in the surface soil, which then behaves like a viscous fluid. Solifluction features lobes, stripes, sheets, and terraces.

Suprapermafrost: The entire layer of ground above the permafrost table.

Sporadic permafrost: A subzone of the zone of discontinuous permafrost: In North American usage, it is permafrost underlying less than 30% of the exposed land surface; in Russian usage, it is permafrost underlying from 3% to 20% of the exposed land surface.

Tangential adfreeze shear: Tangential shear between frozen ground or ice and another material to which it is bonded by freezing.

Thaw consolidation: The process by which a reduction in volume and increase in density of a soil mass occurs, following thaw, in response to the escape of water under the weight of the soil itself, an applied load, or both. Thaw consolidation may proceed for many years.

Thaw-sensitive permafrost: Perennially frozen ground that, on thawing, will experience significant thaw settlement and suffer loss of strength to a value significantly lower than that of a similar material in an unfrozen condition.

Thaw settlement: The differential downward movement of the ground surface resulting from the escape of water on melting of excess ice in the soil and the thaw consolidation of the soil mass.

Thaw slumping: A type of mass movement caused by the conversion of ice into water in a soil by ground thaw, creating the kind of landslide that most closely resembles the more temperate climate earth flow with a well-developed breakaway scarp front.

Thaw-stable frozen soils: Frozen soils that do not, on thawing, show loss of strength below normal, long-time thawed values nor produce detrimental settlement.

Thaw-unstable frozen soils: Frozen soils that show, on thawing, significant loss of strength below normal, long-time thawed values or significant settlement as a direct result of the melting of excess ice in the soil.

B-3.3.1 Temperature-related Terms.

Average annual temperature: The average of the average daily temperatures for a particular year.

Average daily temperature: The average of the maximum and minimum temperatures for one day or the average of several temperature readings taken at equal time intervals for one day, hourly.

Average monthly temperature: The average of the average daily temperatures for a particular month.

Breakup period: The period of the spring thaw during which the ground surface is excessively wet and soft and ice is disappearing from streams and lakes. Duration of the breakup period usually varies usually from 1 to 6 weeks, depending on regions or local climatic conditions.

Degree-days: The degree-days for any one day equal the difference between the average daily air temperature and 32°F. The degree-days are negative when the average daily temperature is below 32°F (freezing degree-days) and positive when above 32°F (thawing degree-days). Degree-days may be computed in either Fahrenheit or Celsius units; this manual uses Fahrenheit degree-days.

Design freezing index: For design of permanent pavements, the design freezing index is the average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, substitute the air freezing index for the coldest winter in a 10-year period. For design of foundations for average permanent structures, compute the design freezing index for the coldest winter in 30 years of record, or estimate to correspond with this frequency if the number of years of record is limited. Use the latest available periods of record. To avoid the necessity for adopting a new and only slightly different freezing index each year, the design index at a site with continuing construction need not change more than once in five years, unless the more recent temperature records indicate a significant change.

Design thawing index: The design thawing index is computed on the same frequency and basis as the design freezing index, except that summer thaw conditions are used.

Freeze-up period: The period during which the ground surface freezes and an ice cover is forming on streams and lakes. The duration of the freeze-up period varies from 1 to 3 months, depending on regional or local climatic conditions.

Freezing index: The number of degree-days between the highest and lowest points on a curve of cumulative degree-days versus time for one freezing season. It is a measure of the combined duration and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperatures at approximately 4.5 ft above the ground surface is commonly designated as the air freezing index, while that determined for temperatures at, or immediately below, the ground surface is known as the surface freezing index.

Freezing season: That period during which the average daily temperature is below 32°F.

Frost-melting period: An interval of the year during which ice in the ground is returning to a liquid state. It ends when all the ice in the ground melts or when freezing starts again. Although in the generalized case there is only one frost-melting period, beginning during the general rise of the air temperatures in the spring, one or more significant frost-melting intervals may take place during a winter season.

Geothermal gradient: The temperature gradient in the ground below the zone of annual temperature fluctuations, produced by the continuous flow of heat from the Earth's hot interior toward the Earth's cool surface.

Mean annual temperature: The average value taken from several years of annual temperature averages.

Mean daily temperatures: The average taken from the averages of the daily temperatures for a given day for several years.

Mean freezing index: The freezing index determined from mean temperatures.

Mean monthly temperature: The average taken from the averages of the monthly temperatures for a given month for several years.

Mean thawing index: The thawing index determined from mean temperatures.

Period of weakening: An interval of the year that starts at the beginning of the frost-melting period and ends when the subgrade strength has returned to normal-period values or when freezing starts again. In seasonal frost areas, the period of weakening may be longer than the frost-melting period; but in permafrost areas, the periods coincide.

Strudel scour: An Arctic phenomenon that occurs every spring when the fresh-water rivers melt and form off-river deltas when river discharge drains through holes in the sea ice cover. Strudel scours constitute a major design consideration for subsea pipelines or other structures near rivers.

Thawing index: The number of degree-days between the lowest and highest points on a curve of cumulative degree-days versus time for one thawing season. It is a measure of the combined duration and magnitude of above-freezing temperatures during any given thawing season. The index determined for air temperatures at 4.5 ft above the ground is commonly designated as the air thawing index, while the temperature at or immediately below the ground surface is known as the surface thawing index.

Thermal regime: The pattern of temperature variations found in the ground with time and at a certain depth from the surface.

Thermal erosion: The erosion of ice-rich permafrost by the combined thermal and mechanical action of moving water or air (sublimation).

Thermal expansion (or contraction) coefficient: The volume change per unit volume of a substance due to a one-degree change in its temperature.

Thermal pile(s): Structural piling modified to passively remove heat from the ground whenever the ambient air temperature is lower than the ground temperature.

Total annual freezing index: The cumulative number of degree-days, calculated by adding all the negative mean daily air temperatures (in degrees Celsius) for a specific station during a calendar year.

Total annual thawing index: The cumulative number of degree-days, calculated by adding all the positive mean daily air temperatures (in degrees Celsius) for a specific station during a calendar year.

Wind chill: The excess rate of removal of body heat from exposed skin by moving air compared to still air at low temperatures. It is often expressed as a lower equivalent air temperature that is a function of actual air temperature and wind speed.

B-3.4 Terrain Terms.

Frost mound: A localized mound-shape on the land surface caused by frost action with or without hydrostatic pressure.

Icing: A surface ice mass formed by freezing of successive sheets of water from seepage, flow from a spring, or emergence from below river or lake ice through fractures.

Muskeg: Poorly drained organic terrain consisting of a mat of living vegetation overlying an extremely compressible mixture of partially decomposed peat, varying in thickness from a few inches to many feet.

Patterned ground: A general term describing ground patterns that result from frost action, such as polygons, circles and nets, stripes, and solifluction features.

Pingo (hydrolaccolith): A large ice-cored frost mound, often 100 ft high or more, consisting of a core of massive ice, produced primarily by injection of water and covered with soil and vegetation.

Strudel scour: A localized, seasonal scour formation that occurs in the spring when melting fresh water in rivers and streams flows over the surface and drains through holes of frozen shore-fast ice.

Thermokarst: The irregular topography resulting from differential thaw settlement or caving of the ground because of excess ice melting in thaw-unstable permafrost; the process by which characteristic landforms result from the thawing of ice-rich permafrost.

Tundra: Treeless terrain of grasses and shrubs characteristic of the Arctic, found at both high latitudes and high altitudes.

This Page Intentionally Left Blank

APPENDIX C SUPPLEMENTAL RESOURCES

The following references are reliable sources for information related to infrastructure planning, design, and construction in the Arctic and Subarctic. These sources provide direction for specific applications not addressed in this UFC or provide additional information to guide or aid the designer in the various phases of the design. This list is provided for the convenience of the designer and may not include references for all specific applications relevant to all projects. The designer is responsible for ensuring the design conforms to all criteria relevant to the project.

STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES, GEOLOGICAL & GEOPHYSICAL SURVEYS, FLOODING & LANDSLIDES, https://dggs.alaska.gov/popular-geology/flooding-landslides.html

U.S. ARMY CORPS OF ENGINEERS

EM 1110-2-1902, *Slope Stability*, https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1902.pdf?ver=E1mrnP_5qHsVXEiXzeka-Q%3d%3d

U.S. GEOLOGICAL SURVEY

ALASKA SCIENCE CENTER, PERMAFROST AND CLIMATE-MONITORING NETWORK, https://alaska.usgs.gov/portal/project.php?project_id=32

OTHER RESOURCES, BY TOPIC

CLIMATE CHANGE AND PROJECTIONS

"The Arctic," *Bulletin of the American Meteorological Society* 102 (8): S263–S316, M.L. Druckenmiller, T. Moon, R. Thoman, T.J. Ballinger, L.T. Berner, G.H. Bernhard, U.S. Bhatt, J.W. Bjerke, J.E. Box, R. Brown, and J. Cappelen, 2021

"River Discharge," *Arctic Report Card 2021,* R.M. Holmes, A.I. Shiklomanov, A. Suslova, M. Tretiakov, J.W. McClelland, L. Scott, R.G.M. Spencer, and S.E. Tank (edited by T.Moon, M. L. Druckenmiller, and R. Thoman), 2021, https://doi.org/10.25923/zevf-ar65

CLIMATE AND CLIMATE DATA

THE CANADIAN NATIONAL REPORT ON SYSTEMATIC OBSERVATIONS FOR CLIMATE, THE CANADIAN GLOBAL CLIMATE OBSERVING SYSTEM PROGRAM, https://unfccc.int/sites/default/files/resource/cangcose%20CAN%20e.pdf

DRAINAGE AND GROUNDWATER

"Flooding," EYE ON THE ARCTIC, https://www.rcinet.ca/eye-on-the-arctic/tag/flooding/

"Floods in Galena, Alaska," FLOODLIST, http://floodlist.com/america/usa/floods-galena-alaska

"Heavy Rain Leads to Mudslide and Rare Flash Flood Warning for Alaska," WHSV, https://www.whsv.com/2020/12/03/heavy-rain-leads-to-mudslides-and-rare-flash-flood-warning-for-alaska/

"Officials Express Concerns About Flooding in Western Alaska," U.S. NEWS & WORLD REPORT, https://www.usnews.com/news/best-states/alaska/articles/2021-04-21/officials-express-concerns-about-flooding-in-western-alaska

"Record-Breaking Rainfall Leaves Muddy Mess Across Southeast Alaska," KTOO, https://www.ktoo.org/2020/12/02/record-breaking-rainfall-leaves-muddy-mess-across-southeast-alaska/

EMBANKMENTS

"Deformations and Ground Temperatures at a Road Embankment in Northern Canada," *Canadian Geotechnical Journal* 51 (3): 260–271, H. Batenipour, M. Alfaro, D. Kurz, and J. Graham, 2014

"Modeling the Thermal Response of Air Convection Embankment in Permafrost Regions," *Cold Regions Science and Technology* 182: 103169, X. Kong, G. Doré, F. Calmels, and C. Lemieux, 2021

FROZEN GROUND ENGINEERING

Geocryology, Characteristics and Use of Frozen Ground and Permafrost Landforms, S.A. Harris, A. Brouchkov, and C. Guodong, CRC Press/Balkema, Leiden, The Netherlands, 2018

"Physical, Thermal, and Mechanical Properties of Snow, Ice, and Permafrost," in *Snow and Ice-Related Hazards, Risks, and Disasters*, 35–71, L. Arenson, W. Colgan, and H.P. Marshall, Elsevier, 2021

ICE COVER AND ICE ON WATER BODIES

GLOBAL LAND ANALYSIS AND DISCOVERY (GLAD), https://glad.umd.edu/dataset/seasonal-water-ice

"Global Seasonal Dynamics of Inland Open Water and Ice," *Remote Sensing of Environment* 272: 112963, A.H. Pickens, M.C. Hansen, S.V. Stehman, A. Tyukavina, P. Potapov, V. Zalles, and J. Higgins, 2022

"Ice Characteristics and Processes, and Remote Sensing of Frozen Rivers and Lakes," *Geophysical Monograph-American Geophysical Union* 163, M.O. Jeffries, K. Morris, and N. Kozlenko, 2005

"Monitoring Lake Ice Seasons in Southwest Alaska with MODIS Images," in *Proceedings of the Pecora Conference*, 18–20, P. Spencer, A.E. Miller, B. Reed, and M. Budde, American Society for Photogrammetry and Remote Sensing, Denver, CO, Nov 2008

SNOW HYDROLOGY

"Integrating Remote Sensing, Geographic Information Systems and Global Positioning System Techniques with Hydrological Modeling," *Applied Water Science* 7 (4): 1595–1608, J.K. Thakur, S.K. Singh, and V.S. Ekanthalu, 2017, https://link.springer.com/article/10.1007/s13201-016-0384-5?lipi=urn:li:page:d_flagship3_profile_view_base;HsiFFD2FRei2dvUjqYgmig&error=co-oies_not_supported&code=6466c98e-9112-48c7-a473-43539eec4eaa

"Modelling River Flow in Cold and Ungauged Regions: A Review of the Purposes, Methods, and Challenges," *Environmental Reviews* 99 (999): 1–15, C. Belvederesi, M.S. Zaghloul, G. Achari, A. Gupta, and Q.K. Hassan, 2022, https://cdnsciencepub.com/doi/full/10.1139/er-2021-0043

"Predicting Snowmelt Runoff at the Source of the Mountainous Euphrates River Basin in Turkey for Water Supply and Flood Control Issues Using HEC-HMS Modeling," *Water* 14 (3): 284, S. Sengül and M.N. Ispirli, 2022

SNOW LOADS AND ROOFS

CODES CANADA, https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada

This Page Intentionally Left Blank

APPENDIX D REFERENCES

AMERICAN CONCRETE INSTITUTE (ACI):

ACI 306R-16, *Guide to Cold Weather Concreting,* https://www.concrete.org/Portals/0/Files/PDF/University/306R-16_excerpt.pdf

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

https://www.astm.org/products-services/standards-and-publications.html

ASTM D2216, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soils and Rock by Mass*

ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes*

ASTM D4083, *Standard Practice for Description of Frozen Soils (Visual-Manual Procedure)*

ASTM D4253, *Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table*

ASTM D5520, *Standard Test Method for Laboratory Determination of Creep Properties of Frozen Soil Samples by Uniaxial Compression*

ASTM D5780, *Standard Test Method for Individual Piles in Permafrost Under Static Axial Compressive Load*

ASTM D5918, *Standard Test Methods for Frost Heave and Thaw Weakening Susceptibility of Soils*

ASTM D6035, *Standard Test Method for Determining the Effect of Freeze–Thaw on Hydraulic Conductivity of Compacted or Intact Soil Specimens Using a Flexible Wall Permeameter*

ASTM D7015/D7015M, *Standard Practice for Obtaining Intact Block (Cubical and Cylindrical) Samples of Soils*

ASTM D7099, *Standard Terminology Relating to Frozen Soil and Rock*

ASTM D7300, *Standard Test Method for Laboratory Determination of Strength Properties of Frozen Soil at a Constant Rate of Strain*

ASTM STP1568, *Mechanical Properties of Frozen Soil,* H. Zubeck and Z.J. Yang (eds.), ASTM International, West Conshohocken, PA, 2013

AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE)

ASCE COLD REGIONS ENGINEERING DIVISION, https://www.asce.org/communities/institutes-and-technical-groups/cold-regions-engineering/committees/cold-regions-engineering-division

ASCE MOP 74, *Guidelines for Electrical Transmission Line Structural Loading*

ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*

Journal of Cold Regions Engineering, https://ascelibrary.org/journal/jcrgei

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS (ASHRAE)

ANSI/ASHRAE 169-2020, *Climatic Data for Building Design Standards*

Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates, A. Zhivov (ed.), ASHRAE, Peachtree Corners, GA, 2021.

DEPARTMENT OF DEFENSE

DoDI 6055.01, *DoD Safety and Occupational Health (SOH) Program*

EXECUTIVE ORDERS

EO 11990, *Protection of Wetlands* (May 24 1977), 42 FR 26961, 3 CFR

INTERNATIONAL PERMAFROST ASSOCIATION

https://www.permafrost.org/

DATA, https://www.permafrost.org/data/

GLOSSARY OF PERMAFROST AND RELATED GROUND-ICE TERMS, https://www.permafrost.org/publication/glossary-of-permafrost-and-related-ground-ice-terms/

WHAT IS PERMAFROST?, https://www.permafrost.org/what-is-permafrost/

INTERNATIONAL STANDARDS ORGANIZATION (ISO)

ISO 2394, *General Principles on Reliability for Structures*, https://www.iso.org/standard/58036.html

ISO 13822, *Bases for Design of Structure—Assessment of Existing Structures*, https://www.iso.org/standard/46556.html

ISO 31000, *Risk Management—Guidelines*, https://www.iso.org/obp/ui/#iso:std:iso:31000,:en

ISO/IEC 31010, *Risk Management—Risk Assessment Techniques*, https://www.iso.org/standard/72140.html.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NCEI, https://www.ncei.noaa.gov/ (home page)

NWS, https://www.weather.gov/ (home page)

NWS, COOPERATIVE OBSERVERS PROGRAM (COOP), https://www.weather.gov/coop/Overview

NCEI, GLOBAL HISTORICAL CLIMATOLOGY NETWORK DAILY, https://www.ncei.noaa.gov/products/land-based-station/global-historical-climatology-network-daily

NCEI, GLOBAL PRECIPITATION CLIMATOLOGY PROJECT (GPCP) CLEARINGHOUSE, https://www.ncei.noaa.gov/products/global-precipitation-climatology-project.

NCEI, LAND-BASED STATION, https://www.ncei.noaa.gov/products/land-based-station

NCEI, U.S. CLIMATE NORMALS QUICK ACCESS, https://www.ncei.noaa.gov/access/us-climate-normals/

NWS, ALASKA WEATHER STATION LIST, https://www.weather.gov/aawu/stnlist

NWS, NATIONAL OPERATIONAL HYDROLOGIC REMOTE SENSING CENTER (NOHRSC), https://www.nohrsc.noaa.gov/

NWS, NWS FORECAST OFFICE: ANCHORAGE, AK, (https://www.weather.gov/afc/)

NWS, U.S. AND NORTHERN HEMISPHERE SNOW COVER, https://www.nohrsc.noaa.gov/nh_snowcover/

NWS, WHAT IS A GROUND BLIZZARD, https://www.weather.gov/safety/winter-ground-blizzard

NWS, WIND CHILL CHART, https://www.weather.gov/safety/cold-wind-chill-chart

NATIONAL SNOW AND ICE DATA CENTER (NSIDC)

https://nsidc.org/

NSIDC DATA, https://nsidc.org/data

NSIDC MODIS/TERRA CGF SNOW COVER DAILY L3 GLOBAL 500M SIN GRID, VERSION 61, https://nsidc.org/data/MOD10A1F/versions/61

NATIONAL STANDARDS

ANSI/EIA/TIA-222, *Structural Standards for Steel Antenna Towers and Antenna Supporting Structures*, American National Standards Institute

FEMA P-749, *Earthquake-Resistant Design Concepts: An Introduction to the NEHRP Recommended Seismic Provision for New Buildings and Other Structures*, National Institute of Building Sciences, https://www.fema.gov/sites/default/files/2020-07/fema_earthquake-resistant-design-concepts_p-749.pdf

IEEE C-2, *National Electrical Safety Code*

STATE OF ALASKA

Department of Commerce, Community, and Economic Development, Division of Community Advocacy, *Floodplain Management in Alaska Quick Guide,* https://www.commerce.alaska.gov/web/portals/4/pub/AKQG2003_web.pdf

Department of Commerce, Community, and Economic Development, Division of Corporations, Business and Professional Licensing, https://www.commerce.alaska.gov/web/cbpl/ProfessionalLicensing/BoardofArchitectsEngineersandLandSurveyors/ApprovedCoursesinArcticEngineering.aspx

Department of Environmental Conservation, Division of Water, https://dec.alaska.gov/water/wastewater/wetlands

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 1-200-01, *DoD Building Code*

UFC 1-201-01, *Non-Permanent DOD Facilities in Support of Military Operations*

UFC 2-100-01, *Installation Master Planning*

UFC 3-130-02, *Arctic and Subarctic Site Assessment and Selection*

UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*

UFC 3-130-04, *Arctic and Subarctic Buildings*

UFC 3-130-05, *Arctic and Subarctic Utilities*

UFC 3-201-01, *Civil Engineering*

UFC 3-220-01, *Geotechnical Engineering*

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*

UFC 3-250-03, *Standard Practice Manual for Flexible Pavements*

UFC 3-250-04, *Standard Practice for Concrete Pavements*

UFC 3-250-07, *Standard Practice for Pavement Recycling*

UFC 3-250-08FA, *Standard Practice for Sealing Joints and Cracks in Rigid and Flexible Pavements*

UFC 3-250-09FA, *Aggregate Surfaced Roads and Airfields Areas*

UFC 3-250-11, *Soil Stabilization for Pavements*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 3-260-02, *Pavement Design for Airfields*

UFC 3-260-04, *Airfield and Heliport Marking*

FC 3-260-06F, *Air Force Design, Construction, Maintenance, and Evaluation of Snow and Ice Airfields in Antarctica*

UFC 3-301-01, *Structural Engineering*

UFC 3-301-02, *Design of Risk Category V Structures, National Strategic Military Assets*

UFC 3-400-02, *Design: Engineering Weather Data*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

U.S. AIR FORCE

Air Force Civil Engineer Severe Weather/Climate Hazard Screening and Risk Assessment Playbook, 2022, https://wbdg.org/FFC/AF/POLICY/af_swch_playbook_2023_06_29.pdf

U.S. ARMY CORPS OF ENGINEERS

Army Climate Resilience Handbook, A.O. Pinson, K.D. White, S.A. Moore, S.D. Samuelson, B.A. Thames, P.S. O'Brien, C.A. Hiemstra, P.M. Loechl, and E.E. Ritchie, USACE, Washington, D.C., 2020

ERDC LIBRARY RESOURCES, https://www.erdc.usace.army.mil/Library/

EM 200-1-4, *Environmental Quality, Risk Assessment Handbook Volume II: Environmental Evaluation*, https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_200-1-4_Vol-02.pdf?ver=MFaYplW6wTZbx3I-5KNGog%3d%3d

EM 1110-1-1802, *Engineering and Design, Geophysical Exploration for Engineering and Environmental Investigations*, https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-1802.pdf?ver=2mc3oDC3mmX-FRZFUrJQug%3d%3d

EM 1110-1-1804, *Geotechnical Investigations*, https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-1804.pdf?ver=X3odvxc01j8BVoN9mwxWCw%3d%3d

EM 1110-2-1406, *Engineering and Design, Runoff from Snowmelt*, https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1406.pdf?ver=2013-09-04-070756-610

EM 1110-2-1612, *Engineering and Design, Ice Engineering*, https://www.publications.usace.army.mil/Portals/76/Users/182/86/2486/EM_1110-2-1612.pdf?ver=AsPAhew1HgU_7lXhhsfccw%3d%3d

EM 1110-2-1906, *Engineering and Design, Laboratory Soils Testing*, https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1906.pdf?ver=LIfrSakZ_5Iv7RCTgg_U_w%3d%3d

EP 1100-1-5, *USACE Guide to Resilience Practices*, https://www.publications.usace.army.mil/Portals/76/Users/182/86/2486/EP%201100-1-5.pdf

PAVEMENT-TRANSPORTATION COMPUTER ASSISTED STRUCTURAL ENGINEERING (PCASE), https://transportation.erdc.dren.mil/pcase/

Snow Hydrology, U.S. Army, North Pacific Division, Portland, OR, 1956

USACE HYDROLOGIC ENGINEERING CENTER–HYDROLOGIC MODELING SYSTEM (HEC-HMS), https://www.hec.usace.army.mil/software/hec-hms/

U.S. DEPARTMENT OF AGRICULTURE

USDA NATURAL RESOURCES CONSERVATION SERVICE NATIONAL WEATHER AND CLIMATE CENTER, https://wcc.sc.egov.usda.gov/nwcc/rgrpt?report=swe

Snow-Survey Sampling Guide, USDA, Soil Conservation Service, 1959, https://handle.nal.usda.gov/10113/CAT87208787

U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds*, 2007, https://www.fema.gov/sites/default/files/2020-08/fema543_design_guide_complete.pdf

FEMA P-749, *An Introduction to the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*, 2020, https://www.fema.gov/sites/default/files/2020-07/fema_earthquake-resistant-design-concepts_p-749.pdf

U.S. DEPARTMENT OF TRANSPORTATION

FHWA-OTS-15-002, *Gravel Roads: Construction & Maintenance Guide* https://www.fhwa.dot.gov/construction/pubs/ots15002.pdf

U.S. GEOLOGICAL SURVEY

LAND PROCESSES DISTRIBUTED ACTIVE ARCHIVE CENTER, https://lpdaac.usgs.gov/

NEW EARTHQUAKE HAZARDS PROGRAM, https://www.usgs.gov/natural-hazards/earthquake-hazards/lists-maps-and-statistics

SCIENCE DATA CATALOG, https://data.usgs.gov/datacatalog/data/USGS:e250fffe-ed32-4627-a3e6-9474b6dc6f0b

UNIVERSITY OF ALASKA

FUNDAMENTALS OF ARCTIC ENGINEERING, https://www.uaa.alaska.edu/academics/college-of-engineering/departments/civil-engineering/arctic/short-course.cshtml

ARCTIC ENGINEERING, https://www.uaf.edu/catalog//catalog_15-16/programs/pdf/graduate/arctic-eng.pdf

ARCTIC ENVIRONMENTAL AND ENGINEERING DATA + DESIGN SUPPORT SYSTEM, PHYSIOGRAPHY, PERMAFROST, UAF, https://arcticeds.org/physiography/permafrost/

ALASKA EARTHQUAKE CENTER, https://earthquake.alaska.edu/earthquakes

OTHER REFERENCES, TEXTBOOKS AND JOURNALS

Cold Climate Landforms, D.J.A. Evans (ed.), Wiley, Chichester,1994

Cold Regions Pavement Engineering, G. Doré and H.K. Zubeck, ASCE and McGraw Hill, New York, NY, 2009

Cold Region Structural Engineering, E. Erranti and G.C. Lee, The McGraw-Hill Companies, Inc., New York, NY, 2000

Cold Regions Science and Technology, https://www.journals.elsevier.com/cold-regions-science-and-technology

Construction in Cold Regions: A Guide for Planners, Engineers, Contractors, and Managers, T.T. McFadden and F.L. Bennett, Wiley-Interscience, New York, NY,1991

Frozen Ground Engineering, O.B. Andersland and B. Ladanyi, John Wiley & Sons, New York, NY, 2004

Frozen in Time: Permafrost and Engineering Problems, S.W. Muller, ASCE, New York, NY, 2008

Introduction to Cold Regions Engineering, D.R. Freitag and T.T. McFadden, ASCE, New York, NY, 1997

The Periglacial Environment, H.M. French, John Wiley & Sons, New York, NY, 2017

Permafrost Engineering Design and Construction, G.H. Johnston, John Wiley & Sons, New York, NY, 1981

OTHER REFERENCES, BY TOPIC (ALPHABETICALLY)

CLIMATE AND CLIMATE DATA

GOVERNMENT OF CANADA, HISTORICAL CLIMATE DATA, https://climate.weather.gc.ca/

GREENLAND – FROZEN GROUND, POLAR PORTAL, http://polarportal.dk/en/greenland/frozen-ground/

SPATIAL CLIMATE ANALYSIS SERVICE, OREGON STATE UNIVERSITY, https://prism.oregonstate.edu/projects/public/alaska/grids/

CLIMATE CHANGE AND PROJECTIONS

"Alaska Terrestrial and Marine Climate Trends, 1957–2021," *Journal of Climate* 36 (13): 4375–4391, T.J, Ballinger, U.S. Bhatt, P.A. Bieniek, B. Brettschneider, R.T. Lader, J.S. Littell, R.L. Thoman, C.F. Waigl, J.E. Walsh, and M.A. Webster, 2023

Arctic Report Card 2022, M.L. Druckenmiller, R. L. Thoman, and T.A. Moon (eds.), 2022, https://doi.org/10.25923/yjx6-r184

"Climate Change 2021: The Physical Science Basis," *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, V.

Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.), IPCC, Cambridge University Press, 2021

"Downscaling of Climate Model Output for Alaskan Stakeholders," *Environmental Modelling & Software* 110: 38–51, J.E. Walsh, U.S. Bhatt, J.S. Littell, M. Leonawicz, M. Lindgren, T.A. Kurkowski, P.A. Bieniek, R. Thoman, S. Gray, and T.S. Rupp, 2018, https://doi.org/10.1016/j.envsoft.2018.03.021

Future Projections of Precipitation for Alaska Infrastructure: Final Report, N. Fresco, C. Tauxe, M. Lindgren, P. Bieniek, J. Walsh, K. Redilla, B. Torgerson, P. Duffy, T. Kurkowski, B. Crevensten, and T. Stockton, prepared by Scenarios Network for Alaska and Arctic Planning, International Arctic Research Center, UAF, prepared for Alaska Department of Transportation and Public Facilities, FHWA-AK-RD-4000(188), HFHWY00132, 2021

"Impacts of Permafrost Degradation on Infrastructure," *Nature Reviews Earth & Environment* 3 (1): 24–38, J. Hjort, D. Streletskiy, G. Doré, Q. Wu, K. Bjella, and M. Luoto, 2022, https://doi.org/10.1038/s43017-021-00247-8

SCENARIOS NETWORK FOR ALASKA AND ARCTIC PLANNING (SNAP), https://uaf-snap.org

"Sea Ice," *Arctic Report Card 2021,* W. Meier, D. Perovich, S. Farrell, C. Haas, S. Hendricks, A.A. Petty, M. Webster, D. Devine, S. Gerland, L. Kaleschke, R. Ricker, A. Steer, X. Tian-Kunze, M. Tschudi, and K. Wood (edited by T.A. Moon, M.L. Druckenmiller, and R.L. Thoman), 2021, https://doi.org/10.25923/y2wd-fn85

DEPTH OF FREEZE AND THAW IN SOIL

"Computer Assisted Calculations of the Depth of Frost Penetration in Pavement-Soil Structures," in *Transportation Systems 2000 Workshop*, 92–105, E.R. Cortez, M.A. Kestler, and R.L. Berg, 2000

"One-Dimensional Computer Models to Estimate Frost Depth," in *Cold Regions Engineering 2009: Cold Regions Impacts on Research, Design, and Construction*, 110–118, L.A. Barna, S.A., Shoop, and B.A. Coutermarsh, 2009

Pavement-Transportation Computer Assisted Structural Engineering (PCASE) Implementation of the Modified Berggren (ModBerg) Equation for Computing the Frost Penetration Depth Within Pavement Structures, ERDC/GSL TR 12-15, A. Bianchini, and C.R. Gonzalez, U.S. Army Geotechnical and Structural Laboratory, Vicksburg, MS, 2012, https://erdc-library.erdc.dren.mil/jspui/handle/11681/10399

EMBANKMENTS

"Convective Cooling in Open Rock Embankments," in *Cold Regions Engineering: Cold Regions Impacts on Transportation and Infrastructure*, 629–644, D.J. Goering, 2002

"Design of Passive Permafrost Cooling System for an Interior Alaska Roadway," *Cold Regions and Construction Conference,* D.J. Goering and S. Saboundjian, *ASCE/CSCE/IWCSEAA,* May 2004

"In-Situ Monitoring of Settlement at Different Layers Under Embankments in Permafrost Regions on the Qinghai–Tibet Plateau," *Engineering Geology* 160: 44–53, F. Yu, J. Qi, X. Yao, and Y. Liu, 2013

"Investigation of Embankment Deformation Mechanisms in Permafrost Regions," *Transportation Geotechnics* 16: 21–28, F. Ming, Q.H. Yu, and D.Q. Li, 2018

"Large-Scale Direct Shear Testing of Compacted Frozen Soil Under Freezing and Thawing Conditions," *Cold Regions Science and Technology* 151: 138–147, E.M.B. De Guzman, D. Stafford, M.C. Alfaro, G. Doré, and L.U. Arenson, 2018, https://www.sciencedirect.com/science/article/pii/S0165232X17302124?casa_token=k0j3lxeEUHkAAAAA:BdymSpGnZ2eTe1Bax0wXj6Zj7CrNmQLdcjKHTGA1LpbDWyXWe_GwMbzT5Zne3rXIRA0bz2Kqkkl7

"Modeling the Performance of an Air Convection Embankment (ACE) with Thermal Berm over Ice-Rich Permafrost, Lost Chicken Creek, Alaska," *Cold Regions Science and Technology* 130: 43–58, M.M. Darrow and D.D. Jensen, 2016

"Optimization in the Use of Air Convection Embankments for the Protection of Underlying Permafrost," *Cold Regions Engineering 2012: Sustainable Infrastructure Development in a Changing Cold Environment*, 12–20, A.S. Jørgensen and T. Ingeman-Nielsen, 2012

"Passively Cooled Railway Embankments for Use in Permafrost Areas," *Journal of Cold Regions Engineering* 17 (3): 119–133, D.J. Goering, 2003

"Performance of Highway Embankments in the Arctic Constructed Under Winter Conditions," *Canadian Geotechnical Journal* 58 (5): 722–736, E.M.B. De Guzman, M.C. Alfaro, G. Doré, L.U. Arenson, and A. Piamsalee, 2021, https://cdnsciencepub.com/doi/full/10.1139/cgj-2019-0121

"Structural Stability of Highway Embankments in the Arctic Corridor," E.M. De Guzman, PhD Thesis, University of Manitoba, 2020, https://mspace.lib.umanitoba.ca/handle/1993/35094

Thermal Stabilization of Embankments Built on Thaw-Sensitive Permafrost, Special Report 01-03, X. Kong, and G. Doré, 2021

EROSION

Climate Change, Permafrost, and Impacts on Civil Infrastructure, Special Report 01-03, U.S. Arctic Research Commission Permafrost Task Force, U.S. Arctic Research Commission, Arlington, VA, 2003

"Mapping Sea Ice Overflood Using Remote Sensing: Alaskan Beaufort Sea," *Cold Regions Science and Technology* 65: 275–285, D. Dickins, G. Hearon, K. Morris, K. Ambrosius, and W. Horowitz, 2011

Responses to Coastal Erosion in Alaska in a Changing Climate: A Guide for Coastal Residents, Business and Resource Managers, Engineers, and Builders, SG-ED-75, O.P. Smith, and M.K. Hendee, Alaska Sea Grant College Program, UAF, 2011

"Riverbank Erosion in Cold Environments: Review and Outlook," *Earth-Science Reviews* 207: 103231, L. Chassiot, P. Lajeunesse, and J.F. Bernier, 2020

FROZEN GROUND ENGINEERING

"Design of Vertical and Laterally Loaded Piles in Saline Permafrost," in *Proceedings of the 3rd International Specialty Conference on Cold Regions Engineering,* 1–6, J. Nixon and R. Neukirchner,1984

"Experimental Study on Influences of Water Content and Temperature on Mechanical Properties of Ice-Rich Frozen Soil," *Journal of Hydraulic Engineering* 41 (10): 1165–1172, M. Huo, S.J. Wang, J.Z. Zhang, and L. Jin, 2010

"Frozen Saline Soils of the Arctic Coast: Their Distribution and Engineering Properties," A. Brouchkov, in *ICOP 2003: Permafrost: Proceedings of the Eighth International Conference on Permafrost*, Zürich, Switzerland, M. Phillips, S.M. Springman, and L.U. Arenson (eds.), 21–25 Jul 2003

"Long-Term Pile Load Testing System Performance in Saline and Ice-Rich Permafrost," *Journal of Cold Regions Engineering* 10: 149–162, K. Biggar, D.C. Sego, and R. P. Stahl, 1996

"Mechanical Properties of Naturally Frozen Ice-Rich Silty Soils," *ASTM STP1568 Mechanical Properties of Frozen Soil*, X. Ge, Z. Yang, and B. Still (edited by H. Zubeck and Z.J. Yang), ASTM International, West Conshohocken, PA, 2013

"Practice of Testing Frozen Soils," *ASTM STP1568 Mechanical Properties of Frozen Soil,* F. Oestgaard, and H. Zubeck (edited by H. Zubeck and Z.J. Yang), ASTM International, West Conshohocken, PA, 2013

"Strength Characteristics of Frozen Saline Soils," *Soil Mechanics and Foundation Engineering* 40: 55–59, V.I. Aksenov, R.G. Kal'bergenov, and A.R. Leonov, 2003

"Strength of Frozen Saline Soils," *Canadian Geotechnical Journal* 32: 336–354, E.G. Hivon and D.C. Sego, 1995

"Triaxial Testing of Frozen Soils—State of the Art," *ASTM STP1568 Mechanical Properties of Frozen Soil,* T. Kornfield and H. Zubeck (edited by H. Zubeck and Z.J. Yang), ASTM International, West Conshohocken, PA, 2013

GENERAL

New Construction Criteria for a Changing Arctic and Subarctic: The UFC 3-130 Series Revision Process, ERDC/CRREL SR-24-X, K. Bjella, R. Affleck, W. Wieder, L. Barna, W. Lein, Mark Musial, John Thornley, and Andrew Daggett, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, forthcoming 2024. http://dx.doi.org/10.21079/11681/45200

INSTALLATION FACILITIES STANDARDS (IFS), https://www.wbdg.org/airforce/ifs

GEOSPATIAL DATA

ARCTIC DEM EXPLORER, https://livingatlas2.arcgis.com/arcticdemexplorer

THE ARCTIC RESEARCH CONSORTIUM OF THE UNITED STATES (ARCUS), https://www.arcus.org/gis/maps-data/metadata

NASA EARTH OBSERVATIONS, https://neo.gsfc.nasa.gov

NATIONAL SNOW AND ICE DATA CENTER (NSIDC), https://nsidc.org/data

GROUND TEMPERATURE

GLOBAL TERRESTRIAL NETWORK FOR PERMAFROST (GTN-P), "Boreholes-Permafrost Temperatures," http://gtnpdatabase.org/boreholes

"A Ground Temperature Map of the North Atlantic Permafrost Region Based on Remote Sensing and Reanalysis Data," *The Cryosphere* 9 (3): 1303–1319, S. Westermann, T.I. Østby, K. Gisnås, T.V. Schuler, and B.J.T.C. Etzelmüller, 2015

"Numerical Modeling of Permafrost Dynamics in Alaska Using a High Spatial Resolution Data Set," *The Cryosphere* 6 (3): 613–624, E.E. Jafarov, S.S. Marchenko, and V.E. Romanovsky, 2012

"Numerical Modeling of Spatial Permafrost Dynamics in Alaska," in *Proceedings of the Ninth International Conference on Permafrost* 29: 1,125–1,130, S. Marchenko, V. Romanovsky, and G. Tipenko, Institute of Northern Engineering, UAF, 2008

HORIZONTAL INFRASTRUCTURE

"Design Considerations for the Use of Ice as a Construction Platform," in *Proceedings of the 10th Workshop on River Ice. River Ice Management with a Changing Climate: Dealing with Extreme Events*, F. Hicks and A. Fayek, Jun 1999

Field Handbook Version of the Winter Roads Manual, Ministry of Highways and Infrastructure, Saskatchewan, Canada, 2009, http://www.highways.gov.sk.ca/Doing%20Business%20with%20MHI/Ministry%20Manuals/Winter%20Roads%20Handbook/Winter%20Roads%20Handbook.pdf

McMurdo Snow Roads and Transportation: Final Program Summary, ERDC/CRREL TR-22-11, S.A. Shoop, W.L. Wieder, and T.J. Melendy, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2022, http://dx.doi.org/10.21079/11681/45200

Overview of Ice Roads in Canada: Design, Usage and Climate Change Adaptation, OCRE-TR-2015-011, P.D. Barrette, National Research Council Canada, 2015, https://nrc-publications.canada.ca/eng/view/object/?id=5984226f-bee8-48fe-a138-5a23c800f435

"Review of Ice and Snow Runway Pavements," *International Journal of Pavement Research and Technology* 11 (3): 311–320, G. White and A. McCallum, 2018, https://doi.org/10.1016/j.ijprt.2017.11.002

Roads and Airfields in Cold Regions: A State of the Practice Report, T.S. Vinson, J.W. Rooney, and W.H. Haas (eds.), ASCE Publications, 1996

Snow-Road Construction and Maintenance, ERDC/CRREL TR-16-16, S.A Shoop, J. Uberuaga, W.L. Wieder, and T.D. Melendy, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2016

A Snow Runway for Supporting Wheeled Aircraft: Phoenix Airfield, McMurdo, Antarctica, ERDC/CRREL TR-19-4, R.B. Haehnel, G.L. Blaisdell, T. Melendy, S. Shoop, and Z. Courville, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2019

"Winter Roads in Manitoba," *12th Workshop of Hydraulics of Ice-Covered Rivers*, D. Kuryk, Edmonton, Alberta, 2003, http://www.cripe.ca/docs/proceedings/12/Kuryk-2003.pdf

ICE COVER AND ICE ON WATER BODIES

"Historical Trends in Lake and River Ice Cover in the Northern Hemisphere," *Science* 289: 1743–1746, J.J. Magnuson, D.M. Robertson, B.J. Benson, R.H. Wynne, D.M. Livingstone, T. Arai, R.A. Assel, R.G. Barry, V. Card, E. Kuusisto, N.G. Granin, T.D. Prowse, K.M. Stewart, and V.S. Vuglinski, 2000

ICE ENGINEERING

"Modelling of Ice Jam Floods Under Past and Future Climates: A Review," *Journal of Hydrology X* 15: 100120, P. Rokaya, K.E. Lindenschmidt, A. Pietroniro, and M. Clark, 2022

MONITORING

Improving Design Methodologies and Assessment Tools for Building on Permafrost in a Warming Climate, ERDC/CRREL TR 20-13, K.L Bjella, Y. Shur, M. Kanevskiy, P. Duvoy, B. Grunau, J. Best, S. Bourne, and R.T. Affleck, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2020, https://hdl.handle.net/11681/38879

PERMAFROST

"Circumpolar Active Layer Monitoring program," ARCTIC DATA CENTER, https://arcticdata.io/catalog/portals/CALM

"Distribution of Near-Surface Permafrost in Alaska: Estimates of Present and Future Conditions," *Remote Sensing of Environment* 168: 301–315, N.J. Pastick, M.T. Jorgenson, B.K. Wylie, S.J. Nield, K.D. Johnson, and A.O. Finley, 2015

"Northern Hemisphere Permafrost Map Based on TTOP Modelling for 2000–2016 at 1 km^2 Scale," *Earth-Science Reviews* 193: 299–316, J. Obu, S. Westermann, A. Bartsch, N. Berdnikov, H.H. Christiansen, A. Dashtseren, R. Delaloye, B. Elberling, B. Etzelmüller, A. Kholodov, and A. Khomutov, 2019

"Permafrost Characteristics of Alaska," in *Proceedings of the Ninth International Conference on Permafrost* 3: 121–122, M.T. Jorgenson, K. Yoshikawa, M. Kanevskiy, Y. Shur, V. Romanovsky, S. Marchenko, G. Grosse, J. Brown, and B. Jones, UAF, Jun 2008

Permafrost Characteristics of Alaska, M.T. Jorgenson, K. Yoshikawa, Y. Shur, V. Romanovsky, S. Marchenko, G. Grosse, J. Brown, and B. Jones, EPA, 2008, https://www.epa.gov/sites/default/files/2017-09/documents/ak-state_attachment_2017-06-19.pdf

"Permafrost of Northern Alaska," in *Proceedings of the Twenty-First International Offshore and Polar Engineering Conference,* M.Z. Kanevskiy, E. Stepahni, Y.L. Shur, M.T. Jorgenson, C. Ping, D. Fortier, and M. Dillon, Maui, HI, 19–24 Jun 2011

"Thermal State of Permafrost in North America: A Contribution to the International Polar Year," *Permafrost and Periglacial Processes* 21 (2): 117–135, S.L. Smith, V.E. Romanovsky, A.G. Lewkowicz, C.R. Burn, M. Allard, G.D. Clow, K. Yoshikawa, and J. Throop, 2010

PERMAFROST DEGRADATION

"Arctic Landscapes in Transition: Responses to Thawing Permafrost," *Eos, Transactions American Geophysical Union* 91 (26): 229–230, J.C. Rowland, C.E. Jones, G. Altmann, R. Bryan, B.T. Crosby, L.D. Hinzman, D.L. Kane, D.M. Lawrence, A. Mancino, P. Marsh, and J.P. McNamara, 2010, https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2010EO260001

"Synthesis of Physical Processes of Permafrost Degradation and Geophysical and Geomechanical Properties of Permafrost," *Cold Regions Science and Technology* 198: 103522, M. Liew, X. Ji, M. Xiao, L. Farquharson, D. Nicolsky, V. Romanovsky, M. Bray, X. Zhang, and C. McComb, 2022

PRECIPITATION AND SNOW DISTRIBUTION

"Arctic Snowfall from CloudSat Observations and Reanalyses," *Journal of Climate* 33 (6): 2093–2109, L. Edel, C. Claud, C. Genthon, C. Palerme, N. Wood, T. L'ecuyer, and D. Bromwich, 2020

"Arctic Terrestrial Hydrology: A Synthesis of Processes, Regional Effects, and Research Challenges," *Journal of Geophysical Research: Biogeosciences* 121: 621–649, A. Bring, I. Fedorova, Y. Dibike, L. Hinzman, J. Mård, S.H. Mernild, T. Prowse, O. Semenova, S.L. Stuefer, and M.-K. Woo, 2016

"Aufeis Formation and Remediation," in *Proceedings of the 15th International Conference on Cold Regions Engineering,* J. Zufelt and S.F Daly, Quebec, Canada, 19–22 Aug 2012

Aufeis Formation in Jarvis Creek and Flood Mitigation, ERDC/CRREL TR-11-5, S.F. Daly, J.E. Zufelt, A. Gelvin, and S.D. Newman, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2011, http://hdl.handle.net/11681/5523

"Denali Park Access Road Icing Problems and Mitigation Options," in *Proceedings of the 8th International Conference on Permafrost,* 1189–1194, T.S. Vinson and D. Lofgren, Zürich, Switzerland, 21–25 Jul 2003

"The Distribution and Dynamics of Aufeis in Permafrost Regions," *Permafrost and Periglacial Processes* 31: 383–395, T. Ensom, O. Makarieva, P. Morse, D. Kane, V. Alekseev, and P. Marsh, 2020, https://doi.org/10.1002/ppp.2051

"Hydrological Response of a High-Arctic Catchment to Changing Climate Over the Past 35 years: A Case Study of Bayelva Watershed, Svalbard," *Polar Research* 32: 19691, A. Nowak and A. Hodson, 2013, https://doi:10.3402/polar.v32i0.19691

"Intercomparison of Precipitation Estimates Over the Arctic Ocean and its Peripheral Seas from Reanalyses," *Journal Climate* 31 (20): 8441–8462, L.N. Boisvert, M.A. Webster, A.A. Petty, T. Markus, D.H. Bromwich, and R.I. Cullather, 2018, https://doi.org/10.1175/JCLI-D-18-0125.1

"Observations of Arctic Snow and Sea Ice Cover from CALIOP Lidar Measurements," *Remote Sensing of Environment* 194: 248–263, X. Lu, Y. Hu, Z. Liu. S. Rodier, M. Vaughan, P. Lucker, C. Trepte, and J. Pelon, 2017

"Processes and Impacts of Arctic Amplification: A Research Synthesis," *Global and Planetary Change* 77 (1–2): 85–96, M.C. Serreze and R.G. Barry, 2011, https://doi.org/10.1016/j.gloplacha.2011.03.004

"Progress in Permafrost Hydrology in the New Millennium," *Permafrost and Periglacial Processes* 19 (2): 237–254, M.-K. Woo, D.L. Kane, S.K. Carey, D. Yang, 2008

"A Review of Hydrological Models Applied in the Permafrost-Dominated Arctic Region," *Geosciences* 10 (10): 401, M.T. Bui, J. Lu, and L. Nie, 2020

"Status of High-Latitude Precipitation Estimates from Observations and Reanalyses," *Journal of Geophysical Research: Atmospheres* 121 (9): 4468–4486, A. Behrangi, M. Christensen, M., Richardson, M. Lebsock, G. Stephens, G.J. Huffman, D. Bolvin, R.F. Adler, A. Gardner, B. Lambrigtsen, and E. Fetzer, 2016, https://doi.org/10.1002/2015JD024546

"Winter Northern Hemisphere Weather Patterns Remember Summer Arctic Sea-Ice Extent," *Geophysical Research Letters* 36 (7), J.A. Francis, W. Chan, D.J. Leathers, J.R., Miller, and D.E. Veron, 2009

RESILIENCE

Adapting Infrastructure and Civil Engineering Practice to a Changing Climate, J.R. Olsen (ed.), ASCE, Reston, VA, 2015

"Best Practices for HVAC, Plumbing, and Heat Supply in Arctic Climates," *ASHRAE Transactions* 127 (1), E.C. Winfield, R.J. Rader, A.M. Zhivov, T.A. Adams, A. Dyrelund, C. Fredeen, O. Gudmundsson, and B. Goering, 2021, https://annex73.iea-ebc.org/Data/Sites/4/media/papers/VC-21-007_Preprint.pdf

"Climate-Resilient Infrastructure: Adaptive Design and Risk Management," *ASCE Manuals and Reports on Engineering Practice 140,* B.M. Ayyub (ed.), prepared by ASCE Committee on Adaptation to a Changing Climate, 2018

Hazard-Resilient Infrastructure: Analysis and Design, B.M. Ayyub (ed.), ASCE, Reston, VA, 2021

"A Novel Framework for Risk Assessment and Resilience of Critical Infrastructure Towards Climate Change," *Technological Forecasting and Social Change* 165: 120532, N. Kumar, V. Poonia, B.B. Gupta, and M.K. Goyal, 2021

"Practical Resilience Metrics or Planning, Design, and Decision Making," *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* 1 (3): 04015008, B.M. Ayyub, 2015

"Reliability-Based Assessment of Deteriorating Performance to Asphalt Pavement Under Freeze–Thaw Cycles in Cold Regions," *Construction and Building Materials* 68: 572–579, W. Si, B. Ma, N. Li, J.P. Ren, and H.N. Wang, 2014

"Resilience and Vulnerability of Permafrost to Climate Change," *Canadian Journal of Forest Research* 40 (7): 1219–1236, M.T. Jorgenson, V. Romanovsky, J. Harden, Y. Shur, J. O'Donnell, E.A. Schuur, M. Kanevskiy, and S. Marchenko, 2010

RISK

"Engineering Risk Analysis in Cold Regions: State of the Art and Perspectives," *Cold Regions Science and Technology* 171: 102963, W. Yu, T. Zhang, Y, Lu, F. Han, Y. Zhou, and D. Hu, 2020

"A Probability-Based Reliability Assessment Approach of Seismic Base-Isolated Bridges in Cold Regions," *Engineering Structures* 197: 109353, M. Nassar, M.L. Guizani, M.J. Nollet, and A. Tahan, 2019

"Qualitative Risk Assessment and Strategies for Infrastructure on Permafrost in the French Alps," *Cold Regions Science and Technology* 189: 103311, P.A. Duvillard, L. Ravanel, P. Schoeneich, P. Deline, M. Marcer, and F. Magnin, 2021

"Quantitative Risk and Optimal Design Approaches in the Snow Avalanche Field: Review and Extensions," *Cold Regions Science and Technology* 79: 1–19, N. Eckert, C.J. Keylock, D. Bertrand, E. Parent, T. Faug, P. Favier, and M. Naaim, 2012

"Reliability-Based Assessment of Deteriorating Performance to Asphalt Pavement Under Freeze–Thaw Cycles in Cold Regions," *Construction and Building Materials* 68: 572–579, W. Si, B. Ma, N. Li, J.P. Ren, and H.N. Wang, 2014

SEISMIC

"Experimental and Analytical Study of Seismic Site Response of Discontinuous Permafrost," *Canadian Geotechnical Journal* 53 (9): 1363–1375, B. Dadfar, M.H. El Naggar, and M. Nastev, 2016

INTERNATIONAL FEDERATION OF DIGITAL SEISMOGRAPH NETWORKS, https://www.fdsn.org/networks/

"Numerical Analysis of Permafrost Effects on the Seismic Site Response," *Soil Dynamics and Earthquake Engineering* 31 (3): 282–290, Z.J. Yang, U. Dutta, G. Xu, K. Hazirbaba, and E.E. Marx, 2011

"Seismic Behavior of Buried Energy Pipelines in Northern Permafrost Regions," *6th International Conference on Earthquake Geotechnical Engineering,* B. Dadfar, M.H. El Naggar, and M. Nastev, Christchurch, New Zealand, Nov 2015

"Vulnerability of Buried Energy Pipelines Subject to Earthquake-Triggered Transverse Landslides in Permafrost Thawing Slopes," *Journal of Pipeline Systems Engineering and Practice* 9 (4): 04018015, B. Dadfar, M.H. El Naggar, and M. Nastev, 2018

SITE SELECTION AND GEOTECHNICAL INVESTIGATIONS

"Sampling, Machining and Testing of Naturally Frozen Soils," *ASTM STP1568 Mechanical Properties of Frozen Soil,* B. Still, Z. Yang, and X. Ge (edited by H. Zubeck and Z.J. Yang), ASTM International, West Conshohocken, PA, 2013

SNOW DRIFT

Antarctic Camps Snow Drift Management Handbook, ERDC/CRREL TR-14-21, R.B. Haehnel and J. Weatherly, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2014

"Blowing Snow Transport Analysis for Estimating Drift Orientation and Severity," *Journal of Cold Regions Research and Engineering* 33: 2, R.B. Haehnel, 2019

"CFD Modeling of Snowdrift Around a Building: An Overview of Models and Evaluation of a New Approach," *Building and Environment* 46 (4): 899–910, Y. Tominaga, T. Okaze, and A. Mochida, 2011

Design Guidelines for the Control of Blowing and Drifting Snow, SHRP-H-318, R.D. Tabler, Strategic Highway Research Program, National Research Council, Washington, D.C., 1994

"Diagnosing Changes in Glacier Hydrology from Physical Principles Using a Hydrological Model with Snow Redistribution, Sublimation, Firnification and Energy Balance Ablation Algorithms," *Journal of Hydrology* 608: 127, 545, D. Pradhananga and J. Pomeroy, 2022

Snow Drift Management: Summit Station Greenland, ERDC/CRREL TR-16-6, R.B. Haehnel and M.F. Bigl, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2016

South Pole Station Snowdrift Simulations, ERDC/CRREL TR-22-7, L. Allen, R. Haehnel, and Y. Wenren, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2022, http://dx.doi.org/10.21079/11681/44943

"Spatial Snowdrift Modelling for an Open Natural Terrain Using a Physically Based Linear Particle Distribution Equation," *Hydrological Processes* 36 (1): e144682022,

N. Ohara, S. He, A.D. Parsekian, B.M. Jones, R.C. Rangel, I.O. Nichols, and K.M. Hinkel, 2022, https://doi.org/10.1002/hyp.14468

SNOW HYDROLOGY

COMMUNITY COLLABORATIVE RAIN, HAIL, AND SNOW NETWORK (COCORAHS), https://www.cocorahs.org/

Daily 4 Km Gridded SWE and Snow Depth from Assimilated In-Situ and Modeled Data Over the Conterminous U.S. Version 1, P. Broxton, X. Zeng, and N. Dawson, NASA National Snow and Ice Data Center Distributed Active Archive Center, Boulder, CO, 2019, https://doi.org/10.5067/0GGPB220EX6A

"Estimating Snow Water Equivalent Using Snow Depth Data and Climate Classes," *Journal of Hydrometeorology* 11 (6): 1380–1394, M. Sturm, B. Taras, G.E. Liston, C. Derksen, T. Jonas, and J. Lea, 2010, https://doi.org/10.1175/2010JHM1202.1

"Guidelines for Ventilating Attics and Cathedral Ceilings to Avoid Icings at their Eaves," in *Proceedings Performance of Exterior Envelopes of Whole Buildings VIII,* W. Tobiasson, J. Buska, and A. Greatorex, ASHRAE, 2001

Modern-Era Retrospective Analysis for Research and Applications, Version 2, NASA, Global Modeling and Assimilation Office, 2019, https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

"MODIS Snow and Sea Ice Products," D.K. Hall, G.A. Riggs, and V.V. Solomonson, *Earth Science Satellite Remote Sensing*, J. J. Qu, W. Gao, M. Kafatos, R. E. Murphy, and V. V. Salomonson (eds.), Springer, Berlin, Heidelberg, 2006, https://doi.org/10.1007/978-3-540-37293-6_9

Wintertime Snow and Precipitation Conditions in the Willow Creek Watershed Above Ririe Dam, Idaho, ERDC/TR 21-16, J.J. Giovando, C.S. Engel, S.F. Daly, D.D. Hamill, M.D. Warner, and E.A. Heisman, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2021, https://apps.dtic.mil/sti/pdfs/AD1130541.pdf

SNOW LOADS AND ROOFS

"Alaska Snow Loads," STRUCTURAL ENGINEER ASSOCIATION OF ALASKA, https://seaak.net/alaska-snow-loads

"Electric Heating Systems for Combating Icing Problems on Metal Roofs," in *Proceedings 4th International Symposium on Roofing Technology,* J. Buska, W. Tobiasson, A. Greatorex, and W. Fyall, National Roofing Contractors Association, 1997

"Guidelines for Ventilating Attics and Cathedral Ceilings to Avoid Icings at their Eaves," in *Proceedings Performance of Exterior Envelopes of Whole Buildings VIII,* W. Tobiasson, J. Buska, and A. Greatorex, ASHRAE, 2001

"Minimizing the Adverse Effects of Snow and Ice on Roofs," in *Proceedings International Conference on Building Envelope Systems and Technologies*, J. Buska and W. Tobiasson, Institute for Research in Construction, 2001

NATIONAL BUILDING CODE OF CANADA, https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada

"Roof Ventilation to Prevent Problematic Icings at Eaves," in *Proceedings Performance of Exterior Envelopes of Whole Buildings VIII*, J. Buska, W. Tobiasson, and A. Greatorex, Toronto, Canada, Jun 1998, https://www.aivc.org/sites/default/files/airbase_11883.pdf

Site-Specific Case Studies for Determining Ground Snow Loads in the United States, ERDC/CRREL SR-20-1, J.S. Buska, A. Greatorex, and W. Tobiasson, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2020, https://erdc-library.erdc.dren.mil/jspui/handle/11681/37574

"Standing Seam Metal Roofing Systems in Cold Regions" in *Proceedings 10th Conference on Roofing Technology*, W. Tobiasson and J. Buska, National Roofing Contractors Association, 1993

"Snow Guards for Metal Roofs," in *Proceedings 8th Conference on Cold Regions Engineering,* W. Tobiasson, J. Buska, and A. Greatorex, ASCE, 1996

STRUCTURAL ENGINEERS ASSOCIATION OF ALASKA, https://seaak.net/alaska-snow-loads

VEGETATION AND WILDFIRES

"The Circumpolar Arctic Vegetation Map," *Journal of Vegetation Science* 16 (3): 267–282, D.A. Walker, M.K. Raynolds, F.J. Daniëls, E. Einarsson, A. Elvebakk, W.A. Gould, A.E. Katenin, S.S Kholod, C.J. Markon, E.S Melnikov, and N.G. Moskalenko, 2005

"Circumpolar Spatio-Temporal Patterns and Contributing Climatic Factors of Wildfire Activity in the Arctic Tundra from 2001 to 2015," *Environmental Research Letters* 13 (1): 014019, A. Masrur, A.N. Petrov, and J. DeGroote, 2018

"Divergent Shrub-Cover Responses Driven by Climate, Wildfire, and Permafrost Interactions in Arctic Tundra Ecosystems," *Global Change Biology* 27 (3): 652–663, Y. Chen, F.S. Hu, and M.J. Lara, 2021

"Estimates of Temporal-Spatial Variability of Wildfire Danger Across the Pan-Arctic and Extra-Tropics," *Environmental Research Letters* 16 (4): 044060, F. Justino, D. Bromwich, A. Wilson, A. Silva, A. Avila-Diaz, A. Fernandez, and J. Rodrigues, 2021

"Evidence for Widespread Wildfires and Their Environmental Impact in the Late Cretaceous Canadian Arctic," *Global and Planetary Change* 203: 103515, D.P. Synnott, L. Schwark, K. Dewing, P.K. Pedersen, and H. Sanei, 2021

"Impacts of Wildfire and Landscape Factors on Organic Soil Properties in Arctic Tussock Tundra," *Environmental Research Letters* 16 (8): 085004, J. He, D. Chen, L. Jenkins, and T.V. Loboda, 2021

"A Raster Version of the Circumpolar Arctic Vegetation Map (CAVM)," *Remote Sensing of Environment* 232: 111297, M.K. Raynolds, D.A. Walker, A. Balser, C. Bay, M. Campbell, M.M. Cherosov, F.J. Daniëls, P.B. Eidesen, K.A. Ermokhina, G.V. Frost, and B. Jedrzejek, 2019

VISIBILITY AND NATURAL ILLUMINATION

"Alerts," GOVERNMENT OF CANADA, https://weather.gc.ca/mainmenu/alert_menu_e.html.

WETLANDS

Status of Alaska Wetlands, J.V. Hall, W.E. Frayer, and B.O. Wilen, U.S. Fish and Wildlife Service, Alaska Region, 1994, https://www.fws.gov/wetlands/documents/status-of-alaska-wetlands.pdf

WIND AND WIND CHILL

"A New Approach to an Accurate Wind Chill Factor," *Bulletin of the American Meteorological Society* 80 (9): 1893–1900, M. Bluestein and J. Zecher, 1999

"The New Wind Chill Equivalent Temperature Chart," *Bulletin of the American Meteorological Society* 86 (10): 1453–1458, R. Osczevski and M. Bluestein, 2005

UFC 3-130-02
16 January 2025

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC SITE ASSESSMENT AND SELECTION

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC SITE ASSESSMENT AND SELECTION

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**

This UFC supersedes UFC 3-130-02, dated 16 January 2004.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

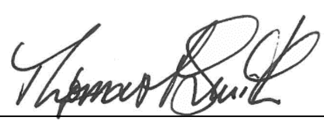
UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

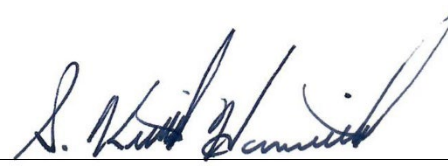
- Whole Building Design Guide website http://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:



THOMAS P. SMITH, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers



S. KEITH HAMILTON, P.E., SES
Chief Engineer and Assistant Commander
Planning, Design and Construction
Naval Facilities Engineering Systems Command

THOMAS P. BROWN, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MARK S. SINDER, SES
Deputy Assistant Secretary of Defense
(Infrastructure Modernization and Resilience)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

The field of Arctic and Subarctic engineering, also known as cold regions engineering, covers a wide range of multidisciplinary topics and principles. Unique issues exist in the planning, design, construction, and operation of infrastructure and facilities in Arctic and Subarctic regions. Among them are permafrost, seasonal ground frost heave and thaw settlement, extreme low temperatures, high wind loads, heavy snow loads, and remote construction sites. Additionally, the implications of the rapidly changing climate in Arctic and Subarctic regions exacerbate these unique challenges.

The Unified Facilities Criteria (UFC) Arctic and Subarctic series includes five volumes that summarize relevant information and the most feasible approaches and solutions for planning, design, construction, and maintenance of infrastructure and facilities in the Arctic and Subarctic areas of the globe.

1-2 NEED FOR SPECIAL APPROACHES.

The importance of selecting the proper project site in Arctic and Subarctic regions cannot be overemphasized. The type of data collected for site selection is essentially the same as that used for engineering design in temperate regions, but due to the high probability of heterogenous ground ice conditions in the Arctic and Subarctic, it is essential to collect more detailed information. It is not feasible to provide a detailed list of the information required for a given site-selection problem because each project requires unique judgment in the development of an adequate program of investigation and analysis; however, understanding the basic principles and considerations of cold regions site assessment and selection is crucial. Observations made in the Arctic and Subarctic, or cold regions, of North America form the basis for this UFC, and while local details may vary considerably, the basic concepts presented are generally applicable.

1-3 REISSUES AND CANCELS.

This document supersedes and cancels inactivated UFC 3-130-02, dated 16 January 2004.

1-4 PURPOSE AND SCOPE.

The Arctic and Subarctic UFC series provides technical guidance and available technical requirements for planning, design, construction, and maintenance of DoD facilities worldwide for all service elements in Arctic and Subarctic environments. These guidance and technical requirements are based on the International Building Code (IBC) and the requirements in UFC 1-200-01. The UFC 3-130 series covers many aspects of Arctic and Subarctic engineering with the specific exception pavements, which is incorporated into the UFC 3-250 and 3-260 series as discussed in UFC 3-130-01, paragraph 1-6.3. In addition to this volume, there are four other series volumes:

- UFC 3-130-01, *Arctic and Subarctic Engineering*. UFC 3-130-01 serves as an introduction to the Arctic and Subarctic UFC series.

- UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*. UFC 3-130-03 includes horizontal and vertical foundations, considerations affecting foundation design, and construction and monitoring of facilities in the Arctic and Subarctic areas.

- UFC 3-130-04, *Arctic and Subarctic Buildings*. UFC 3-130-04 includes building design in the Arctic and Subarctic areas.

- UFC 3-130-05, *Arctic and Subarctic Utilities*. UFC 3-130-05 provides criteria and guidance for the design of utility systems for military facilities in Arctic and Subarctic regions.

This UFC provides criteria and guidance for selecting sites for military facilities in Arctic and Subarctic regions. Only criteria and guidance unique to cold regions, where extreme low temperatures, permafrost, and seasonally frozen ground are likely to occur, are provided. UFC 3-130-02 is in no way all inclusive, and other cold regions resources are cited to provide sources of additional information. These minimum technical requirements are determined by UFC 1-200-01. Where other statutory or regulatory requirements are referenced, the more stringent requirement must be met. This UFC describes a phased approach to site assessment; the phases include planning, preliminary assessment, ground reconnaissance, detailed geotechnical site investigation (geophysical and geotechnical subsurface exploration), and reporting. Additional topics include general considerations for site characterization and, within the phases, data and data acquisition, desktop survey, remote sensing, ground reconnaissance, and geotechnical data analyses.

1-5 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, for those geographic locations in Arctic and Subarctic regions worldwide.

1-6 GENERAL BUILDING REQUIREMENTS.

This UFC is an integrated part of the Arctic and Subarctic UFC 3-130 series. Use the other documents of this series in conjunction with this UFC to address construction aspects unique to cold regions. See UFC 3-130-01, Chapter 2 for the definitions of Arctic and Subarctic.

Often, conventional construction practices are acceptable in Arctic and Subarctic regions with appropriate modification to account for extreme cold temperatures, frost heaving soils, and permafrost areas. This UFC modifies and supplements the criteria found in the core UFCs. Utility provider’s or Installation specific requirements must be considered.

1-7 LEVEL OF CONSTRUCTION.

See UFC 1-200-01, paragraph 1-3.2, for the definitions of permanent construction, temporary construction, and facilities in support of military operations.

1-8 CYBERSECURITY.

All facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-9 BEST PRACTICES.

In cold regions engineering planning, design, and construction, much of the state of the practice is not codified. Lessons learned and the experiences of the Installation engineering staff are invaluable and may help avoid costly and catastrophic infrastructure failures. Appendix A, Best Practices, provides guidance for accomplishing certain utilities design and engineering services in extreme Arctic and Subarctic environments. The Designer of Record (DoR) must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any UFC, the UFC takes precedence. For Best Practices guidelines not discussed in a UFC, the DoR must submit a list of the guidelines or requirements being used for the project to the Government Project Manager, with documentation sufficient for review and approval, prior to completing the design.

1-10 GLOSSARY.

Appendix B contains acronyms, abbreviations, and terms. See UFC 3-130-01 for definitions of additional terms that are specific to cold regions.

1-11 REFERENCES.

Appendix C contains a list of references used in this document. The publication date of the code or standard is not included. Unless otherwise specified, the most recent edition of the referenced publication applies. In addition, the fundamentals for Arctic and Subarctic engineering are widely available in cold regions textbooks. See Appendix C in UFC 3-130-01 for a list of these resources.

This Page Intentionally Left Blank

CHAPTER 2 PLANNING

2-1 INTRODUCTION.

Use UFC 3-201-01 for general site development, design, and planning requirements and for specific issues, such as natural hazards, drainage, grading, and infrastructure siting. Also see UFC 3-220-01 prior to starting the project design phase to determine geotechnical requirements and other site classification requirements.

2-2 COORDINATION.

Site selection planning requires coordinated processes, including knowledge of environmental requirements, land use restrictions, building setbacks, flood hazard areas, utility connections, utility offsets, vehicle circulation, and buffers from natural and manmade features.

Coordinate all site work, including topographic, hydrographic, and soil surveys, with representatives of the Command, District, and Installation engineering staff and with other design personnel. The exact location of the geotechnical subsurface exploration, whether by drilling or excavation, must be approved by the appropriate authorities, such as the local utility service or a company hired by the geotechnical engineering firm to locate utilities.

2-3 APPROVALS AND PERMITS.

See UFC 3-130-01, paragraph 1-13, for the general approval and permit processes for Arctic and Subarctic planning, design, and construction, including site investigation and its associated drilling and excavations.

2-4 PERSONNEL.

Project site selection requires personnel who are cognizant of engineering problems peculiar to Arctic and Subarctic regions and familiar with the various types of data collection and interpretation used in site assessments. To ensure the best possible site is selected and that an optimal amount of accurate and detailed information is obtained, the combined effort of a number of specialists is essential. Different phases of the site assessment require different expertise and different personnel.

Interpreting remote sensing data requires trained, experienced interpreters who, if possible, participate in the field verification program to enhance their understanding of the terrain patterns to be viewed from acquired data. For high-risk and mission-critical Installations, personnel should include an air photo analyst, a coordinator who is a civil or geological engineer and is familiar with the immediate and ultimate uses of the Installation, a geotechnical engineer, a civil engineer (hydrologist), a geologist, and an ecologist. Ground and subsurface surveys require a survey crew and party chief, a geophysical technician and data interpreter, a drill crew and foreman, and a guide to provide local knowledge. Frequently, crews are required to go into the field with preliminary soil and terrain maps as their only means of orientation. In undeveloped regions where readily identified cultural features, such as roads, structures, and cleared areas, are absent, field crews must be able to identify landforms on the ground and on profile maps to aid in their interpretation.

2-5 UNCERTAINTY.

A large part of permafrost analysis, in the context of this UFC, relies on the likelihood of occurrence and variability based on surface expression. Ground ice content is inherently difficult to predict in Arctic and Subarctic regions because of the complex, mutually dependent, and highly dynamic nature of the many factors influencing permafrost occurrence and expression. Surficial expressions commonly associated with ice intrusion and freeze-thaw processes are used as markers and are assigned a high or low likelihood of indicating permafrost based on how closely tied they are to perennially frozen ground and its co-existing features. These surficial features must be interpreted while considering climate, region, topography, vegetation, and so on. The presence of multiple surficial features in the same area increases the likelihood that permafrost is present. Unfortunately, an absence of markers does not necessarily indicate a lack of permafrost. Due to the complex, codependent, and dynamic nature of climate, hydrology, vegetation, and landform in cold regions, evaluating surficial features is the best starting point from which to determine areas most likely to be underlain by permafrost.

2-6 RISK.

UFC 3-130-01, Chapter 4, discusses risk assessment principles as they apply to cold regions. For site selection, the intensity of the site assessment process is proportionally dependent on the risk and sensitivity of the proposed construction, as outlined by the risk assessment method appropriate to the project. Risk reflects unknowns and relates to the variability of the site conditions, which are described by the site characterization. The characterization process consists of a range of resolutions and costs, from low resolution, perhaps using remote sensing methods, to high-resolution geotechnical investigations with drilling and sampling. Installation risk and risk assessment must be carefully considered throughout the site selection process to determine which resolution and methods of site characterization are appropriate. Risk assessment is to occur on a project-by-project basis.

2-7 SITE SELECTION AND ASSESSMENT PROCESS.

Arctic and Subarctic regions are host to unique site characterization features that are not found in temperate regions and require additional attention for engineering planning, design, and construction purposes. Use UFC 3-130-01 for guidance on various factors that may be encountered when working in cold regions and are critical to effective site assessment and selection. This UFC is broken into chapters to describe both the general workflow and the step-by-step processes for site characterization.

2-7.1 General Workflow.

The primary objectives of site selection and assessment are to obtain data on the

- boundaries of frozen and thawed zones within the depth influenced by construction activities,
- amount and mode of occurrence of ice in frozen soil, and
- composition and properties of the soil itself.

The type of exploration is dictated, to a large extent, by the relative inaccessibility of many northern areas, expensive and limited logistics, and climatic limitations. In addition, special techniques are frequently required for explorations in frozen ground due to its properties. Figure 2-1 illustrates general steps and strategies, from preliminary characterization to quantitative examination, for site evaluation and assessment. However, all site assessment must be performed and documented as prescribed in the approved contract documents.

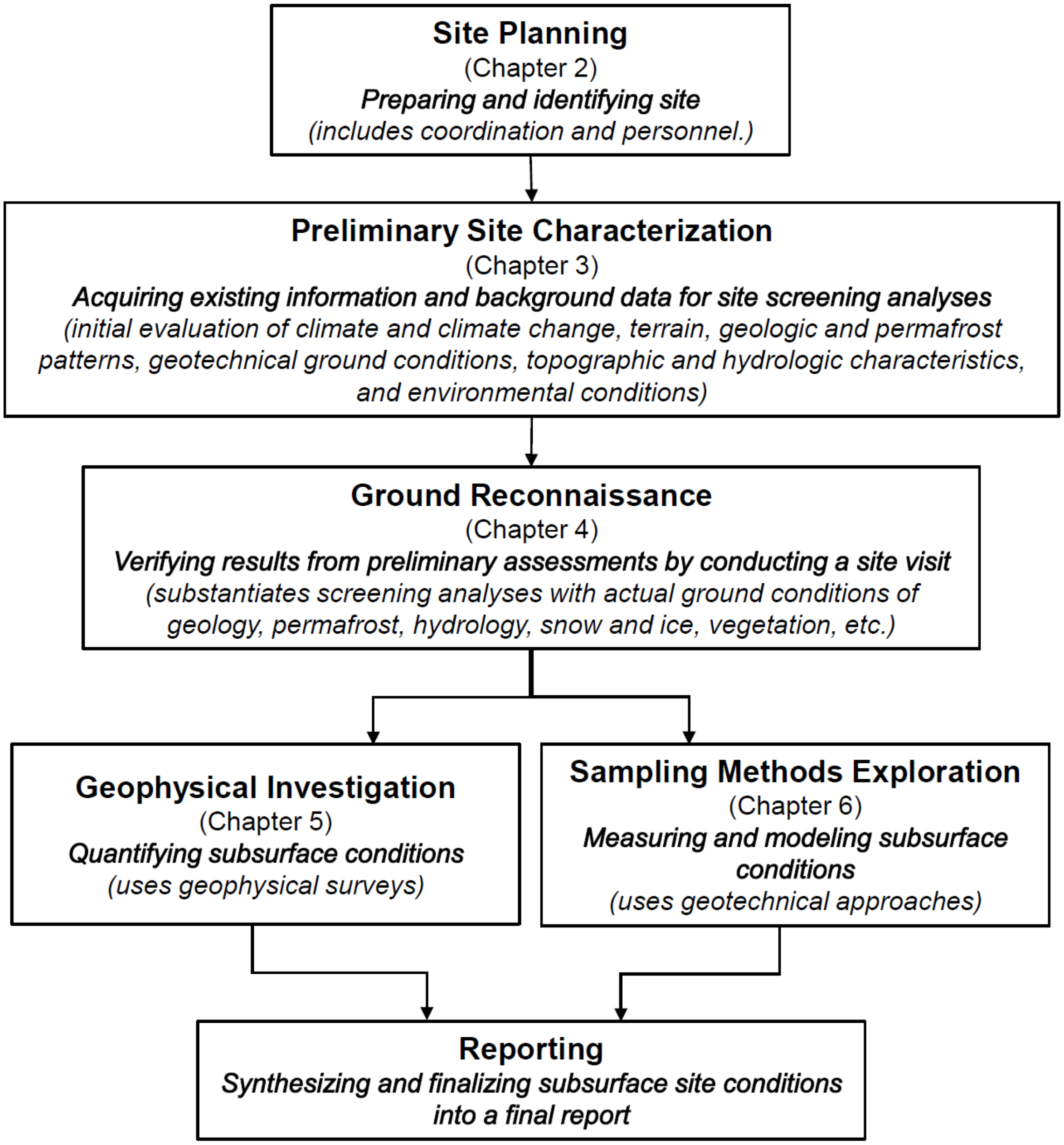
2-7.2 SUBSURFACE EXPLORATION WORKFLOW.

Once background data have been collected, detailed geophysical and geotechnical investigations (described in Chapters 5 and 6) can begin. An example workflow is shown in paragraph A-2 and highlights detailed processes. This workflow applies to organizing geotechnical investigations for both large projects, such as multibuilding installations and linear infrastructure developments (such as dams, roads, airfields, pipelines, or dikes), and small-scale projects.

2-7.3 Final Reports.

The site selection and assessment final report is the product of the investigation, as shown in Figure 2-1. The report synthesizes the final geotechnical profile, ground conditions (such as ground ice), and material properties of the site. More detailed reporting requirements are project or design specific (for example, draft and final reports; 35%, 65%, 95%, and 100% design submittals; number of document copies submitted and format; review procedures). The outline of the report includes, but is not limited to, the scope of the project, climate conditions, site screening, seismicity, geology, geomorphology, ground water, vegetation, permafrost (profile and spatial distribution), active layer, snow, ice, geotechnical properties, recommendations, and limitation of investigation. However, final reports must be followed as prescribed in the approved contract documents.

Figure 2-1 Arctic and Subarctic Site Selection and Assessment Process



CHAPTER 3 PRELIMINARY ASSESSMENT

3-1 INTRODUCTION.

Conduct detailed consultations with the Government to clearly define requirements and preferences. Use UFC 2-100-01 to develop a preliminary approach that is appropriate for the site and adjacent facilities and integrates sustainable strategies with a long-term outlook on the climate. Conduct a preliminary site analysis by obtaining photographs of the site. Research and obtain the Installation's master plan, utility maps, and as-built record drawings for information related to topography, utilities, and storm drainage availability in the project vicinity. Evaluate the likelihood of abandoned and unmapped utilities. Research and review available subsurface investigation data and reports to evaluate subsurface conditions. Identify flood hazard areas in accordance with the International Building Code (IBC), Section 1612, and UFC 3-201-01, paragraph 2-7.1. Research and adhere to safety requirements. Consult with the Government Project Manager to establish contact with the Installation's environmental personnel to determine if the site has environmental concerns, such as radon, pesticides, or known contamination. Evaluate the need for additional analysis based on project requirements and site conditions.

3-2 DATA ACQUISITION AND NECESSARY INFORMATION.

When preparing for site selection and development, existing information and data pertinent to the project requirements are essential for enhancing understanding of the climate, terrain, geologic and permafrost patterns, geotechnical ground conditions, topographic and hydrologic characteristics, and environmental conditions. Adequate maps and existing reports are beneficial for the selection of the site for any structure. In more populated areas, a wide variety of maps and reports are available. In more remote areas, there may be a limited number of preexisting maps and data available. Geographic information systems (GIS) are very useful for displaying data, creating maps, and storing collected information. The information required for a given site varies considerably according to the size and complexity of the project and the Installation's importance or focus, its geographical location, and whether the proposed facilities are in an unmapped or undeveloped area or are an addition to an existing Installation. Important considerations in information types with respect to Arctic and Subarctic regions are discussed in the sections that follow.

Existing reports and records published by various government agencies, engineering firms, mining companies, researchers, and others that give information on the characteristics of the terrain and on the climate, hydrology, and geology of the site must be thoroughly examined. These sources provide excellent background information for preliminary site assessment. Make effort to investigate and acquire reports from the project area because they may contain pertinent information for future construction or information on known conditions in an area. Reports of any type must be critically examined to ensure conclusions drawn hold true for current site conditions.

3-2.1 Access.

The availability of existing commercial and military surface, water, and air routes for the transportation of personnel and materials, the location of way stations and terminals, and prospective sites for such facilities must be determined. Obtain information on existing or abandoned access roads. Determine navigable depths of rivers, lakes, and harbors where water transportation is contemplated. Obtain data on the beginning and end of shipping seasons where shipments of materials, equipment, and supplies by oceangoing vessels may be scheduled. Determine the availability of calm water for the landing of float planes. Analyze weather phenomena, such as fog prevalence, low ceiling prevalence, and high wind conditions, that affect the availability of air operations. Determine appropriate vehicles to be used for overland transportation during winter and summer.

3-2.2 Climate.

UFC 3-130-01 discusses where to obtain data on climate. Obtain temperature information so that freezing and thawing indexes can be computed for use in estimating depths of freeze and thaw and so that possibilities of degradation or aggradation of permafrost can be determined. UFC 3-130-01 also describes the effects of climate change on the project. In particular, the long-term effect on the mean annual ground temperature (MAGT) is important when constructing in a manner that utilizes the strength of the frozen ground for bearing or adfreeze capacity.

3-2.3 Snowfall.

Snow data can come in several forms, such as snowfall maps, snow depth maps, and snow water equivalent maps. See UFC 3-130-01.

3-2.4 Vegetation.

Profiles of vegetation type and distribution must be carefully constructed. Also, past vegetation reports and characterizations must be considered. Current vegetation distribution maps can be constructed based upon remote-sensing data and recent imagery. See paragraph 2-5 for surface indicators and see UFC 3-130-01 for general descriptions of vegetation characteristics.

3-2.5 Geological.

Accurate information on surface and subsurface conditions is very important; in many instances, it may be the determining factor in the selection of a site. Geological maps are an important basis for terrain mapping and site characterization, and they depict the type and distribution of surficial discernable geological features in a region. These features can include soil and rock units and geologic structures such as faults and stratigraphic orientations, and they may identify areas of specific geotechnical hazard (for example, landslides). Obtain soil maps, if possible, because they depict the type and distribution of soils in a region; soil maps are useful for determining areas of thaw-stable or thaw-unstable material.

Well-drained gravels and sands are frequently found in coastal plains, river terraces, glacial deposits, and outwash plains. Such soils are generally ideal for almost any type of construction in Arctic and Subarctic regions because they are generally ground-ice poor to ground-ice free, and thus thawing is not a major problem. However, any type of construction can be troublesome if located on frost-susceptible soils, such as clays and silts. Where such foundation materials must be built upon, it is usually necessary to employ special design and construction measures to maintain structural stability. These measures are discussed in UFC 3-130-03. Obtain subsurface information to a degree commensurate with the importance, complexity, and size of the proposed structures. Minimum laboratory soil tests typically include density, moisture content, and Atterberg limits for various horizons, while additional tests, such as permeability, consolidation, shear strength, and compaction, may be required to support the project design. These test results, coupled with the survey data regarding topography, ground type, and location, can be compiled into a terrain unit map (see paragraphs 3-2.5.3 and 3-3.3.4).

3-2.5.1 Permafrost.

In Arctic and Subarctic regions, permafrost is often a determinant in the selection or rejection of a building site. Additionally, it can have major impacts on costs and the functionality of an Installation if it is not properly addressed early in the process. As such, it is important to determine the extent and characteristics of permafrost under any proposed building site. Update permafrost maps as more detailed data become available. Until confirmed through geophysical and geotechnical investigation, permafrost maps should be treated as probability-of-occurrence maps.

Knowledge of the extent and nature of the permafrost is vital where segregation ice occurs because this is generally the result of a supersaturated condition. Determine the depth and thickness of the permafrost layer, the depth of the annual freezing or thawing zone (active layer), and the nature of the soils present. Information on whether the permafrost contains massive ground ice and if the ice is homogeneously or heterogeneously distributed is very important. The frozen versus thawed boundaries within discontinuous permafrost, as often found in the Subarctic latitudes, are important because the thawed zones most often provide more stable foundation conditions. Also, baseline data are especially important in areas where permafrost may be discontinuous or sporadic; where ground temperature is relatively warm, defined as >28° to 30° Fahrenheit (F) (>−2 to −1° Celsius [C]); or where saline conditions may be present in coastal areas (such as around Utqiagvik [formerly Barrow], Alaska) that have been influenced by historic changes in sea level. Permafrost is generally continuous north of the Arctic Circle (latitude 66.56° N) and in Antarctica, some mountainous areas, and offshore in northern latitudes.[1] See UFC 3-130-01, paragraph 2-2, for the description, characteristics, and distribution of permafrost.

[1] "Recent Advances in the Study of Arctic Submarine Permafrost," Angelopoulos et al.; "Northern Hemisphere Permafrost Map Based on TTOP Modeling for 2000–2016 at 1 km^2 Scale," Obu et al.

3-2.5.2 Drainage and Groundwater Table.

Hydrological maps detail waterways, drainages in an area, and general maximal and minimal runoff data. Hydrological reports detail the movement of water in an area via rainfall, runoff, evapotranspiration, and so on. Hydrological studies can be useful for site characterization in several ways, such as classifying groundwater and soil permeability and identifying permafrost occurrence markers. For structures located near a river, information on stream-flow variations throughout the year and on the levels and frequency of flooding are of substantial importance for proper selection of the site. Obtain information on the ice-forming characteristics of the stream and on the locations of previous ice jams. For any structure or other infrastructure such as pavements, drainage is an important consideration. Define the usefulness of existing drainage courses for the removal of excess storm water. Where applicable, determine the position of the water table and patterns of subsurface flow.

When the groundwater table is encountered, provide the stabilized groundwater elevation with the anticipated variation and the local causes for variation (for example, seasonal or tidal). Measure the stabilized groundwater elevation 24 hours after drill-hole completion, unless determined otherwise by the registered design professional. If drilling techniques that prevent the measurement of the water table levels are used, the contractor should install at least two piezometers per drilling site to accurately measure the depth to the water table. Obtain a sufficient number of readings (locations) to establish a representative groundwater depth profile for the project site. Piezometers are required for stormwater pond investigations. Piezometers are not required if the groundwater levels can be accurately measured during drilling operations, if significant seasonal variations in groundwater level are not anticipated, or if there is good evidence that the water table is not within the depth of the borings or zone of influence for the foundation or structure.

3-2.5.3 Terrain Unit.

A terrain unit is a delineation of landscape elements often outlining zones of thaw-stable or thaw-unstable soil types and ice-rich or ice-poor soils of the site. Terrain-unit maps are generally derived from soil maps or aerial photographs. These map types are useful in the selection of stable foundation sites and material sources. Terrain-unit maps are most likely found in geotechnical reports or foundation reports from existing construction. They can also be generated as iterations of published geologic maps or surficial geologic maps. Terrain-unit maps must be as detailed as possible and updated as more detailed data, including the mechanical and engineering properties, become available.

3-2.5.4 Topography.

Accurate topographic information, including data on surface features and vegetative cover, is necessary. Obtain survey information for planning drainage, roads, and infrastructure layout. In investigations for airbases, consider topography in accordance with UFC 3-260-01 and for future snow removal operations on the airfield. For structures adjacent to bodies of water, information on shorelines, harbor lines, high-water marks, hydrographic and bathymetric data, and wave action is important.

Topographic maps or digital elevation models (DEMs) exist for nearly all areas of the earth's surface and should be acquired at both higher and lower scales for the given region. Topographic maps provide a ready base map on which to build further site characterizations (such as hydrological and vegetative). See UFC 3-130-01, Appendix A, for sources for topographic maps. Refer to UFC 3-201-01, paragraph 2-4.2.1, for additional resources and considerations.

3-2.5.5 Seismology.

See UFC 3-130-01, paragraph 2-10, for additional information on seismic considerations when performing site assessments. For site assessments, take note and examine any evidence of seismic activity in or near the selection area (such as active or potentially active faults, surface breaks or ground subsidence from past seismic events, and offset drainage and topographic features). Information regarding regional seismic features (from maps or reports) must also be consulted to construct a full seismic assessment of the selection area.

Seismic maps and site-specific seismic hazard assessment reports (if available) depict the likelihood and possible severity of an earthquake event based on known seismic hazards, past events, or conditions likely to result in seismic events.

3-2.6 Water Supply and Wastewater.

Obtain information on the feasibility of developing a water supply for the needs of the Installation. Perform pumping tests and water analyses for proposed wells. In some instances, a dam site may need to be selected for impounding water. In addition to determining sources of potable water and possible means of waste disposal, location conditions and regulations must be examined to avoid conflict. If water supply is to be developed from surface water, possible pollution sources must be identified. It may prove necessary in the Arctic to develop water supplies from two different sources, one for summer and one for winter. For example, where groundwater supplies cannot be developed and surface sources freeze in the winter, the surface source may be used during the summer, while melted snow or ice or storage tanks may have to be the source of supply in winter. See UFC 3-130-05 for additional information.

3-2.7 Construction Materials.

Knowledge of the location of suitable sources of quarry stone or rock deposits, gravel, and sand for aggregates is essential. Identify local sources of materials to aid in the production of pavements and concrete and determine the nearest points at which non-native materials and supplies can be obtained.

3-2.8 Existing Construction.

Map any construction or land development on or near the selection area, including both current structures and past projects. Maps of existing construction projects provide useful information regarding data sources in the form of previously collected construction reports.

3-2.9 Electrical Grounding.

Frozen earth materials offer high resistance to electrical current flow, preventing adequate earth grounding that is typically required for safe electrical distribution operations at structure locations. Locations are required to allow for a common electrical grounding site, where earth ground is created in a district configuration. These locations may be near water features (rivers or lakes), where the heat from the water allows limited thawed ground to exist. Grid arrays have been placed in such thawed areas or laid in water bodies, such as salt-water bays, where seasonal ice does not reach to the depth of the water body. See UFC 3-130-05 for further discussion.

3-2.10 Existing Reports.

3-2.10.1 Construction.

Construction reports are likely to contain as-built drawings and information on the scope of the construction project, permitting, engineering reports, storm water and hydrology mitigation planning, and site condition. Construction companies or state and federal regulatory bodies may have these reports.

3-2.10.2 Geological and Soil Survey.

Geological and soil survey reports, and their accompanying maps, contain important site details that aid with infrastructure siting. Locate previous geological and soil surveys conducted in the area of interest when possible. Surveys adjacent to areas of interest may be of use as well. State and federal geological or agricultural services may have these geological and soil survey reports.

3-2.10.3 Geophysical.

Geophysical reports detail the process and returns of geophysical survey methods, such as ground penetrating radar (GPR), electrical resistivity, electrical conductivity, and seismic refraction. Geophysical reports contain site characterizations, descriptions of the geophysical method used, data collected, and an interpretation of subsurface conditions based upon the collected data. Geophysical reports are useful in the interpretation of subsurface conditions over the survey area but are best verified by geotechnical means. Mining operations, academic sources, and construction site evaluations may have these geophysical reports.

3-2.10.4 Geotechnical.

Locate and examine geotechnical reports in and around areas of interest because they contain information pertaining to previous subsurface exploration, site evaluation, laboratory and field test results, and soil and rock conditions. State and federal geological or transportation services, academic sources, mining operations, and survey and construction companies that have operated in the region of interest may have these reports.

3-2.10.5 Mining.

Mining reports and mineral exploration literature generally contain information regarding subsurface mineral deposits, geotechnical data, and geological characterization. Mining reports can be a dense source of information regarding characterization of an area. State and federal geological services and mining companies may have these reports.

3-2.11 Local Considerations.

If possible, consult local knowledge sources. Local records and long-time residents are excellent sources of information on prevalent seasonal and weather patterns, changes in weather and natural conditions, changes in permafrost and ground freezing conditions, and other points of interest.

3-2.12 Remote Sensing.

Remote sensing encompasses a wide variety of sources and platforms, from satellites, to high altitude aerial platforms, to low altitude and geophysical methods and platforms, including multispectral imaging, radar, and lidar. Some of these remote-sensing platforms and methods are relatively recent, so older datasets may not exist. However, there may be legacy datasets of satellite imagery and archival air photos or aerial imagery for most regions of the globe. Make effort to locate and incorporate legacy datasets into site characterization because changes over time are difficult to account for without a long-term dataset. Air photos and satellite imagery are useful for locating boundaries of soils with different characteristics, identifying the extent of frozen and unfrozen soils, and predicting the engineering characteristics of soils in a given area. Air photos can also be used to eliminate the selection of totally undesirable areas and to suggest possible usable sites.

The resolution of remote-sensing data is an important consideration in regard to ground surface. Obtain datasets of the highest spatial resolution for the purpose of site characterization. Use image resolutions of 1:10,000 or better when possible. In addition, obtain other geospatial datasets in the highest resolutions possible.

3-3 INITIAL DESKTOP ASSESSMENT.

In the selection of a suitable site for military Installations, information is usually available (from maps, aerial imagery, or other sources) for the identification of general areas that may be suitable. To identify a specific site of interest within a general area, more detailed information, if available, is required prior to conducting any site reconnaissance. Begin initial investigations and preliminary assessments with a comprehensive desktop survey of current and historical maps and records pertaining to the general area.

3-3.1 Climate Profile.

Climate characterization must include expected or observed winter precipitation because snow and ice loading can have a significant effect on the design of an Installation. Snow loading can also have major effects on the hydrological characterization and regime of an area. See UFC 3-130-01 for snow considerations.

Climate profiles of an area provide context for site characterization and aid in analyses of later steps in the process. A large part of Arctic and Subarctic site selection is permafrost based, and accurate and complete climate profiles improve permafrost likelihood estimates, both directly (climatic conditions do or do not favor permafrost occurrence and growth) and indirectly (vegetation profiles are influenced by the occurrence of frozen ground). Accurate climate profiles on a regional scale provide information on possible permafrost conditions occurring where mean annual air temperature (MAAT) values are near 31°F (−0.5°C). Important parameters to be collected are air thawing degree-days (ATDD), air freezing degree-days (AFDD), MAAT, MAGT, wind rose for month of the year, mean seasonal precipitation (rain and snow), and graphs of hours of daylight versus months of the year.

3-3.2 Aerial Reconnaissance.

Aerial reconnaissance is especially valuable in initial regional studies to obtain data on factors such as flooding and icing conditions, the presence of flight hazards, possible access-route locations, the suitability of lakes and clearings for landing small aircraft, and military considerations, such as logistics and defense. Large areas can be covered in a relatively short time, and the less-constructable sites can be eliminated. Aerial reconnaissance is also valuable in recognizing geologic and environmental ground conditions (such as faults and delineations of landslides and rock outcrop features with erosion potential and distinctive changes in vegetation cover) that may otherwise be difficult to visualize from on-site inspection.

3-3.3 Analysis and Mapping.

Utilizing current or most recent datasets, construct a base map and overlays of the entire region. Historical images are used to track changes in slope stability, permafrost degradation, drainage, and settlement over time. Include the entire area of interest in the initial analysis of remote-sensing data, with an emphasis on ground conditions. A special note is needed to plot the construction sequence of existing structures. Note any changes in the natural condition due to infrastructure placement. Include the focus areas discussed in paragraphs 3-3.3.1 through 3-3.3.6 in the analysis. GIS is a very powerful tool that allows for plotting, viewing, and analyzing the mapped data. In addition, vast amounts of metadata can be stored with the GIS layers and shapefiles.

3-3.3.1 Vegetation.

Use image analysis to construct vegetation profiles of the region, and focus on large-scale trends such as forested areas, brush land, shrub land, tundra, and so on. Subdivide forested areas into evergreen and deciduous. Note stand density and height when possible. Differentiate areas of scrub brush and second-growth brush and tundra as possible. Demarcate forest fire scarring if present. If resolution allows, look for tussock ground, grasses, and heavy moss layers. Mapping must be accompanied by documentation of local vegetation types and identifiers to aid in the mapping process. Research characteristics of local vegetation types; specifically, average root depth and general habitat (such as well drained, wetland, or marshland).

3-3.3.2 Topographic.

Generate topographic overlays and DEMs for the area of interest.

3-3.3.3 Geological.

Map geological conditions via image analysis, as possible, noting origin, deposition type, and areal extent of soil and rock units. Indications of underlying geologic structure (such as apparent fault traces, surface lineations, exposed rock outcrops, areas of subsidence, and possible unstable slopes) as obtained from imagery and local or regional published information should also be delineated. Estimate geological characteristics of each soil and rock unit based upon site location, local geomorphology, and unit type. Published geological maps provide an initial baseline from which to begin geologic mapping for engineering design study. It is common for existing published geological maps to be incomplete or inaccurate at the scale needed for a detailed investigation. When existing information is incomplete or outdated, supplemental information and data and detailed information taken from field reconnaissance are required.

3-3.3.4 Terrain-Unit Maps

Construct terrain-unit maps, as possible, based on geological maps, aerial photographs, historical boring data, drainage patterns, and vegetation patterns. Update preliminary terrain-unit maps based on on-site observations and investigations to be performed.

Terrain-unit maps should map the extent of, and characterize, each unit on the map by its composition and basic engineering properties. There are many ways to map rock and soil units. Where time and budget constraints preclude a complete detailed mapping effort, prioritize mapping in the following order:

1. Type, extent, and location of permafrost terrain units
2. Type, extent, and location of major rock and soil units
3. Orientation and location of contacts between major soil types
4. Orientation and location of contacts between major rock types

5. Orientation of major faults and weak zones
6. Orientation and location of erosion, landslides, and subsidence features
7. Surface properties of discontinuities

3-3.3.5 Permafrost.

Construct permafrost feature maps using available remote-sensing data. Note beaded streams, pothole lakes, pingos, polygonal ground, thermokarst, and other permafrost surface expression features when discernable.

3-3.3.6 Hydrology.

Hydrological details of the area of interest should include all waterways, drainages, watersheds, and so on when discernable.

3-3.4 Interpretation.

The culmination of remote sensing data is to create a detailed base map (elevation and imagery) of the entire area of interest with overlays delineating vegetation, geology, terrain unit, and hydrology. Compile historical information collected during the desktop survey into separate overlays (GIS layers) and contextualize it on the base map. Once data compilation is complete, areas can often immediately be identified as undesirable and can be eliminated from selection based upon inferred ground-ice content, soil type, hydrology, topography, geology, hydrology, and so on. Conversely, sites of interest can be selected for further investigation. Verifying the unsuitability of previously eliminated sites may also be a part of further investigation.

CHAPTER 4 GROUND RECONNAISSANCE

4-1 INTRODUCTION.

Ground reconnaissance is used to verify results from preliminary assessments based on remote sensing and historical datasets, collect detailed information on site conditions, improve site profile resolution, and further refine criteria for desirable versus undesirable building sites. Features that may not be visible in remote-sensing datasets or unexpected occurrences can be addressed during ground reconnaissance.

4-2 GEOLOGICAL CHARACTERIZATIONS.

Ground-based geological characterizations of a site provide more detailed information than is possible with remote-sensing datasets. These written reports include maps of particular soil and rock units and geological features. Much of the geological characterization is focused on the site features in paragraphs 4-2.1 through 4-2.4, but note any anomalous geological features in detail.

4-2.1 Lithological Profile.

The lithological profile is a characterization or description of the stratigraphic section of geologic units in the project area. The geologic units are composed of surficial deposits, typically soils and sediments, and bedrock formations. The lithological profile describes all the geologic units of the project area in order, from youngest to oldest.

4-2.1.1 Bedrock.

Bedrock units are typically divided into three primary lithologic divisions, which are as follows:

- Igneous rocks—Igneous rocks are formed when molten rock cools and crystalizes. Igneous rocks are classified based on texture and composition, where texture describes the physical characteristics of the minerals, such as grain size, and this relates to the cooling history of the molten magma from which it came. Composition refers to the rock’s specific mineralogy and chemical composition. Cooling history is also related to changes that can occur to the composition of igneous rocks. Identifiers include color, texture, alteration, and accessory minerals. Color is taken from the Munsell Rock Color Chart (Munsell Color [https://munsell.com/color-products/color-communications-products/environmental-color-communication/munsell-rock-color-chart/]). Alteration is a description of the chemical and physical weathering processes that are dominant in a rock. Accessory minerals are a list of secondary minerals that are visible in a hand sample. An example of igneous rock is granodiorite of the Talkeetna Formation.
- Metamorphic rocks—Metamorphic rocks are formed when a source rock is subjected to high temperature or to high-pressure geologic processes,

including, but not limited to, contact with plutons or lava sources or tectonic burial and exhumation, that alter the parent rock's original structure and minerology. Metamorphic rocks are classified based on foliation (orientation of mineral texture in rock), field relationships, the chemical composition of the rock, and inferred pressure–temperature conditions of metamorphism. An example is of metamorphic rock is schist of the Neruokpuk Formation.

- Sedimentary rocks—Sedimentary rocks are formed by weathering or decomposition of rock masses and redeposition of weathered particles via wind or water or by chemical processes in sedimentary basins where the particles are compacted over time and lithify to form rock. Sedimentary rocks are classified as chemical (formed by chemical precipitates), evaporates (formed by evaporation of sea water and consolidation of remaining chemical constituents), or clastic (formed by lithification of weathered detritus). An example of sedimentary rock is sandstone of the Sagavanirktok Formation.

4-2.1.2 Structural Classification of Rocks for Engineering Purposes.

Rocks are typically classified by petrologic type, such as from an intact hand sample (for example, coarse-grained granite), and are then described with physical properties of the larger rock mass as occurs in the field, which may be broken by numerous discontinuities (such as planes of weakness, including faults, shears, joints, and fractures). Physical properties of rock that are of interest in engineering analysis include, but are not limited to, the following:

- Rock strength
- Weathering or alteration
- Hardness
- Discontinuity description and orientation
- Joint or fracture infilling
- Mineralogy affecting foundation performance
- Specific gravity and unit weight
- Moisture content and porosity

For more information on the classification of rock types, refer to "Classification of Rocks," by Travis.

4-2.1.3 Soil and Sediment.

Soil and sediment can be classified in several different ways. In the engineering profession, soil is typically described via the Unified Soil Classification System (USCS) and follows ASTM D2487.

The field description of soils is based on the size and distribution or volume of coarse-grained particles and the volume and behavior of fine-grained particles in a given representative sample of soil. In the absence of laboratory testing, USCS symbols and descriptions can be used in accordance with the visual-manual procedure of ASTM D2488. Typically, soils are broken down into the following constituents:

- Boulders—rocks 12 in.(30 cm) in diameter or greater
- Cobbles—rocks with diameters between 3 and 12 in. (7.5 and 30 cm)
- Gravel—particles of rock with diameters between 0.19 in. and 3 in. (0.48 and 7.5 cm)
- Sand—particles of rock with diameters between 0.003 in. and 0.19 in. (0.0075 and 0.48 cm)
- Silt—soil particles that are smaller than 0.003 in. (0.0075 cm) but exhibit little or no plasticity and have negligible dry strength
- Clay—soil particles that are smaller than 0.003 in. (0.0075 cm), exhibit plasticity within a range of certain moisture contents, and have significant dry strength
- Organic soil—soil composed primarily of organic matter in various stages of decomposition

4-2.2 Surficial Lineation.

Natural surficial lineation can have many implications for design. Surficial lineation often indicates the presence of faults, which are tectonic structures occurring at the point where rock formations fracture and slide past, over, or under each other as they are driven by tectonic forces. The actual plane of fracture and movement is the fault line, which is a planar surface that can be measured spatially. Faults have serious implications for construction because they can destroy structures by shearing foundations with relative fault movement or with severe seismic-induced vibrations from earthquakes. For design purposes, active faults are of the utmost concern and are typically classified as active when the oldest movement on the fault is Holocene (11,650 years) or younger. Linear drainages, tree lines, or offset drainages along a linear path are often good indicators of a fault line.

The wide majority of faults are not active; however, significant fault zones may still have negative impacts on site development due to changes in drainage patterns and rock lithologies below the site and the presence of low strength zones of sheared rock along the fault trace.

Other surface expressions commonly associated with fault lines include the following:

- Abrupt and imposing hillside fronts
- Linear base on scarps

- Sharp V-shaped canyons
- Suddenly increasing stream gradients (fault benches)
- Springs along the base of the scarp
- Sudden loss of drainage on down-gradient side of scarp

Another significant feature of outcropping or underlying bedrock is its resistance to weathering. Distinct changes in slope angle, debris material size, and stratigraphic contact occurs when stronger rock abuts weaker rock. These lineations are easily identified in the field and from aerial and satellite imagery.

4-2.3 Ground Disturbance.

In Arctic and Subarctic regions, disturbed ground can indicate recent changes in the hydrological or permafrost regime, among other changes. Disturbed ground includes, but is not limited to, landslides, tension cracking, area subsidence, thermokarst, erosion, and heaving. Take special note of the chronological sequence of the disturbed ground.

4-2.4 Geo-Hazard Assessment.

Geologic-hazard assessments at the reconnaissance level begin with desktop identification and assessment of terrain units and geomorphological features. Some terrain units are associated with common geological hazards, including the following:

- Permafrost terrain units—These units commonly contain geological hazards, including ice-rich permafrost, ice wedges, thermokarst, retrogressive thaw slumps, and perched water tables.
- Bedrock terrains with intersecting joint sets, bedding planes, or foliation planes—These units have potential for planar, wedge, or toppling risks if adversely oriented along slopes and excavations.
- Terrain units with clay—It is common for clay to exhibit excessive shrinkage and expansion.
- Soil slopes with groundwater seepage, shallow active layers, or hummocky terrain—It is common for landslides in these units.
- Artesian conditions and water tables—These present a significant risk, especially if the potentiometric surface is above the permafrost table, where it can cause widespread accelerated permafrost degradation if drilled.
- Seismic—Seismic history is required to understand the overall seismic hazard of the project area. In general, the seismic hazard (liquefaction hazard) is low provided the site location remains in the frozen condition; it increases by many factors if the site has been forcefully thawed.
- Flooding—Examine the flood recurrence interval and look for surficial indicators of scour to determine if flooding is a risk in the project area.

- Aufeis—Groundwater flowing over frozen terrain in the winter season causes sheets of slow moving ice to move toward and across valley bottoms. This is known as aufeis, and it occurs chronically or intermittently at a certain area. Often, these sheets of ice block river and drainage flow, creating flooding and difficult maintenance operations for roadways and airfields (see paragraph 4-5.1).
- Volcanic hazards—Construction in volcanically active regions may be at risk of damage from mudflows, pyroclastic flows, airfall tephra, lava flows, floods or tsunamis, and even direct blast hazards. Although rare, permafrost regions composed of historic lava flows require special attention because this porous rock may be mischaracterized as containing detrimental percentages of matrix (pore) ice.
- Frozen debris lobes (products of hillside erosion)—Contained on steeper slopes, frozen debris lobes may have a central core of ice that slows the movement downslope, where the debris lobe may be masked or determined to not be an immediate hazard. Careful examination can find entire overturned trees, the lobe front moving at only meters per year, and basal water generation during winter and summer. Over the longer term, frozen debris lobes can cause serious maintenance issues if not avoided or mitigated early on.

4-3 HYDROLOGICAL CHARACTERIZATION.

Identify small-scale hydrological features that are not discernable from airborne or remote sensing during ground reconnaissance.

4-3.1 Surficial Hydrology.

Note any standing water, episodic or seasonal waterways, evidence of past flooding events, and other high water events, such as from river ice jamming. Water-killed standing forests are indicative of rapid changes in the hydrological regime. Drunken forests in permafrost terrain are indicative of thawing ground, often due to flooding or slow inundation.

4-3.2 Hydrogeological Indicators.

At the reconnaissance level, basic surface hydrology can be assessed by first examining the site drainage patterns, where the ground monitoring equipment locations can be planned and installed during the site-exploration phase (Chapters 5 and 6). Drainage patterns are highly indicative of the underlying soil or rock type, the frozen or thawed condition, massive ice features and bulk ground ice content, the degree of slope, and the effect of the vegetation. A list of common drainage patterns is as follows:

- Dendritic—Dendritic drainage patterns are irregular branching streams with confluences oriented at angles less than 90° and depicting a stream pattern that suggests no control by underlying rock structure. This is often a mature drainage pattern that signifies shallow dipping horizontal bedding and is found on shallow dipping slopes.

- Parallel—Parallel drainage patterns are consistently branching streams with parallel drainages in a preferred orientation. These typically form on steep slopes with a relatively uniform gradient and are often found on recently tectonically uplifted terrain.
- Trellis—Trellis drainage patterns show drainage directions in intersecting, sometimes perpendicular, patterns. This drainage pattern requires structural control to form and is typically associated with strongly bedded bedrock. The pattern forms as the water moves along bedding planes and crosses between existing planes via intersecting cleavages.
- Rectangular drainage—This refers to channels created at right angles. This pattern is created by structural control via right-angle jointing and faulting.
- Radial—Radial drainage patterns are multiple semiparallel stream channels branching out away from a certain point. This drainage pattern develops when water is running off a dome.
- Annular—This refers to a ring-like pattern in drainage channels joined together by subparallel drainages perpendicular to the rings. This pattern typically forms on eroded up-warped domes and down-dropped basins.
- Thermo-erosion gullying—This occurs in moderate to high slopes composed of frozen fine-grained materials, such as silts and sandy-silts. Surface water generally migrates through the active layer and at the top of the permafrost table, but in this case, aggressive thermo-mechanical erosion removes frozen material and creates gullies that rapidly expand with continued running water and above freezing air temperatures.

4-4 PERMAFROST CHARACTERIZATION.

Permafrost characterization is best done during midsummer to early fall. During months when snow is prevalent, permafrost markers may not be visible, except in very windy locations. Features indicative of ice-rich permafrost may be difficult to differentiate with snow cover. Frost probing of the active layer is best implemented during late summer or early fall, when the active layer is at its deepest thaw depth of the year.

4-4.1 Surficial Expression.

Permafrost surface expressions of underlying soil types and massive ice features are most often visible during airborne and remote sensing, but at ground level, they may appear as indicators of other features, such as disturbed ground, surface hydrology, and vegetative cover. This is especially the case in many boreal forest areas, where massive ice expression is masked by the trees and ground cover. Identify areas with evidence of recent permafrost degradation (thermokarst). For example, note pothole lakes or standing water with sharp or shear banks, as they may be evidence of rapid degradation with bank-lined trees tilted toward the pothole (drunken forest) or stress cracking occurring parallel to the bank.

4-4.2 Frost Probe.

Current active layer depth and permafrost table depth can be accurately determined by driving a tile probe (rod with T-handle) into the ground by hand and recording the depth of deepest rejection; permafrost tables of 10 to 12 ft (3 to 3.7 m) are detectable. Frost probing is a relatively simple, lightweight, and effective field method of detecting active layer thickness and depth to the permafrost table. However, accurate measurements can only be made at the very end of the summer thawing season, when air freezing degrees become approximately equal to air thawing degrees.

4-5 SNOW AND ICE CHARACTERIZATION.

Snow and ice characterizations may not be possible, depending on the season. If winter reconnaissance is not feasible, probable occurrence based on regional weather patterns and historical records suffice.

4-5.1 Aufeis.

During winter seasons, aufeis may be directly observed as massive, multilayer ice buildup in or near an active stream or waterway, at the toe of a slope, or along the length of a slope. Likely areas of aufeis formation are shallow streams with abundant groundwater under elevated hydraulic head pressures. The toes of hills with perennial water sources should be noted as likely sources of aufeis.[1]

4-5.2 Drifting.

Snowdrifts form on the lee side of an obstacle if prevailing winds are strong enough to transport snow and ice crystals. Drifting severity directly depends upon the prevailing seasonal winds and the relative position of obstacles (or disruption of air currents) that allow a drift to begin forming. Large, open areas upwind of obstacles provide ample opportunity for snow or ice entrainment and provide the source of snow or ice for drift building. Snow is a very efficient thermal insulator. Drifted snow and snow plowed into piles, or deposited along ditches from roadway or airfield snow removal, insulate the ground from the severe winter cold, locally raising the overall permafrost temperature.

4-5.3 Avalanche.

Note evidence of avalanche and slope failure in detail for further analysis. It is important to note that avalanches travel great distances downslope with considerable speed and force. As such, if an area of interest is at the foot of substantial terrain, areas upslope of the site must be evaluated for avalanche hazard.

---

[1] *River Ice Engineering*, Ashton.

4-6 VEGETATION CHARACTERIZATION.

Note vegetation variation and typology during ground reconnaissance because it is often hard to discern from air photos or remote-sensing datasets. With respect to permafrost, give careful consideration to groundcover types because, often, heavy moss layers create a subsurface environment that is conducive to permafrost occurrence.

4-7 INTERPRETATION.

Compile and interpret ground reconnaissance observations as a means of developing a more complete, higher resolution representation of the area under investigation. Many of the characteristics observed during ground reconnaissance are interdependent and should be carefully examined to determine the nature of any possible interactions.

CHAPTER 5 GEOPHYSICAL INVESTIGATION

5-1 INTRODUCTION.

Chapter 5 provides an overview of some of the geophysical methods available for characterizing subsurface conditions. The geophysical methods discussed specifically pertain to characterizing permafrost, such as frozen regions versus thawed regions in discontinuous terrain or ice-rich versus ice-poor regions, because these characteristics are a major consideration when undertaking any construction project in Arctic or Subarctic regions. Alternate geophysical technologies are used to ascertain specific engineering properties, such as seismic refraction used in cross-borehole surveys to determine potential for mobilization during earthquakes.

5-2 GROUND PENETRATING RADAR.

GPR is a geophysical method that transmits high frequency radio waves (10 megahertz [MHz] to 4 gigahertz [GHz]) into the subsurface and records the reflections of these waves from subsurface discontinuities. The velocity of radar waves is altered due to the differing dielectric permittivity of substances. This contrast results in electrical phase changes that visually produce an image for interpretation. Radar waves reflect most readily from regions of dielectric contrast. In most cases, the radar is operated at the surface and the radar energy is directed downward; in this case, horizontal contrasts, such as the top of the water table, the top of the permafrost, and the bottom of the active layer, are most readily imaged.

5-2.1 Strength and Limitation.

GPR provides detailed subsurface returns, often to within inches of accuracy if calibrated to a known dielectric constant. Without calibration, absolute depth is less accurate, but it is still acceptable for shallow (~30 ft [~9 m]) survey depths. GPR survey systems, however, do not provide usable returns to the same depths possible from other geophysical survey methods. The advantages of GPR units include their rapid data acquisition, ease of deployment, and short survey start length. Active layer depth and the depth of permafrost are often defined by a layer of liquid water or heavily saturated soil, and such polarity change between reflective water and dry soils is easily discernable in GPR returns. However, water attenuates radar signal, and it is often difficult to discern features beyond saturated areas with any reasonable accuracy. As a result of the radar–water interaction, GPR systems are not optimal in areas with standing water or heavily saturated soils. Clay and silt-sized earth mineral derivatives are known to absorb radar energy,[1] especially when the material is wet or saturated.

[1] "Complex Permittivity and Clay Mineralogy of Grain-Size Fractions in a Wet Silt Soil," Arcone.

Radar data often require filtering during collection mode to eliminate cultural electronic noise, and postprocessing is almost always required to deconvolute complex reflections, conduct migrations to reveal hidden reflections, and conduct other filtering and resolution gaining processes. This makes the process less user friendly and requires significant training for the operator to be proficient from collection to final data display.

5-2.2 Effective Survey Length.

Radar units can easily produce very long (thousands of feet) survey lengths. Because of the compact nature of GPR units, when the radar survey is initiated the data received is immediate and collected from the soil directly below the radar unit. There is no offset in distance or time between the equipment at the surface and location of data collection at depth.

5-2.3 Resolution.

GPR accuracy under ideal conditions is approximately within one to two feet-scale in the horizontal direction and the inch-scale in the vertical direction. Vertical resolution of this order requires a known depth, to within an inch, to an object easily discernible in the radargrams, which allows for the exact determination of the dielectric constant. Soil drilling and coring, or digging of pits, may be required to determine the depth to subsurface features or material changes that reflect the radar energy.

5-3 ELECTRIC RESISTIVE TOMOGRAPHY.

In electric resistive tomography (ERT), subsurface earth material resistivity is measured by injecting current (galvanic) into the subsurface via two current electrodes and reading the resultant voltage via two potential electrodes. Cable arrays often consist of 50 to 100 electrode positions; therefore, the current and voltage pairs are re-ordered for each pulse measurement, moving through a multitude of configurations per survey setup. Modern systems use a computer to cycle through the many possible pair configurations, greatly reducing work for the operator. By measuring the current, voltage, and geometry of the electrodes, one can calculate the resistivity of the subsurface. Averaging algorithms are then used to calculate the apparent resistivity over a range of depths along an electrode line. This type of system is time consuming to set because the electrodes must be hammered into the subsurface, and each survey is limited to the length of the cables at maximum electrode spacing. Surveys can use different measurement geometries and different electrode pair separation distances to alter the overall survey depth and resolution. Subsequent surveys can be sequentially conducted and overlapped with preceding surveys in what are called *leap-along* surveys.

5-3.1 Strength and Limitation.

ERT provides subsurface returns to depths in the magnitude of hundreds of feet, depending on the surface geometry of the electrode array and the geological conditions. This method is robust in data collection, provided good contact between the electrode array and the ground is maintained. ERT is suitable for a wide variety of ground conditions, and it generally has less noise in return data because of stable ground contact between the electrode array and subsurface. If the physical position of the electrode array is recorded, these surveys can be accurately repeated. Acquisition of raw data via computer switching can take a few hours. The survey method is minimally postprocess intensive because instrument returns require little processing and can be averaged with commercial software rather quickly.

5-3.2 Effective Survey Length.

ERT is a static, array-based method, and survey length is dictated by electrode configuration. The effective depth of the ERT survey directly correlates to array geometry at the surface, primarily to the spacing between electrodes. Most systems can conduct leap-along surveys, where subsequent electrode arrays can be coupled with the previous, allowing for total survey lengths of many thousands of feet. The limitations to this process are computation time and the stability of the averaging algorithms with large amounts of data.

5-3.3 Resolution.

Due to the averaging nature of ERT postprocessing, the resulting pseudosections typically produce graphical changes in color contours, where the colors represent levels of resistivity in units of ohm-meters. The averaged results graphically present boundaries between highly resistive frozen ground (ice-rich) and highly conductive thawed ground (ice free or ice-poor) materials. As a consequence of the averaging process and the large electrode spacings utilized for engineering surveys, these boundaries cannot be depicted by tight contour intervals, such as high resolution. This method is less precise than what can be achieved with the reflection returns from GPR. Based on the electrode spacing, the boundaries between high and low resistive units may be as long as 10 ft (3 m).

5-4 CAPACITIVE-COUPLED RESISTIVITY.

Capacitive-Coupled Resistivity (CCR) surveying is an earth resistivity method that does not require installing stationary electrodes into the ground. The drag-along system uses the earth as one conductor of a parallel plate capacitor. The transmitter and receivers are composed of two coaxial cables, or dipoles. The transmitter sends a continuous-current sine wave through the dipole, polarizing the surrounding earth material; the passing receiver then measures the induced polarization, from which the resistivity can then be calculated. This system does not require inserted electrodes and can continuously collect pulsed readings at one-second intervals while traveling along the surface. Altering the separation between the transmitter and the receivers provides additional survey depths.

5-4.1 Strength and Limitation.

CCR units operate along principles that parallel those of ERT, although they do not require a static array. As a result, CCR units are easier to deploy than ERT arrays and are capable of covering much longer transects in less time, much like GPR. CCR units do not have the capability to penetrate to the same depths as ERT, and they often produce datasets with more noise than ERT. Comparisons of CCR and ERT surveys generally yield very similar to often identical results, when comparing the location and extent of the varied resistive materials. Due to the collection method, the absolute value of the measurements often disagree by hundreds of ohm-meters between CCR and ERT. However, for engineering studies and for determining frozen versus thawed ground, or ice-rich versus ice-poor ground, these differences are not consequential. As with ERT, CCR does not require a substantial amount of postprocessing before interpretable results are available.

The cable dipoles are available in two different lengths, 8.2 ft and 16.4 ft (2.5 m and 5.0 m). As an example, when using the 16.4 ft (5.0 m) cables for deeper surveys, the length of the electronic component of the array is 120 ft (40 m). Additionally, the system requires the transmitter portion to be separated from the receiver portion by a nonconductive rope, and while this separation is variable by the user, it is most often equal to or longer than 33 ft (10 m). The total length of the array is now at least 164 ft (50 m). Careful planning of the transect is required to ensure the array follows the operator in the manner required, and this often requires helpers to keep the system guided on the correct alignment.

When mineralogical clays and silts may be present, especially near the ground surface, careful ground truth analysis is required to ensure masking or amplification of the underlying soils true electrical signature does not occur. In addition to the ability to retain more soil moisture, the mineral content of these soils can cause an increase in electrical conductivity, which can decrease the frozen resistivity value.

5-4.2 Effective Survey Length.

Depending on the geometry of the CCR array, the minimum effective survey length depends on the length of the transmitter and receiver array. One rule of thumb is to assume the minimal effective survey length is 1.5 times the length of the array’s longitudinal footprint.

5-4.3 Resolution.

As with ERT, CCR postprocessing relies on averaging algorithms to produce usable data plots. Because of the capacitive nature of the voltage generation, the boundaries between resistive and conductive bodies can be less definitive than with ERT. However, as with ERT, the value is the information gained in identifying ice-rich versus ice-poor regions, or identifying frozen versus thawed regions. The CCR system collects this information more rapidly and continuously than the ERT system.

CHAPTER 6 GEOTECHNICAL EXPLORATION METHODS

6-1 INTRODUCTION.

Perform soil exploration, testing, and evaluation under the direction of a licensed professional geotechnical or civil engineer who is experienced in cold regions site investigations. Determine the required extent of exploration and testing based on recommendations from the geotechnical engineer, structural engineer (for foundations), and civil engineer (for pavements, wells, septic systems, and retention ponds). Geotechnical site investigations (sampling, testing, and evaluation) must be in accordance with UFC 3-201-01, UFC 3-220-01, UFC 3-250-01, and UFC 3-260-02. EM 1110-1-1804 is a supplementary reference with extensive guidance on performing geotechnical site investigations.

Geotechnical data are the baseline for foundation design in buildings, roadways, airports, bridges, dams, and levees, as discussed in UFC 3-130-3. Upon completion of the initial desktop data acquisition, desktop survey, remote sensing data acquisition, ground reconnaissance, and geophysical data acquisition, detailed geotechnical investigation and exploration can begin. Investigations and evaluations must be in accordance with applicable ASTM standards to the fullest practical extent. Where ASTM methods are not applicable, procedures and apparatuses used must be in accordance with generally accepted cold regions engineering practice. Indicate the results of the subsurface investigation, including boring locations, boring logs, groundwater observations, summary of laboratory test results, and any details required to convey requirements for site preparation, on the contract documents.

6-2 DRILLING AND SAMPLING.

The majority of data collected during a detailed geotechnical investigation is collected from hand samples, drilling, and test pits or trenches. Table 6-1 and Table 6-2 are designed to be used in conjunction with data collected during the desktop study, geophysical data, and field reconnaissance studies to determine which drilling method is most suitable, where the drilling should take place, and the drilling density (number of boreholes).

Table 6-1 Material Tests and Applicable Standards

	Material Quality				Atterberg Limits	
	Los Angeles Abrasion	Degradation	Sodium sulfate loss	Gradation	Liquid limit	Plastic index
Applicable standard	ASTM C131	ATM 313*	ASTM C88	ASTM C117/C136	ASTM D4318	ASTM D4318

*Alaska Test Method (ATM) 313, Degradation Value of Aggregates (*Alaska Test Methods Manual*)

Table 6-2 Data Needs and Drilling Techniques

	Data Needs								
Drilling Method	**SPT or LPT***	**Continuous Soil Coring**	**Water Table Depth**	**Soil Class**	**Bedrock Class/ Quality/ RQD****	**Permafrost Cryostructure**	**Undisturbed Soil Samples**	**Torvane**	**Groundwater Pressure**
Solid stem auger	Not effective	Not effective	Effective	Limited	Not effective	Limited	Not effective	Not effective	Not effective
Hollow stem auger	Effective	Effective	Effective	Effective	Limited	Effective	Effective	Effective	Limited
Core drilling	Not effective	Not effective	Limited	Not effective	Effective	Not effective	Not effective	Not effective	Not effective
Air percussion	Effective	Not effective	Limited	Effective	Limited	Effective	Limited	Effective	Not effective
Air rotary	Effective	Not effective	Limited	Effective	Limited	Limited	Effective	Not effective	Not effective
Direct push technology	Not effective	Effective	Effective	Effective	Not effective	Effective	Limited	Not effective	Not effective
Wash bore rotary	Effective	Not effective	Limited	Effective	Effective	Limited	Effective	Effective	Effective
Excavated test pits, trenches	Not effective	Effective	Effective	Effective	Effective	Effective	Effective	Effective	Not effective

Note: *SPT is standard penetration test and LPT is large penetration test. These tests provide material for laboratory testing but should not be used for soil consistency or density correlations, as the frozen soils have artificially elevated blow counts. **RQD is Rock Quality Designation.

6-3 HAND SAMPLES.

Hand samples are typically limited in that they can only be collected at the surface or from disturbed samples taken from the auger flights during auger drilling. The advantage of hand sampling campaigns is that they are relatively inexpensive compared to drilling or trenching and require minimal logistical planning and execution, but they are limited in deep-depth collection. Hand samples can be broken down into the construction-related categories presented in Table 6-3.

Table 6-3 Hand Sampling Breakdown

	Typical Sample Size	Generalized Analyses Methods	Limitations	Optimal Uses
Materials	• 25–150 lb (11–68 kg) • Sample size is dependent on test method (small volume for gradation, large volume for quality testing) • Gradation sample size dependent on particle size	• Gradations • Los Angeles Abrasion • Degradation • Nordic Abrasion • Sodium Sulfate Soundness • Acid-Base Accounting	• Limited to surficial sampling, no quantification of material at depth • Contamination with fill is likely	• Material site reconnaissance • Bedrock sampling for quality testing and acid-base accounting
Foundation	• 1–25 lb (0.5–11 kg) • Sample size is dependent on test method (small volume for moisture contents, larger volume for gradations) • Gradation sample size dependent on particle size	• Gradations • Moisture content • Expansion/collapse potential • Atterberg limits • Organic content • Soluble sulfates • Thaw consolidation	• Limited to surficial sampling, no quantification of material at depth • Contamination with fill is likely	Index testing of material on surface where deep fills are to be placed and no subexcavation is needed
Environmental	Variable	Various analyses for contaminants	Limited for surficial contaminants	Baseline screening
Naturally occurring asbestos	1–5 lb (0.5–2.3 kg)	CARB 435* with Transmission Electron Microscopy or Polarized Light Microscopy	Limited to surficial exposures	Documentation of naturally occurring asbestos hazards easily identified in the field.

*California Air Resources Board (CARB) Test Method 435, California Environmental Protection Agency

6-4 DRILLING.

Seven types of drilling are typically used for geotechnical investigations. This section is not intended to be an all-inclusive list of drilling techniques but, rather, to give an overview of the more common cold region geotechnical drilling techniques and the capabilities of each technique. Table 6-2 includes a list of data that are commonly needed in geotechnical explorations and the suitability of each drilling method to fulfill those needs. Specific site conditions (such as include ground ice content, soil type, depth to bedrock, presence of surface and ground water, and allowable risk for structure damage) determine final borehole density and depth. For horizontal projects that cover long distances, such as roads, changing conditions may dictate changes in drilling strategy.

6-4.1 Solid Stem Auger Drilling.

Solid stem auger drilling is generally limited to environments with silty or cohesive soils, or frozen fine-grained soils, because the walls of the boring remain stable throughout the drilling process. The flights on the augers are continuous throughout the drill string and convey cuttings to the surface. Samples are acquired by stopping drilling at the desired depth and pulling (tripping) the entire string to allow for grab-sampling from the lead auger. Alternatively, the drill string is rotated quickly until returns are spun to the surface. This method yields a highly disturbed sample and should only be used to estimate changes in strata or other gross indicators.

In permafrost regions, solid stem augers are useful for documenting depths to frozen soil because the transition from thawed to frozen soil is highly recognizable due to the dramatic change in drilling resistance. Solid stem augers have limited effectiveness for identifying ice content and cryostructure due to the disturbed nature of the samples, although ground ice is often easily discernable and can help to identify massive ice features.

6-4.2 Hollow Stem Augers.

Hollow stem augers advance in the same manner as solid stem augers. The hollow stem allows the use of soil samplers like split-spoons, Shelby tubes, and continuous samplers driven through the auger flight, and in this manner, the hollow stem auger acts as a casing to prevent collapse of the drill hole and allow for continuous sampling. Other geophysical tools, like torvanes, thermistors, and piezometers, can be inserted in the ground through the hollow stem auger. Samples, such as core samples collected with continuous samplers, are collected during drill advancement.

Hollow stem augers are effective in both cohesive and granular soils, where they provide a cost-effective method to collect representative soil samples, blow counts, and samples for determining moisture content and organic content. In permafrost regions, hollow stem augers are a cost-effective method for identifying cryostructure.

6-4.3 Core Drilling.

Core drilling is primarily used in bedrock or in frozen soil or sediment environments. Core drilling is used to recover cylindrical cores. Core tooling consists of a coring bit attached to a core barrel, while the lifter advances the sample through the barrel. Core drilling can be completed using a wide array of barrel types (single, double, and triple tube), and core sizes are widely variable and generally range from 21.5 mm to 85.0 mm in diameter. To facilitate core drilling of frozen soils or sediment, chilled brine can be circulated down the hole to maintain the drill hole and sample in the frozen condition. Samples retrieved in this manner are contaminated with brine fluid on the outside and interior of the core, where fractures and joints may exist. For a more detailed explanation of core drilling, see ASTM D2113 and AASHTO T 225.

6-4.4 Air Percussion Drilling.

In air percussion drilling, both the drill bit (attached to the end of an air percussion hammer) and the casing are advanced at the same time through the use of an under-reamer. Air flows through the rods and the hammer and up the casing, removing the cuttings through the casing up to the surface. Once the desired sampling depth has been reached, the rods and air percussion are removed, and sampling tools are installed.

Air percussion drilling is particularly effective in environments where excessive cobbles prevent time-effective progress using augers, and it is also effective for very deep holes. Air percussion drilling is less effective beneath the water table and in frozen fine-grained materials, where the hot air thaws the frozen soil. Cuttings using air percussion are delivered to the surface relatively instantaneously, although they are pulverized and not closely representative of gradations in situ.

6-4.5 Air Rotary Drilling.

Air rotary drilling is accomplished by advancing a rotating drill bit through the substrate while moving cuttings to the surface via high pressure air. This method is useful in arid environments with soils that have high dry strengths or in thawed silts and clays where the hole stays open. As the drill advances to desired sample depths, the rod and bit can be extracted from the boring, and the sampler is attached to the rods, taking the place of the bit. Cuttings are moved to the surface relatively instantaneously, and this is useful for detailed logging of complex stratigraphy. Maintaining materials in the frozen state is generally not possible with this method.

6-4.6 Macro Core.

Macro core drilling, also known as *direct push technology*, is accomplished by driving a continuous core barrel into the substrate utilizing a high-frequency hammer. The core barrel is filled with a clear plastic liner that receives the sample, and the liner is extruded once at the surface. This method is very useful for logging detailed stratigraphy, particularly in environments with fine-grained sediments. This method also provides for detailed logging of permafrost cryostructure. Larger size core barrels are required for gravelly soils to prevent plugging of the core. Also, sampling in massive ice, such as in ice-wedge features, can cause the ice to compress and, upon retrieval, to expand outward through the end of the sample barrel. However, this can be prevented with experience.

6-4.7 Wash Bore Rotary.

In wash bore, a rotary drilling casing is advanced ahead of a drill bit with a mechanical or sonic hammer. The casing is driven into the ground, and the material in the casing is drilled out with the drill bit. Once the drill bit reaches the desired depth for sampling, the rods are pulled out of the hole, and the sampler is attached to the end of the rod and lowered down to collect the sample.

To stabilize the boring or control heaving sands below the water table, drilling muds (typically bentonite) or polymers are used to keep positive pressure on soils below the bit as the bit is removed. This is generally the most effective method for drilling below the water table. However, samples above the water table are likely to have contaminated moisture contents due to the water required for the drilling process leaking into the system. Examinations of cuttings pumped to the surface between sample intervals are typically accomplished by using a wire mesh sieve or strainer to collect cuttings from the stream of water that is pumped out of the casing at the surface.

6-5 FREQUENCY AND DEPTHS OF BORINGS.

An experienced geotechnical engineer or geologist familiar with the region is required to determine the frequency and depths of borings. In general, the location, frequency, sampling method and interval depend on the type of structure to be built, degree of heterogeneity in subsurface conditions, and type of soil and rock formations. The drilling program is also influenced by the anticipated presence of any geotechnical or environmental conditions of concern to the project (for example, faulting and seismicity, unstable slopes, ground contamination). Geophysical data allows for a higher level of subsurface mapping resolution and can be used to help guide subsurface investigations.

6-6 EXCAVATED TRENCHES AND TEST PITS.

Sampling trenches and test pits are typically excavated with backhoes or excavators and offer superior stratigraphic data collection because sediments can be seen in long horizontal lengths and in vertical detail that is not attainable with drilling techniques. Hand samples can also be collected very effectively in trenches. The disadvantage of test pits and trenching is the depth profile, which is typically limited by the length of the excavator or backhoe armature or water table. However, benching can be conducted to allow for deeper operation levels for the excavating equipment. Frozen ground disaggregation is accomplished with buckets equipped with frost teeth or by the installation of a single tooth ripper attachment. Take proper to ensure the safety of personnel within test pits and trenches, and this may include widening the trench with safe bench intervals or utilizing a trench box.

6-7 GEO-HAZARD ASSESSMENT.

Exercise professional diligence when collecting data for and designing around geologic hazards. Geological hazards cover a wide range of topics. The Alaska Department of Transportation and Public Facilities' *Alaska Geological Field Investigations Guide* provides a list of common geological hazards, which has been supplemented by this publication:

- Permafrost terrain and thaw-unstable soils (yedoma, syngenetic permafrost)
- Organic soils and deep peat deposits
- Unsuitable soil gradations
- Metastable soils (loess, mud flows, permafrost terrain)
- Highly weathered rock with variable competency
- Faults, joints, bedding planes, foliation planes, slickensides, and other planar weakness surfaces in rock (unstable rock slopes)
- Naturally occurring asbestos in soil and rock
- Moisture-sensitive or quick clays
- Landslides and debris flows
- Meandering streams (stream cutoffs and oxbow lakes)
- Preconsolidated glacial soils
- Boulders and cobbles (particularly when not adequately described)
- Loose granular soils, particularly gap-graded soils
- Noxious or explosive formation gasses
- Substandard fill material
- Shallow groundwater, groundwater in artesian conditions, and saturated soils
- Misleading sample data collected from beneath the water table
- Nonrepresentative sample data from coarse-grained deposits
- Contaminated soils

6-8 INSTRUMENTATION.

A wide array of different instrumentation techniques is deployed in geotechnical investigations. A breakdown of some of the most common types of instrumentation, including their function and application, are presented in Table 6-4.

Table 6-4 Downhole Instrumentation

Type	Function	Application
Piezometers	Groundwater level measurement	Groundwater Earthwork and foundation design
Vane shear	Shear strength measurement of soils	Design in plastic soils Slope stability investigation
Thermistors	Ground temperature measurement	Permafrost investigation
Slope indicator tubes	Subsurface movement	Slope stability investigations
Spontaneous potential electric loggers	Record naturally occurring potentials between borehole fluid, formation, and surrounding rock as a function of depth	Determination and correlation of lithology, bed thickness, and salinity of formation water
Resistivity logging	Measures impedance to flow of electricity in rock formations	Lithology determinations
Cone penetrometer test (various downhole sensors)	Measures soil shear strength, shear wave velocity, and pore pressure, with soil classification interpretations	Foundation design Seismic response analyses
Optical and acoustic televiewers	Provide 360° view and interpretation of soil and rock conditions within unlined boreholes	Lithology and geologic structure determinations Foundation design

6-9 SAMPLE ANALYSIS.

Obtain representative samples of soil and rock during the field reconnaissance and field exploration phases of geotechnical investigations in a way that allows them to be classified according to existing classification schemes (for example, AASHTO and USCS soil classification) and to have their engineering properties quantified. Samples are acquired at considerable cost to the project and must be properly stored, preserved, catalogued, and shipped to avoid sample disturbance and loss.

Preserving, protecting, and transporting samples may be accomplished by the following methods:

- Inventory all samples daily and store in a central location. Do not store samples in areas where they can be agitated, especially if they are undisturbed samples.

- Rock cores need to be stored in purpose-built containers (core boxes) that protect the rock from shock. Rock cores must be logged by a trained geologic professional and photographed at the drill site before being transported off-site. Typical core log information includes lithology descriptions, depth of recovery, core run length, percent core recovery, and Rock Quality Designation (RQD).
- Store permafrost samples at temperatures as close to in situ conditions as possible. Do not freeze thaw consolidation samples to temperatures below those of the natural environment for the soil.

A breakdown of some of the more common geotechnical tests is presented in Table 6-1 and Table 6-2. Further information on sampling can be found in the AASHTO *Manual on Subsurface Investigations*, section 7.9, and in EM 1110-1-1804.

This Page Intentionally Left Blank

APPENDIX A BEST PRACTICES

A-1 INTRODUCTION.

The Best Practices Appendix is considered to be guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned but may not be the only solution to meet the requirement. It identifies additional background information and practices for accomplishing site assessment and selection in the Arctic and Subarctic. The DoR must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any, the UFC takes precedence. For Best Practices guidelines not discussed in a UFC, the DoR must submit to the Government Project Manager a list of the guidelines or requirements being used for the project with documentation sufficient for review and approval prior to completing the design.

A-2 EXAMPLE ASSESSMENT WORKFLOW.

The steps for organizing geotechnical investigations include basic scenarios, such as those described in Figure A-1, that are applicable for large- and small-scale projects, which are defined here:

- Large scale: multibuilding Installations that cover 50 acres or more on land with three or more terrain units and linear infrastructure developments, including roads, airfields, and pipelines
- Small scale: linear infrastructure and small developments with single buildings

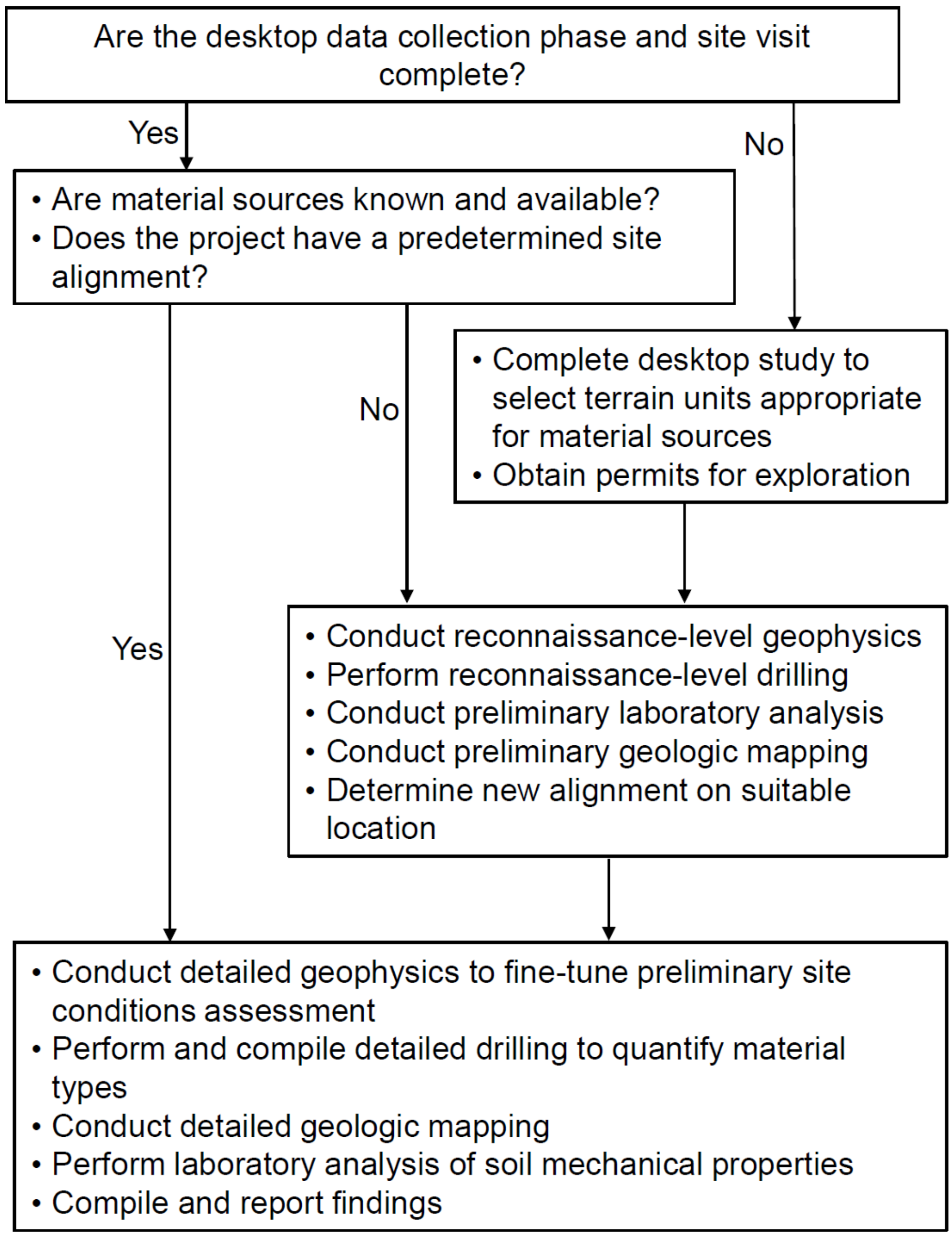
In general, once the background data have been collected, the workflow for most geotechnical investigations follows the flow chart in Figure A-1.

A-3 LARGE-SCALE AND LINEAR INFRASTRUCTURE.

Repair or improvement of large scale (airfields) or linear (roads and pipelines) infrastructure on predetermined or existing alignments requires far less data acquisition as critical infrastructure siting decisions have previously been made. In this case, a single geophysical transect that runs parallel to the centerline followed by detailed geotechnical drilling is typically sufficient unless there is a particular area experiencing geotechnical issues. In the case where predetermined alignment does not exist, geophysical reconnaissance transects designed to obtain the characteristics and boundaries of the terrain units involved is of primary importance.

Borehole spacing and depths are typically controlled by the diversity of terrain units at the reconnaissance level. Identify adverse terrain units (for example, heaving sands, permafrost, and expansive clays) and the more solid foundation soils (alluvial plains, bedrock, colluvium, and so on) at the reconnaissance level, especially if the studies are used to provide a detailed alignment location. Basic geological descriptions of each terrain unit need to be completed in the field along with baseline descriptions of geological hazards present in the project area. Also identify candidate locations for crossings of rivers and canyons at the reconnaissance level.

Figure A-1 Geotechnical Site Investigation Flow Chart



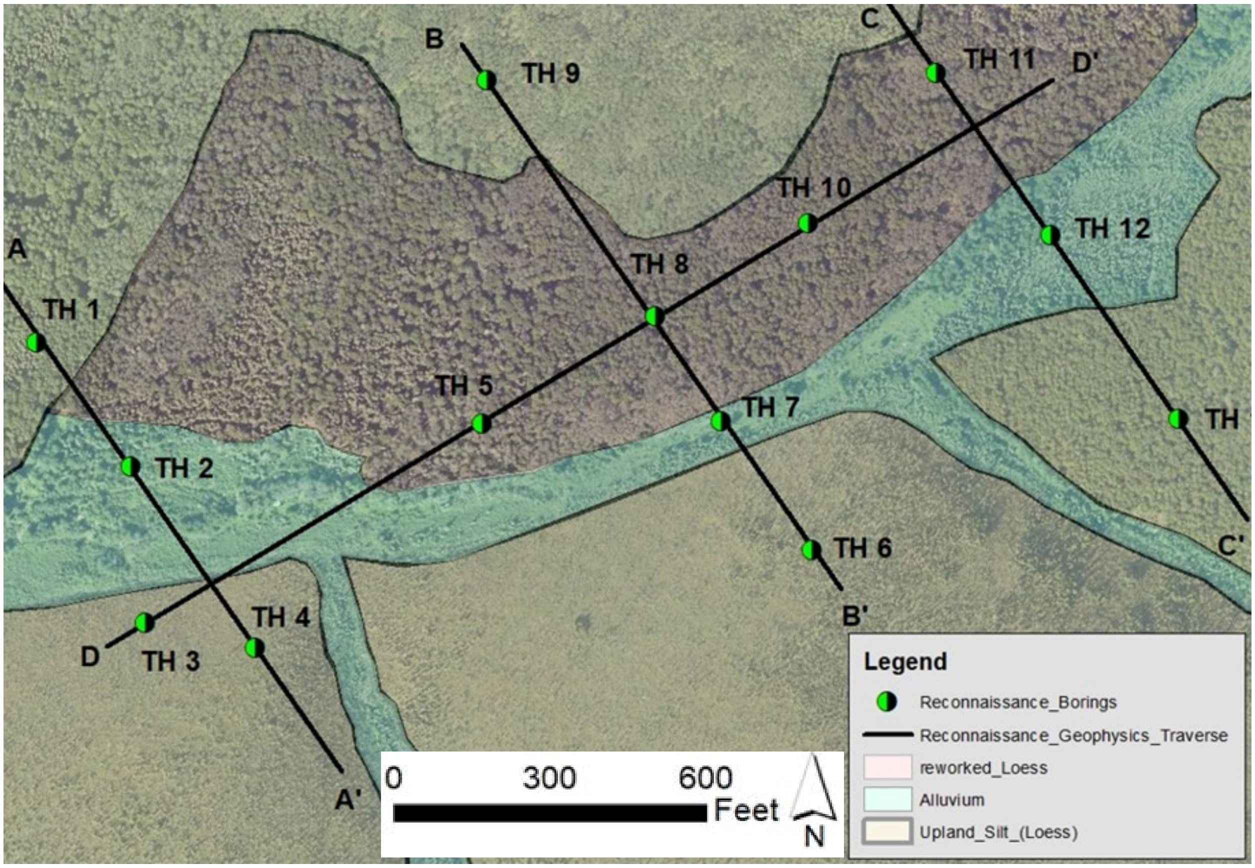
A-4 FIELD RECONNAISSANCE EXAMPLES.

Construction projects for large developments of linear infrastructure and multibuilding vertical construction share many similarities. Both types of development require a multiphase design. Regardless of the type of infrastructure to be constructed, large areas with multiple terrain units are best explored in several phases, the first of which is the reconnaissance phase. In the reconnaissance phase, the primary objectives are as follows:

1. Assess material availability. This is especially important for linear infrastructure, where it is best to have an available material site every 5–10 miles (8–16 kilometers) of pipeline, road, or tunnel alignment.
2. Identify and describe geological features located in geophysical transects, if available.
3. Fine-tune existing terrain-unit maps.
4. Provide preliminary characterization of each of the terrain units present in the area so that the critical structures can be located in the most favorable terrain units and construction can be minimalized on structurally adverse terrain units. The preliminary characterization should including the following:
    - Foundation information at candidate locations for high-load structures
    - Type and extent of adversarial terrain units' characteristics
    - Type and extent of favorable terrain units
    - Geological hazards
    - Drainage assessment
    - Vegetation types

Figure A-2 shows a hypothetical project area with an area of greater than 50 acres and three terrain units. The reconnaissance-level geophysical transects are plotted so that they provide soil deposit geometry via three transects oriented perpendicular to the strike of terrain units and one transect oriented parallel to the strike of terrain units. Reconnaissance-level boreholes are positioned to provide ground truth information and explore anomalies identified in the geophysics information.

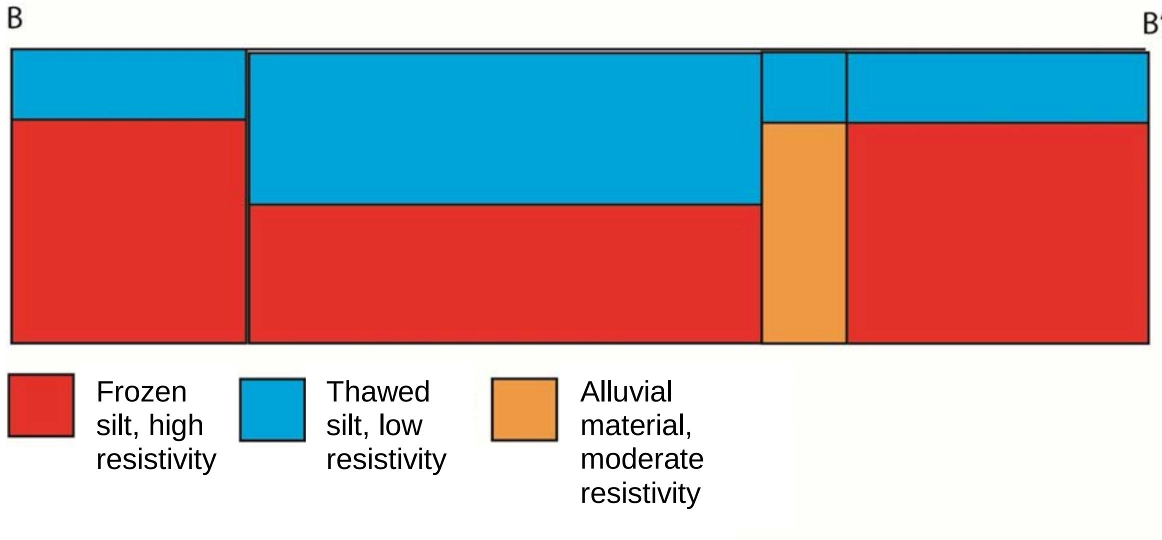
Figure A-2 Reconnaissance-Level Geophysical Transect Layout and Drilling Footprint



The reconnaissance phase relies on both geophysical data and traditional boring data as the backbone of subsurface data on which the detailed geotechnical investigation is built. Identify locations for critical structures in the reconnaissance phase.

Each geophysical transect and subsequent drilling provides a base of data to describe terrain units so that the units with optimum foundation conditions can be identified. Figure A-3 depicts a graphical-type cross section that depicts B-B’ in Figure A-2. In this cross section, we see three terrain units. Two units consist of ice-rich loess (wind-driven silt) and reworked loess, while the third consists of alluvial material. This base-level reconnaissance cross section suggests limiting building locations to the terrain unit with alluvial material in foundation soils. Once favorable locations for key structures have been identified, the detailed phase of investigation begins.

Figure A-3 Generalized Cross Section Showing Resistivity and Corresponding Soil Conditions from Transect B-B' in Figure A-2



A-5 SMALL-SCALE INSTALLATIONS.

For small-scale Installations, of less than 50 acres, and to be built on a predetermined location, a single phase of geophysical and geotechnical drilling data collection is sufficient (Figure A-4). Existing information may be available for the site and geophysics may not be required. When needed, geophysical data should be collected prior to drilling to help identify subsurface anomalies to be explored further with drilling or test pits. For small-scale Installations on land with two terrain units or less, one geophysical transect parallel to the strike of the terrain units and two geophysical transects perpendicular to the strike of terrain units is sufficient. Drilling frequency, spacing, and depth are controlled by design parameters specific to the structure and the acceptable risk; with risk being the detriment to the mission if the infrastructure should need foundation maintenance, foundation repair, or if the infrastructure should become unusable.

A-6 DETAILED DRILLING AND FIELD INVESTIGATION EXAMPLES.

Once baseline reconnaissance has been completed, detailed investigation can begin. Critical structures are ideally constructed on favorable terrain units identified during the reconnaissance phase. Detailed geotechnical investigations consisting of geophysical transects and soil borings are then planned and executed. It is preferred to span the foundation footprint with at least two geophysical transects oriented perpendicular to the terrain unit and at least one geophysical transect oriented parallel to the strike of the terrain unit (Figure A-5). As the geophysics data become available, they can be used to formulate for more geophysics if required and provide planning for the geotechnical drilling campaign (Figure A-4).

Figure A-4 Example of Geophysical Transect Layout in Small-Scale Development with One Terrain Unit

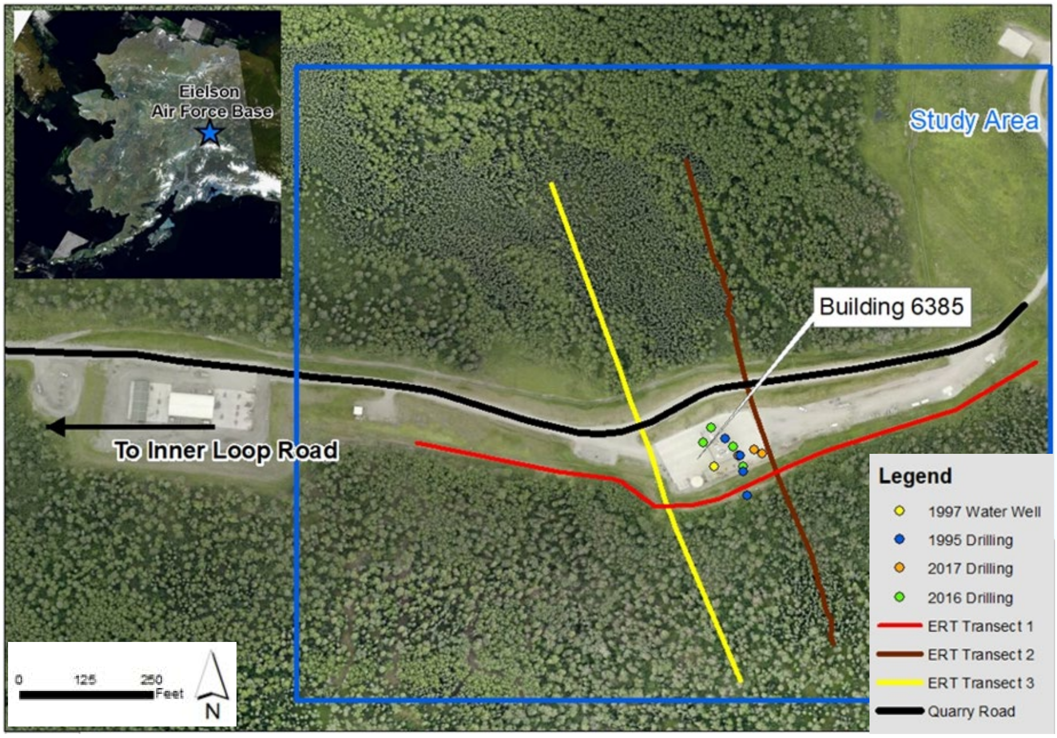
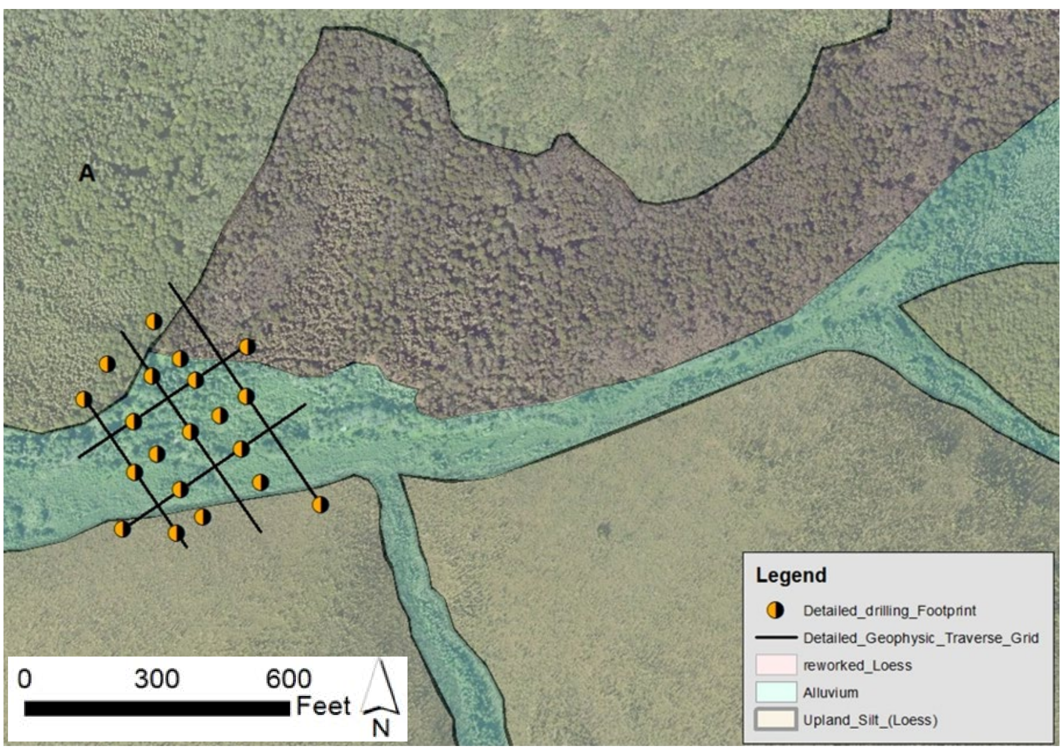


Figure A-5 Orientation of Geophysical Transects and Drilling Footprint for Collection of Detailed Subsurface Data



This two-phase approach works well for large projects that cover an area in excess of 50 acres. The reconnaissance-level geophysics and reconnaissance-level drilling allow designers to narrow down the best locations within a large plot of land to build foundation-critical structures. Once the structure's foundation design requirements have been identified (such as refined building footprint, tentative foundation loads, and allowable settlement criteria), the more rigorous geophysical and drilling data can be collected for the design.

This Page Intentionally Left Blank

APPENDIX B GLOSSARY

B-1 INTRODUCTION.

The following acronyms and terms are used in this document. UFC 3-130-01 provides a more comprehensive list of acronyms and terms for general cold regions engineering.

B-2 ACRONYMS.

AFCEC	Air Force Civil Engineer Center
AFDD	Air freezing degree-days
ATDD	Air thawing degree-days
ATM	Alaska Test Method
BIA	Bilateral Infrastructure Agreements
CARB	California Air Resources Board
CCR	Capacitive-Coupled Resistivity
cm	Centimeters
DEM	Digital elevation model
DoR	Designer of Record
ERT	Electric resistive tomography
FHWA	Federal Highway Administration
ft	Feet
GHz	Gigahertz
GIS	Geographic information systems
GPR	Ground penetrating radar
HNFA	Host Nation Funded Construction Agreements
HQUSACE	Headquarters, U.S. Army Corps of Engineers
IBC	International Building Code
in.	Inch
kg	Kilogram

lb	Pound
LPT	Large penetration test
m	Meters
MAAT	Mean annual air temperature
MAGT	Mean annual ground temperature
MHz	Megahertz
mm	Millimeter
NAVFAC	Naval Facilities Engineering Systems Command
NOAA	National Oceanic and Atmospheric Administration
RQD	Rock Quality Designation
SOFA	Status of Forces Agreements
SPT	Standard penetration test
UFC	Unified Facilities Criteria
USCS	Unified Soil Classification System

B-3 DEFINITION OF TERMS.

Heterogenetic permafrost growth: A mode of permafrost growth whereby freezing temperatures penetrate into previously unfrozen ground of uniform composition.

Syngenetic permafrost growth: A mode of growth of permafrost whereby additional material is deposited on a permafrost site during freezing conditions, causing the permafrost layer to build upward.

Yedoma: Ice-rich silty deposits penetrated by large ice wedges (“Yedoma Permafrost Genesis: Over 150 Years of Mystery and Controversy,” by Shur et al.)

APPENDIX C REFERENCES

ALASKA DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES

Alaska Geological Field Investigations Guide

Alaska Test Methods Manual

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

http://www.transportation.org

AASHTO T 225, *Standard Method of Test for Diamond Core Drilling for Site Investigation*

Manual on Subsurface Investigations

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

https://www.astm.org

ASTM C88, *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*

ASTM C117, *Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing*

ASTM C131, *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*

ASTM C136, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*

ASTM D2113, *Standard Practice for Rock Core Drilling and Sampling of Rock for Site Exploration*

ASTM D2488, *Standard Practice for Description and Identification of Soils*

ASTM D4318, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*

INTERNATIONAL CODE COUNCIL

http://www.iccsafe.org

International Building Code

FEDERAL HIGHWAY ADMINISTRATION (FHWA)

FHWA-NHI-01-031, *Subsurface Investigations—Geotechnical Site Characterization, Reference Manual*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 1-200-01, *DoD Building Code*

UFC 2-100-01, *Installation Master Planning*

UFC 3-130-01, *Arctic and Subarctic Engineering*

UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*

UFC 3-130-05, *Arctic and Subarctic Utilities*

UFC 3-201-01, *Civil Engineering*

UFC 3-220-01, *Geotechnical Engineering*

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 3-260-02, *Pavement Design for Airfields*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

U.S. ARMY CORPS OF ENGINEERS

EM 1110-1-1804, *Geotechnical Investigations,* https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-1804.pdf?ver=X3odvxc01j8BVoN9mwxWCw%3d%3d

OTHER

"Classification of Rocks," *Quarterly of the Colorado School of Mines* 50 (1), R.B. Travis, 1955

"Complex Permittivity and Clay Mineralogy of Grain-Size Fractions in a Wet Silt Soil," *Geophysics* 73 (3): J1–J13, S.A. Arcone, S.A. Grant, G. Boitnott, and B. Bostick, 2008

Determination of Asbestos Content of Serpentine Aggregate: Field Sampling and Laboratory Practices, Implementation Guidance Document: Air Resources Board Test Method 435, California Environmental Protection Agency, Air Resources Board, 2017, https://ww2.arb.ca.gov/sites/default/files/2022-05/2017%20Apr28%20M435%20Guidance%20Version4%20POST.pdf

"Northern Hemisphere Permafrost Map Based on TTOP Modeling for 2000–2016 at 1 km^2 Scale," *Earth-Science Reviews* 193: 299–316, J. Obu, S. Westermann, A. Bartsch, N. Berdnikov, H. Christiansen, A. Dashtseren, R. Delaloye, B. Elberling, B. Erzelmüller, A. Kholodov, A. Khomutov, A. Kääb, M. Leibman, A. Lewkowicz, S. Panda, B. Romanovsky, R. Way, A. Wesergaard-Nielsen, T. Wu, J. Yamkhin, and D. Zou, 2019, https://doi.org/10.1016/j.earscirev.2019.04.023

"Munsell Rock Color Chart," MUNSELL COLOR, https://munsell.com/color-products/color-communications-products/environmental-color-communication/munsell-rock-color-chart/

"Recent Advances in the Study of Arctic Submarine Permafrost," *Permafrost and Periglacial Process* 31: 442–453, M. Angelopoulos, P.P. Overduin, F. Miesner, M.N. Grigoriev, and A.A. Vasiliev, 2020

River Lake Ice Engineering, G.D. Ashton (ed.), Water Resources Publications, LLC., 1986

"Yedoma Permafrost Genesis: Over 150 Years of Mystery and Controversy*," Frontiers in Earth Science* 9, Y. Shur, D. Fortier, M.T. Jorgenson, M. Kanevskiy, L. Schirrmeister, J. Strauss, A. Vasiliev, and M. Ward Jones, 2022

UFC 3-130-03
16 January 2025

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC FOUNDATIONS FOR FREEZING AND THAWING CONDITIONS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UFC 3-130-03
16 January 2025

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC FOUNDATIONS FOR FREEZING AND THAWING CONDITIONS

The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement by DOD.

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes UFC 3-130-04, *Foundations For Structures - Arctic and Subarctic Construction*, and UFC 3-130-06, *Calculation Methods for Determination of Depth of Freeze and Thaw in Soil - Arctic and Subarctic Construction*, dated 16 January 2004.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and the Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website https://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

THOMAS P. SMITH, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

S. KEITH HAMILTON, P.E., SES
Chief Engineer and Assistant Commander
Planning, Design and Construction
Naval Facilities Engineering Systems Command

THOMAS P. BROWN, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MARK S. SINDER, SES
Deputy Assistant Secretary of Defense
(Infrastructure Modernization and Resilience)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

The field of Arctic and Subarctic engineering, also known as cold regions engineering, covers a wide range of multidisciplinary topics and principles. Unique issues exist in the planning, design, construction, and operation of infrastructure and facilities in Arctic and Subarctic regions. Among them are permafrost, seasonal ground frost heave and thaw settlement, extreme low temperatures, high wind loads, heavy snow loads, and remote construction sites. Additionally, the implications of the rapidly changing climate in Arctic and Subarctic regions exacerbate these unique challenges.

The Unified Facilities Criteria (UFC) Arctic and Subarctic series includes five volumes that summarize relevant information and the most feasible approaches and solutions for planning, design, construction, and maintenance of infrastructure and facilities in the Arctic and Subarctic areas of the globe.

1-2 NEED FOR SPECIAL APPROACHES.

A defining characteristic of the Arctic and Subarctic in the context of this UFC is the presence of permafrost in soil and rock, as described in Chapter 2 of this UFC and in UFC 3-130-01. One definition of Arctic and Subarctic used by the Arctic Council, an intergovernmental group, includes permafrost and nonpermafrost areas located north of 51° N latitude, including most of Alaska, Greenland, and Iceland, as delineated on the “Geographical Coverage” page of the Arctic Monitoring & Assessment Programme website (www.amap.no/about/geographical-coverage). More broadly, principles described in this UFC apply to areas below the Arctic Circle, based on extreme cold weather and environmental characteristics like flora and fauna.

Frozen soil exhibits unique characteristics because of the ice within its interstitial spaces and the massive ice features that may be present in permafrost. The presence of ice introduces an important variable that can make material properties sensitive to changes over time. As a result, foundation design must consider factors such as variability in ground temperature (both seasonally and over the design life of a facility); ice content and heterogeneity, which affect material behavior under loading and produce additional variability within the frozen soil or rock matrix across a site; and pore water salinity, which changes the freezing point and affects a variety of material properties. Site development, changes in vegetation, and climate must also be considered because they affect permafrost conditions at a project site.

1-3 REISSUES AND CANCELS.

This document supersedes and cancels inactive UFC 3-130-04 and inactive UFC 3-130-06, dated 16 January 2004.

1-4 PURPOSE AND SCOPE.

The Arctic and Subarctic UFC series provides technical guidance and available technical requirements for planning, design, construction, and maintenance of DoD facilities worldwide for all Service elements in Arctic and Subarctic environments. These guidance and technical requirements are based on the International Building Code (IBC) and the requirements in UFC 1-200-01. The UFC 3-130 series covers many aspects of Arctic and Subarctic engineering, with the specific exception of pavements, which is incorporated in the UFC 3-250 and UFC 3-260 series, as discussed in UFC 3-130-01, paragraph 1-6.3. In addition to this volume, there are four other series volumes:

- UFC 3-130-01, *Arctic and Subarctic Engineering*. UFC 3-130-01 serves as an introduction to the Arctic and Subarctic UFC series.
- UFC 3-130-02, *Arctic and Subarctic Site Assessment and Selection*. UFC 3-130-02 provides applicability and technical guidance for geotechnical site assessment for the Arctic and Subarctic environment conditions.
- UFC 3-130-04, *Arctic and Subarctic Buildings*. UFC 3-130-04 includes building design in the Arctic and Subarctic areas.
- UFC 3-130-05, *Arctic and Subarctic Utilities*. UFC 3-130-05 provides criteria and guidance for the design of utility systems for military facilities in Arctic and Subarctic regions.

This UFC addresses foundation planning, design, construction, and maintenance issues pertinent to the Arctic and Subarctic that are related to the technical disciplines of geotechnical engineering, engineering geology, and construction engineering for buildings (vertical structures) and facilities such as roads and airfields (horizontal structures). Careful planning and consideration of both current site conditions and the changes in those conditions that may occur over the life of a project are essential when designing foundations in the Arctic and Subarctic. In addition to unique physical considerations (such as the difference between saline and nonsaline permafrost, variations in ice content within the soil, and geomorphic features such as ice wedges), the designer must also consider how conditions might change over time due to factors such as the following:

- Site development affecting ground thermal conditions and drainage
- Adjacent structures altering snow accumulation and shade sites
- Surface drainages that might change course over time
- Changes in climate affecting ground freezing and thawing

1-5 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, for those geographic locations in Arctic and Subarctic regions worldwide.

1-6 GENERAL BUILDING REQUIREMENTS.

This UFC is an integrated part of the Arctic and Subarctic UFC 3-130 series. Use the other documents in this series in conjunction with this UFC to address construction aspects unique to cold regions. See UFC 3-130-01, Chapter 2, for the definitions of Arctic and Subarctic. This UFC modifies and supplements the criteria found in the core UFCs. Utility provider's or installation-specific requirements must be considered.

1-6.1 Geotechnical and Foundation Engineering.

Conventional foundation practice must be modified and adapted for use in Arctic and Subarctic regions to account for extremely low temperatures and unique ground conditions, such as permafrost, seasonal frost heave and thaw in soils, and climatic changes affecting ground conditions over time (for example, permafrost degradation and slope erosion and instability).

The designer of record (DoR) must also comply with the following UFCs, except when cold regions requirements dictate otherwise:

- UFC 3-220-04FA, *Backfill for Subsurface Structures* (Army and Air Force only)
- UFC 3-220-05, *Dewatering and Ground Control*
- UFC 3-220-08FA, *Engineering Use of Geotextiles* (Army and Air Force only)
- UFC 3-220-10, *Soil Mechanics*
- UFC 3-220-20, *Foundations and Earth Structures*

These documents present regulatory and industry standards that must be considered. They include general requirements that are applicable to foundation systems and are therefore not specifically covered in this document. Other (USACE) Engineering Manuals (EM), such as EM 1110-1-1804, *Geotechnical Investigations*, and EM 1110-2-2906, *Design of Pile Foundations*, may also contain general criteria not specifically covered in this UFC.

1-6.2 Structural.

Use UFC 3-301-01, *Structural Engineering*, and UFC 3-301-02, *Design of Risk Category V Structures, National Strategic Military Assets*, as needed for design and analysis of DoD buildings and other DoD structures assigned to Risk Category V for national strategic military assets (see UFC 3-301-01, Table 2-2).

1-7 LEVEL OF CONSTRUCTION.

See UFC 1-200-01, paragraph 1-3.2, for the definitions of permanent construction, temporary construction, and facilities in support of military operations.

1-8 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*, and as required by the system's individual service implementation policy.

1-9 BEST PRACTICES.

Much of the state of practice for cold regions engineering, planning, design, and construction is not codified. Lessons learned and the experiences of the facility installation engineering staff are invaluable and may help to avoid potentially costly or catastrophic infrastructure failures. Appendix A presents general guidance on best practices for accomplishing certain foundation design and engineering services in extreme Arctic and Subarctic environments.

The DoR must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a best practices document guideline differs from any UFC, the UFC takes precedence. The DoR must submit a list of any best practices guidelines or requirements not discussed in a UFC that are being used for the project, along with documentation sufficient for review and approval prior to incorporation within the design, to the Government Project Manager.

1-10 GLOSSARY.

Appendix B contains acronyms, abbreviations, and a glossary of terms used in this document. See UFC 3-130-01 for definitions of additional terms.

1-11 SUPPLEMENTAL RESOURCES.

Appendix C contains a list of supplemental sources for information on subjects related to cold regions engineering, design, and construction. These resources are valuable tools for the civil engineer and contain additional information on topics pertinent to and affiliated with construction of foundations in the Arctic and Subarctic. See UFC 3-130-01 for additional resources for cold regions engineering.

1-12 REFERENCES.

Appendix D contains a list of references used in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 PLANNING AND DESIGN

2-1 INTRODUCTION.

This chapter describes general factors to consider during planning and initial selection of the foundation concept and highlights some unique issues associated with foundations in the Arctic and Subarctic that should be considered.

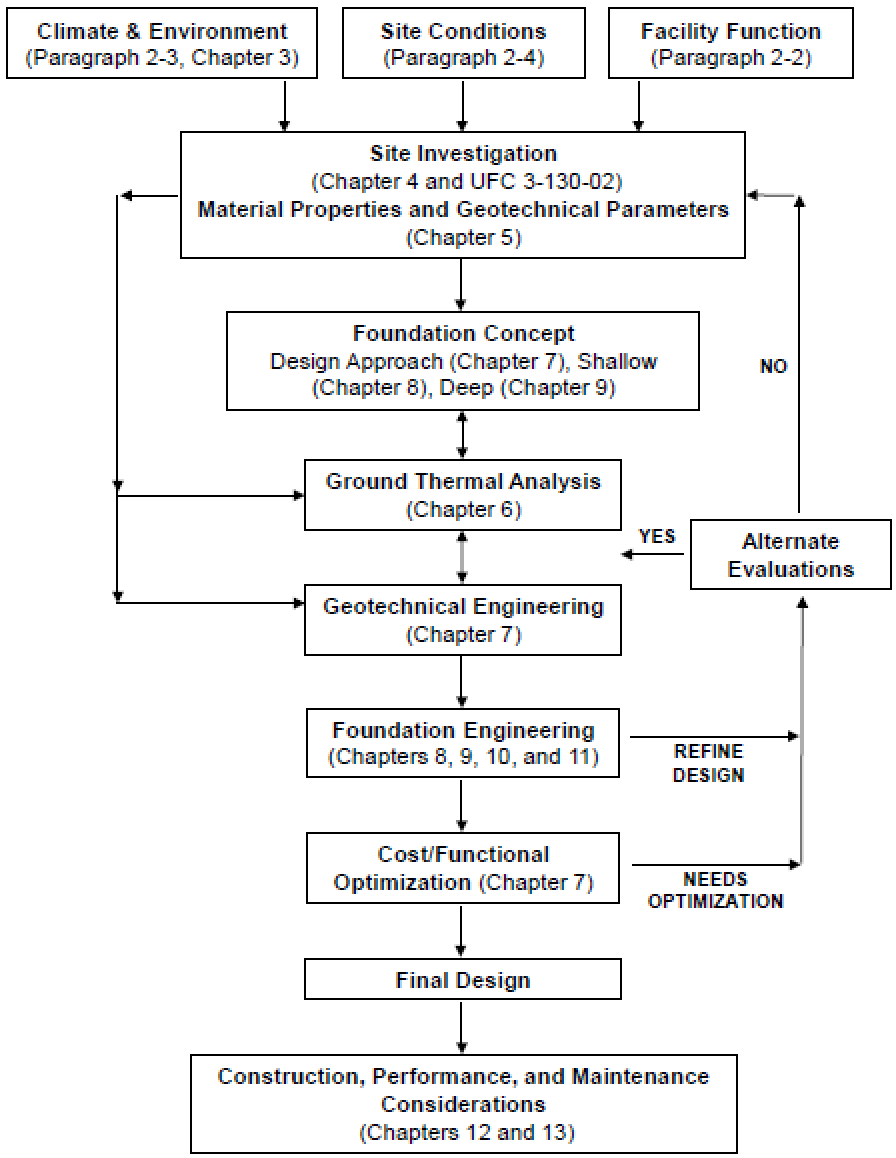
The planning, design, construction, and maintenance of foundations in the Arctic and Subarctic are affected by the unique conditions found in these regions, including the presence of permafrost and deep seasonal frost, extreme air temperatures, and sensitive environmental conditions. Complex supply and construction logistics associated with remote locations add to these challenges. Planning and formulating the foundation concept is an important first step in the design process. Figure 2-1 illustrates general steps to follow when evaluating foundations. As shown in Figure 2-1, facility function, site conditions, climate, and environment need to be considered early in the process because these considerations influence the geotechnical design parameters, the site investigation approach (see UFC 3-130-02), and the laboratory testing approaches. Figure 2-1 also shows how subsequent steps may provide feedback loops, leading to further iterations of site characterization and design before a final solution is selected.

2-2 FACILITY FUNCTION AND OTHER PLANNING CONSIDERATIONS.

The facility function helps define the level of site investigation required and relates to design loads and design life, with mission-critical facilities and life safety concerns typically having more stringent design criteria. Design life is an important consideration because, as noted in paragraph 1-1.2, frozen ground is subject to changes in behavior over time that may be the result of many factors. Changes in frozen ground behavior may include the following:

- Thaw settlement due to warming ground temperatures;
- Seasonal frost heave due to freezing of frost-susceptible soil;
- Changes in active layer depth due to changes in surface conditions;
- Differences in response to load duration and type (such as creep under long-term loads or loss of adfreeze strength due to vibratory loading);
- Changes in soil response because of frost heave; and
- Changes in material properties, depending on factors such as duration of load, change in ground temperature, change in surface conditions, or the duration of load and type of loading.

Figure 2-1 Arctic and Subarctic Foundation Evaluation Process



2-2.1 Approvals and Permits.

See UFC 3-130-01, paragraph 1-13, for the general approval and permit processes for Arctic and Subarctic construction.

2-2.2 Risk and Resilience.

See UFC 3-130-01 and UFC 2-100-01, *Installation Master Planning*, for a discussion of risk and resilience. The concepts of reliability-based design are incorporated into industry standard documents such as American Society of Civil Engineers (ASCE) Standard 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. Risk assessment and infrastructure vulnerability or resilience assessment are emerging topics for cold regions engineering, and guidance is limited. However,

Figure 2-1 illustrates a feedback loop showing how a design evolves as different factors are considered.

2-2.3 Planning and Logistical Considerations.

In the Arctic and Subarctic, foundation systems are often significant cost items affected by facility use and operational constraints. For example, hangars must have at-grade access for aircraft and require special foundation systems to control potential differential movement between the structure and the apron, whereas one- or two-story buildings may be more easily elevated to decouple heat flow from the building into the underlying soil and ensure permafrost preservation. See UFC 3-201-01, *Civil Engineering*, to conduct a preliminary analysis of the existing conditions at the site; this might include conducting a geotechnical site investigation or a topographic survey and documenting environmental considerations. See UFC 3-130-02 for site analysis topics specific to the Arctic and Subarctic. Installation-specific design preferences and standards may also apply. These installation-specific issues must be considered with input from responsible engineering and operations personnel as part of the system design analysis.

2-2.3.1 Remote Site Logistics.

Military installations in the Arctic and Subarctic are frequently in remote locations and may only be seasonally accessible. Remote site logistics must be considered because these will differ with location and may include seasonal restrictions on access to some sites due to shipping arrival and departure restrictions caused by sea ice and weather and mobility changes that occur as the ground freezes and thaws. Construction schedules may dictate procuring materials up to 12 months in advance or prepositioning equipment and materials because of seasonal restrictions on access. Careful planning is required to establish and maintain construction schedules. Project design teams should be consulted early in the planning process to help identify project criteria with significant logistical impacts.

Modular construction techniques and prefabricated elements are important for military construction because these facilities may need to be expediently constructed in all seasons. Where road or airfield access was possible, truck- and airlift-capable modules have been used successfully in Alaska to expedite the construction of facilities. Additionally, large sealift modules weighing greater than 5,000 short tons (4,500 metric tons) have been used to deploy complex facilities when there were limited windows of operation. If heavy modules are to be moved, it is critical to design roads and module offloading facilities to accommodate loads imposed by self-propelled module transporters used to move heavy modules. Bridges for river crossings are especially important during module movement, and local ground conditions or other logistical considerations will dictate the locations of suitable crossings.

2-2.3.2 Personnel and Equipment.

Personnel and equipment requirements must also be considered. The efficiency and productivity of personnel and equipment are reduced when working in low temperatures, and the combination of wind and blowing snow can create major construction and operational problems even when the total precipitation is low. Equipment often requires winterization to ensure proper operation during periods of very low air temperatures. Logistics may not allow properly sized equipment to be used, thereby constraining the earthwork and foundation construction. See UFC 3-130-01 for additional resources on personnel and equipment operations.

2-2.4 Foundation Materials.

Specific materials, such as low-temperature steel or cement and grout formulated for placement at freezing temperatures, are often required for constructing Arctic and Subarctic foundation systems to ensure proper performance. In addition, earthworks may require nonfrost-susceptible soil (NFS). Specialized cold regions building design criteria and guidance are fully discussed in UFC 3-130-04.

2-3 CLIMATE AND ENVIRONMENT.

Climate and environment are two major elements to consider when planning projects and selecting foundation alternatives in the Arctic and Subarctic. For general information on environmental conditions, see UFC 3-130-01, reports such as *Permafrost and Related Engineering Problems in Alaska,* by Ferrians et al., and other supplemental references listed in Appendix C.

2-3.1 Climate Models and Predictive Tools.

Climate refers to the average weather conditions described statistically over periods of months to years, while *weather* refers to short-term variations in the state of the atmosphere (for example, wind, air temperature, cloudiness, and moisture) that occur over a period of minutes to about 15 days.[1] Climate-related inputs have traditionally been estimated by interpolating datasets that are often limited. While using historical data may be appropriate for estimating conditions in the next 10 to 20 years, observed trends suggest that these data may be less suitable for predicting climate more than 30 to 40 years in the future. Therefore, current practice is evolving toward using global climate models (GCM) to understand both the magnitude and uncertainty of possible changes. Chapter 3 and paragraph A-5 contain further discussion of the application of GCMs and climate modeling.

In addition to GCMs, there are predictive tools, such as the Scenarios Network for Alaska + Arctic Planning (SNAP) tool that was created by the University of Alaska Fairbanks and is available on their website (www.uaf-snap.org). SNAP is based on an average of five GCMs and can be used to facilitate estimating factors such as future air temperature and precipitation when a full analysis of GCM models is not warranted due to limitations in scope, schedule, or budget. Considerable judgement is required when selecting climate inputs for use in design, whether from specific tools or GCMs. Limitations and assumptions built into models must be understood before adopting the results as a basis for design.

---

[1] *Glossary of Permafrost and Related Ground-Ice Terms*, Harris et al.; *Multi-Language Glossary of Permafrost and Related Ground-Ice Terms*, van Everdingen.

2-3.2 Environmental Considerations.

Paragraphs 2-3.2.1 through 2-3.2.4 describe aspects of the environment that can affect site conditions over the life of the project. These elements are also significant factors in ground thermal analyses (see Chapter 6) and are used to forecast the depth of seasonal frost penetration and changes in ground temperature over the life of the project.

2-3.2.1 Vegetation.

The presence or absence of vegetation on a site affects the surface energy balance and ground thermal regime in complex ways.[2] For example, vegetation provides shading that helps keep solar effects low in summer, but it can also enhance snow accumulation that insulates the ground surface, thereby reducing winter cooling. Figure 2-2, which is based on a study of permafrost dynamics near Fairbanks, Alaska, illustrates the effects of vegetation on the depth of the active layer and the top of permafrost.

2-3.2.2 Air Temperature.

In the Arctic and Subarctic, air temperatures have been increasing and are expected to increase further, based on both observed trends and future projections. Air temperature is an important driver of changes in ground surface temperature and, thus, is a factor in the design of shallow and deep foundation systems and passive refrigeration, such as thermosyphons. GCMs tend to have a higher level of agreement (less uncertainty) regarding future air temperature than other environmental parameters. See UFC 3-130-01 for additional information.

2-3.2.3 Precipitation.

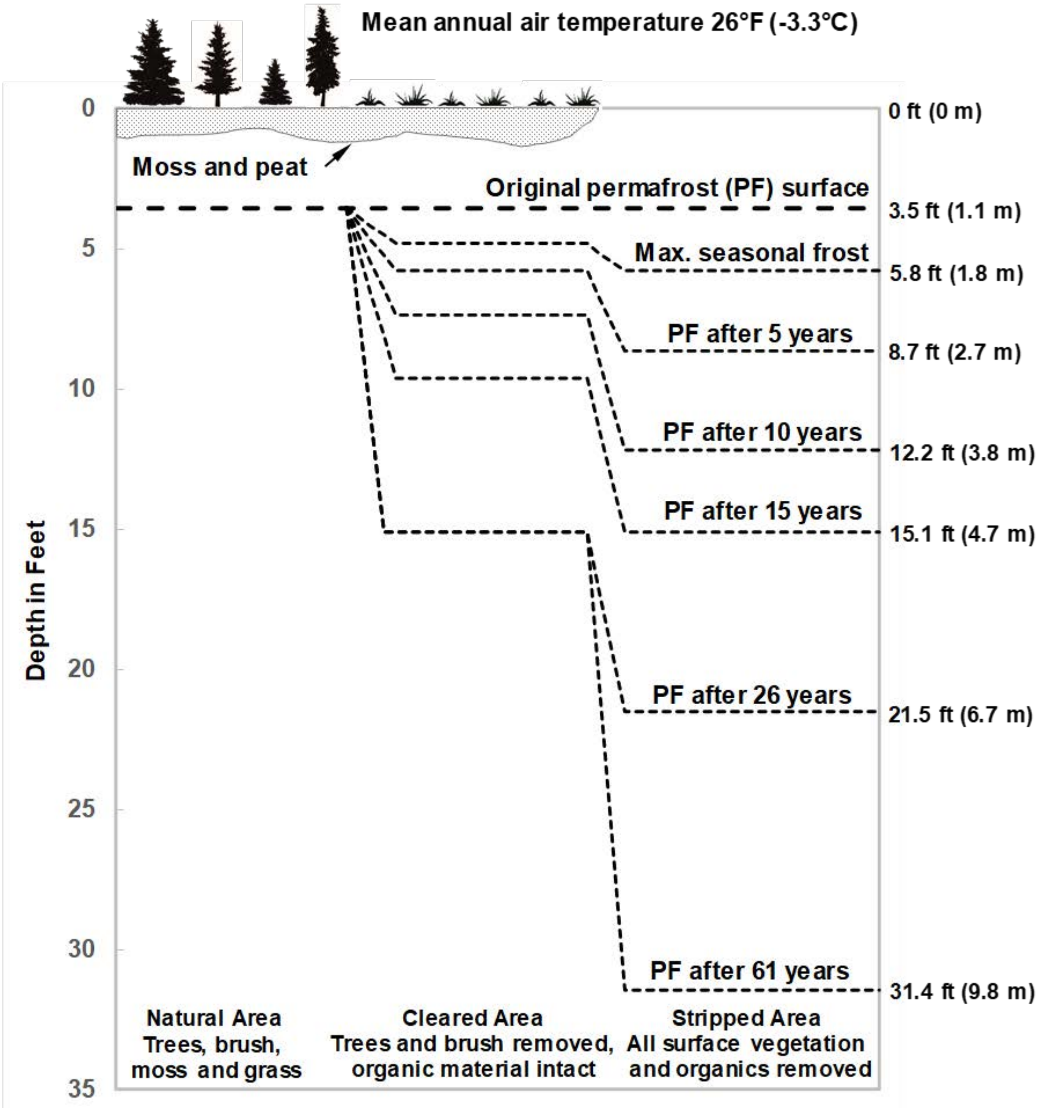
2-3.2.3.1 Effects.

Precipitation in the form of rain or snow can alter ground conditions. Snow insulates the ground surface, locally affecting ground temperature and the depth of the active layer in permafrost areas. Changes in precipitation can also lead to alteration of drainage patterns and saturation in subsurface materials. In seasonal frost areas, increased saturation can lead to increased frost heave and to soil strength changes that affect the performance of horizontal structures. Developing appropriate design criteria for precipitation and runoff may require considering future conditions, which can be predicted using GCMs. However, judgment must be used when interpreting predictions of future precipitation because these often involve a greater amount of uncertainty than temperature predictions (see paragraph 3-3.2).

---

[2] “Permafrost and Terrain Conditions at Northern Drilling-Mud Sumps: Impacts of Vegetation and Climate Change and the Management Implications,” Kokelj et al.; “Ground Temperatures and Permafrost Warming from Forest to Tundra, Tuktoyaktuk Coastlands and Anderson Plain, NWT, Canada,” Kokelj et al.

Figure 2-2 Permafrost Degradation and Vegetation Effects



Source: "Permafrost Dynamics at the Fairbanks Permafrost Experimental Station Near Fairbanks, Alaska," by Douglas et al., Figure 9. Reproduced with permission of the International Permafrost Association.

2-3.2.3.2 Volume and Runoff.

Precipitation volume and patterns of runoff are changing due to changes in climate. These changes influence the design of drainage and hydraulic structures in various ways:

- They exacerbate permafrost degradation, requiring relocation of drainage structures.
- They can affect both surface water and groundwater flow, creating design issues such as increasing aufeis and thermo-erosion of permafrost.

- Increased surface water flow may cause flooding if culverts are not appropriately sized to accommodate increasing flows over time.
- An increase in ponded water intensifies the degradation of permafrost and increases the total depth of thawed soil and the formation of taliks.
- Changes in drainage pathways can lead to increased pore pressures, in turn reducing slope stability and altering the seismic hazard, because shallow surface slope failures may increase if these materials become saturated, and the potential for liquefaction may increase with changes in saturation.

Chapter 11 presents additional drainage considerations.

2-3.2.3.3 Snow Accumulation.

The accumulation of snow around structures must be considered during design. Blowing snow that can cause snow drifts influences the orientation of the facility and the type of foundation that is selected. Specialized modeling may be required to understand snow accumulation patterns for complex structures or for sites with multiple components or terrain variation. See UFC 3-130-01 for information on snow drifts.

2-3.2.4 Wind.

Wind affects surface energy balance and knowledge of wind speed may be required for some analyses of ground freezing. See UFC 3-130-01 for a discussion of snow drifting, wind, and wind chill. Buildings must be designed to ensure snow does not accumulate beneath elevated structures or create drifts that impede access. Deep snow drifts, especially at the margins of work pads and embankments, can affect the thermal balance and result in unanticipated accumulations around buildings.

2-4 SITE CONDITIONS.

Subsurface conditions at sites in the Arctic and Subarctic may be underlain by continuous or discontinuous permafrost or may be seasonally frozen (absent of permafrost). Each of these conditions poses unique challenges for the foundation designer that require some level of site investigation and field testing, coupled with laboratory testing, to determine appropriate geotechnical properties. Ground temperature monitoring, as discussed in UFC 3-130-02, must be considered at sites in permafrost areas. As illustrated in Figure 2-1, the design properties selected will also be influenced by the climate, environment, and facility type or function. Chapter 4 provides further details on site conditions.

2-4.1 Permafrost.

The presence of permafrost is a significant factor to consider when designing foundations; the effects of thawing, creep under sustained load, and changes in strength parameters due to changes in ground ice content and temperature must be considered. The engineering parameters of frozen ground include soil type, soil or rock temperature, moisture (ice) content, saline content, bulk unit weight, unfrozen moisture content, and structure of ground ice. Chapter 5 presents a general discussion of the material properties of frozen ground.

Although ground temperature is used to define permafrost, for engineering purposes ice content and thaw stability are of critical importance when discussing frozen ground. Figure 2-3 and Figure 2-4 illustrate the change that can occur when frozen ground containing excess ice undergoes a phase change from the frozen to the unfrozen state. Note the loss of structure and the production of excess moisture as free water.

Figure 2-3 Frozen Silt with Excess Ice

Figure 2-4 After Thawing (Settlement and Strength Loss)

2-4.1.1 Standard Terminology and Classification.

For definitions of terms describing frozen ground for engineering purposes, see UFC 3-130-01 and ASTM International (ASTM) Standard D7099, *Standard Terminology Relating to Frozen Soil and Rock*. ASTM D7099 references other documents, such as *Multi-Language Glossary of Permafrost and Related Ground-Ice Terms,* by van Everdingen, and *Glossary of Permafrost and Related Ground-Ice Terms,* by Harris et al., that include terminology for permafrost, ground ice, and cryogenic processes.

During site investigations, frozen soil and rock must be classified according to ASTM D4083, *Standard Practice for Description of Frozen Soil (Visual-Manual Procedure)*, in addition to standard logging procedures. This standard describes the classification of important conditions such as ice bonding and the presence of excess ice.

2-4.1.2 Ground Temperature—Seasonal Change.

Ground temperatures change seasonally in the Arctic and Subarctic. Therefore, seasonal freezing and thawing are design considerations in both the Arctic and Subarctic. Additionally, when permafrost is present, variations in ground temperature with depth must be considered during foundation selection and design. The behavior of frozen ground is both temperature and time dependent, and properties such as adfreeze strength can change from strong to weak depending on the season and loading conditions.

Ice strength is a function of temperature and applied stress. In general, the mechanical properties of frozen ground, such as stiffness, improve or increase as ground temperatures decrease. Stiffness dramatically decreases when soils, and the ice within them, change from frozen to thawed. Therefore, it is beneficial to prevent frozen ground from warming and, in some cases, to cool the ground through a combination of refrigeration and insulation. However, the magnitude and duration of load application are also significant because ice in the foundation materials will creep over time.

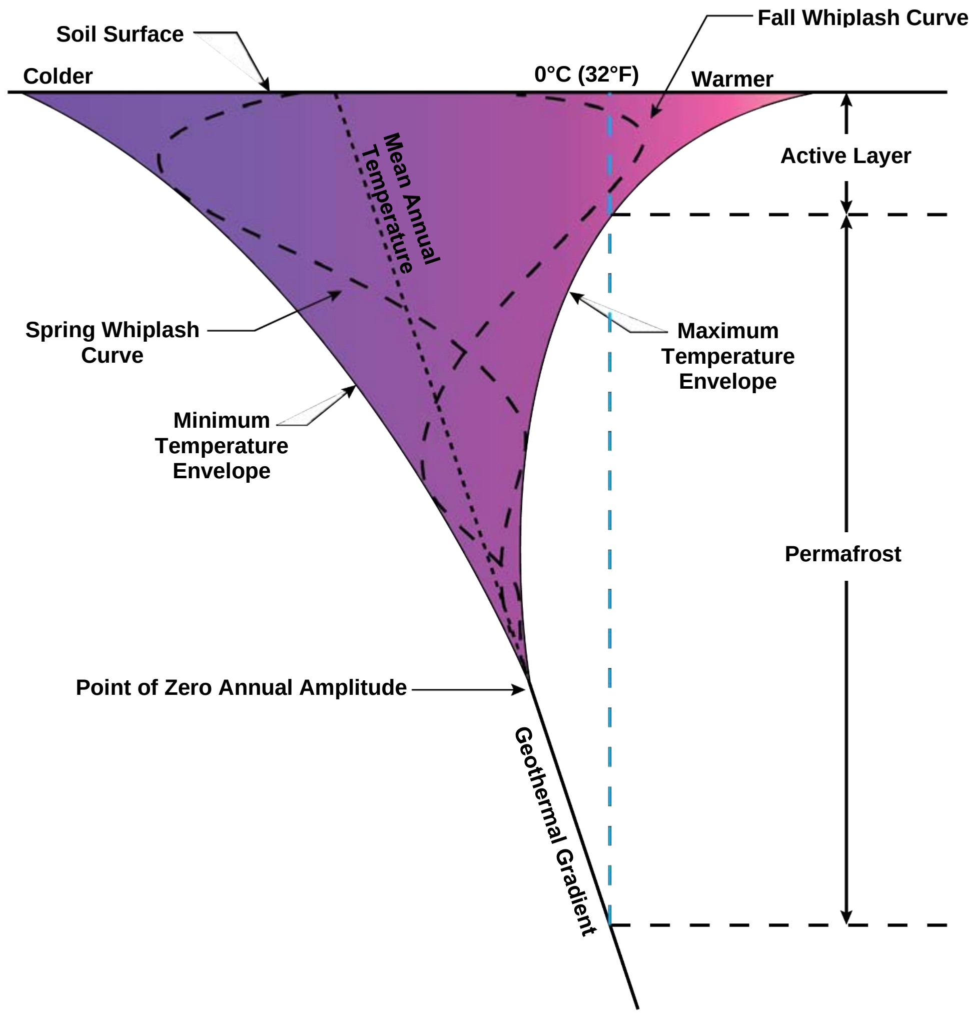
2-4.1.3 The Trumpet Curve.

A trumpet curve like that shown in Figure 2-5 is often used to depict the range of ground temperatures that occur at depth over time. The Figure 2-5 curves are generalized and trumpet curves will differ at each site depending on site conditions and the site's location within the Arctic and Subarctic. Trumpet curves are useful for illustrating important features that are commonly referred to in literature and in engineering documents, such as the following:

- Active layer: The zone of seasonally unfrozen ground extending to some depth below the ground surface in permafrost areas, or the depth of seasonally frozen ground in nonpermafrost areas.
- Whiplash curve: Ground temperature at a given moment; in aggregate, these form the trumpet curve.
- Trumpet curve: The envelope of ground temperature bounding all whiplash curves. The shape and limits of the trumpet curve may shift right or left depending on ground temperature and with time at a given site in response to changes in ground temperature.
- Point of zero annual amplitude: The point where the average ground temperature does not change seasonally.

The zone within 1 ft to 6 ft (0.3 m to 1.8 m) below the base of the active layer is sometimes referred to as the *transient layer*. The transient layer is not defined by its thermal state but is instead characterized as an ice-rich zone that acts as a thermal buffer to protect the underlying permafrost due to its relatively higher ice content and the significant heat needed to thaw this layer.[3] This layer can thaw partially or completely when the active layer deepens due to factors such as climate change or site development, resulting in significant thaw settlement. In areas where permafrost has been degraded, the transient layer may not be present.

Figure 2-5 Trumpet Curve Bounding Changes in Ground Temperature with Depth



2-4.1.4 Sources of Ground Temperature Data.

Direct measurement of ground temperature is preferred during the definition of site conditions, which will support the final design. During planning, site-specific data may not be available, and in this case, reference data can sometimes be obtained from other sites that are part of a global permafrost monitoring network and from UFC 3-130-01. Predictive tools, such as the Permafrost Temperature Tool from the University of Alaska Fairbanks Geophysical Institute Permafrost Laboratory, are also being developed to

[3] "The Upper Horizon of Permafrost Soils," Shur; "The Transient Layer: Implication for Geocryology and Climate-Change Science," Shur et al.

facilitate assessment of ground temperatures within 3 to 6 ft (1 to 2 m) of the ground surface. Synthetic ground temperature profiles can also be generated using numerical modeling, but reference data are still needed for calibration of these models (see Chapter 6).

2-4.1.5 Permafrost Distribution and Extent.

Gathering sufficient baseline data about site conditions in permafrost areas, including ground temperature, the heterogeneity of ice content, and soil and rock types, is an important aspect of early development planning. This is discussed further in UFC 3-130-02. It is important to consider the vertical extent of permafrost present at a site and to understand the ground temperature profile at a given location when planning projects. In the absence of site-specific data, refer to UFC 3-130-01 and to regional maps produced by regional governmental agencies or to other information in technical literature that can provide context that may be useful for estimating baseline conditions for planning studies.

The depth of permafrost exceeds 1,000 ft (305 m) along the Arctic coast of North America, and average ground temperature may be approximately 19°F (−7°C), while further south or in areas such as the Yukon-Kuskokwim Delta and interior Alaska, permafrost is discontinuous or sporadic, with ground temperature warmer than 28°F (−2°C). At a regional scale, climate is the main factor controlling permafrost distribution. At a local scale, permafrost conditions are also related to the local terrain and geological history. The permafrost–terrain relationships in the zones of discontinuous permafrost are generally more complex than those in the continuous zone.[4] Permafrost in the discontinuous zone is also typically warmer and more sensitive to factors such as terrain, vegetation, climate, and site development. The presence of ice-rich or saline permafrost at relatively shallow depths (<50 ft [15 m]) will also affect the overall performance of foundation systems.

2-4.1.6 Submarine Permafrost.

Special attention is required when designing infrastructure or utilities, such as pipelines or subsea cables, at the transitions between onshore and offshore permafrost areas. Historic sea level changes around coastal areas have resulted in nearshore areas where soil salinity may cause unique foundation engineering concerns. In these areas, the permafrost soil may be unbonded because the soil salinity can exceed that of seawater (which freezes at approximately 28.4°F [−2°C]). In these areas, it may be necessary to add additional cooling (such as passive thermosyphons) to foundation systems, especially in transition areas crossed by pipelines and other utilities.

2-4.1.7 Soil Salinity.

Soil salinity is an important material property to define during site investigation because it affects both ice bonding and soil strength. Depending on the depositional history at a site, it may be a significant design consideration, resulting in unfrozen moisture content,

[4] *The Periglacial Environment*, French.

brine pockets, and the presence of soil that behaves as if it is unfrozen. Paragraph 5-3.1 presents an additional discussion of soil salinity and its effect on material properties.

Saline permafrost is found in coastal areas of the Arctic that were submerged during periods of sea level rise and marine sedimentation and in areas, such as around Hudson Bay, that have experienced isostatic uplift. Saline soil is also found in permafrost areas with limited precipitation and relatively dry climates, such as the Tibetan Plateau.[5] For engineering purposes, salinity values are typically reported as concentrations in parts per thousand (ppt), with values greater than 10 to 12 ppt being high enough to influence mechanical behavior. Values up to 30 ppt are not uncommon, but higher concentrations, such as 80 to 100 ppt, also occur and are of particular concern because of the reduction in shear strength and the increased creep rate associated with frozen saline soil (see paragraph 9-5.3.4.2).

2-4.2 Seasonal Frost When Freezing Index Greater than 4,500°F-Days.

2-4.2.1 IBC and SEI/ASCE 32.

Section 1809.5 of the *International Building Code* (IBC) addresses frost protection of shallow foundations and requires, with limited exceptions, that the foundation extend below the frost line; be constructed in accordance with SEI/ASCE 32, *Design and Construction of Frost-Protected Shallow Foundations*; be erected on “solid rock”; or bear on soil that is permanently frozen. However, as noted by SEI/ASCE 32, it “applies to buildings on potentially frost susceptible ground with slab-on-ground or suspended floor foundations” but “does not apply to buildings on permafrost, to areas with mean annual outdoor air temperatures less than 32°F (0°C), or to areas with air-freezing indexes greater than 4,500°F-days (60,000°C-hr).”

The limitation on the applicability of SEI/ASCE 32 precludes its use in most of Alaska and other Arctic and Subarctic areas. The concepts outlined in this guidance can still be applied but require an extension to colder climates, such as in *Frost Protected Shallow Foundations (FPSF) for Interior Alaska Freezing Indices Between 4,000 and 8,000 Degree-Fahrenheit-Days: A Research Report,* by Perreault. In the absence of local building codes or other guidance, the DoR must be familiar with and apply fundamental principles related to permafrost and cold regions ground engineering, and perform thermal analyses when appropriate, to show that the design will not be affected by the freezing of foundation soils.

2-4.2.2 Floor Insulation.

Building foundations often incorporate floor insulation to enhance energy efficiency. Floor insulation in proximity to foundation elements reduces heat flow to the foundation soils, which may increase insulation requirements for shallow frost-protected foundations, even in areas where SEI/ASCE 32 is applicable. Areas with high heat flux, such as vehicle entrances and personnel doors, are especially susceptible to frost

[5] *Geocryology: Characteristics and Use of Frozen Ground and Permafrost Landforms*, Harris et al.

penetration below foundation elements and may require additional thermal analysis. Frost effects on foundations are discussed further in Chapter 7 through Chapter 9.

2-4.3 Topography and Slope Geohazards.

Topography and slope orientation affect permafrost distribution and properties, due mainly to the absorption of solar radiation. In general, the effect will be greater in areas of discontinuous permafrost. For instance, in the discontinuous permafrost zone, frozen ground is more common on north-facing slopes, where absorption of solar radiation is lower; the active layer on north-facing slopes is also generally thinner than on south-facing slopes. Higher levels of solar radiation absorption also occur due to reflection from the walls of buildings.

Slopes in permafrost areas can migrate downslope over time due to the force of gravity and depending on ground ice content, active layer moisture, and ground ice temperature. Some common slope movements that constitute geohazards and associated foundation engineering issues that must be considered when planning a project are discussed in paragraph A-7 and in other publications, such as in Chapter 25 of *Landslides: Investigation and Mitigation,* by Turner and Schuster, and in *National Assessment of Shoreline Change—Historical Shoreline Change Along the North Coast of Alaska, U.S.–Canadian Border to Icy Cape,* by Gibbs and Richmond.

2-4.4 Earthwork (Cut and Fill).

Development in the Arctic and Subarctic changes the local thermal regime in ways that may cause long-term degradation of permafrost or initiate changes in ground conditions that could affect foundation support and site stability. In general, unless engineering measures are implemented to mitigate thawing, earthwork leads to increased permafrost degradation due to changes in the surface energy balance. Earthworks may also modify the flow of surface water in ways that could lead to ponding at the toe of slopes or concentrate drainage along ditches that will enhance permafrost degradation if the drainage crosses ice-rich areas. In addition, cut slopes will expose underlying permafrost due to the removal of protective vegetation, which will lead to thawing and may initiate slope instability.

2-4.5 Surface Water Bodies.

Surface waters are often underlain by thawed zones, especially if they do not annually freeze to the bottom. Foundations and embankments located near lakes can be affected by degrading permafrost around the water body. These thawed zones are most significant when routing linear structures.

2-4.6 Site History.

An understanding of the changes in vegetation that may have occurred or been initiated by events such as wildfires, earthwork, or site development helps engineers determine appropriate foundation types.

2-4.6.1 Wildfire.

Wildfires occurring in areas of permafrost, including on tundra terrain, can trigger permafrost degradation with an increase in the active layer.[6] Primarily a concern during site selection, permafrost in areas that have had wildfires is likely to be different than in surrounding unburned areas. For instance, the insulation properties of burned vegetation are lower than for living vegetation, and, as a result, this change in insulation property can trigger a deepening of the active layer, an increase in permafrost temperature, and the melting of ground ice.

2-4.6.2 Past Development.

Past development and use of a site may affect permafrost conditions and is therefore an important consideration. While development is often easy to identify in the Arctic, in the Subarctic, where vegetation is more abundant, past use may not be evident, even though the past use may have already begun a process of long-term changes in the ground thermal regime.

2-4.6.3 Adjacent Structures.

It is important to consider the location of a facility and the effect it may have on other structures in the area. Adjacent structures in the Arctic and Subarctic can be affected by seemingly minor shading that locally changes environmental conditions and soil temperatures, changes in wind patterns and snow drifting that result in increased thawing, or changes in drainage that affect surface water and groundwater movements. Snow drifting may also affect building egress and increase snow removal requirements.

[6] “The Response (1958–1997) of Permafrost and Near-Ground Temperatures to Forest Fire, Takhini River Valley, Southern Yukon Territory,” Burn.

CHAPTER 3 CLIMATE

3-1 INTRODUCTION.

Climate is a key consideration for Arctic and Subarctic ground engineering projects because temperature, precipitation, and wind regimes can affect the thermal conditions of permafrost and partially frozen ground (see paragraph 2-3). Climate change has the potential to alter existing conditions in ways that may affect foundation design. It is important to understand how future climate projections can be considered for assessments of frozen ground to improve the resilience of foundation designs.

This chapter discusses the potential impacts of climate change on key climate variables associated with foundation engineering and outlines a strategy for using future climate projections to inform designs.

3-2 CLIMATE CHANGE CONSIDERATIONS.

Climate projections may be used to gain valuable insights on the magnitude and uncertainty of projected changes in climate from a range of GCMs and emissions scenarios. General information and a summary of the overall climate projection trends can be found in UFC 3-130-01.

The effects of climate change and site development are especially important considerations that must be addressed in design and construction planning to ensure that designs are resilient and adaptable. The following effects may need to be considered:

- Changes in ground ice temperature due to rising air temperatures.
- Changes in liquefaction potential that may occur due to ground thawing, whether natural or because of site activities.
- Changes in drainage requirements during the life of the facility that may occur due to changes in precipitation associated with changing climate in the Arctic and Subarctic. For example, increased precipitation may require larger-than-normal drainage structures or the incorporation of resilient design features that allow easy adaptation in the future. These changes may include shifts in natural drainages, increased flow, or changes in erosion-control requirements.
- Changes in coastal erosion processes are especially important in areas where changes in sea ice extent are creating longer open water seasons and increased thawing of coastal permafrost.

3-2.1 Global Climate Models.

As of 2024, future climate conditions are typically projected using GCMs that involve the mathematical representation of global land, sea, and atmospheric interactions over a long period of time. These GCMs were developed by various government agencies, but they share a number of common elements described by the Intergovernmental Panel on

Climate Change (IPCC). Climate projection data are available from over 30 GCMs in reports available from the IPCC (see paragraph A-5.1).

3-2.2 Downscaling Climate Data and Sources.

The climate projection resolution of GCMs is generally too coarse for direct use in foundation engineering applications because they do not resolve weather and extreme weather patterns or climatology at local scales. Rather than use GCM output directly, there are different options for analyzing climate projections at a regional scale. Downscaling methodologies incorporate region-specific information in various ways to improve the representation of climate and the temporal and spatial resolution of GCMs. Downscaled climate model outputs are available from a variety of sources, depending on the region being considered. Review available downscaled future climate data sources to select appropriate climate model outputs to inform foundation designs. To estimate climate change effects using downscaled future climate data, compare a long-term average future period, which will vary depending on the type of project and its design life, to a long-term modeled baseline period. See paragraph A-5.2 for data and resources available as of 2024.

3-3 KEY ENVIRONMENTAL PARAMETERS.

The following key parameters, estimated using downscaled GCM output, are used to inform foundation engineering design in a changing climate:

- Air temperature: Increasing air temperature will influence ground temperature. This will result in thawing of permafrost, thereby affecting ground engineering designs that assume frozen ground.
- Precipitation (rain and snow): Precipitation in the form of rain and snow will both remove heat from and insulate the ground. Changes in precipitation patterns and related consequences (such as water ponding or increased drainage) can be important design considerations when evaluating uncertainty in long-term performance.
- Wind: Projected changes in wind speeds affect surface energy balance and are especially important to consider when evaluating the performance of passive thermosyphons when selecting appropriate boundary conditions for thermal models (see paragraph 6-4.2).

Using a multi-model ensemble of climate projections, changes in the key environmental parameters may be estimated across a set of climate models and emissions scenarios to gain an understanding of the magnitude and uncertainty of projected changes from an established modeled baseline period. Paragraphs 3-3.1 through 3-3.3 describe considerations when using climate projections for this set of key environmental parameters.

3-3.1 Air Temperature.

In the Arctic and Subarctic, air temperatures are expected to increase and be more variable, given both observed trends and projections. GCMs tend to have a higher level of agreement (less uncertainty) for air temperature than for other environmental parameters. In addition, it may be necessary to consider uncertainty in air temperature projections for some foundation engineering designs. For example, thermosyphons may need to be sized to take advantage of short periods of colder-than-average temperatures rather than using annual averages that include periods when the thermosyphons may not be effective due to warm air temperatures.

SNAP downscaled climate projections include multiple climate models and emissions scenarios, including representative concentration pathways (RCP)4.5 and RCP6.0 (moderate emissions) and RCP8.5 (high emissions). See paragraph A-5.1 for discussion of RCPs. Using SNAP's set of downscaled climate projections, the mean annual temperature in Fairbanks, Alaska, under RCP4.5 is projected to increase by 4.7°F (2.6°C) in the near term (2030–2039) and by 7.6°F (4.2°C) in the longer term (2090–2099) relative to historical climate conditions under RCP4.5. Under RCP8.5, a mean annual temperature increase of 5.4°F (3.0°C) in the near term and 22.3°F (7.0°C) in the longer term are projected. With a wide range of possible future temperatures, uncertainty may be considered to inform foundation engineering design based on the design lifespan and level of risk involved.

3-3.2 Precipitation (Rain and Snow).

Precipitation changes surface and subsurface water flows related to the drainage and degradation of frozen ground and also insulates the ground when in the form of snow; hence, it is a significant design consideration. While climate models tend to have greater agreement regarding projected changes in temperature, projections of precipitation often involve a greater amount of uncertainty due to the finer spatial and temporal resolutions involved in the physical processes that are being modeled.

Using downscaled climate projections from SNAP, annual total precipitation for Fairbanks, Alaska, is projected to increase by 18% in the near term (2030–2039) and by 25% in the long term (2090–2099) under RCP4.5. Under RCP8.5, an annual total precipitation increase of 18% in the near term and 52% in the long term is projected. With a wide range of future total precipitation amounts (along with mean air temperature), more precipitation may be projected, with a greater portion falling as rain. The timing and magnitude of snow depth may also change, depending on how precipitation and temperature amounts are projected to change seasonally and the uncertainty across climate models and emissions scenarios. These changes in climate may be considered for engineering foundation design because they may affect permafrost depths and the underlying soil thermal properties.

3-3.3 Wind.

Wind affects the surface energy balance and must be considered when evaluating model inputs, such as n-factors, that are used to predict changes in the depth of thaw or in other boundary conditions noted in paragraph 6-4.2. Wind is also a significant factor when evaluating the performance of passive thermosyphons. Wind and related icing also have a significant effect on horizontal loadings and can result in harmonic motions that are accounted for in the IBC and other building codes. Historically, global wind speeds have been decreasing; however, in recent years, wind speeds have begun to increase.[7] Like precipitation, model agreement is typically low for wind speeds due to the finer spatial and temporal resolutions involved in the physical processes that are being modeled.

The community wind tool provided by SNAP provides historical and projected wind speeds for several Arctic communities. For Fairbanks, Alaska, this tool demonstrates that wind events above 7 mph (11.3 kph) may become more common in the future. This is especially true for durations of 12 hours or less and for wind events of 11.5 mph (18.5 kph) or less. More detailed information regarding projected wind speeds can be obtained from downscaled datasets such as the National Aeronautics and Space Administration (NASA) Earth Exchange Global Daily Downscaled Projections (NEX-GDDP). Extreme wind speeds are generally not well represented by climate models.[8] Projected wind speeds may be an important consideration for engineering foundation design because more frequent wind events may increase blowing snow, which can form drifts that insulate the ground and lead to increased thawing and can cover foundation elements that should remain exposed. Conversely, more frequent wind events may increase ground heat loss through convection, which may be beneficial to cooling and to the performance of foundation systems.

3-4 CLIMATE UNCERTAINTY.

3-4.1 Climate Projections.

When using climate projections, it is important to understand the limitations and assumptions built into the models before adopting the data as a basis for design. Because climate models generally provide outputs in a coarsely gridded (greater than 60 mi [100 km] grid resolution) format, differences can be expected when comparing to point observations, especially for climate variables that differ on finer spatial and temporal scales (for example, precipitation and wind). When using climate projections to inform design, use downscaled climate model output to better capture site-level conditions (see paragraph 3-2.2).

3-4.2 Use of Multiple Models.

Due to differences in future climate scenarios (RCP versus shared socioeconomic pathways [SSP], as discussed in paragraph A-5.1), climate model structure, parameterization, and initialization, an ensemble of climate projections must include different representations of both current and future climate for a given location. Because no one model or climate scenario can be viewed as completely accurate, the IPCC recommends that climate change assessments use as many models and climate scenarios as possible, or a “multi-model ensemble” (see page 79, *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Stocker et al.). For this reason, the multi-model ensemble approach is used to delineate

[7] “A Reversal in Global Terrestrial Stilling and Its Implications for Wind Energy Production,” Zeng et al.
[8] “Evaluating Wind Extremes in CMIP5 Climate Models,” Kumar et al.

the probable range of results and better capture the actual outcome (an inherent unknown). Percentiles may be used to express the distribution of future climate projections while also considering each of the models in the multi-model ensemble. The selection of which percentile to use should be based on the balance between the conservatism of the geotechnical engineering inputs used for design and the consequential risks. For example, projections at the 50th percentile represent the median projections, while the projections at the 95th percentile represent an outcome where 95% of the projections are at or below this value.

3-5 CLIMATE AND CONTINUAL IMPROVEMENT.

The *Guide on Climate Change Adaptation for the Mining Sector*, prepared by Golder Associates, provides a stepwise approach to incorporating climate change adaptation into decision-making processes to increase climate change resilience at mine sites. This document is not specific to Canada and can be applied globally. The document provides a three-stage framework for incorporating climate change in decision making:

- Assessing climate risk. This assessment must include use of DoD-specific tools as applicable to the project type.
- Developing adaptation pathways.
- Implementing adaptation pathways.

In this iterative three-stage process, each stage of the cycle should be reevaluated based on the outcomes of previous stages, updates to climate projections, and changes to infrastructure. Reevaluation is based on the results of monitoring and surveilling the adaptation pathways and whether established triggers or thresholds were met. For example, the need for reassessment will arise when there are updates to the climate projections or changes to the infrastructure or operations of the mine component. The reassessment can be included as part of existing continual improvement processes.

This Page Intentionally Left Blank

CHAPTER 4 SITE INVESTIGATIONS

4-1 GENERAL.

Requirements and guidance regarding site assessment, characterization, and monitoring for Arctic and Subarctic construction are presented in UFC 3-130-02. Additional general site investigation criteria are provided in UFC 3-201-01 and UFC 3-220-01, *Geotechnical Engineering*. See paragraph A-2 for additional resources.

4-2 INVESTIGATION APPROACH.

4-2.1 Scope.

The scope of site investigations in areas characterized by permafrost or by freezing and thawing ground conditions must follow the approach outlined in UFC 3-130-02 and incorporate strategies and investigation techniques discussed in references such as *Cold Regions Pavement Engineering,* by Doré and Zubeck; *Permafrost Engineering Design and Construction,* by Johnston; and *National Standard of Canada CAN/BNQ 2501-500/2017: Geotechnical Site Investigations for Building Foundations in Permafrost Zones*, by Bureau de Normalisation du Quebec. In general, the scope of a field program should progress from broad (low resolution) reconnaissance that defines general conditions to site-specific (high resolution) investigations designed to address issues specific to the design. The actual level of investigation varies depending on the complexity of the project and may include multiple phases of field investigation.

Following initial site investigation, additional investigation may be needed to refine understanding of the subsurface conditions that are most important to foundation design and estimated construction costs, especially when foundation systems or subsurface conditions are complex. As data gaps are filled through investigation, knowledge of the site conditions will move from poor, to fair, to good or excellent, and both the site model and design will be refined.

4-2.2 Multi-phase Investigation.

The design of the Trans-Alaska Pipeline System is one example of a multi-phase investigation program. This very large project spanned many degrees of latitude and various types of permafrost and nonpermafrost terrain. Multiple site investigations were completed, beginning with early scoping and reconnaissance-level investigation, followed by site-specific investigations to generally confirm the conditions along the alignment, and other investigations to address design-specific concerns. The final level of characterization occurred during the construction process, when field design changes were made based on actual site conditions at each foundation. As the pipeline became operational, changes in terrain, drainages, and climate resulted in continuing changes to adapt to these changed conditions.

This Page Intentionally Left Blank

CHAPTER 5 PROPERTIES OF FROZEN GROUND

5-1 INTRODUCTION.

This chapter provides an overview of testing that may be required to define mechanical properties of frozen and unfrozen ground used in geotechnical analyses for projects in the Arctic and Subarctic. Soil properties may either be measured as part of field investigations and laboratory testing or estimated based on correlations in the literature.

As for conventional foundation design, the level of effort expended to determine the properties of frozen ground will depend on the complexity of the project and the foundation engineering risk to be addressed. Frozen ground properties used in design may differ depending on ground temperature and may change over the life of the facility and duration of load.

5-2 LABORATORY TESTING.

Laboratory testing is an integral part of the overall site characterization processes outlined in Figure 2-1 and a necessary component of the design if site investigations are conducted. General requirements on laboratory testing are provided in UFC 3-201-01 and UFC 3-220-01, and applicable standards for many laboratory tests are published by ASTM. However, when using available data from the literature, it is important to validate the testing conditions to ensure the results are appropriate for use for a given site because, as discussed in MIL-STD-810G, *Department of Defense Test Method Standard: Environmental Engineering Considerations and Laboratory Tests*, test data should be representative of ground conditions at the site.

5-2.1 Index Testing.

Index tests provide important data on the fundamental characteristics of soil and rock materials. Frozen soil classifications must include the Unified Soil Classification System (USCS) symbol (ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes [Unified Soil Classification System]*) and a description of the ice in the soil. For engineering purposes, a simplified visual method of characterizing the ice in frozen soil is described in ASTM D4083 and is summarized as a three-step process in Table 5-1. The classifications in ASTM D4083 are based on the size and morphology of ice and on the ice bonding and content as described in *Description and Classification of Frozen Soils,* by Linell and Kaplar, and *Guide to a Field Description of Permafrost for Engineering Purposes,* by Pihlainen and Johnston. The classifications used in ASTM D4083 can also generally be related to water transfer and freezing processes and to ice type, as discussed in *Permafrost Engineering Design and Construction,* by Johnston.

Table 5-1 Frozen Soil Classification Process

Step	Process				
1. Describe soil independent of frozen state	Classify soil by the USCS				
2. Modify soil description by description of frozen soil	***Major Group***		***Subgroup***		
	Description	*Designation*	*Description*		*Designation*
	Segregated ice not visible by eye	N	Poorly bonded or friable		Nf
			Well bonded	No excess ice	Nbn
			Well bonded	Excess ice	Nbe
	Segregated ice visible by eye (ice less than 25 mm thick)	V	Individual ice crystals or inclusions		Vx
			Ice coatings on particles		Vc
			Random or irregularly oriented ice formations		Vr
			Stratified or distinctly oriented ice formations		Vs
			Uniformly distributed ice		Vu
3. Modify soil description by description of substantial ice strata	Ice greater than 25 mm thick	ICE	Ice with soil inclusions		ICE+ soil type
			Ice without soil inclusions		ICE

Source: Adapted from ASTM D4083.

5-2.1.1 Frost Design Classification.

5-2.1.1.1 USACE System.

Table 5-2 presents the USACE frost design soil classification system from *Frost Action Predictive Techniques for Roads and Airfields, A Comprehensive Survey of Research Findings*, by Johnson et al. Frost groups are classified into eight categories, and three types of screening are used to determine frost susceptibility.

1. Soil types are determined based on the USCS, initially in the field.
2. The percentage of soil particles finer than the 8×10^{-4} in. size (0.02 mm) is determined based on measurement in the laboratory (ASTM D7928, *Standard Test Method for Particle-Size Distribution [Gradation] of Fine-Grained Soils Using the Sedimentation [Hydrometer] Analysis*).
3. Laboratory frost heave testing is performed to verify the estimated percentage estimated in step 2 (refer to paragraph 5-2.5 for a discussion of frost heave testing). Frost heave testing may not be performed on every sample and is optional, depending on project requirements.

5-2.1.1.2 Frost Heave.

Frost heave in soils occurs when soils freeze, but the extent of frost heave depends on soil type and the presence of contributing water through capillary rise determined through index testing.[1] For frost heave to occur, there must be what is sometimes referred to as the 3 Ws (water, wicking, and winter). Water must be available to create ice, wicking (capillary action) is required to bring water to the freezing front, and winter (freezing temperatures) is required to convert the water into ice. Reducing one or more of these conditions reduces the magnitude of heave or even prevents it.

5-2.1.1.3 Segregation Potential.

An alternative approach for estimating frost heave potential is to measure the segregation potential of the soil (see “Procedure for Determining the Segregation Potential of Freezing Soils,” by Konrad). See paragraph A-2 for additional resources.

5-2.1.2 Pore Water Salinity.

5-2.1.2.1 Measurement.

For geotechnical engineering purposes, the salinity of pore water in permafrost soil is measured to estimate freezing point depression and unfrozen water content. ASTM D4542, *Standard Test Methods for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer*, is used to quickly estimate the soluble salt content of soils. However, electrical conductivity methods have also been widely used. Other methods have been developed for agronomy studies and are not necessarily appropriate for comparison to historical data or application to permafrost engineering problems. It is critical to understand the test method used when comparing test results from different sources.

5-2.1.2.2 Effects.

If saline conditions are identified at a site, the design must account for the behavior of the saline permafrost. Salinity in the pore water causes a freezing point depression, resulting in frozen soil that is weaker than nonsaline soil for a given ground temperature and load duration. Saline soil will also undergo higher levels of creep than nonsaline soil at the same stress level. The presence of pore water salinity may create permafrost that is not ice-bonded because of freezing point depression (the approximate freezing point depression in soil with 10 ppt pore water salinity is 1°F [0.56°C]). Typical sediments deposited in Alaskan offshore marine environments commonly have salinities that vary between 30 to 35 ppt. Salinity at this concentration in soil results in a freezing point depression to 28°F (−2.2°C), with the result that the sediment may be classified as permafrost, but because ice-bonded soil will not form at temperatures above the freezing point depression, the soil behaves as an unfrozen material. Pockets of high salinity can also form onshore and are not uncommon in coastal areas in northern Alaska.

[1] *Frost Susceptibility of Soil: Review of Index Tests*, Chamberlain.

Table 5-2 USACE Frost Design Soil Classification System

Frost Susceptibility[1]	Frost Group	Kind of Soil	Amount Finer than 0.02 mm (% by weight)	Typical Soil Type under USCS
Negligible to low	NFS	a) Gravels	0–1.5	GW, GP
		b) Sands	0–3	SW, SP
Possibly	PFS[2]	a) Gravels	1.5–3	GW, GP
		b) Sands	3–10	SW, SP
Low to medium	S1	Gravels	3–6	GW, GP, GW-GM, GP-GM
Very low to high	S2	Sands	3–6	SW, SP, SW-SM, SP-SM
Very low to high	F1	Gravels	6–10	GM, GW-GM, GP-GM
Medium to high	F2	a) Gravels	10–20	GM, GM-GC, GW-GM, GP-GM
Very low to very high		b) Sands	6–15	SM, SW-SM, SP-SM
Medium to high	F3	a) Gravels	>20	GM, GC
Low to high		b) Sands except very fine silty sands	>15	SM, SC
Very low to very high		c) Clays, PI > 12	--	CL, CH
Low to very high	F4	a) All silts	--	ML, MH
Very low to high		b) Very fine silty sands	>15	SM
Low to very high		c) Clays, PI < 12	--	CL, CL-ML
Very low to very high		d) Varved clays and other fine-grained, banded sediments	--	CL and ML; CL, ML and SM; CL, CH, and ML; CL, CH, ML and SM

Source: Reproduced from *Frost Action Predictive Techniques for Roads and Airfields, A Comprehensive Survey of Research Findings,* by Johnson et al., Table 1.

Notes:
1. Based on laboratory frost heave tests.
2. Requires laboratory frost heave test to determine frost susceptibility.

Abbreviations:
-- = none
C = clay
G = gravel
H = high plasticity
L = low plasticity
M = silt
NFS = nonfrost-susceptible
P = poorly graded
PFS = possibly frost susceptible
S = sand
USCS = Unified Soil Classification System
W = well graded

5-2.1.3 Bulk Unit Weight.

Bulk unit weight is determined from undisturbed samples (ASTM D7263, *Standard Test Methods for Laboratory Determination of Density and Unit Weight of Soil Specimens*).

In a design context, terms like *ice-rich* and *ice-poor* may be specific to a particular design methodology. For example, permafrost with excess ice is defined as ice-rich,[2] but it also can be described in terms of frozen bulk density,[3] with densities less than about 106 lb/ft^3 (1,700 kg/m^3) exhibiting ice-rich behavior in terms of pile design. Bulk density is also related to the relative compaction and thaw stability of in situ material and engineered fills.[4] Extensive studies of the placement and compaction of frozen soil have shown the difficulty in achieving commonly specified levels of compaction, which are required if there is the potential for the materials to thaw or creep under load.

5-2.2 Thermal Conductivity and Moisture Content.

Thermal conductivity is an important property used in ground thermal analyses. Thermal conductivity values are not constant but, rather, vary with moisture content, temperature, salinity, and soil types. Information on the thermal conductivities of ice-rich permafrost in frozen and thawed states is available in “Thermal Conductivity of Some Ice-Rich Permafrost Soils,” by Slusarchuk and Watson. Thermal conductivity is measured by laboratory testing or calculated based on empirical methods such as those developed in “Thermal Properties of Soils,” by Kersten, or *Thermal Conductivity of Soils,* by Johansen. Kersten’s results are not applicable to ice-rich soils. Generally, the Johansen method gives better results for soil saturation above 10%.[5] Errors have been corrected in the original translation of Johansen’s publication with respect to peat,[6] and this new version offers improvements to the method by accounting for natural and crushed base-course material and mineral composition.

In general, unfrozen water content will decrease as ground temperatures get colder and thermal conductivity increases. Unfrozen water content and thermal conductivity are especially sensitive to changes in low-salinity soil when ground temperatures are between 28°F and 32°F (−2°C and 0°C). As salinity increases in frozen soil, so does the unfrozen moisture content and the range of ground temperatures within which the effect on thermal conductivity is significant. However, unfrozen water content is not accounted for by Kersten. Thus, it is estimated the Kersten equations calculate values for thermal conductivity within ±25% of measured values, which is arguably less variation than the natural variance due to soil inhomogeneity.[7]

---

[2] *Glossary of Permafrost and Related Ground-Ice Terms*, Harris et al.
[3] “Pile Design in Permafrost,” Weaver and Morgenstern.
[4] “Cold Regions Earthwork,” Tart.
[5]“ The Thermal Properties of Soils in Cold Regions,” Farouki.
[6] “A Generalized Thermal Conductivity Model for Soils and Construction Materials,” Côté and Konrad; “Thermal Conductivity of Base-Course Materials,” Côté and Konrad; “Estimating Thermal Conductivity of Pavement Granular Materials and Subgrade Soils,” Côté and Konrad.
[7] “The Thermal Properties of Soils in Cold Regions,” Farouki.

5-2.3 Advanced Testing.

Advanced testing is typically used to measure mechanical properties, such as creep, in uniaxial compression (ASTM D5520, *Standard Test Method for Laboratory Determination of Creep Properties of Frozen Soil Samples by Uniaxial Compression*) and shear strength under constant rate of strain (ASTM D7300, *Standard Test Method for Laboratory Determination of Strength Properties of Frozen Soil at a Constant Rate of Strain*). Other tests are used to measure unfrozen moisture content. For a general overview of frozen soils testing, see *Mechanical Properties of Frozen Soils,* by Zubeck and Yang, and Appendix C of *Frozen Ground Engineering,* by Andersland and Ladanyi.

Advanced testing of frozen soil requires specialized test apparatuses and is often conducted in a cold room to better control environmental conditions. Temperature control is an important consideration for advanced testing and may require multiple layers of insulation or circulating baths with precision controls. Samples must be maintained at an appropriate temperature that is representative of temperatures at the site. In addition, future changes in ground temperature may need to be considered in the design of the test procedures. Specialized considerations for handling and shipping frozen samples may be required.[8]

5-2.3.1 Thaw Strain.

5-2.3.1.1 Soil.

Thaw strain tests measure the total deformation that occurs upon thawing. This measurement can be a relatively simple test that provides useful index data indicative of the total settlement that may occur when frozen ground undergoes a phase change from frozen to unfrozen. Values of thaw strain can vary considerably, as shown in “Thaw Strain Data and Thaw Settlement Predictions for Alaskan Soils,” by Nelson et al., who discuss laboratory testing and report thaw strain of between 0% and 80% for a variety of soil types found in Alaska. When comparing reported values from the literature, it is important to understand the actual test setup and procedure used to measure reported values because there is no ASTM standard for this test. Figure 5-1 shows multiple thaw strain tests underway using custom fabricated equipment.

5-2.3.1.2 Rock.

Thaw strain and frost susceptibility in rock masses is related to the presence of frost-susceptible material and water within joints and infillings. If significant ice is present in a fractured rock mass, creep may also occur. Evaluation on a case-by-case basis is required.

[8] “Transportation, Preparation, and Storage of Freezing Soil Samples for Laboratory Testing,” Baker.

Figure 5-1 Thaw Strain Tests

5-2.3.2 Thaw Consolidation.

Thaw consolidation tests incorporate elements of thaw strain testing and measurement of conventional consolidation parameters after the sample has thawed. These tests measure initial strain as the sample thaws and then measure consolidation of the thawed material. For representative values determined during design and construction of the Trans-Alaska Pipeline, see “Thaw Strain Data and Thaw Settlement Predictions for Alaskan Soils,” by Nelson et al.

There is no ASTM standard for this test.[9] Hence, it is important to understand the actual test setup and procedure used to measure reported values.

5-2.4 Creep Tests.

The creep process depends on soil type, ice content, temperature, and pore water salinity; it also depends on loading rate and duration of load application. For testing procedure descriptions, see ASTM D5520 and other sources, including the following:

- *Creep of Frozen Soils*, by Sayles
- “An Engineering Theory of Creep of Frozen Soils,” by Ladanyi

[9] *Mechanical Properties of Frozen Soils*, Zubeck and Yang.

- "Uniaxial Compressive Strength of Frozen Silt Under Constant Deformation Rates," by Yuanlin and Carbee
- "In Situ Creep Properties in Ice-rich Permafrost Soil," by Savigny and Morgenstern
- "The Influence of Cryostructure on the Creep Behavior of Ice-Rich Permafrost," by Bray
- *Creep in Engineering Structures*, by Hult

Creep may occur at low stress levels. When ground temperatures are warm and conditions are ice-rich, the creep potential increases, with the result that creep may govern allowable loads and required embedment depths to limit structural deformation.

5-2.5 Frost Heave Test.

Frost heave testing is commonly conducted to understand changes in ground conditions that may occur along chilled gas pipelines or similar facilities. For structure foundations, it is preferable to mitigate potential frost heave, and this type of testing is generally not conducted. Mitigation of frost heave is discussed further in Chapter 7, Chapter 8, and Chapter 9.

Historically, the susceptibility of soils to weakening due to frost heave and thaw was measured using ASTM D5918, *Standard Test Methods for Frost Heave and Thaw Weakening Susceptibility of Soils*, but this test method is now inactive. Frost heave testing has also been conducted by academic and industry staff using proprietary methods developed to measure specific aspects of frost heave.[10] Frost heave test data must be carefully evaluated when comparing historic data from different sources.

5-3 STRENGTH PROPERTIES AND CREEP.

In general, frozen soil has high shear strength under short-term loads, with maximum strength decreasing as temperatures warm. However, the presence of salinity will reduce the shear strength and creep behavior will affect allowable long-term design loads.

5-3.1 Saline Permafrost.

Salinity in permafrost soil has a significant effect on material properties, including reducing the freezing point (freezing point depression), increasing the unfrozen moisture content, and decreasing shear strength.[11] Creep and creep rate are also affected by saline conditions; hence, it is a very important parameter to define. The strength of frozen saline sand will decrease with increasing salinity and unfrozen water content, as it does in clayey soil.[12]

---

[10] "Frost Heave Predictions for Alaskan Soils," Hazen et al.
[11] "Creep and Strength Testing of Frozen Saline Fine-grained Soils," Nixon and Lem.
[12] Ibid.

Details of the relationship between salinity and unfrozen water content in sand are described in “Shear Strength in the Zone of Freezing in Saline Soils,” by Chamberlain, “Salt Concentration Effects on Strength of Frozen Soils,” by Ogata et al., and “Strength of Frozen Saline Soils,” by Hivon and Sego. Sand strength is generally expected to be greater than the strength of clay for similar loading conditions, temperatures, and salinity. In addition, the freezing extent is also expected to be larger in sandy soil than in clayey soil for the same temperatures because of differences in the thermal conductivity and moisture content of the soil.

5-3.2 Creep in Frozen Soils.

Creep is a highly complex phenomenon that depends on soil type, ice content, temperature, pore water salinity, and the loading rate, magnitude, and duration of load application. However, in practice, creep effects are limited by controlling stress levels along a pile or below a foundation or by decreasing the ground temperature, which reduces the creep rate. Because creep is time, applied-stress, and temperature dependent, it is important to establish the service life and the acceptable total and differential settlement tolerances of structures and anticipated changes in thermal conditions because these will dictate allowable stress levels over time. Creep of footings is discussed further in paragraph 8-5.3.1 and creep for piles is discussed in paragraph 9-5.3.4.

5-4 PROPERTIES FOR ESTIMATING DYNAMIC RESPONSE.

Dynamic material properties are used to estimate the response of a foundation to loads, such as those due to seismic events or vibrations from reciprocating machinery, that may require consideration of small or repetitive strain. Properties can vary at a site and parametric analysis may be required to understand the effect on a foundation system. For example, the difference in the thickness and depth of organic soil across the site, or the presence of unfrozen zones, is a common variable that may warrant a parametric evaluation when evaluating site response. These properties will also vary with ground temperature. Testing may be conducted to estimate these properties, for both frozen and thawed conditions, using methods such as geophysical surveys like those discussed in UFC 3-130-02 or laboratory testing such as bender element tests (ASTM D8295, *Standard Test Method for Determination of Shear Wave Velocity and Initial Shear Modulus in Soil Specimens Using Bender Elements*). For more advanced projects, cyclic testing (such as triaxial, direct simple shear, or even centrifuge testing) can be performed; however, these methods are not typical for frozen soil.

5-4.1 Frozen Soil.

Shear wave velocities are expected to be higher in frozen soil than in thawed. In general, sites with fully frozen and bonded permafrost, and with temperatures colder than 25°F (−4°C), can be considered to have IBC Seismic Site Class B conditions unless shown otherwise by site investigation and testing. Warmer permafrost temperatures will result in lower shear wave velocities. Compressional (*p*) wave and shear (*s*) wave velocities (*Vp* and *Vs*) are measured in the field using seismic refraction survey methods, and variations of the surface wave velocities are determined using the multichannel analysis of surface waves, a seismic method that measures the shear-wave velocity distribution. Downhole methods, including those in ASTM D7400, *Standard Test Methods for Downhole Seismic Testing*, can also be used to measure *Vp* and *Vs*, which can then be used to calculate other properties used in dynamic analysis, such as Poisson's ratio (ν), shear modulus (G_{max}), and the impedance ratio (ζ).

Different methods may be used to measure *Vp* and *Vs*. For example, *Vp* and *Vs* were measured to a depth of 36 ft (11 m) at a site in the North Slope of Alaska[13] using three different seismic methods (such as cross-hole, downhole, and surface wave methods). The soil was well-bonded permafrost and included layers of sand and gravel with variable fines, a layer of organic silt, and a 10 ft (3 m) thick layer of massive ice. The different methods yielded *p*-wave velocities between 4,100 and 4,850 m/s and *s*-wave velocities between 1,800 and 2,200 m/s.

5-4.2 Thawed Active Layer and Underlaying Soil.

Particular attention must be given to the interface between the thawed active layer and the underlying frozen soil, where a large difference or variation in properties exists. The shear wave velocity in the active layer soil is expected to be 10 to 15 times less than the velocity in underlying frozen soil when the active layer soil is thawed. This difference results in a calculated value of G_{max} in thawed soil that is more than 100 times lower than G_{max} in the underlying frozen soil. Also, surface wave velocities in frozen soil have been shown to decrease significantly at temperatures warmer than approximately 30°F (−1°C).[14]

Guidelines for Estimation of Shear Wave Velocity Profiles, by Wair et al., provides a summary and comparison of several methods for estimating shear wave velocity. Additional methods and commentary regarding shear wave velocity estimates and considerations for vertical construction in thawed ground are provided in Section C20.3 of ASCE/SEI 7.

[13] "The Measurement of Compressional and Shear Wave Velocities in Permafrost: A Comparison of Three Seismic Methods," Black et al.
[14] "Advances in Geophysical Methods for Permafrost Investigations," Kneisel et al.

CHAPTER 6 APPLICATION OF NUMERICAL MODELING FOR GROUND THERMAL RESPONSE

6-1 INTRODUCTION.

This chapter discusses the use of numerical modeling and the different approaches available to the designer, including the use of climate inputs discussed in Chapter 3. Geotechnical thermal analysis is a broad topic requiring an understanding of thermodynamic principles, heat flow in soils, climate science, and site conditions. General background can be found in several cold regions engineering textbooks and papers, such as the following:

- *Geotechnical Engineering for Cold Regions*, by Andersland and Anderson
- "Geotechnical Thermal Analysis," by Zarling and Braley
- *Frozen Ground Engineering*, by Andersland and Ladanyi

Thermal modeling is considered fundamental for many projects because it is a useful tool for assessing ground temperature response to site development, such as the change to the depth of freeze and thaw and the potential for permafrost degradation and subsidence. It is also becoming more important due to climate change and its effect on ground temperatures. Numerical thermal modeling can also be complex due to the number of variables, including foundation geometry, climate, material properties, and ground temperature regime, that are included. Thermal modeling must be conducted by experienced practitioners and based on site-specific information and measurements.

6-2 HEAT FLOW.

Complex thermal models using finite element or finite difference methods are based on the first law of thermodynamics, which states that the total energy of a system is conserved unless energy crosses its boundaries. The rate of change in the stored thermal energy must equal the heat flux into the system minus the heat flux out of the system. Changes in thermal energy are associated with sensible heat (changes in temperature), latent heat of fusion (freeze–thaw), and latent heat of vaporization (vaporization and condensation). These parameters can be represented with one-, two- or three-dimensional (1D, 2D, or 3D) analyses in various finite element or finite difference methods like those noted in paragraph 6-3.

6-3 APPLICATIONS.

Ground thermal analyses are facilitated using computer programs. Available programs range from relatively simple programs that can calculate the depth of freeze and thaw using analytical methods to more complex software programs that use finite element or difference methods. There are several commercially available programs (as of 2024) that use finite element methods of analysis, such as TEMP/W by Seequent, RS2 by Rocscience, general programs such as Plaxis from Bentley, and various software products produced by Comsol.

Selecting the appropriate software tool for a given foundation design problem is an important consideration. For complex site conditions or geometry, fully coupled models incorporating seepage or airflow in porous media with thermal analyses may be used to understand ground temperature fluctuations in a dynamic environment. It is important to understand the internal calculations and assumptions inherent to each program and to consider comparing results from more than one software package and against known exact solutions. Sensitivity analysis is required, especially when modeling warm permafrost conditions (such as permafrost with ground temperatures warmer than about 30°F [−1°C]). It is also important to consider the properties of the soils being modeled. In many cases, it is best to focus on the foundation and then expand to a larger soil scenario so the final results portray the real thermal regime. Perform iterations including mesh refinement and time-step reduction to ensure the model results have converged on an acceptable solution. Additionally, some software may offer 3D analysis, which may prove very useful for complex geometries. It is critical that inputs to and results of 3D analysis be confirmed as realistic, which may require comparing them to output from other software products or 2D analyses with known solutions.

6-3.1 Depth of Freeze and Thaw.

For simple 1D scenarios, the active layer, depth of seasonal thaw (permafrost site), or depth of seasonal freeze (seasonal frost site) can be determined from field measurements or estimated using closed form equations such as the modified Berggren equation. The active layer thickness can be calculated by hand following UFC 3-130-05 or using software such as USACE’s Pavement-Transportation Computer Assisted Structural Engineering software (PCASE).

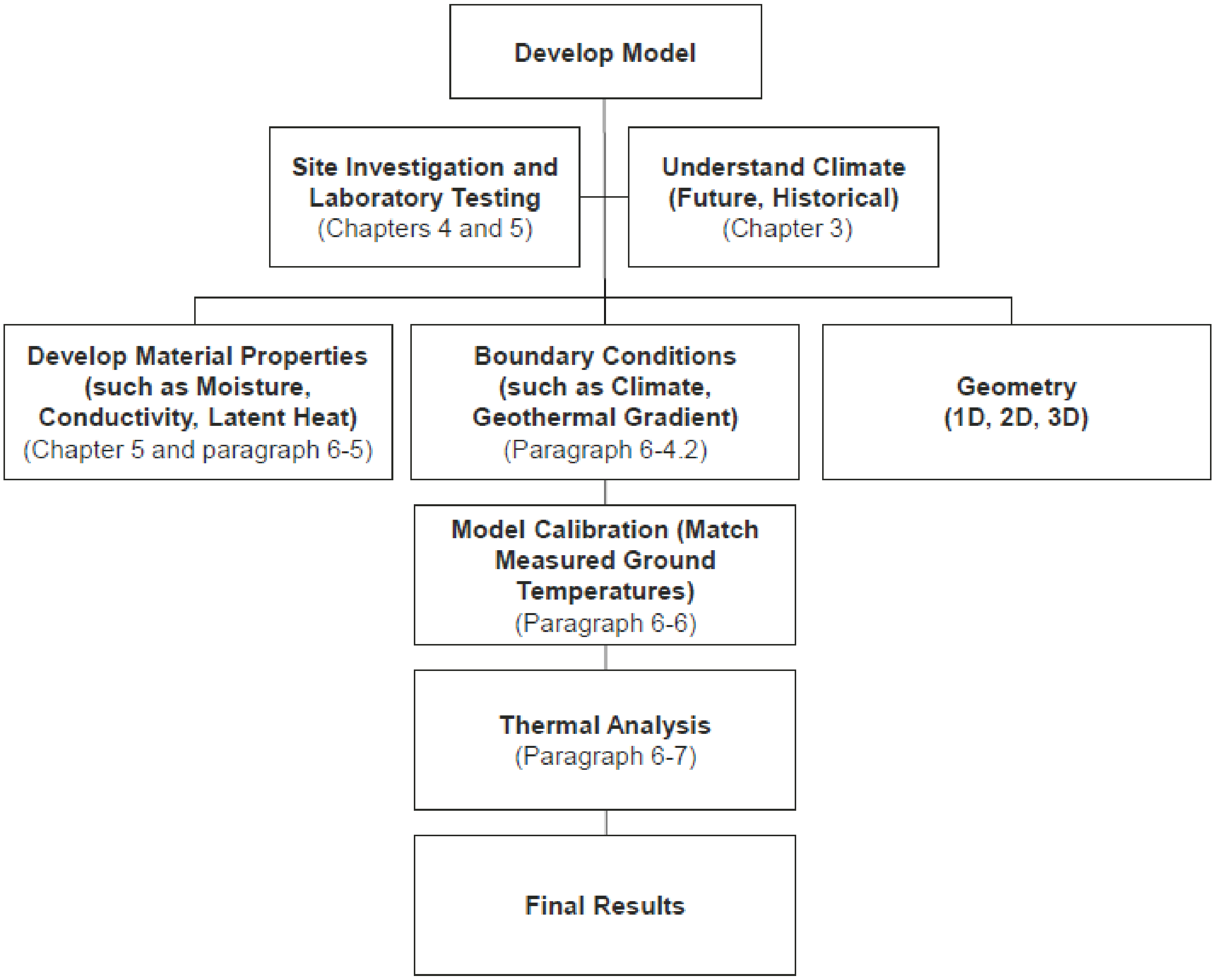
6-3.2 Permafrost Degradation and Subsidence.

Use thermal analyses to assess the effect of site development on ground temperature and the potential for permafrost degradation and subsidence. Methods for estimating potential thaw consolidation are outlined in “Estimating Thaw-Strain Settlement of Frozen Fill,” by Crowther, and “Cold Regions Earthwork,” by Tart. Projects with complex geometry may require the use of finite element analyses.

6-4 THERMAL MODELING PROCESS.

The process for developing an accurate thermal model relies on a comprehensive site investigation with ground temperature measurements, soil samples, subsequent laboratory analysis of the samples (soil type, dry unit weight, and moisture content are the minimum required), and good understanding of the climate. Thermal modeling is typically an iterative process to ensure the model matches site conditions. Figure 6-1 describes the steps of the thermal modeling process.

Figure 6-1 Typical Thermal Modeling Process



6-4.1 Geometry.

One of the first steps in numerical modeling is to define the geometry. Simple problems can be solved with a 1D model, but typical problems require a 2D model laid out with plan, profile, or axisymmetric views. In some instances, 3D analyses may be needed to accurately define foundation geometry. The mesh size must be considered when laying out the geometry. Areas with high temperature gradients require smaller mesh.

Circular structures, such as tanks and isolated piles, can be modeled symmetrically around the axis using 2D analysis to obtain 3D results from the model. This is done by modeling a vertical slice through the center of the tank or pile, including the area outside the structure, and revolving it around this central axis. For other structures, such as rectangular foundations, a vertical slice taken through the center of the foundation footprint, including the area outside the footprint, is the typical approach. The center axis is often a line of symmetry, which allows the modeled geometry to be reduced by one half. The boundary beyond the outside of the tank, pile, or foundation element must be far enough removed so that heat flow is 1D or vertical (zero heat flow normal to the boundary).

6-4.2 Boundary Conditions.

A number of boundary conditions, such as constant or varying temperature, heat flux, convective surfaces, and thermosyphons or other cooling systems, may be included in a typical thermal model. The ground surface boundary condition typically incorporates climatic variables to develop a relationship between air and ground temperatures. The bottom boundary uses a heat flux equivalent to the geothermal gradient at the site. The vertical boundary in a cross-sectional model must be a sufficient distance from the structure so that zero heat flux occurs across the boundary. The centerline of the structure may also be a zero heat flux boundary if the centerline is a line of symmetry. Boundary conditions at the ground surface depend on climate and other inputs that must be processed for use in thermal modeling. Two common approaches used in engineering analyses are highlighted in paragraphs 6-4.2.1 and 6-4.2.2. Thermal model results should be correlated with historical weather data and ground temperatures to calibrate the model before applying future climate projections for the thermal analysis.

6-4.2.1 The n-Factor Approach for Surface Boundary.

The n-factor approach uses a simplified empirical relationship (n-factor) between air and surface temperatures that implicitly includes factors such as net radiation, snow cover, soil thermal conductivity, latent heat, and surface vegetation. It is especially useful when only limited site data are available, but use of n-factors requires considerable judgement when selecting values and must be calibrated with historical ground temperatures.

The freezing and thawing n-factors are the ratio of the surface freezing or thawing index to the air freezing or thawing index, respectively. Tables of typical n-factors for many surfaces can be found in both *Frozen Ground Engineering,* by Andersland and Ladanyi, and *Heat Transfer in Cold Climates,* by Lunardini. Published n-factors can vary by location and orientation, and it is important to consider a range of values during model calibration.

6-4.2.2 Surface Energy Balance Approach.

The surface energy balance approach for establishing surface temperatures considers surface energy inputs and outputs at the ground surface over a given interval of time. The approach can more accurately reflect actual site conditions, but it also requires a higher level of site data than does using n-factors. An example of this approach applied to an elevated building is presented in “Thermal Design Considerations for Raised Structures on Permafrost,” by Oswell and Nixon. Required inputs can include air temperature, wind speed, snow depth and its thermal conductivity, longwave and shortwave radiation, surface albedo, vegetation height, and evaporation data, if appropriate.

6-5 MATERIAL PROPERTIES.

Values for the material properties should be derived from a detailed site investigation and testing. Some material properties commonly required for thermal analyses are listed in Table 6-1 and discussed in Chapter 5. Values used in early analyses may be refined based on the results of the model calibration step or analysis.

Table 6-1 Common Material Properties Used in Thermal Analyses

Material Property	Typical Source
Unit weight	Derived from site investigation following ASTM D7263
Moisture content	Derived from site investigation following ASTM D2216, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*
Heat capacity (frozen/unfrozen)	Typically estimated from empirical relationships discussed in *Frozen Ground Engineering,* by Andersland and Ladanyi
Thermal conductivity (frozen/unfrozen)	Derived from site investigation following ASTM D5334, *Standard Test Method for Determination of Thermal Conductivity of Soil and Rock by Thermal Needle Probe Procedure*, or estimated using empirical relationships (see paragraph 5-2.2)
Unfrozen water content	Estimated from the empirical relationship proposed, by Tice, Anderson, and Banin, found in *Frozen Ground Engineering,* by Andersland and Ladanyi

6-6 MODEL CALIBRATION—GROUND TEMPERATURE.

During the exploration phase, it is typical to install temperature-measuring strings (such as thermistors or digital temperature sensors) in the boreholes created to log the soil profiles and retrieve soil samples for laboratory analysis. If this drilling and installation is done a year or two before construction, then the temperature profiles retrieved from these strings (whiplash curves) can be used to calibrate the thermal model. Probing for permafrost in early fall provides the depth of the active layer for a permafrost site and can be used to check the accuracy of the model for the area of undisturbed ground.

Thermal models must be developed using historical data and the results compared to the measured ground temperatures. This calibration is a critical step in the thermal modeling process. The input boundary conditions must be reevaluated if the model does not match measured temperature data.

6-7 THERMAL ANALYSIS.

After completing the model calibration, the thermal model can be used to make future predictions. Thermal modeling is an effective tool for understanding the relative difference of conditions. Consider the uncertainty in climate projections when developing thermal models and evaluating the resulting predictions. It can be impractical to run all the climate scenarios, so it is important to look at the range of the results. For example, a normal distribution of climate scenarios can be developed by comparing mean annual air temperature or freezing–thawing indices from each projection. This can be used to provide a range of the anticipated results. It is important to scrutinize results for realism, especially when modeling in warm permafrost zones (where there may be discontinuous permafrost).

CHAPTER 7 FOUNDATION DESIGN APPROACH

7-1 INTRODUCTION.

This chapter presents an overview of the foundation selection and design process for vertical and horizontal structures. Further discussion related to the design of shallow foundations is presented in Chapter 8 and discussion related to pile (deep) foundations is presented in Chapter 9. Examples of various types of foundations that have been used in Arctic and Subarctic areas are in Appendix A.

Selecting the general foundation concept is one of the first steps in the design process, following consideration of the general planning and design requirements and initial site investigation (discussed in Chapter 2 and outlined in Figure 2-1). Subsequent analysis and additional characterization may be required before a final design is selected. Although specific design issues may vary over the life of the facility, the concepts discussed are generally applicable to both new and rehabilitated foundation systems. Prior to finalizing the design, the designer must reconsider the estimated cost and how the design meets the functional requirements of the facility. Additional optimization may be required. For example, a pile design may have been developed for an unusual pile size that is either expensive or difficult to procure within the schedule limitations. Review and optimization could provide an alternate design using a different size or more readily available materials.

7-2 UNIQUE LOAD CONDITIONS AND LOCAL REQUIREMENTS.

Structures in areas characterized by frozen and thawing ground conditions are subject to geotechnical load conditions that are not common in temperate areas. Conditions unique to frozen ground are:

- Frost action
- Downdrag and settlement due to permafrost degradation and thaw subsidence
- Seasonal changes in near-surface materials
- Ice wedges and other massive ice formations

Different approaches to addressing foundation load conditions may be applied, and, in some instances, local practice or code requirements will dictate when a particular approach is required. Therefore, it may be necessary to check the design using different methods to ensure it is adequate. Each of the load conditions highlighted in the preceding list is briefly discussed in the following paragraphs.

7-2.1 Frost Action.

Frost action refers to both the process of (a) water freezing in soil, leading to a total volume increase or the build-up of expansive forces, and (b) subsequent thawing and related compression and reduction in soil strength. Very high loads are applied when ice forms at the freezing front, with varying effects on structures (see paragraphs 7-5 and 7-6).

7-2.2 Permafrost Degradation, Thaw Subsidence, and Downdrag.

7-2.2.1 Ground Thaw.

The thawing of frozen ground is another type of impact on foundation stability. The thawing of soil that has excess amounts of ground ice is of particular concern because it will cause settlement of shallow foundations and downdrag on deep foundations; therefore, it must be considered in the design. Permafrost degradation may be caused by multiple factors (see paragraphs 2-3.2 and 6-3.2), including construction activities that result in modification of the site thermal regime, normal facility operations, and naturally occurring climate change. Heat loss through the floor of a structure is an example of a cause of permafrost degradation that can affect the foundation to the extent that the structure is no longer sound and requires partial or full reconstruction. In other cases, where ground temperature in the permafrost is near freezing (for example, warmer than about 30°F [approximately −1°C]) or where saline conditions are found, site grading and development alone may raise ground temperatures enough to cause permafrost degradation.

7-2.2.2 Estimating Thaw Subsidence.

Estimate potential thaw subsidence using data from literature such as "Estimating Thaw-Strain Settlement of Frozen Fill," by Crowther, "Permafrost Thaw and Ground Settlement Considering Long-Term Climate Impact in Northern Alaska," by Yang et al., and "Frost Heave and Thaw Settlement Estimation of a Frozen Ground," by Sinnathamby et al., preferably with correlation to site-specific index properties and laboratory testing, such as the thaw strain and thaw consolidation testing discussed in Chapter 5. If practical, field testing is an excellent method for estimating thaw consolidation and developing site-specific correlations for earthen structures. The test sections and monitoring incorporated into the design of the Inuvik Tuktoyaktuk Highway in the Northwest Territories, Canada, are examples of field testing and are discussed in "Monitored Thermal Performance of Varying Embankment Thickness on Permafrost Foundations," by De Guzman et al.

7-2.3 Seasonal Changes in Near-Surface Materials.

Foundation designs must be evaluated for both winter and summer load and soil strength conditions. Freezing air temperatures cause a seasonally frozen and thawed zone (an active layer) to form near the ground surface. These changes may result in frost heave or loss of soil strength. In addition, as soil freezes and thaws, material properties, such as elastic modulus and its ability to resist loads, also change. For example, piles resisting lateral loads from seismic events or wind forces will have different soil structure responses in summer and winter.[1] Moreover, thermal expansion

[1] "Analysis of Laterally Loaded Piles in Frozen Soils," Yang et al.

and contraction of bracing induces opposing strain loads in summer and winter that need to be considered in structural design.

7-2.4 Ice Wedges and Other Ground Ice Formations.

Massive ice formations, such as ice wedges, are common and generally ubiquitous on permanently frozen terrain. For examples of the types of ground ice found in northern Alaska and along the Beaufort Sea coast, see "Permafrost of Northern Alaska" and "Ground Ice in the Upper Permafrost of the Beaufort Sea Coast of Alaska," both by Kanevskiy et al. The presence of these massive ground ice features must be addressed in design documents. For example, pile design criteria commonly allow for some amount of massive ice, with provisions for increasing the depth of piles if more ice is encountered than was already accounted for. Footings or slab foundations underlain by massive ice formations must be designed to prevent thawing the underlying soil and may require the use of insulation[2] and ground cooling (see paragraphs 8-5.5.2 through 8-5.5.4). In cases where the ice formation is extensive, such as due to buried glacial ice or ice wedges, relocating facilities may be required[3] or the ice may need to be removed as part of a ground improvement program.

7-3 FOUNDATION DESIGN APPROACH.

Design, construction, and maintenance of foundations on permafrost and freezing or thawing ground conditions must satisfy certain material, environmental, and logistical challenges, as discussed in Chapter 2 and outlined here:

- Special properties and behaviors of soils, rocks, and building materials at low temperatures and under cyclic freeze–thaw action
- Permafrost that is subject to thawing and subsidence during and after construction
- Seasonal freezing and thawing of ground associated with frost heave, thaw settlement, and other effects
- Difficulty of excavating and handling frozen ground
- Limited availability of natural construction materials and support facilities
- Adverse conditions of temperature, wind, precipitation, distance, accessibility, working seasons, and cost

For general design approaches for permafrost areas, see *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost,* by Linell and Lobacz, and *Frozen Ground Engineering,* by Andersland and Ladanyi. Both are based on the thaw stability of the site and include examples of different foundation types for facilities of varying design life. These general approaches for permafrost areas are outlined in

---

[2] "Design, Construction and Operation of an Insulated Ice Drilling Pad, North Slope, Alaska," Hazen et al.
[3] "Structure and Properties of Ice-rich Permafrost Near Anchorage, Alaska," Kanevskiy et al.; "ARRC Rail Alignment Improvements Birchwood, Alaska Railroad Design—Construction in Marginally Frozen Relic Ice and Soil," Krzewinski et al.

Figure 7-1 and discussed in paragraphs 7-4.1 through 7-4.4. In areas with deep seasonal frost that affects foundations, designing a stable foundation still requires considering how the foundation soil changes and affects foundations as ground temperatures and properties of the soil change seasonally.

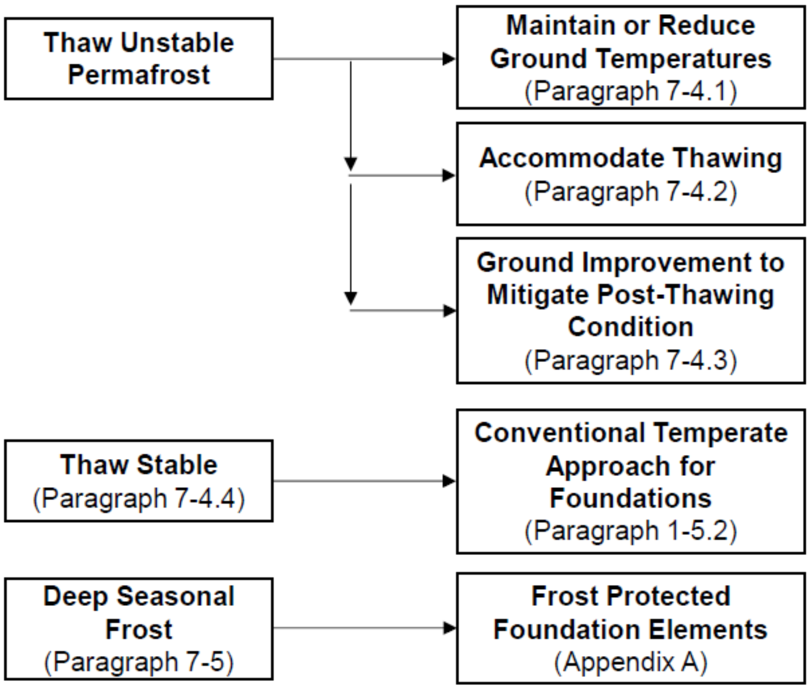
7-3.1 Maintain or Reduce Permafrost Ground Temperature.

The existing thermal regime must be maintained when foundations are resting on or within thaw-unstable permafrost because of the excess settlement and loss of bearing that occurs when ice-rich soil thaws. This approach is used in regions of both continuous and discontinuous permafrost and is typically accomplished for permanent structures by elevating the structure to decouple it from the underlying soil or by using a combination of insulation and cooling to control heat flow from the structure into the ground. Strategies to maintain ground temperatures in areas of deep seasonal frost may include insulation of the foundation perimeter (as for shallow frost-protected foundations), modification of site conditions, or, in the case of structures with internal temperatures that are below freezing (such as liquified natural gas tanks or refrigerated warehouses), a combination of insulation and heat loops can be designed to keep foundation soils thawed. Different approaches to meeting these objectives are described in paragraph 7-5.

7-3.2 Accommodate Thawing (Accept Thermal Regime Changes).

Foundations can be designed to accommodate changes in ground conditions when permafrost thaws. These conditions occur when facility development results in degradation of permafrost or when permafrost degradation is expected to occur naturally due to environmental changes. Common examples of site activities that can induce changes in the underlying permafrost include placement of granular soil over undisturbed permafrost to create an at-grade work pad for construction staging (which allows heat flow into the underlying soil) and activities that modify drainage or disturb surficial organic soil and vegetation. Even if a granular pad is thick enough to insulate the underlying permafrost from thawing, settlement may be induced along the perimeter of the fill area due to changes in surface drainage and a decrease in pad thickness in those areas. An example of this design approach is described in “Marginal Permafrost, a Foundation Material in Transition,” by Musial and Wyman, for pile foundations installed for a transmission line in Alaska. In the case of horizontal structures, allowing for thawing must include annual costs for releveling the embankment surface and patching the surface pavement. Most often, this annual maintenance is more cost-effective than constructing an embankment that is resistant to thawing.

Figure 7-1 General Design Approaches



Source: Adapted from *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost,* by Linell and Lobacz, and *Frozen Ground Engineering,* by Andersland and Ladanyi.

Foundations that allow some thawing of thaw-unstable permafrost are generally applicable for temporary facilities, facilities in support of military operations with a design life of five years or less, lighter structures, and horizontal structures (such as roadways and airfields), or when the thaw-unstable permafrost is underlain by relatively dense, thaw-stable materials. For lighter structures, this approach can involve limiting the heat input into the soil by thermally decoupling the structure from the permafrost using a raised foundation. This reduces settlement of the structure during its design life while also allowing access for releveling if required. This method is used for single-family housing and can be an effective foundation when costs are a limiting factor. Provisions for releveling are typically incorporated into the design.[4]

7-3.3 Ground Improvement to Mitigate Post-thawing Conditions.

Foundation soils may need to be modified or improved in all types of permafrost terrain, depending on expected conditions after a project is built. This approach entails either thawing and consolidating the frozen soil or over-excavating the soil and replacing it with soil that is not susceptible to frost. Thawing is accomplished using electrodes, heating mats, or steam, and the amount of energy applied depends on the ice content and the heat of fusion of the soil. The drainage characteristics of the thawed soils must be considered to allow the excess water to drain or be pumped and to improve stability by compacting the thawed soils to an appropriate density. The thaw-unstable soils must

[4] "Adjustable Foundation Design Development in Arctic Engineering," Borjesson and Clarke.

be relatively thin and NFS material readily available to make excavation and replacement a viable option. Once the ground conditions have been improved, conventional temperate foundation options are available for design and construction.

Soils that have been thawed may be in a weak or loose condition unless further modification or replacement is performed. If the thawed soils within an excavation are not drained and adequately compacted before winter weather sets in, they can refreeze and heave upon refreezing. If the refrozen soil subsequently thaws after placement of fill or completion of foundations, thaw-induced settlement may occur.

7-3.4 Thaw-Stable Permafrost.

When thaw-stable conditions are present at a site, such as sites underlain by ice-poor granular soil, foundations can be designed using the conventional foundation engineering practice outlined in the documents referenced in paragraph 1-5.2.

7-4 PROTECTION FROM FROST ACTION.

Protecting the foundation from seasonal frost action must be a consideration for each foundation design alternative. Frost action involves the harmful process of frost heave resulting from the formation of segregated ice lenses at the freezing front in soil during the freezing period, followed by thaw weakening or the loss of bearing strength when the seasonally frozen soil thaws. Heave forces may occur due to the formation of these ice lenses below the foundation or when frozen soil bonds to the foundation through adfreeze and lifts it as the surrounding soil freezes. Methods to protect a foundation from frost action involve using NFS foundation materials within the depth of frost, providing adequate drainage away from the foundation, maintaining a thawed condition around the foundation, resisting the potential frost heave forces, or isolating the foundation so it is not affected by the frost heave forces.

Design frost depths are developed using the thermal analysis methods described in Chapter 6. Results are heavily influenced by assumed climatic conditions (air freezing index), ground surface conditions (n-factors), and soil thermal properties. References for freeze and thaw depth determination are noted in Chapter 6 and more general discussion is included in several references, such as *Frozen Ground Engineering,* by Andersland and Ladanyi.

For frost heave to occur, the soil must be frost susceptible, a source of water must be available, and freezing temperatures must take place. If one or more of these conditions is prevented or eliminated, frost heave will not occur. See paragraph 5-2.1.1.2 for additional information.

7-4.1 Frost Susceptibility.

Frost susceptibility must be considered when designing foundations in Arctic and Subarctic areas. The frost susceptibility of a soil is generally defined by the content of material finer than the 0.02 mm size, as summarized in Table 5-2 and outlined in UFC 3-220-10. However, frost susceptibility is also related to the plasticity of fine-grained soil and the permeability of the foundation materials. Coarse-grained soil (such as sand and gravel) with trace to no fines is generally considered to have low frost susceptibility, whereas a silty or clayey soil is typically highly susceptible to frost. Generally, NFS material is specified, but in some instances where material sources are limited or facilities have a design life of less than five years, material with a low frost susceptibility may be appropriate and may satisfy design criteria. Additional testing may be required to justify the use of low-frost-susceptible material.

The percent passing the No. 200 sieve size is sometimes used to assess frost susceptibility, but this approach is typically used in areas where local experience and knowledge of material quality and performance is understood. Basing acceptance of materials during construction on the No. 200 result also will be beneficial during construction because the test can be more quickly performed than the hydrometer test needed to determine the 0.02 mm particle size.

7-4.2 Drainage.

Drainage is a very important consideration when trying to protect foundations against frost heave. Providing positive drainage away from the structure and the foundation subgrade through surface grading and buried drainage pipes limits the potential for ice lenses to form in the foundation materials. See Chapter 11 for requirements and paragraph 5-2.1.1.2 for information regarding the importance of groundwater on frost action.

The percent passing the No. 200 sieve size is sometimes used to assess frost susceptibility, but this approach is typically used in areas where local experience and knowledge of material quality and performance is understood. Basing acceptance of materials during construction on the No. 200 result also will be beneficial during construction because the test can be more quickly performed than the hydrometer test needed to determine the 0.02 mm particle size.

7-4.3 Maintain Thawed Conditions.

Maintaining the thawed condition around a foundation is usually accomplished for slab-on-grade buildings by insulating the perimeter as is done for frost-protected shallow foundations (see SEI/ASCE 32). The methods described by SEI/ASCE 32 are not directly applicable when the freezing-degree days exceed 4,500°F-days. However, the approach can be modified for colder temperatures like those found around Fairbanks, Alaska, as outlined in *Frost Protected Shallow Foundations (FPSF) for Interior Alaska Freezing Indices Between 4,000 and 8,000 Degree-Fahrenheit-Days: A Research Report,* by Perreault. At minimum, foundation insulation must consist of vertical insulation on the outside of footings. It is preferable to include insulation boards placed horizontally outside of the building perimeter, but this may be modified by local practice. The width and thickness of the insulation used depends on climatic conditions at the site. In addition to preventing freezing of soil beneath the foundations, the insulation helps with building energy efficiency.

Using floor insulation to improve the energy efficiency of a building is becoming more common. This is an important consideration when designing perimeter insulation because the reduction in heat loss through the floor increases the requirements for foundation insulation.

7-4.4 Resist Frost Heave Forces.

Frost heave can affect both deep and shallow foundations. Deep foundations are designed to provide sufficient embedment to resist the uplift loads applied to the perimeter of the foundation. Shallow foundations can be anchored or can incorporate structural elements such as lateral extensions to increase uplift resistance. Where practical, shallow foundations should extend to below the depth of frost to eliminate potential basal heave. Frost heave forces also may be resisted by increasing the weight of the structure, which is usually not cost effective.

Frost heave forces can be significant but varies with material type, as discussed in paragraph 9-7 and in other sources ("Russia and North American Approaches of Pile Design in Relation to Frost Action," by Nidowicz and Shur; *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost,* by Linell and Lobacz).

7-4.5 Isolate from Frost Heave Forces.

Isolating foundations from frost heave forces is accomplished in various ways, depending on if the foundation is deep or shallow. Insulation, which can include polystyrene, wood chips, or added soil fill, can be used to control freezing around the foundation. For piles, the portion of the pile in the active layer subject to uplift can be covered with a low-friction material to limit or prevent soil and ice from bonding to the pile. Materials used for this include soil-oil-wax mixtures, plastic, coal tar, Teflon, multiple layers of polyethylene sheeting, or similar nonadhering surface materials. For shallow foundations, it is common practice to place the footing below the depth of the active layer or to replace frost-susceptible soil in the subgrade with NFS material that extends below the anticipated depth of frost.

Compressible inclusions are another type of structural element that can be included in the foundation design to control frost heave on the base of footings or structural slabs.[5] This type of frost heave control involves limiting water movement in the soil and reducing the effect of ice expansion, versus the use of NFS materials. It can include low-strength expanded polystyrene (EPS) or extruded polystyrene (XPS) boards and blocks, rubber or plastic materials, or other collapsible materials analogous to those used to control foundation loads in areas with expansive soil. The success or failure of the approach depends on specific site conditions and good quality assurance and quality control during construction; hence, design should proceed carefully and include an evaluation of the elastic characteristics of each type of material used and its compatibility with applied loads, design life, and site conditions.

[5] "Foundation Design for Frost Heave," Widianto et al.; "The Compressible Inclusion Function of EPS Geofoam," Horvath.

7-5 DYNAMIC RESPONSE TO LOADING.

Dynamic loading is typically a result of seismic ground shaking or rotating machinery. The foundation response to each is different.

7-5.1 Seismic Ground Shaking.

Frozen ground is very stiff compared to unfrozen ground. For planning purposes, continuous permafrost regions that have a thin (on the order of a few feet) active layer can initially be characterized as Site Class B (as defined in the IBC) pending direct measurement of shear wave velocities and further site investigation. In regions of discontinuous permafrost, site classes will vary depending on the depth to permafrost, thickness of the permafrost, and designed long-term condition of the facility. Other aspects of seismicity to consider are seasonal changes in near-surface soils from frozen to unfrozen and how the depth of permafrost over time may increase due to site development and changes in climate. Deep seasonal frost affects site responses[6] and must be considered during design.

7-5.2 Liquefaction and Seismically Induced Settlement.

Frozen ground is not considered to be liquefiable, but liquefaction and seismically induced settlement become design considerations when permafrost is expected to thaw over the life of a facility or if the site was previously frozen in recent times. Recently thawed soils may be in a normally consolidated state or, more likely, an unconsolidated condition. Analyses must be conducted considering both the immediate and long-term thermal state of the foundation soils and the presence of layers of frozen and unfrozen material that may develop over time.

The site response of facilities is influenced by the presence of permafrost. Of particular concern is the change in response as subsurface conditions change from frozen to thawed, either seasonally or due to construction or climate change. For example, relatively deep thawing was predicted due to construction and facility operations at a site with warm permafrost on Eielson Air Force Base near Fairbanks, Alaska. This change in site conditions would have caused an increased risk of liquefaction due to regional seismicity; therefore, a mitigation program (consisting of thawing and ground improvement) was conducted to reduce the potential impacts from both thawing permafrost settlement and potential liquefaction-induced damages that may have occurred because of an earthquake after the ground thawed. Other common options to improve ground conditions and reduce liquefaction potential and seismically induced settlement are deep dynamic compaction and vibrocompaction.

7-5.3 Cyclic Machine Loading.

Rotating machinery, such as turbines, compressors, and generators, may induce cyclic loads that are sustained or continuous over the project life. Cyclic loads due to rotating machinery are different from those imposed by earthquakes and other transient state

[6] "Frozen and Unfrozen Shear Wave Velocity Seismic Site Classification of Fairbanks, Alaska," Cox et al.; "Effects of Seasonally Frozen Soil on the Seismic Behavior of Bridges," Xiong and Yang.

design forces, which typically have varying frequency, amplitude, and duration. Usually, the cyclic loads have well-defined operational amplitude and frequency domains that can be dampened structurally so that loads imposed on foundations are minimized. If the thermal state of foundation soils is expected to change over the life of a structure, additional analysis will be required to check the foundation's response to differing thermal states. Engineering judgment is required to determine the most suitable means and measures for addressing the effect of cyclical loads on pile foundations. Paragraph 9-11 presents further discussion regarding the effect of cyclical loads on adfreeze piles.

7-6 INSULATION AND CONTROL OF HEAT FLOW.

Structures are often elevated above the ground surface to decouple heat flow from the building into the ground in areas underlain by permafrost. Insulation is also commonly incorporated into the design of foundations to control heat flow and is an integral part of both structural foundation systems discussed in Chapter 9 and within fills used for horizontal structures (see Chapter 10).

For vertical and horizontal structures, insulation in foundations is typically either EPS or XPS. Cellular glass and other materials, such as urethane foam, are also used in specific applications. The insulation must have strength and strain characteristics compatible with applied dead and live loads and environmental conditions. Consider cellular glass products when heavy loads like those beneath liquefied natural gas tanks, aircraft ramps and tarmacs, or rotating radars are present; when little or no compression under load is a design requirement; when high fire resistance is needed; or when resistance to petroleum and solvents is a design requirement.

7-6.1 Insulation for Structural Foundations.

In general, XPS and EPS insulation beneath structural foundations should have a minimum compressive strength of 60 psi (414 kPa) measured at 5% strain. In addition, geomembranes must be placed over insulation installed beneath foundations to protect the insulation from degradation due to spills of hydrocarbons or other solvents that will degrade the material.

Polystyrene insulation is degraded by petroleum products and solvents, and it should be protected by a membrane liner when used in a foundation application, such as a flat loop thermosyphon (see paragraph 8-5.5), or in other situations where degradation by exposure to petroleum products and hydrocarbons will adversely affect its intended function.

7-6.2 Insulation for Horizontal Structures.

For horizontal structures, consider XPS or EPS insulation with a minimum compressive strength of 40 psi (276 kPa) measured at 5% strain. The most severe loading conditions in horizontal structures may occur during construction. It is imperative that the insulation material characteristics be matched to applicable design and performance criteria, and it must be recognized that constructability considerations may control the selection of materials in horizontal structures.

7-7 FACTOR OF SAFETY.

7-7.1 Working Stress Design.

Much of the design practice for foundations in frozen and freezing ground conditions was developed based on working stress design principles and use of a single global factor of safety (FS). The appropriate global FS for a given working stress design analysis may vary, depending on factors such as the criticality of a structure, uncertainty of conditions, or uncertainty in potential climate impacts. FS values for DoD projects are provided in UFC 3-220-01 and additional discussion is presented in Chapter 8 and Chapter 9 of this UFC.

7-7.2 Limit State Design.

Geotechnical engineering practice in temperate conditions increasingly is applying limit state design, including consideration of serviceability limit state and ultimate limit state principles or using limit state design based on load resistance factor design, but these are not widely applied in frozen ground situations. These general concepts and an approach to bridging the gap in working stress design and limit state design concepts in unfrozen conditions is presented in the *Canadian Foundation Engineering Manual* by the Canadian Geotechnical Society and in “Eighteenth Canadian Geotechnical Colloquium: Limit States Design for Foundations,” Parts I (“An Overview of the Foundation Design Process and Limit States Design for Foundations”) and II (“Development for the National Building Code of Canada”), both by Becker.

Consideration of limit states is an implicit part of codes. There are many national and local codes and standards that may need to be considered during design that may or may not have specific code requirements for foundation design in Arctic and Subarctic regions, especially when permafrost is present. Some of these national and local codes can be found as follows:

- In the U.S., consult the American Petroleum Institute, IBC, and Uniform Building Code.
- In Canada, consult the National Research Council Canada, National Standard of Canada, and Canadian Standards Association.
- In Europe, consult the Eurocode.

In the absence of specific requirements, it will be necessary to consider site conditions and recommendations found in the professional literature, including this and other UFCs in the series, texts such as *Frozen Ground Engineering,* by Andersland and Ladanyi, and supplemental resources like those listed in Appendix C.

This Page Intentionally Left Blank

CHAPTER 8 SHALLOW FOUNDATION DESIGN

8-1 INTRODUCTION.

Shallow foundations may be used in areas of freezing and thawing soil, including those underlain by permafrost, provided that both the thermal impacts of structures and the overall behavior of foundation materials discussed in previous chapters are considered. Shallow foundations may be placed on granular pads and may incorporate insulation or, where the granular pad is underlain by permafrost, systems to maintain or cool the foundation soils. The timing of construction is an important consideration in permafrost areas to avoid thawing foundation soils that will support shallow foundations.

Design of the foundation system generally involves conventional bearing capacity and settlement calculations, whereas design of the granular pad subsystem involves thermal analyses like those discussed in Chapter 6. Calculating settlement involves conventional techniques for consolidation potential if permafrost will be allowed to thaw and evaluation of creep of frozen soil. Establishing these design criteria requires good site data, including information about ice content and its extent, ground temperature, and subsurface stratigraphy and material type. Consideration also must be given to the duration and magnitude of applied loads. For example, even relatively low ground pressures applied for the duration of the project life may result in significant creep in ice-rich soil, while relatively high ground pressures may be carried with little deformation if the load is only applied for a short period of time. Refer to Appendix A for representative examples of foundation configurations.

8-2 SHALLOW FOUNDATIONS ON THAW-STABLE PERMAFROST.

Shallow foundations on thaw-stable permafrost, such as coarse granular soil and rock without excess ice, should be designed according to conventional temperate zone methods that consider bearing capacity and settlement. For coarse granular soil, the friction angle may be estimated from information, such as drilling action or blow counts, collected during the geotechnical investigation. Similar to the way these data are affected when sampling coarse gravel and cobbles, blow count data from methods such as split spoon sampling (ASTM D1586, *Standard Test Method for Standard Penetration Test and Split-Barrel Sampling of Soils*) may be exaggerated in frozen ground. Thus, blow count data in frozen ground must be considered a relative measure of consistency between sample locations at the time of the investigation and should not be used with standard correlations between blow count and material property used in temperate conditions.

One case where correlations between field parameters and material properties may be useful is for estimating soil strength in ice-poor material. Soil strength may be conservatively estimated by assuming a saturated unfrozen soil at the same frozen dry density as in situ material and using correlations such as those found in UFC 3-220-10.

8-3 SHALLOW FOOTING WITH GROUND IMPROVEMENT.

Shallow footings and ground improvement are often used by USACE, Alaska District, in areas of discontinuous permafrost. Most commonly, pockets of discontinuous permafrost are thawed. The thawed soil may require densification to reduce settlement potential and potential for liquefaction (see paragraph 12-3.5). Foundations are designed to provide frost action protection that is appropriate for the area.

Permafrost may be prethawed beneath heated buildings using techniques such as electric probe thawing, cold or warm water injection thawing, steam thawing, or heating mats. However, if the near-surface permafrost to be thawed is thaw-unstable and ice-rich, it must have thaw-stable and ice-poor permafrost underneath to provide stability. If there is sufficient time in a project schedule, clearing a site of vegetation can be a cost-effective method for thawing ground, especially in areas of discontinuous permafrost; however, years may be required to accomplish this, depending on the depth of thaw desired and other local conditions. After the permafrost has been thawed, conventional temperate zone ground improvement techniques, such as preconsolidation of deep dynamic compaction, may be needed to further stabilize the site. Design shallow spread footings according to conventional temperate zone methods that consider bearing capacity, settlement, and seasonal frost. Additional ground truthing activities, such as soil borings, cone penetration tests, or compaction testing, are generally required to verify that conditions meet the design expectations after the area has been thawed and consolidated.

8-4 SHALLOW FOOTINGS ON GROUND SURFACE.

Shallow foundations bearing on the ground surface or at shallow depth can be used when they are supported on NFS fill and when no excessive long-term settlement is anticipated due to changes in the thermal regime of the foundation soil. Surface footings can also be used to accommodate anticipated settlement or heave.

Buildings supported on surface footings often incorporate a rigid base or space frame structure to maintain the building’s integrity in the event of differential movement and to span footings that may lose support until the system can be re-leveled. Space frames are rigid structural systems that are laterally connected to the vertical supporting elements. These systems can be releveled while the structural system serves to maintain the integrity of the superstructure by limiting differential movement between the structural elements, such as doors and framing, while also limiting horizontal displacement of the supporting elements during vertical displacement and dynamic (such as seismic) loading. Typically, these systems are built on a granular pad, but they can also be placed on natural ground that has suitable bearing capacity. The benefits for lighter structures are ease and rapid construction with provision for releveling as needed.

8-5 SHALLOW FOOTINGS ON IN SITU PERMAFROST.

This foundation method involves installing footings below the maximum anticipated depth of permafrost thaw over the life of the foundation (See *Permafrost Engineering*

Design and Construction, by Johnston). Typically, the footings are set on a bed of NFS granular fill or within an embankment, as shown in the typical sections in Appendix A. This foundation method is applicable for temporary facilities, facilities in support of military operations with a design life of five years or less, lighter structures, horizontal structures (such as roadways and airfields), and for cold permafrost soils that have minimal potential for thaw strain or long-term degradation of the thermal regime. Thermal analysis or site monitoring is used to estimate the active layer depth in the backfilled pits, which will likely be deeper than baseline conditions due to the backfill material and disturbance of the ground surface. Insulation placed near the ground surface may often further reduce the active layer depth and may be combined with other methods of ground cooling to maintain ground temperatures.

Elevate heated structures to provide ventilation to minimize heat transfer from the structure into the ground. A rigid framework and an adjustable leveling system may also be considered for lightweight structures to mitigate potential differential settlements.

8-5.1 Foundation Design Process.

The foundation design for shallow footings on in situ permafrost requires checking the bearing capacity, displacement under load, and settlement that may occur due to creep. Thermal analysis is required to estimate long-term changes in ground temperature and the potential for thawing due to construction and must recognize potential climate impacts during the design life. Depending on the structure, frost-protected shallow foundations like those described in paragraph 7-5.3 may be appropriate, provided thermal effects and differences in heated and unheated structures are considered. The general procedure for designing shallow foundations in permafrost is outlined here:

1. Select footing depth based on the expected deepest thaw and required lateral support.
2. Estimate the warmest ground temperature, including temperatures beneath the structure, using appropriate material properties.
3. Select footing based on bearing capacity theory and the desired FS.
4. Modify footing size as appropriate.
5. Check settlement during design life.

8-5.2 Bearing Capacity.

The ultimate bearing capacity, q_u, follows the general form taken from conventional bearing capacity theory and includes conventional terms (N values) for cohesion, surcharge, and self-weight and factors (F) for shape, depth, load inclination, base, and ground inclination. Refer to *Frozen Ground Engineering,* by Andersland and Ladanyi, section 7.2, for the equation, definition of terms, and details on application. Analyses to estimate ultimate bearing capacity must be performed in terms of total stress. The effects of ground temperature, time of loading, and ice content of the soil must be considered when estimating values of cohesion and friction angle. In addition, the friction angle used to estimate N values should correspond to an unconsolidated-undrained value for a given frozen soil density. (See pages 171–179 in *Frozen Ground Engineering,* by Andersland and Ladanyi, for details on application.) In general, for short-term loads and cold ground temperatures, the bearing capacity of frozen soil can be relatively high. As time and load increases, creep and changes in ground temperature become a consideration. Refer to paragraph 7-8 for a discussion of FS.

Strength testing under temperature-controlled conditions must be considered if relying on the long-term bearing capacity of ice-rich material. Strength testing also must be used to verify long-term creep behavior (see paragraph 8-5.3.1).

8-5.3 Settlement.

Footing size is generally controlled by considering settlement rather than by the bearing capacity of frozen ground. Both short-term and long-term settlement occurs when loads are applied to frozen soil. Five types of deformation occur when loading frozen ground:

- Instantaneous-elastic (soil may rebound partially)
- Instantaneous-plastic (irreversible, bearing failure)
- Viscoelastic (reversible)
- Consolidation (irreversible)
- Creep or viscoplastic (irreversible)[1]

Of the five types of deformation in frozen soil, instantaneous-plastic, consolidation, and creep are the most significant. Creep and consolidation of frozen soil require special attention. Instantaneous-plastic deformation is determined using conventional soil mechanics and accounting for the temperature dependency of short-term cohesion in frozen soil. Creep and consolidation of frozen soil are time dependent and are discussed in paragraphs 8-5.3.1 and 8-5.3.2.

8-5.3.1 Creep Settlement of Footings.

Creep settlement of footings can be substantial at low stresses if the soil has a high ice content, temperatures warmer than 23°F (−5°C), or both. Low ice content soils with low stress conditions will have lower rates of creep; however, creep must still be considered in design. Additional discussion of creep and guidelines for pile foundations are presented in paragraph 9-5.3.4.

Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost, by Linell and Lobacz, outlines methods for estimating the creep of footings. However, cavity expansion theory has also been shown to give good results for ice-rich homogeneous frozen soil[2] and other soil types. Creep parameters may be estimated from published data, provided the materials and site conditions associated with the published data are appropriate for use in the analysis. Alternatively, creep rates can be

[1] *Frozen Ground Engineering*, Andersland and Ladanyi; *Rheological Properties and Bearing Capacity of Frozen Soils,* Vailov.
[2] “Creep of a Strip Footing on Ice-rich Permafrost,” Sayles.

measured for specific soil types, ground temperatures, and loading rates in the laboratory (see paragraph 5-2.4).

8-5.3.2 Consolidation.

The consolidation behavior of frozen soil is poorly understood. Initial evaluations must consider consolidation to be a design consideration when ground temperatures are warmer than between 31.5°F (−0.3°C) in silty sand and 29°F (−1.7°C) in clay. When ground temperatures are colder than the threshold values, consolidation is expected to be very slow and thus not a design consideration.[3]

Upon thawing, total potential thaw settlement under a footing can be approximated based on the total volume of ground ice within a unit of soil within approximately 6.5 ft (2 m) of the footing. Using this approximation for deeper depths overestimates potential thaw settlement at deeper depths due to bridging of underconsolidated soils. Consolidation will also occur once the soil is thawed and can be estimated using soil mechanics principles for unfrozen soil. Perform laboratory testing to determine total thaw strain. Consolidation after thawing must be considered for some soil types, but it requires specialized testing, as noted in Chapter 5 and discussed in UFC 3-130-02.

8-5.4 Frost Heave Forces.

Shallow foundations may be subjected to frost heave forces along the base of footings. This can result from the refreezing of seasonally thawed soil or the refreezing of sites where the thermal regime was disturbed during construction. Analysis methods for estimating frost heave forces are outlined in *Frozen Ground Engineering,* by Andersland and Ladanyi. Alternatively, frost heave tests can be conducted to measure uplift forces in the laboratory or in the field.

8-5.5 Shallow Foundation Configurations on Permafrost.

Shallow foundations may be configured in various ways in permafrost areas, depending on site conditions and specific design requirements. Common practice is to elevate a heated structure when practical to provide ventilation and minimize heat transfer to limit thawing beneath the building. However, this is not always a practical solution, and other options, like those discussed in the following paragraphs, may need to be considered. See Figures A-6 through A-14 for example foundation configurations. Additional examples can be found in the following:

- *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost*, by Linell and Lobacz
- *Permafrost Engineering Design and Construction*, by Johnston
- *Cold Region Structural Engineering*, by Eranti and Lee

[3] *Handbook for the Design of Bases and Foundations of Buildings and Other Structures on Permafrost*, Vyalov and Porkhaev.

- *Construction in Cold Regions, A Guide for Planners, Engineers, Contractors, and Managers*, by McFadden and Bennett
- *Frozen Ground Engineering*, by Andersland and Ladanyi
- *Review of Thermosyphon Applications*, by Wagner

8-5.5.1 Shallow Footings on or Below Granular Pads.

8-5.5.1.1 Granular Pads.

Footings may be placed on or within granular pads or embedded beneath the pad. The footing depth depends on the depth of thawing anticipated over the life of the foundation. Granular pads provide insulation that protects the underlying permafrost from thawing and a working surface around the structure. Preferably, the fill will be thick enough that the active layer remains within the pad and above frozen soils that could potentially thaw and cause settlement. Penetrations of building foundations for drains or other utilities can be a source of unanticipated thawing and settlement due to leakage of fluids or other heat sources. Extra attention should be given to the details of penetrations and quality control around them during construction.

Thermal analysis is required to estimate the granular pad thickness needed to prevent thawing to the level of footing foundations. If the active layer extends below the footing elevation into underlying thaw-unstable soils during the design life, excess settlement of footings may result, and frost heave may occur when refreezing the following winter. Settlement due to creep also must be considered. Bearing capacity and settlement are calculated according to the methods described in paragraphs 8-5.2 and 8-5.3.

8-5.5.1.2 Post and Pad Foundations.

Post and pad foundations are another type of foundation that is often used for temporary facilities, facilities in support of military operations with a design life of five years or less, lighter structures, and horizontal structures (such as roadways and airfields). The footing in this case may be supported on a granular pad or below the depth of anticipated thawing. This type of foundation is illustrated in Figures A-7 through A-9. The support, or post, rising from the footing is often adjustable to accommodate potential settlement, especially when the footings are shallow and might be within the depth of potential thawing or subject to long-term creep settlement.

8-5.5.2 Shallow Footings on Insulated Granular Pad.

This foundation method is designed using techniques like those for a shallow foundation on a granular pad, except insulation is used to decrease the required pad thickness or enhance thermal isolation of the footing. Insulation is often placed near the bottom of granular fill, based on consideration of constructability and to minimize potential damage during construction. The location and extent of insulation beyond the edge of a structure needs to be checked to avoid thawing under the edges. It is good practice to include some depth of granular soil beneath the insulation to accommodate the potential for thaw penetration into the underlying soils. The amount of granular soil beneath the insulation and the location within the granular pad will depend on variation in the natural ground surface, design requirements, climate, and local experience.

Insulation alone will not generally be sufficient to prevent the thawing of frozen ground below continuously heated structures unless the insulation layer is very thick, which is typically not economical. Thermal analysis must be conducted to show that the underlying permafrost will not be degraded during the life of continuously heated structures. For temporary construction, insulated rig mats have been used to preserve underlying pads of snow and ice and allow operations over multiple seasons.[4] Ground thermal analyses must be conducted to support the design of these types of temporary facilities, facilities in support of military operations with a design life of five years or less, lighter structures, and horizontal structures (such as roadways and airfields), which may also be applied to gravel pads.

8-5.5.3 Shallow Footings on Ventilated Granular Pad.

Ventilated granular pads are cooled by natural or forced ventilation through ducts that have commonly been metal pipes but could be other materials, provided they can sustain the applied loads and provide the desired ventilation performance. An example of this type of system is shown in Figure A-10.

The ventilation ducts within the pad are opened during the freezing season and closed in the spring when air temperatures approach 32°F (0°C). As discussed in “Active Freezing Techniques,” by Mageau and Nixon, in warm permafrost regions, natural ventilation may be feasible for a small building in the range of 33 ft (10 m) in the lateral dimension (width), and has been shown to be effective in cold permafrost regions to widths of 100 to 150 ft (30 to 45 m). However, Mageau and Nixon indicate that forced-air systems are likely needed to achieve the required airflow for larger structures. In general, use has decreased due to both operational challenges and as flat loop thermosyphon systems have improved. The performance of air-ducted foundations over a 50-year period was reviewed in “Air-Ducted Hangar Foundations at Thule, Greenland,” by Bjella, who noted that drainage effects of the design must also be considered.

8-5.5.3.1 Ventilated Pad Design Method.

An overview of active freezing design methods using air ducts and other methods is presented in “Active Freezing Techniques,” by Mageau and Nixon. They note that for larger structures, an airflow rate of 0.32 ft^3/s (0.009 m^3/s) would be required for each 10 ft^2 (1 m^2) of heated floor area for a 70°F (21°C) structure having up to 10 in. (254 mm) of insulation. They also provide insulation and gravel pad thickness requirements for different ground surface temperatures. Forced air ducts are normally 1 ft to 2.5 ft (0.3 to 0.8 m) in diameter, with center-to-center spacing of three to four diameters, which are then sometimes connected to buried or aboveground manifolds in groups of four to six.

[4] “Design, Construction and Operation of an Insulated Ice Drilling Pad, North Slope, Alaska,” Hazen et al.

8-5.5.3.2 General Design Considerations.

Pad design considerations include winter prevailing wind direction and snow drifting, airflow rate, duct spacing, duct length, thermal properties of the pad and duct system, and pad thickness. Due to the uncertain nature of wind velocities that will occur in the ducts, base designs on natural convection circulation induced using dissimilar height duct plenums. This intake and outlet stack differential is designed to provide minimum design airflow at zero wind conditions. Increased airflow due to changes in wind velocity is assumed to be greater than the natural convection circulation and enhance cooling. Designing natural ventilation systems requires extensive data on year-round average air velocities in ducts, high safety factors, or a high tolerance to insufficient heat removal and resulting settlements. Forced ventilation systems using fans require maintenance but allow for design using predetermined air velocities. Use differential temperature controllers to control fan and damper operation, and establish ground temperature monitoring within the granular pad. Changes in drainage must also be considered and provided for in the design to ensure the ducts do not become flooded or blocked by icing.

8-5.5.3.3 Maintenance Considerations.

Ventilated pads have a history of failure when maintenance and monitoring is not performed. The ducts tend to fill with snow and other wind-blown debris, effectively eliminating the airflow needed to cool the soil. In addition, warm air circulation can increase the thaw rate of the underlying permafrost if duct dampers are left open or are opened by wind during the summer.

Cooling effects can be enhanced by placing insulation on the ground surface beneath and around structures in the summer to limit heat gain and by removing this insulation in winter to enhance cooling. For raised structures with passive refrigeration, care needs to be taken to prevent snow accumulation and storage of materials in the raised space. Planning for long-term seasonal maintenance of these systems is critical to their successful application, as is understanding snow drifting and wind direction. Snow fences may be required to mitigate snow drifting, but there are also long-term issues to consider with degradation of permafrost where snow accumulates due to snow fences.

8-5.5.4 Shallow Foundations on Refrigerated Granular Pad.

8-5.5.4.1 Refrigerated Granular Pads.

Refrigerated granular pads are composed of an insulated granular pad that is cooled by a refrigeration system (for example, piping) placed within the pad, as shown schematically in Figure A-12. These foundation systems are usually used for slab foundations on permafrost with excess ice that is susceptible to unacceptable displacements if thawed. These systems are used in bulk fuel storage tanks, heated warehouses, industrial process facilities, and high-floor-load facilities such as hangars and vehicle maintenance facilities. Refrigeration systems may be passive (meaning they do not require external energy sources) or active (meaning they require external power to operate).

8-5.5.4.1.1 Passive Refrigeration.

Refrigeration of granular pads is commonly accomplished using passive two-phase thermosyphons configured with flat loop evaporators within the fill beneath a building. This and other applications of thermosyphons for refrigeration are described in *Review of Thermosyphon Applications*, by Wagner; “Thermosyphon Applications in Cold Climates,” by Zarling; and “Some Considerations Regarding the Design of Two-Phase Liquid/Vapor Convection Type Passive Refrigeration Systems” and “Recent Developments in Thermosyphon Technology,” both by Yarmak and Long. Passive thermosyphons use natural convection and have no external power requirements. Include accommodation for ground temperature measurement beneath the structure in the design, and allowance must be made for periodic monitoring and maintenance as part of integrity management and life-cycle planning.

8-5.5.4.1.2 Active Refrigeration.

Active refrigeration systems or refrigeration systems that rely on a mechanical method to remove heat include chilled-liquid systems, forced-air convection systems, and direct-expansion systems. Their advantage is year-round cooling. Mechanical cooling can be added to a two-phase thermosyphon to create a hybrid thermosyphon,[5] or mechanical cooling can be used alone to achieve rapid cooling using a cold fluid such as brine. Active systems require active management of operation, ongoing maintenance, and a source of power. Long-term operations and maintenance costs must be considered when planning the use of mechanical systems of refrigeration.

8-5.5.4.2 Design.

Design of a slab-on-grade structure with two-phase passive thermosyphons is described in “Passive Techniques for Ground Temperature Control,” by Long and Zarling, but thermal analyses can readily be accomplished using commercial 2D analysis software such as TEMP/W. Thermosyphon technology continues to improve the performance of horizontal thermosyphons (flat-loop systems), which allows for thinner pad construction, more space between aboveground finned condenser sections, and reduced costs. Design methodology requires that the NFS pad placed below the building floor and insulation containing the thermosyphon evaporators does not thaw to its base prior to the onset of the next winter’s freezing season because thermosyphon systems only work when air temperatures are colder than ground temperatures. Important design variables include air temperature, wind speed and direction, building temperature (boundary condition), and details regarding embankments used to support the facility, such as insulation type and thickness, thickness of NFS fill, soil thermal properties, and thermosyphon conductance and spacing.

8-5.5.5 Complex Foundation Configurations.

Complex foundation configurations may be required for some facilities involving different types of foundations for the same structure. This type of combined and complex

[5] *Demonstration of an Artificial Frozen Barrier*, by Wagner and Yarmak.

foundation requires thorough site investigation and analysis such that bearing capacity and settlement remains uniform and acceptable across the entire structure.

8-5.5.6 Structure Location on Granular Pad Overlying Permafrost.

When siting buildings on granular pads, it is important to locate footings back from the edge of the pad so they will not be affected by thawing during the life of the structure. The depth of thaw tends to be deeper at the edge of pads, which can result in more cracking and settlement in these areas. The deeper thaw is a function of snow drifting, solar radiation, and water ponding near the toe of the slope that frequently develop when gravel pads are placed on permafrost.

General practice has been to increase the setback from the edge of granular pads built on permafrost as climate has changed. In the absence of other data or site-specific ground thermal modeling, structures should be set back from the crest of embankment slopes a minimum of 12 to 16 ft (4 to 5 m) or 1.5 times the pad thickness, whichever is greater. Using insulation or construction techniques such as air convection embankments (ACE) and changes in the design life may warrant reducing the setback requirement. For example, embankments for facilities that will be operational for short periods, such as a year or two, will be less sensitive to the effects of thawing at the edges of pads than those in place for longer periods of time.

CHAPTER 9 PILE FOUNDATION DESIGN

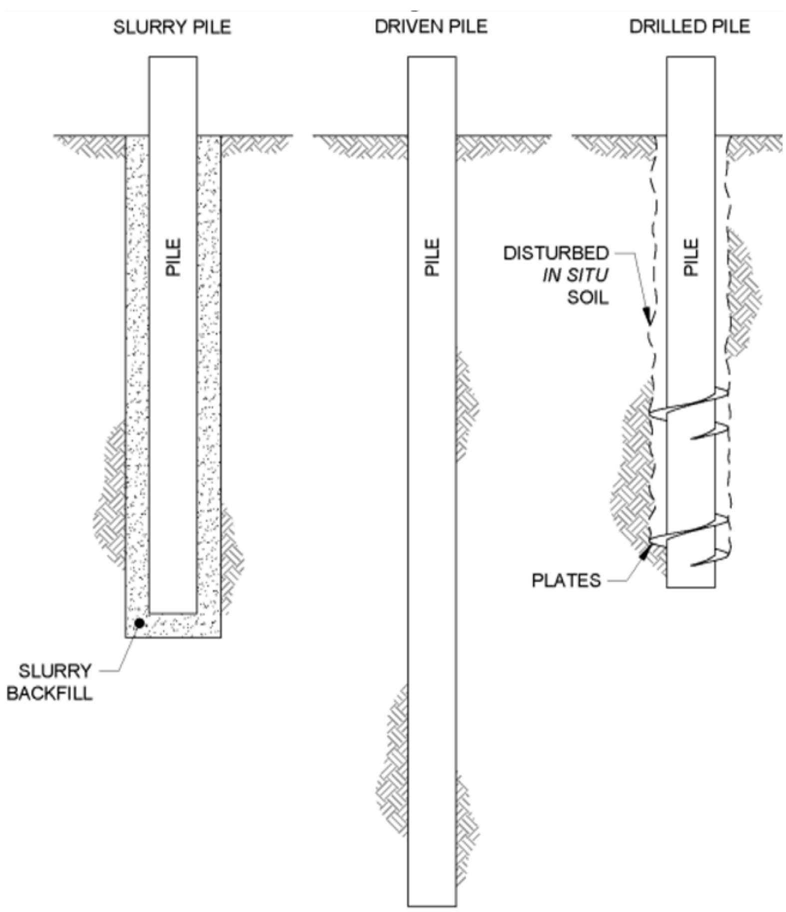
9-1 INTRODUCTION.

Piles are a common type of deep foundation used in Arctic areas of North America. The installation of pile foundations causes changes to the ground and requires varying design methods for different types of deep foundations. Piles are readily available, adaptable to a variety of conditions, and have a long history of successful installation. For general design principles for piles in permafrost and a discussion of frozen soil properties, see Chapter 8 of *Pile Foundations in Engineering Practice,* by Prakash and Sharma. Photographs of pile installations are included in Figures A-15 through A-19.

9-2 GENERAL PILE TYPES.

Pile types may be broadly classified by installation method. Several different types of piles commonly used in North America are shown conceptually in Figure 9-1. Pile material and structural sections will vary, and their selection must consider local practice and availability.

Figure 9-1 Typical Pile Types for Permafrost Areas



9-2.1 Slurry Piles.

Slurry piles are installed by drilling an oversized hole and setting either an open or closed end pile into place. The annular space between the pile and borehole wall is backfilled with slurry, as described in paragraph 9-2.1.5, that freezes after a few days to weeks. The hole diameter should be a minimum of 2 in. (50 mm) larger than the outside diameter of the pile, but providing a 3 to 4 in. (76 to 100 mm) annular space with a larger diameter hole is not uncommon and may facilitate densification. The oversized hole allows for very accurate positioning of the pile but may also require specialized drilling equipment like that shown in Figure A-16. Slurry is densified by vibrating the pile or using concrete vibrators. For piles longer than 30 to 40 ft (9 to 12 m), the entire pile should be vibrated, and more care must be given to specification and control of the gradation of the slurry.

9-2.1.1 Slurry Adfreeze.

Slurry piles gain support from the bond between the pile and frozen slurry, which is termed adfreeze strength and is discussed further in paragraph 9-5. The adfreeze strength can be greatly reduced by the presence of pockets of saline groundwater or the inflow of surface water from the active layer in summer. Saline groundwater may be encountered during drilling and will reduce the adfreeze capacity and potentially lead to increased creep if allowed to mix with the slurry. Tip resistance is commonly not included in North American practice because the vertical displacement that occurs due to adfreeze bond creep is usually less than the vertical displacement required to engage the tip resistance.

Pile capacity is controlled by the adfreeze bond between the slurry and pile. The pile–slurry bond can be increased by roughening the pile surface or incorporating measures such as shear studs or other deformations on the pile. The strength gained through roughening the pile surface may increase pile capacity on the order of three to seven times, based on testing of deformed bars and relatively small-diameter piles.[1] Adding helical shear plates greatly increases capacity and reduces creep deformation by shifting the location of the shear plane into the slurry. An example of a helically wrapped pile is shown in Figure A-17.

9-2.1.2 Ground Temperature Sensitivity.

Ground temperature is one of the most important criteria for the design of piles, influencing both strength and creep behavior. The sensitivity of pile capacity to ground temperature is especially important in warm permafrost, which is permafrost with ground temperatures warmer than about 30°F (−1°C). For example, a pile in permafrost at 30°F (−1°C) will have twice the sustained adfreeze capacity as a pile at 31°F (−0.56°C) and four times the capacity of a pile at 31.5°F (−0.28°C). Hence, refrigeration systems are commonly employed in combination with ground insulation to maintain or reduce the ground temperature and are frequently part of foundations for critical structures.

[1] “Thread Bar Pile for Permafrost,” Holubec.

9-2.1.3 Helical Shear Piles.

A helical shear pile is a specialized type of pipe pile that has a narrow (typically 2- to 4-in. wide [50 to 100 mm]) helical wrap (flight) around the circumference of the pile. The helix can be installed on pipe piles to increase capacity and reduce creep. Helix shear piles are especially effective at improving load resistance in areas with warm or saline permafrost because the helix moves the critical shear plane away from the surface of the pile into the slurry or slurry–permafrost boundary. A typical use is to provide added resistance to frost heave or uplift so that pile length can be minimized.

9-2.1.4 Slurry Shear Piles.

Shear piles are like helical shear piles, but instead of a continuous helical wrap, individual rings are welded onto the pile. Their use is not common in the U.S. (in 2024) but may have application, depending on local resources.

9-2.1.5 Slurry Mixtures.

Slurry mixtures typically consist of water and either sand, silt, or a mixture of the two, but they may include cement additives for some conditions (see paragraph 9-2.1.6). Sand–water mixtures result in an adfreeze capacity that is about 50% greater than silt slurry. Also, the sand–water mixture will have a lower moisture content than when mixed with silt, so the latent heat of fusion is less and, consequently, the freezeback time is faster. To develop dense backfill, the slurry must be fully thawed when placed, but the slurry temperature must also be kept near freezing to reduce freezeback times. Mixing water with frozen sand generally results in a slurry with high ice content, which should be avoided. If the piles do not include a refrigeration system, the time for freezeback of the slurry can be slow if the ground temperatures are warm or saline conditions are present. In this case, the slurry around open pipe piles can be frozen quickly by blowing cold winter air through a duct to the bottom of the pile, allowing it to return up the annulus. Mechanical refrigeration has also been incorporated within piles to enhance freezeback.

A typical sand–water slurry specification has 93% to 100% passing the U.S. No. 4 sieve size and 0% to 17% passing the U.S. No. 200 sieve size, mixed to a 6-in. (150 mm) slump that is mixed with clean water so the temperature is no warmer than 40°F (4.4°C).[2]Slurry specifications will vary, depending on local practice and the availability of material. Frozen material should not be included in slurry mixtures. Proper mixing of slurry materials is critical, especially if cuttings are used, and the ability to do so may dictate the slurry materials used.

9-2.1.6 Cement Slurry Piles.

9-2.1.6.1 Standard Cement Slurry Piles.

Cement slurry consists of a mixture of cement, sand, and water in the annular space between the pile and permafrost. Depending on the grout mix design and water-to-

[2] *Permafrost Engineering Design and Construction*, Johnston; *Frozen Ground Engineering*, Phukan.

cement ratio, cement slurry can provide very high bond strength between the pile and slurry, especially in saline soil conditions. If very high bond strength is developed, the capacity of the pile will be controlled by shearing at the permafrost–slurry interface instead of at the pile–slurry interface.

Attention must be given to the grout mix design to ensure the grout sets before freezing and does not shrink or crack. Cement must be formulated for use in cold temperatures, but with proper mix design, cement slurry can be used effectively at ground temperatures as cold as 14°F (−10°C). Load testing to confirm the permafrost–adfreeze slurry bond strength is required when relying on the cement content of the slurry to increase capacity if conditions vary from previous installations. For further description of the use of cement slurry for piles, see "Laboratory and Field Performance of High Alumina Cement-Based Grout for Piling in Permafrost," by Biggar et al., and paragraph 9-5.3.3.

9-2.1.6.2 Grouted Micropiles.

Grouted micropiles are a special type of cement slurry pile. Micropiles use a small-diameter (typically <4 in. [100 mm]) steel bar, such as those manufactured by Dywidag or Williams, that is installed in a grout-filled hole. They are best suited to use as anchors when they can be installed in bedrock or thaw-stable ground, although micropiles can also be used to carry vertical and horizontal loads in other types of material when used in conjunction with surface casings. The capacity of micropiles is very sensitive to installation methods and ground conditions. Testing has shown that they may not develop significant capacity when bonded in ice-rich permafrost;[3] therefore, they should be used cautiously in this type of material, in combination with a load test program during design and a proof testing program during construction to verify that capacities are being achieved.

9-2.2 Driven Piles.

Piles can be driven in frozen ground using a conventional impact hammer or vibratory hammers, often in combination with thermal modification. However, soil type and ground temperature must be considered because these factors affect drivability. Pile installation methods depend on the soil type, subsurface temperatures, and pile type. Local experience and equipment availability are often important factors affecting how successfully piles are installed, especially in remote areas. The presence of ice lenses or cobbles frozen in the soil matrix may inhibit pile driving or result in stress concentrations associated with damaged piles. For general background on pile installation in frozen ground, see *Frozen Ground Engineering,* by Andersland and Ladanyi; *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost,* by Linell and Lobacz; and *Driven Piles in Permafrost, State of the Art*, by Nottingham and Christopherson. Driving steel H-sections and open-end-pipe piles into frozen ground can be accomplished using a wide range of impact-driving equipment, including vibratory hammers[4] and hydraulic rock-breaker-type hammers. Reinforced pile

[3] "Field Tests of Grouted Rod Anchors in Permafrost," Johnston and Ladanyi.
[4] "The Adfreeze Strength Characteristics of Vibratory Driven Piles," Mayrberger et al.

tips must be included with the design to reduce the potential for damaging piles during installation.

9-2.2.1 Predrilling or Thermal Modification (Prethawing).

Direct driving may not be possible, depending on several factors, including ground temperature, soil type, and the presence of saline soil. In general, piles are easier to advance when ground temperatures are warmer and in finer-grained soils. In colder ground with significant gravel content, pile driving may require predrilling and, in some cases, thermally modifying (prethawing) a small volume of soil around the predrilled hole. Prethawing can be accomplished by adding warm water to the predrilled hole or inserting a steam probe. The temperature of the water and amount of time for prethawing must be monitored, especially if steam thawing is used, to control the volume of soil thawed.

The ratio of the predrilled hole size to the pile diameter may vary, but it is typically on the order of 80% to 90% unless the soil is thermally modified. For criteria on minimum hole diameter for thermal modification, see “Pile Construction Practices in Arctic Regions State-of-the-Art,” by Nottingham et al. A predrilled hole that is not prethawed can promote stress concentrations at the pile tip during installation, which can lead to localized buckling. Local practice and equipment must be considered when developing specifications, or installation of test piles must be planned for during design to verify means and methods. Refer to “Pile Construction Practices in Arctic Regions State-of-the-Art” for further discussion of this approach to facilitate pile installation.

9-2.2.2 Pile Testing.

When driving piles in unfrozen ground, it is standard practice to perform high strain dynamic load testing using a pile driving analyzer to estimate capacity and monitor pile performance during driving. Testing driven piles with a pile driving analyzer in frozen ground may provide some information regarding pile stresses, but the data are not a reliable indicator of final capacity in permafrost areas due to the way in which load capacity in permafrost is developed. Measuring penetration resistance under an impact hammer or penetration rate under a vibratory hammer provides qualitative data but should not be used as a basis for determining the axial capacity. Use conventional static pile load tests performed according to ASTM procedures instead of impact testing for piles installed in permafrost. Special consideration is needed for long-term testing to measure creep rate because of the time required to hold loads and the potential for seasonal changes in ground temperature to affect results.

9-2.3 Helical (Drilled) Piles.

Helical (drilled) piles are used in permafrost areas of Alaska and Canada, but, depending on ground conditions, predrilling may be required to facilitate installation. For example, installations in coarse-grained materials such as those around Deadhorse, Alaska, may require both predrilling and thermal modification. Helical piles have one or more spiral plates welded at specific locations along the shaft. The shaft width typically varies from 1.5 to 36 in. (40 to 910 mm) in diameter, with helices that can vary from 6 to

48 in. (150 to 1220 mm) in diameter. The diameter of the top shaft section may be increased to provide greater lateral capacity to allow for retrofitting or because of anticipated thaw degradation and reduction of soil strength.

Helical piles are installed by drilling each pile into the ground using hydraulic drill equipment. The rate of advancement must be carefully matched to the rotation so soil disturbance is minimized, and the pile is essentially drilled into the soil. Their use is limited by the torque capabilities of the equipment, but they have been used in areas with degrading permafrost or high salinity soil conditions. Perform load testing to validate the design, but production installation is commonly monitored based on applied torque.

Helical (drilled) piles are commonly used for projects that require higher pull-out capacity (anchors) or where frost jacking forces control the design loads. Other benefits include rapid installation, little installation noise or vibration, no casing or dewatering requirement, lightweight installation equipment, the ability to be loaded immediately after installation, and their ability to be removed and reused (temporary facilities or facilities in support of military operations with a design life of five years or less).

9-2.4 Structural Materials.

Pile materials should be selected based on local practice, availability, and structural requirements, but steel, concrete, and timber piles have historically been widely used. In northern Alaska, steel pipe and H-piles are the most common types used in permafrost (in 2024); this is due to their drivability, high vertical and lateral load capacity, and ease of modification through welding. Pile design must consider corrosion potential, which will vary with location, and may include consideration of saline pore water (for example, in Utqiagvik, Alaska) and external environmental conditions such as salt spray or flooding salt water. Concrete piles are rarely used in the Arctic areas of North America but are more common in other parts of the world, where they are installed in permafrost using predrilling and slurry backfill methods. Concrete piles are typically precast and pretensioned to resist tensile loads due to frost heave forces. Timber piles may also be used, provided they have sufficient capacity and are protected from decay and deterioration in the active layer.[5]

9-3 PILE SYSTEMS WITH ADDITIONAL GROUND COOLING.

Ground cooling systems may be used with each general pile type, in combination with insulation, to enhance or maintain the capacity of piles by controlling ground temperature.[6] Cooling systems in common use in North America include passive thermosyphons installed within or adjacent to adfreeze piles, piles built as passive thermosyphons, and active ground freezing systems used to stabilize excavations. Air or liquid cooling can also be used to enhance freezeback or maintain ground

---

[5] *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost*, Linell and Lobacz.
[6] *Review of Thermosyphon Applications*, Wagner.

temperature, but these methods are less common for permanent installations in North America at this time (2024) given the availability of thermosyphon systems.

The purpose of incorporating cooling with pile systems is to reduce ground temperature so the piles can be designed for higher adfreeze and reduced creep, or to maintain ground temperature over the life of the structure. Additional cooling is generally required when ground temperatures are warmer than 30°F (−1°C), as they often are in western Alaska, or because ground temperatures are expected to warm over the life of the facility. They may be integral to the pile or installed adjacent to the foundation or structure.

9-4 END-BEARING PILES.

End-bearing piles are best suited to conditions where stable, dense sand, gravel, or bedrock is present. Conventional design procedures for temperate conditions can be applied to estimate capacity.

End-bearing capacity of deeper piles (such as slurry piles) is typically ignored in permafrost unless the tip is seated on undisturbed, ice-poor, dense sand, gravel, or bedrock materials that will not creep more than design tolerances over the life of the foundation. Studies of pile performance in ice-rich permafrost have shown that the end-bearing resistance of the pile on undisturbed frozen soil or ice is low until the pile has settled about 30% of the base diameter, assuming constant ground temperature. Given common design settlement rates of about 1 mm/year, the end-bearing resistance mobilized over the life of the foundation will generally be very low and is neglected in practice.

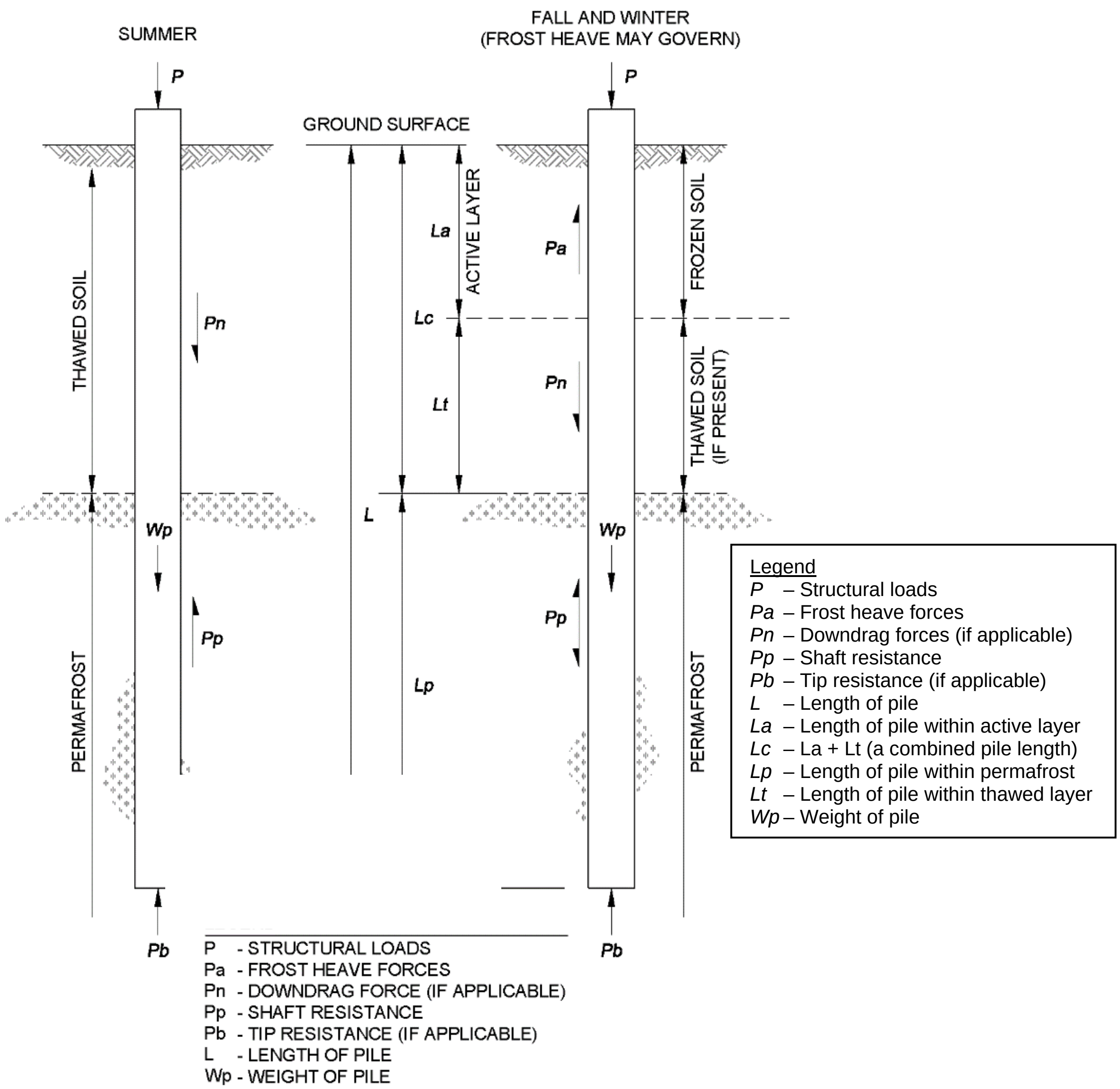
9-5 ADFREEZE PILES.

Piles installed in permafrost can provide long-term support for heavy loads if the design considers the mechanics and changeable nature of permafrost. The pile capacity, in compression or tension, will be significantly influenced by site conditions, such as ice content, thermal condition, and soil salinity, and by the nature and duration of the load application, pile type, and installation method. Therefore, a thorough understanding of both the thermal regime throughout the intended structure's service life and the soil properties is needed to determine the optimal pile design and allowable pile capacity. Considerations in the design of adfreeze piles are presented in the following paragraphs.

9-5.1 Pile Capacity—Seasonal Change in Resistance.

The capacity of piles in permafrost will vary from winter to summer due to changes in the ground temperature and corresponding changes in the mechanical properties of the permafrost (see Figure 9-2). In the later part of the summer season, the active layer will become fully thawed (see Figure 2-5). As winter cooling begins, the active layer begins to refreeze, with attendant development of seasonal frost heave forces along that portion of the pile within the active layer. However, adfreeze shear strength (shaft resistance) will increase as the permafrost temperatures oscillate toward the cold side of the trumpet curve.

Figure 9-2 Seasonal Load and Resistance



9-5.2 General Relationships.

The geotechnical pile capacity is determined by integrating the shaft and tip resistance over the respective pile areas and including an appropriate FS for both adfreeze and creep-controlled conditions, as indicated in Equation 9-1. The effect of potential downdrag must also be considered and is discussed further in paragraph 9-9. The general relationship for pile capacity expressed in Equation 9-1 is applicable to both adfreeze and creep-controlled conditions, provided appropriate values are used for each of the parameters.

Equation 9-1. General Form of Equation for Vertical Pile Capacity

$$Q_a = \frac{1}{FS}(Q_s + Q_p)$$

Where:
Q_a = allowable pile capacity for a given load condition
Q_s = adfreeze capacity based on allowable adfreeze strength for given ground temperature and design creep rate
Q_p = pile capacity mobilized at the tip when ground conditions are appropriate (Tip capacity may be ignored for ice-rich conditions because the strain needed to mobilize the tip resistance typically exceeds allowable strain along the shaft.)
FS = factor of safety, which will vary with load case (Refer to paragraph 7-8 and UFC 3-220-01 for additional requirements.)

9-5.3 Adfreeze (Shaft Resistance).

The term adfreeze refers to the tangential shear strength developed along the interface of a pile and the surrounding in situ soil or engineered slurry. Adfreeze strength is a function of ground temperature, salinity, soil-slurry type, moisture content (including ice content), pile material and roughness, and installation method (typically either a slurry or driven pile). The pile shaft condition and presence of adfreeze reduction agents, such as paints, oil, and mill slag, can also affect the adfreeze strength. The ultimate resistance to compression or tension loads on the pile can be estimated by summing the unit resistance over the surface area of the pile that is exposed to soil or slurry within the permafrost.

9-5.3.1 Common Values of Adfreeze.

Commonly applied values of adfreeze strength are presented in the following references.

9-5.3.1.1 Linell and Lobacz.

In *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost,* Linell and Lobacz developed recommended adfreeze strengths based on an analysis of specific dimensioned steel and timber test piles embedded approximately 10 ft (3 m) in permafrost at ground temperatures between 32°F and −27°F (0°C and −33°C) with gradual incremental loading. Their recommendations are in terms of average sustainable adfreeze for both in-place soil and engineered silt or granular slurry. The creep displacement associated with the sustainable adfreeze strength is implied to be less than 1 in. (25 mm) over a 20-year service life. They also note that hard, sound freshwater ice shows a lower rate of creep deformation (and higher adfreeze strength) than frozen slurry at some temperatures.

9-5.3.1.2 Weaver and Morgenstern.

“Pile Design in Permafrost,” by Weaver and Morgenstern, presents recommendations for the adfreeze strength of ice and soil at ground temperatures between 30°F and 23°F (−1°F and −5°C) in terms of the long-term cohesive strength of the frozen soil and an empirical roughness coefficient given by the factor, *m*, as shown in Equation 9-2.

Equation 9-2. Long-Term Shear Strength

$$\tau_{lt} = mc_{lt}$$

Where:
τ_{lt} = long-term shear strength
m = an empirical roughness parameter
c_{lt} = long-term cohesive strength of the soil

Suggested values for *m* in Equation 9-2 from “Pile Design in Permafrost,” by Weaver and Morgenstern, were 0.6 for steel piles, 0.7 for concrete piles, and 1.0 for corrugated steel pipe piles. Equation 9-2 is based on a review and analysis of published pile test data, with the caution that piles supported in permafrost at temperatures warmer than 30°F (−1°C) may require special precautions, such as the addition of (artificial) cooling, to develop axial capacity.

9-5.3.1.3 Continued Research.

Research continues on the capacity of piles in frozen ground, and specific research may develop alternate values for the empirical roughness parameter or the form of Equation 9-2. For example, research on the adfreeze strength of a steel pile installed in Leda clay under varying ground temperature and normal stress indicated that a higher roughness coefficient, *m*, may be appropriate for the testing conditions and that the strength equation should include an additional frictional factor.[7] These results demonstrate the evolving nature of frozen ground engineering and the value of test programs for assessing design variables.

9-5.3.2 Roughness.

Adfreeze values in the literature generally do not consider differences in pile roughness, other than the roughness inherent in different pile materials (such as steel, concrete, timber). For steel piles, surface conditions have been shown to have a significant effect on pile capacity. In “Effect of Backfill Properties and Surface Treatment on the Capacity of Adfreeze Pipe Piles,” by Sego and Smith, sandblasting a steel pile was shown to double the adfreeze strength at the pile–slurry interface, relative to untreated mill-finished steel pipe piles.

[7] “Interface Shear Strength Characteristics of Steel Piles in Frozen Clay Under Varying Exposure Temperature,” Aldaeef and Rayhani.

9-5.3.3 Cement Slurry (Shaft Resistance).

Cement grout is a type of slurry that is considered separately from the conventional sand–water slurry discussed in paragraph 9-2.1.5 because of the considerable strength gain that can be achieved. In “Laboratory and Field Performance of High Alumina Cement-Based Grout for Piling in Permafrost,” Biggar et al. show that using cement grout doubled the pile load carrying capacity for a given displacement rate when the native soil had salinity up to 30 ppt, which is not an uncommon value (see paragraph 2-4.1.7). Although grout backfill will likely be more expensive than sand–water slurry, it may be preferable because of a lack of suitable material or because of the salinity in the soil.

The use of cement grout will likely move the critical shear plane from the pile–slurry interface to the interface between the soil and slurry for properly prepared steel pile surfaces. By shifting the critical shearing surface, the overall pile capacity increases because the surface area where shearing occurs is increased. However, in ice-bonded permafrost, the grout–in situ soil interface adfreeze bond should be reduced from the steel pile–grout interface adfreeze strength due to the material property differences between the steel and in situ soils. The reduction factors depend on the in situ soil material at the ground interface, with well-graded, clean sands and gravels having greater strength then high-plasticity clays for similar environmental conditions.

9-5.3.4 Creep Settlement.

Piles in permafrost will creep when installed in both ice-rich and ice-poor conditions, but consideration of creep becomes especially important when soils are ice-rich or have a high saline content because of the higher creep potential associated with these materials. In ice-poor soil or bedrock, piles can be designed for end bearing, provided frost jacking and uplift forces do not control the design.

Although creep is a highly complex phenomenon (see paragraph 5-3.2), in practice, creep effects are limited by controlling stress levels along the pile or by decreasing the ground temperature, which reduces the creep rate. Because creep is time and temperature dependent, it becomes important to establish the service life and the acceptable total and differential settlement tolerances of structures because these will dictate allowable stress levels over time. A common design standard is to design structure foundations for a creep rate of 1 in. in 100 years.

9-5.3.4.1 Creep Criteria.

If there is no slip between the pile and the soil, the pile settlement is equal to the cumulative shear deformation of frozen soil in contact with the pile. Equation 9-3, based on Equation 7.3-15 in *Frozen Ground Engineering,* by Andersland and Ladanyi, expresses the settlement (S) from primary creep using the International System of Units, as shown here:

Equation 9-3. Creep Criteria

$$s = \frac{3^{(n+1)/2}}{n-1} * a * \left(\frac{\dot{\varepsilon}_c}{b}\right)^b * \left(\frac{\tau_a}{\sigma_{c\theta}}\right)^n * t^b$$

Where:
a = pile radius (m)
τ_a = average shear stress along the pile–soil interface (MPa)
$\dot{\varepsilon}_c$ = creep strain rate (m/t)
t = time (hours)
$\sigma_{c\theta}$ = reference stress = $\sigma_{c0} * (1 + \theta/\theta_c)^w$ (Mpa)
σ_{c0}, n, b, w = experimentally determined values based on soil type
θ = soil temperature, −T(°C) or absolute value
θ_c = reference temperature, arbitrarily 1°C

Representative creep parameters that may be used in Equation 9-3 were compiled in *Frozen Ground Engineering*, by Andersland and Ladanyi, from a variety of source documents. Considerable judgement is required when using creep parameters, and designers must be familiar with the source documents and properties of the materials tested to confirm they are representative of the material being analyzed. Use field or laboratory testing like that described in *Creep of Frozen Soils*, by Sayles, to confirm the applicability of the values chosen for the design when warranted by project complexity.

Because creep of ice and ice-rich materials is poorly defined at temperatures warmer than 30°F (−1°C), piles in warm ice-rich permafrost must be refrigerated (see paragraph 9-6). Lowering ground temperature reduces the creep rate. However, it might take multiple winters to cool the soil to less than 30°F (−1°C) when using thermosyphons in warm permafrost areas. In addition, horizontal insulation may be required to assure stable ground temperatures are maintained.

9-5.3.4.2 Soil Salinity Effects.

Soil salinity in permafrost is an important parameter that must be characterized during site investigation and laboratory testing (see paragraph 5-3.1). The effect of salinity on creep was investigated in “Design of Vertical and Laterally Loaded Piles in Saline Permafrost,” by Nixon and Neukirchner, and in “Time-Dependent Displacement Behaviour of Model Adfreeze and Grouted Piles in Saline Frozen Soils,” by Biggar and Sego, who provide a design approach for saline soils. They show that soil salinity may increase the creep displacement of vertically and horizontally loaded piles by as much as 10 to 100 times that of nonsaline frozen soil.

9-5.3.4.3 Ground Temperature Effects.

Creep rate increases with increasing ground temperature. The creep of ice and ice-rich materials is poorly defined at temperatures warmer than 30°F (−1°C); therefore, piles in warm, ice-rich permafrost should be refrigerated, either passively or through mechanical means, to maintain or reduce the creep rate. In addition, horizontal insulation may be required to ensure stable ground temperatures are maintained. If ice-poor soils or bedrock are present in areas with warm, saline permafrost, piles should be designed as end bearing in these materials.

9-5.3.5 Allowable Adfreeze Shear Stress.

Creep is considered in the design of adfreeze piles by determining an allowable adfreeze shear stress. The allowable shear stress depends on several factors, including time of loading, ground temperature, and allowable displacement over the design life. Estimated values of adfreeze shear stress are established based on an understanding of site conditions, published data from the literature, and site-specific testing. Design values are selected from the developed relationships by either reducing the allowable shear stress for a given time of loading by a factor or selecting an allowable value for an increased time of loading.

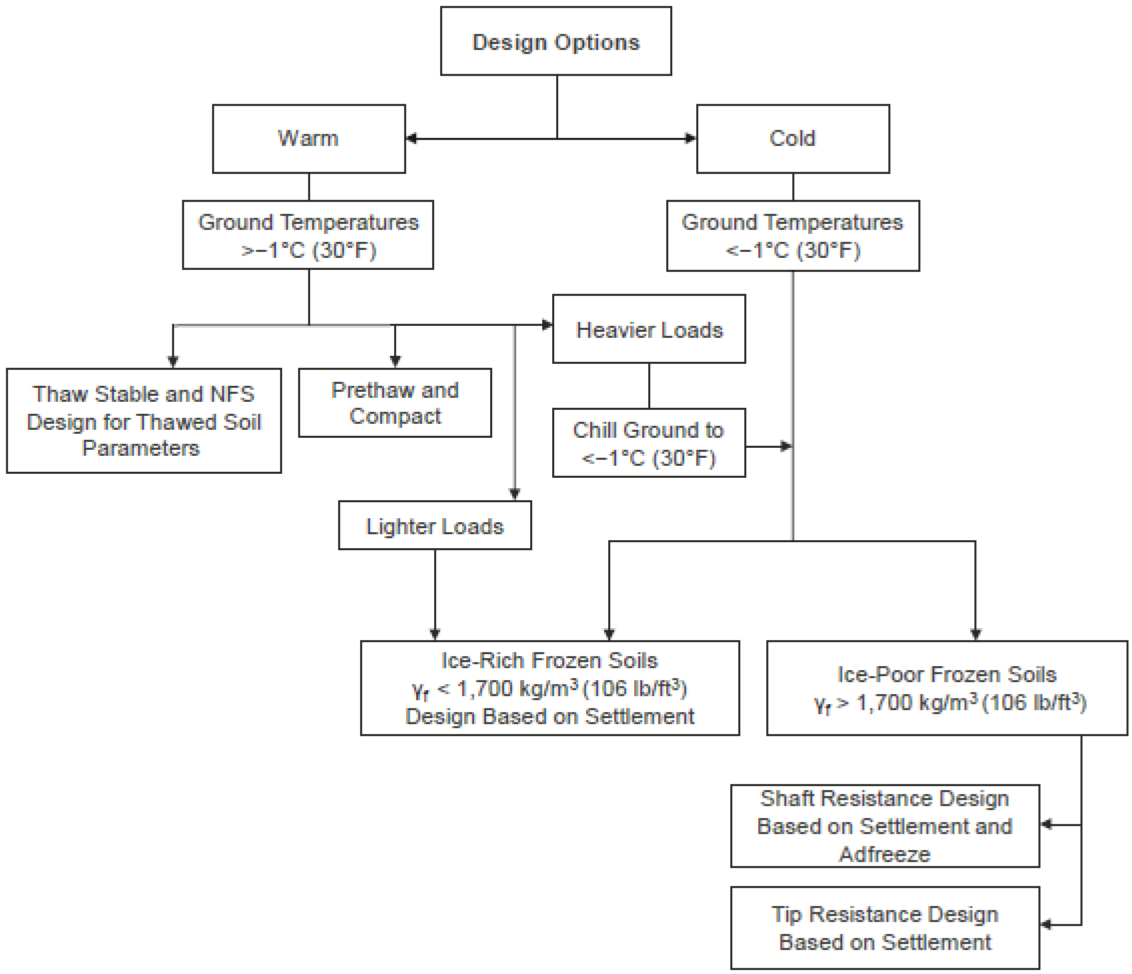
9-6 ADFREEZE PILE DESIGN PROCESS.

General design procedures for adfreeze piles, including charts for estimating adfreeze bond strengths and creep parameters, are presented in *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost,* by Linell and Lobacz; “Pile Design in Permafrost,” by Weaver and Morgenstern; *Pile Foundations in Engineering Practice,* by Prakash and Sharma, and *Frozen Ground Engineering,* by Andersland and Ladanyi. Recent updates to engineering practice must also be considered and include issues such as the following:

- The projected warmest or average permafrost temperature of the site for design and how this will be established. Ground thermal modeling may be required to predict changes in ground temperature.
- The tangential adfreeze bond strength along the pile length in permafrost as a function of temperature in ice-poor permafrost.
- The allowable shear strength associated with the design pile displacement for piles in ice-rich or saline permafrost.
- The embedment depth in permafrost to support the structural loads and resist downdrag and upward frost heave forces.
- The pile material, size, shape, and method of installation.
- Complete freezeback to the design temperature before loading, which is typically monitored using thermistor strings.

One approach to the design of piles in permafrost proposed in “Pile Design in Permafrost,” by Weaver and Morgenstern, is based on maximum ground temperature and the performance of piles, depending on their installation in ice-rich or ice-poor permafrost (see Figure 9-3). However, Figure 9-3 should be applied cautiously at sites where the permafrost is warmer than 30°F (−1°C) and creep effects or potential site changes over time may control the design.

Figure 9-3 Adfreeze Pile Design Process in Permafrost



9-7 TANGENTIAL ADFREEZE (FROST HEAVE).

The magnitude of frost heave forces is related to many factors, including soil and ground ice type and heterogeneity, variation of soil temperature with time and depth, rate of freezing, availability of water, foundation surface type, overburden pressure, pile load, and pile type. The following variables are especially significant when determining the minimum pile length necessary to resist frost heave:

- Pile loads and duration of loading
- Active layer thickness
- Tangential adfreeze bond strength in the active layer
- Pile shaft resistance below the active layer
- Serviceability limit state or failure criteria (pile vertical or lateral displacement at which maintenance must be done)

Design values of tangential adfreeze used in North American practice commonly are on the order of 30 psi (~200 kPa) to 60 psi (~400 kPa), depending on the standards being used (Table 9-1). However, 40 psi (275 kPa) is a very commonly applied value in North America for silty, frost-susceptible soil in the absence of other data.

Table 9-1 Published Values of Tangential Adfreeze in Absence of Other Data or Specification

Soil Type	Tangential Adfreeze
Silty frost-susceptible soil (commonly applied in North America)	40 psi (275 kPa)
Organic soil	10 psi (70 kPa)
Silty granular soil	20 psi (140 kPa)

Source: Adapted from "Foundations in Cold Regions," by Phukan.

9-7.1 Minimum Pile Embedment and Frost Heave.

The minimum embedment needed to resist frost heave must be considered in every design. Pile heave due to frost action cannot occur unless the uplift force, *Pa*, exceeds the resistance provided by the length of pile embedded below the active layer, *Pp*, and the applied load on the pile (pile weight plus normally applied dead and live loads), as illustrated in Figure 9-2. The uplift force depends on the active layer thickness, the adfreeze bond strength in the active layer, the supply of water to the freezing plane, and the ability of the material to transmit water to the freeze plane. The pile uplift resistance depends on the embedded length of the pile below the active layer and the integration of shaft resistance along that length.

9-7.2 Engineering Measures to Mitigate Frost Heave.

Three conditions are required for frost heave and the development of the resulting tangential heave load:

- Freezing temperatures that change water in unfrozen soil to ice when the soil freezes
- Availability of water that moves to the freezing front due to capillary forces
- Frost-susceptible soils that can wick the available water to the freezing front

If one of these necessary conditions are eliminated, frost heave should not occur. Examples of engineering measures used to control and mitigate frost effects are discussed in paragraph 7-2.1 and paragraph A-8.

9-8 LATERAL LOADS.

Piles embedded in permafrost to sufficient depth to resist uplift forces and structural loading generally have high resistance to lateral loads during short-term loading, such as due to wind. If these same piles are subjected to sustained lateral loads, the capacity must be reduced due to creep that will occur. For methods for estimating the p-y (load-deformation) response of laterally loaded piles in permafrost for various load durations, see "Analysis of Laterally Loaded Piles Embedded in Layered Frozen Soil" and "Lateral Pile Analysis Frozen Strength Criteria," both by Crowther, and "Analysis of Laterally Loaded Piles in Frozen Soils," by Yang et al. *Frozen Ground Engineering,* by Andersland and Ladanyi, reports that long-term lateral loads on piles installed in ice-rich frozen ground, whether slurry or drilled, can rotate about the length of the pile over time, virtually eliminating the depth of fixity.

9-9 DOWNDRAG.

Downdrag will develop on a pile installed in frozen ground for several reasons, including thawing and settlement of ice-rich permafrost along the length of the pile and seasonal heave and thaw of frost-susceptible soil at the ground surface. In areas of significant seismic risk, liquefaction of soils that have thawed is another significant cause of downdrag that requires mitigation through ground improvement. As noted in paragraph 9-5.2, downdrag effects should be considered during design, and, if they are found to be a significant design issue, measures to mitigate the downdrag must be incorporated into the design. These mitigation measures include isolation of the pile from shallow frost heave and settlement effects, use of insulation or cooling to prevent a decrease in the depth of permafrost or thawing of ice-rich material along the length of the pile, changes in the pile geometry to provide greater resistance to anticipated load conditions, and ground improvement after thawing.

9-10 TENSION LOADS.

Design pile resistance to applied uplift or tension loads using appropriate adfreeze values for the design conditions and appropriate reduction for uplift, like that applied in the design of foundations in temperate regions using standards discussed in paragraph 1-5.2.

9-11 CYCLIC LOADS.

9-11.1 Machine Loads.

The behavior of adfreeze piles subjected to cyclical loads from machine loads such as from generators and other vibrating equipment is a special case (see paragraph 7-6.3) that requires careful analysis because the effects of these loads on adfreeze are not well defined. Model testing and monitoring indicate that cyclic loads increase the displacement rate of adfreeze piles relative to static-only axial loads for similar engineering and geologic conditions.[8] The magnitude of the increase is related to the

[8] "Displacement of Piles Under Dynamic Loads in Frozen Soils," Parameswaran; *Vibration Amplitudes in the Inuvik Powerhouse*, Pernica et al.; "Dynamic Load Effect on Settlement of Model Piles in Frozen Sand," Stelzer and Andersland; "Adfreeze Strength of Model Piles in Frozen Soil Under Dynamic Loads," Zhang et al.; "The Settlement of Model Piles in Frozen Soil Under Dynamic Loading," Zhang et al.

amplitude of the load, pile roughness, foundation rigidity, and other factors influencing creep in permafrost.

9-11.2 Sustained Axial Loads.

Adfreeze piles subjected to sustained axial cyclic loads require careful evaluation during the site assessment and engineering design phases. Site evaluation is particularly important if pore water salinity is present along or near pile embedment depths in the planned development area. Depending on geotechnical conditions and structural loadings, a comprehensive site and project analysis may be required for adfreeze pile design, including pile load testing. General adfreeze pile design recommendations are described below.

9-11.2.1 Structural Methods.

Structural methods to eliminate or reduce the cyclic loads to the adfreeze piles must be evaluated early in the design process and are the preferred approach to mitigating the effects of dynamic loads on adfreeze piles. Structural methods may include base isolation and dampening for machine-induced cyclic loads. If structural methods will not eliminate cyclical loading on adfreeze piles, engineering methods to permanently decrease the ground temperatures around cyclically loaded piles must be implemented because this will reduce the creep rate. Ground cooling is particularly important for sites with warm permafrost or elevated pore water salinity. Engineering methods may include the use of rigid insulation within pad fill, passive subgrade cooling, and active refrigeration.

9-11.2.2 Slurry.

For slurry adfreeze piles, dense slurry consisting of saturated, well-graded sand and gravel is recommended. Potable water is recommended for the slurry to reduce weakening by salt or other contaminants. Grout can be used in lieu of slurry in specific applications, although it should be designed for the expected ground temperatures and tremie placed.

9-11.2.3 Pile Surface Texture.

Steel and concrete adfreeze pile surfaces planned for slurry backfill should either be roughened by sand blasting to remove coatings, corrosion, and expose bare metal or lugs, helix wraps, or other structural protrusions that extend into the slurry or grout backfill should be installed around the piles. Structural protrusions should also be considered for timber adfreeze piles.

9-11.3 Creep.

Testing results showed that small cyclical loads will accelerate the creep of adfreeze piles in frozen sand by a factor of about 2 for alternating stresses of as little as 3% to

5% of the static stress.[9] Therefore, a 50% reduction from the allowable static adfreeze strength is sometimes considered as an initial estimate for design. For critical facilities, pile load tests should be conducted to determine or confirm a site-specific creep rate due to applied dynamic loads.

9-12 ADDITIONAL CONSIDERATIONS.

9-12.1 Pile Load Testing.

Pile load tests are used to verify design assumptions and optimize pile design. The results may provide insights on site conditions and foundation responses that cannot be captured by field investigation and laboratory testing alone. Pile load tests should be conducted on up to approximately 10% of the piles installed, but the actual number tested will depend on the scale of the project, uncertainty of soil conditions, confidence in the soil property characterization, and confidence in the installation method. Procedures for load tests are found in ASTM D5780, *Standard Test Methods for Individual Piles in Permafrost Under Static Axial Compressive Load*.

In selecting the number of piles to be tested, the uncertainty of soil conditions and confidence in the soil properties and thermal regime should be considered. For example, when the length of helical piles installed within the active layer is designed to carry a portion of the load, soil and moisture content variation across the site may have a higher potential to affect pile capacity. In comparison to slurry piles, which can be closely monitored and controlled, approximately 10% of helical piles should be tested, while fewer slurry piles can be tested. Design of pile load tests conducted in freezing air temperatures, or under long-term sustained loads, requires specific measures, such as providing shelter for test equipment or load cells that are susceptible to freezing. Significant time and effort are required when conducting long-term load tests in the Arctic and Subarctic. Examples of longer-term load tests in permafrost conditions are presented in "The Adfreeze Strength Characteristics of Vibratory Driven Piles," by Mayrberger et al., and in general references such as *Frozen Ground Engineering,* by Andersland and Ladanyi.

9-12.2 Utility Connections to Buildings.

Incorporate flexible utility connections into the design to accommodate potential differential movements between the building and surrounding ground surfaces that occur due to seasonal frost action. For example, properly designed pile-supported structures will have little long-term settlement, but the surrounding ground surface may continue to settle because of thermal changes caused by site development or longer-term environmental changes at the site. If only vertical displacement is anticipated, the utility connections can be made with slip interfaces to facilitate movement between the structure and the underlying soils. See UFC 3-130-05 for further discussion.

[9] "Displacement of Piles Under Dynamic Loads in Frozen Soils," Parameswaran; *Effect of Dynamic Loads on Piles in Frozen Soils*, Parameswaran.

9-12.3 Monitor Drilling for Slurry Piles and Predrilled Holes.

Design criteria commonly assume a certain amount of massive ice will be present along the length of the pile, which needs to be confirmed through logging cuttings produced during installation to confirm that conditions are as expected or that specific geologic units, such as a bearing layer, have been encountered. Therefore, drilling operations must be monitored and logged by personnel who are experienced with logging frozen soil and familiar with the anticipated subsurface conditions assumed in the design. If necessary, additional confirmation of subsurface materials can be accomplished using a downhole camera or lights to illuminate the borehole sidewalls and allow direct observation of conditions. When the amount of massive ice exceeds the design criteria, it is common to extend the pile an additional foot per foot of excess massive ice. Changes in pile length may require field splicing, which will affect the production of pile installation and schedule, especially if sufficient material is not on hand, which is often the case if the site is in a remote location.

A percentage of slurry piles should include installation of small-diameter casings to allow for installation of thermistor strings, which will in turn allow for measurement of ground temperatures to confirm that slurry has frozen back. The actual number of thermistors installed will depend on the number and configuration of the slurry piles.

This Page Intentionally Left Blank

CHAPTER 10 HORIZONTAL STRUCTURE DESIGN

10-1 SITE INVESTIGATION CONSIDERATIONS FOR HORIZONTAL STRUCTURES.

In general, the site investigations for horizontal structures (such as road and airfield embankments, pipelines, and other long linear infrastructure) must follow the criteria referenced in UFC 3-130-02, UFC 3-220-01, UFC 3-250-01, *Pavement Design for Roads and Parking Areas*, EM 1110-1-1804, and Chapter 7 of this UFC. Other general discussion is found in technical literature, such as the following:

- *Roads and Airfields Constructed on Permafrost, A Synthesis of Practice*, by Connor et al.
- *Thaw Stabilization of Roadway Embankments Constructed Over Permafrost Areas*, by Zarling and Braley
- *Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions*, by the Transportation Association of Canada

Foundations for horizontal structures will cross or span varying terrain or permafrost conditions and must consider not only the stability within the specific terrain unit and the transitions between terrain units, but also water features and mitigation of thermal erosion due to water. Foundations for horizontal structures may affect the subsurface conditions over time, and those effects need to be considered for the design life of the structure. The site investigation results will allow for evaluating and selecting appropriate foundation types for the project alignment and structure.

10-2 SELECTION OF FOUNDATION TYPE.

Foundation selection depends on the conditions of the existing terrain. In areas of seasonal frost, embankments and other horizontal structures should be constructed when the ground is thawed, using methods described in UFC 3-250-01, where several methods to protect the embankment section from seasonal frost effects are described in detail.

There are several different foundation options for permafrost regions. These options generally require active methods that provide thermal protection of the underlying soil, achieved either through thickened embankment fill or a combination of insulation such as rigid XPS or EPS insulation and embankment fill. Other methods may also be utilized, including air-convective embankments, air-convective shoulder treatments, or passively cooled embankments using open ducting or thermosyphons. In some cases, if the underlying permafrost is relatively thaw-stable, passive methods (such as allowing the permafrost to thaw) may be used. Additional details and considerations can be found in documents such as the following:

- *Embankment Design and Construction in Cold Regions*, by Johnson
- *Cold Regions Utilities Monograph*, by Smith

- *Frozen Ground Engineering*, by Andersland and Ladanyi

10-3 CONTROL OF HEAT TRANSFER AND DEGRADATION OF PERMAFROST.

Heat transfer from horizontal structures can be costly to control, and total prevention of the thawing of the underlying embankment and natural soil is often impractical. A cost analysis may dictate allowing for thaw with intervals of maintenance or patching prior to developing excessive differential settlement. Allowing for thawing must include annual costs for releveling the embankment surface or patching the surface pavement. Most often, this annual maintenance is more cost-effective than constructing an embankment that is resistant to thawing.

When insulation is used, material properties must be appropriate to provide sufficient strength and performance over time. For example, EPS, commonly used as lightweight fill, requires a more robust structural section above it to withstand repetitive loads than higher density materials with better strength in combination with low strain would require. Both EPS and XPS may be appropriate for a given application, but material properties must be carefully considered to attain proper performance. Insulation must also have a shear strength sufficient to resist applied loads and loads anticipated during construction, which may be higher than the structural loads.

10-3.1 Site Selection.

Terrain unit analysis and site investigations that characterize changes in near-surface conditions are critical to selecting the best route or alignment for horizontal structures, especially in permafrost environments where thaw-unstable terrain may be avoided by careful site selection. Passive methods may be utilized in terrain units classified as thaw stable. In areas that are thaw unstable (such as ice-rich polygonal ground), active methods may be employed; however, these are costly in long structures such as roadways. Route or alignment selection must consider the potential effects of thaw-unstable terrain and related geohazards on the project. A combination of desktop, remote sensing, and field methods can be effectively employed to characterize sites and monitor their performance over time.

10-3.2 Removal—Excavate and Replace.

This method is typically used where thaw-unstable permafrost conditions exist. A variety of excavation methods are available for frozen ground, depending on soil type, moisture (ice) content, and planned excavation depth. Typical frozen ground excavation equipment consists of single-tooth rippers, cutters, hydraulic impact breakers, and conventional bucket excavators with frost teeth. Drilling and blasting may be cost effective if large volumes of material must be moved. For options and additional details, see Chapter 9 of *Frozen Ground Engineering,* by Andersland and Ladanyi.

10-3.3 Stability of Slopes during Thaw.

The thermal effects and subsequent stability of embankment side slopes can be substantial. Embankments over frozen ground typically must be designed to be wider and to have flatter side slopes than those in temperate climates. Embankments wider than those used in temperate areas, along with flattened side slopes, can be used to provide sacrificial slopes that can deform while having little significant effect on the working embankment.[1] A recent study, “Thermal Stabilization of Embankments Built on Thaw-Sensitive Permafrost,” by Kong and Doré, used very shallow shoulder slopes, most prominently on the downwind side of the embankment, that allowed for wind scouring of the snow and prevented snow piling and drifting in the ditch areas, preventing warming due to increased winter insulation from snow. Thermal analysis and a review of studies such as *Embankment Design and Construction in Cold Regions,* by Johnson, and Chapters 9 and 11 of *Frozen Ground Engineering,* by Andersland and Ladanyi, provide additional information.

10-4 PAVEMENT STRUCTURES.

Horizontal structures, or embankments, are designed to support concrete and asphalt airfields, roads, parking areas, and other linear structures (including unsurfaced, or gravel, roads). Embankment and pavement design must follow UFC 3-260-02, *Pavement Design for Airfields*, for airfields and UFC 3-250-01 for roads and parking areas. Additional considerations for embankment and pavement structures in cold regions can be found in *Cold Regions Pavement Engineering,* by Doré and Zubeck.

Construction of embankments often changes the natural thermal regime of the ground, creating the potential for thaw settlement, frost heave, and consolidation. Thaw settlement often occurs at ice-rich locations, such as those with wedge ice. The subsequent free water produced during thawing will then freeze the following winter season, creating frost heave. Frost heave can occur just as readily at nonthaw-settled locations in cases where there are frost-susceptible soils, water, and freezing temperatures, which can create ice lenses within the embankment. The formation of these ice lenses can result in differential surface movement during freezing and significant loss of strength during thaw. Embankments constructed of NFS material perform well but can still undergo destructive deformation and settlement if constructed over thaw-unstable subgrades.

10-5 DRAINAGE STRUCTURES.

Effective drainage is critical for the long-term performance of horizontal structures. Improper design or construction, in combination with thermal degradation, can affect the stability and functionality of these structures. Retention and storage requirements may be different than those in temperate areas due to impermeable freezing ground. Appurtenances must also be sized to accommodate changes in precipitation due to climate and vegetation changes during the life of the structure. Drainage structures, including culverts, are addressed in Chapter 11.

Horizontal structures have the potential to affect surface water and groundwater flow across a site, such as by altering runoff patterns or blocking drainages. These changes,

---

[1] *Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions,* Transportation Association of Canada.

including cross-embankment flow, may alter the permafrost depth, inducing catastrophic thawing of thaw-unstable materials in the drainage pathway. Careful consideration of both the number of drainage structures and their potential to affect the thermal conditions at a site (such as ponding water, ditches, and culverts) must be considered. It is critical that embankments that become impoundments during periods of high runoff are sufficiently impervious and incorporate measures to prevent seepage pathways from developing along culverts that may penetrate the embankment.

CHAPTER 11 DRAINAGE AND DRAINAGE STRUCTURES

11-1 INTRODUCTION.

General guidelines for drainage and groundwater are covered in UFC 3-130-01. Surface water and groundwater can have very detrimental effects in permafrost areas and require special consideration for every project. Proper drainage is necessary to maintain the thermal stability of the structure and reduce the need for future maintenance. When possible, avoid construction of foundations in areas where natural groundwater and surface water flow exists. In most cases, this is impossible; therefore, additional drainage pathways are required to ensure water is conveyed through the embankment in a nondestructive manner. Permafrost features, such as ice wedges or other types of massive ground ice, are especially sensitive to thawing, and these areas should be avoided when possible.

11-2 VERTICAL STRUCTURES.

Positive drainage must be developed to drain water away from the foundations of vertical structures to prevent ponding and degradation of frozen ground conditions. When embankments or pads are used over permafrost terrain, the physical limits of the pads must include room for setbacks and insulation that may be required. This allows for sacrificial slope edges that can fail due to permafrost degradation related to the effects of ditching, ponding water, and thawing related to seasonal snow drifting, without damaging the embankment.

11-3 HORIZONTAL STRUCTURES.

Several surface water and groundwater mechanisms can negatively affect horizontal structures by enhancing permafrost degradation and erosion along ditches and drainage along the toe of embankments, forming aufeis when natural drainage is blocked, building up ice, and causing cross-drainage thawing of permafrost below the structure. Adverse drainage effects can be avoided by rerouting the alignment around or away from natural drainage features or can be mitigated by drainage improvements. Drainage improvements can be challenging, and it is difficult to ensure flow moves through the designed structures. Examples of aufeis mitigation can be found in “Aufeis Formation and Remediation,” by Zufelt and Daly, and “Aufeis Formation and Prevention,” by Slaughter.

The highway between Inuvik and Tuktoyaktuk in Northwest Territories, Canada, is an all-weather road that traverses varied permafrost terrain and opened in 2017. The highway construction incorporated innovative test sections with minimal fill thickness in select areas that are being monitored to support research into the performance and are focused on (1) assessing performance of the highway, (2) providing advance alerts to potential problems, and (3) building expertise for future application. Recent updates on insights gained from the Inuvik Tuktoyaktuk Highway should be considered for relevance to planned project activities.

11-3.1 Surface Water Control—Culverts.

Culverts are generally required to ensure control of water movement across horizontal structures. Culverts have a history of poor performance in cold regions due to the thawing of frozen materials adjacent to and under the drainage structure, ice buildup due to impeded flow, inadequate installation, and thermal effects on the underlying soil. In addition, buried piping and culverts frequently heave or settle, due to the previously mentioned errant flows, creating irregularities in the surface that may require long-term maintenance. Carefully consider the frequency of placement and the sizing of these structures. Often, the number of drainage structures specified during design is inadequate to ensure no cross-embankment flow occurs. In general, overdesign culverts with respect to the number of cross-embankment appurtenances, strategically placed for effective water conveyance, oversized to accommodate seasonal icing, and properly constructed. Inlets and outlets may heave or become filled with ice; this may warrant installation of heat trace or steam pipes to keep culverts from being blocked by ice in winter. Inclinations on both the shoulder slope and the cut slope, as well as the drainage ditch inclinations, will change as permafrost degrades under the side slopes and ditches. This creates areas where water ponds and fails to reach drainage structures. Also, thawing at the location of a drainage structure will increase the height required for the water to pond before running through the drainage structure, resulting in stranded culverts many feet above the elevation of the ditch line.

Consider phasing culvert installation during construction. Installing culverts during embankment construction often leads to better long-term performance than installing culverts after embankment construction. Careful consideration of location is required. When possible, systematically place culverts at specific locations that are identified as drainage pathways during spring thaw, thereby avoiding ponding related to the embankment construction. It is common practice to install culverts at two elevations at critical water crossings. This ensures water can flow in the spring when the lower culvert is iced up and covered in snow and also provides a second flow path in the event of a storm surge. Compaction must be controlled to ensure the long-term performance of the culvert and the embankment. Additional information can be found in *Cold Regions Hydrology and Hydraulics: An American Society of Civil Engineers Monograph,* by Ryan and Crissman, and *Frozen Ground Engineering,* by Andersland and Ladanyi.

11-3.2 Surface Water Control—Storage.

The design of surface water storage used for stormwater or snowmelt management systems must be carefully considered. In regions with seasonally frozen ground, these considerations must include the effects of early winter shallow freezing on drainage pathways versus the deep frost late into the spring, when snowmelt runoff storage must be accommodated. In permafrost regions, the impoundment of surface water often causes thermal alterations to the underlying permafrost, with unintended consequences such as thermal erosion and talik development or subsidence.

11-3.3 Subsurface Water Control.

Subsurface groundwater is generally present both above and below permafrost. The subpermafrost groundwater can have enough hydrostatic pressure to cause artesian flow when wells are constructed through the frozen mantle and the hydraulic potential is much greater in elevation. These types of artesian conditions can also be found in regions with high-salinity soils, where zones of hyper-saline permafrost may have high hydrostatic pressure and behave in a thawed manner. Wells with unintended artesian conditions will cause thawing of the immediately surrounding permafrost, which can affect the stability of the well and adjacent structures. Ground freezing has been used to reverse the thermal erosion and reduce adverse effects.

A gravel pit in the Fairbanks area, adjacent to a local hillside, was advanced in permafrost terrain. The thickness of the frozen zone of gravel was approximately 100 ft (30 m). A groundwater well was installed in the pit to measure water depth. Due to the artesian conditions, unintended flow through the installed well occurred, and the gravel pit quickly filled with water and had to be abandoned until the well could be refrozen in place using active freezing methods. Once the well was refrozen, the pit was dewatered, and gravel mining commenced.

This Page Intentionally Left Blank

CHAPTER 12 CONSTRUCTION CONSIDERATIONS

12-1 INTRODUCTION.

Construction in the Arctic and Subarctic often occurs at self-contained work sites that are remote and have long supply chains and limited logistical support. The challenges of working at remote sites are compounded by weather extremes that affect equipment and the productivity of personnel, as well as potentially limiting sea-ice access during sealift operations. The cold regions environment is also sensitive to construction impacts that can greatly modify site conditions, as well as permitting issues and other limitations on operations discussed in Chapter 2. This chapter discusses general considerations relative to construction planning and logistics, site development and ground improvement, and other development activities. Additional discussion regarding construction issues in the Arctic and Subarctic can be found in many sources, such as the following:

- *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost*, by Linell and Lobacz
- *Permafrost Engineering Design and Construction*, by Johnston
- *Cold Region Structural Engineering*, by Eranti and Lee
- *Embankment Design and Construction in Cold Regions*, by Johnson
- *Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground*, by Esch
- *Construction in Cold Regions, A Guide for Planners, Engineers, Contractors, and Managers*, by McFadden and Bennett

12-2 PLANNING AND LOGISTICS.

Prior planning and consideration of supply chain and logistical limitations are critical for successful implementation of work in the Arctic and Subarctic. Often, years of preparation and preliminary site work are needed prior to development of a new facility at a remote site. For example, it may be necessary to first establish temporary facilities or facilities in support of military operations using soft-sided structures (such as tents) for fuel, power, water, sanitation, and communications to facilitate primary site development and permanent structure construction. Depending on mission and schedule requirements, site development must include planning for work during winter conditions. Airport and dock construction may also be part of the site development work, requiring careful planning for material logistics and delivery schedules. For terrestrial logistics, seasonal ice roads may be needed to allow overland access (see UFC 3-130-01), and these activities generally will require completion of multiple environmental studies to secure permits, access (see UFC 3-130-01), and withdrawal of water from lakes or rivers.

12-3 SITE DEVELOPMENT.

Site development typically will include construction of a work pad that is graded to provide a level working surface. The extent of grading and fill placement at a facility depends on the number and size of embankments needed to support the full build-out of vertical and horizontal structures and the intended life of the site. For example, temporary facilities or facilities in support of military operations with a design life of five years or less may perform adequately with less fill than is required to support pavements and activities that are expected to occur over decades. To facilitate rapid construction, special considerations are required when constructing an embankment in the Arctic, particularly when construction occurs during winter months (see UFC 3-130-01). Challenges include compacting and engineering testing of the granular fill placed during freezing weather.[1] Also, the potential for thaw settlement is high if portions of the winter-constructed embankment thaw in summer and require recompaction of structural material to achieve proper stiffness.[2]

12-3.1 Protection of Natural Ground Surface.

Minimize disturbance of natural tundra overlying frozen ground because this will increase thaw degradation and potentially affect the functionality and stability of facilities.

12-3.2 Construction Constraints.

The use of granular pad foundation subsystems will be limited by the subgrade conditions. In areas where seasonal subgrade thawing will result in difficult construction, granular pad foundation subsystems are typically constructed in the winter to mitigate summer construction problems. These summer construction problems may include instability of the thawed surface soils and thawing of permafrost in excavations or where surface organics are disturbed. Water entering excavations through the active layer may also complicate summer construction. However, construction of granular pads in the winter presents its own set of problems that must be considered. The soil in granular pads constructed in the winter tends to bind together, making compaction difficult and resulting in fill that is looser than desired. Measures such as using thawed aggregate or reworking materials in the summer may be required depending on design criteria, which may affect construction schedules or design selection. Similarly, providing good drainage at the edges of pads is an important consideration (see Chapter 11).

Use select granular materials for best results, which may be a limitation in some areas where high-quality fill is not available. The granular materials must be relatively dry and free of frozen clods to allow proper placement and compaction during freezing conditions. Granular materials must also have low frost susceptibility.

[1] “Construction—Wintertime Compaction and LNG Facilities in Fairbanks, Alaska,” Prusak et al.
[2] “Estimating Thaw-Strain Settlement of Frozen Fill,” Crowther; “Cold Regions Earthwork,” Tart.

12-3.3 Compaction During Periods of Freezing Air Temperatures.

Proper placement and compaction of structural fill can be conducted in temperatures below freezing. Careful planning and selection of the embankment material is required. Fill can be placed to an appropriate density in freezing weather with little to no detrimental effects upon thawing. This is especially important at sites where there is a limited window of time, either when air temperatures are above freezing (such as in Antarctica and Greenland) or due to other schedule constraints. The limiting temperature will depend on the material properties and method used to keep fill material in a thawed or near-frozen state. However, in “Construction—Wintertime Compaction and LNG Facilities in Fairbanks, Alaska,” Prusak et al. showed the limiting air temperature to be approximately 15°F (−10°C). At air temperatures below that value, it became difficult to achieve the desired fill density.

Around-the-clock construction monitoring (engineering controls) is especially important for placement of compacted fill in freezing conditions to ensure the site is free of snow and prepared in accordance with the specifications before placing additional lifts. Around-the-clock inspection also allows for the density of the lift to be measured immediately after placement, but prior to freeze.

An alternate method for establishing compaction criteria is to use a test fill that is built to establish compaction criteria and verify that desired compaction is being achieved using the available equipment at a site. It is important to establish correlations between in-place density and number of passes from specific compaction equipment supplemented by laboratory testing. Test fills are most applicable when the materials used do not exhibit a normal moisture density relationship, which may be the case for coarse crushed rock. A testing plan is required to establish the geometry of the test fill, testing and measurement methods, and acceptance criteria. The testing plan should include laboratory testing to develop compaction curves and establishing moisture–density relationships on the test fill material as a reality check on the field-generated data, whenever possible.

12-3.3.1 Winter Fill Placement.

12-3.3.1.1 General Use.

Winter construction and placement of frozen fill for roads and work pads may be required due to rapid construction schedules, improved mobility during the winter, and the need to meet permit restrictions aimed at minimizing environmental impacts and disturbance of the tundra. Placement of fill in freezing weather requires careful planning and control to ensure performance is as intended. Roads are often constructed according to standards that differ from those applied to embankments supporting building foundations. For example, fill that is supporting structures may need to be kept in a thawed condition so the fill can be compacted before it freezes. Frozen fill may be suitable for roads so long as provision is made in the schedule to recompact the fill as it thaws in the summer.

12-3.3.1.2 North Slope.

Winter construction and placement of frozen fill for roads and pads is a common practice on Alaska's North Slope. Winter construction offers improved mobility and the ability to meet permit limitations on operations aimed at minimizing environmental impacts and tundra disturbance. This process generally requires a two-season operation. Sand and gravel used for roads and pads are mined in the winter and placed frozen, typically with 10% to 20% overbuild to allow for the thawing and settlement that occurs in the summer, when the material is reworked and compacted. Winter-placed gravel must be reworked to thaw and drain excess moisture before being compacted. Other factors to consider include breaking frozen clods of soil and preparation of the site to remove surficial snow and ice that may thaw and result in an unstable fill upon thawing.

12-3.3.1.3 Permanent Structures.

A different approach is applied for pads supporting permanent structures, such as those discussed by Prusak et al. in "Construction—Wintertime Compaction and LNG Facilities in Fairbanks, Alaska." In this instance, fill materials were pre-thawed and placement was closely monitored to ensure compaction could be achieved before the material began to freeze. Compaction was successful to temperatures of 20°F (−6.7°C).

12-3.3.2 Seasonal Considerations for Incorporating Insulation.

When insulation is incorporated into embankment design, the schedule for construction must be considered. If fill material is placed late in the season, the insulation has the effect of limiting winter cooling. In general, it is preferable to place insulation early in the construction season to help maintain the colder ground temperatures while site work is completed. If schedule constraints dictate that insulation must be placed in late summer or fall, when ground temperatures are at their warmest, it is prudent to review design assumptions and implement mitigations, such as adding extra cooling capacity to foundations where thermosyphons are being installed.

12-3.4 Site Improvement Methods.

Site improvement methods such as those described in the paragraphs that follow may be required if there is long-term potential for thawing at permafrost sites that can lead to a reduction of bearing capacity and an increase in liquefaction potential. The extent of ground improvement will depend on site history, design life, and anticipated changes in ground conditions over the life of the facility. These activities may add one or more years to project schedules, especially when there are seasonal access constraints, which are often associated with remote sites.

12-3.4.1 Ground Thawing.

12-3.4.1.1 General.

Ground thawing is used when post-construction conditions are expected to degrade over time due to high ice content, such as when permafrost areas thaw over the life of a facility. Ground thawing is often used in conjunction with other ground improvement techniques, such as deep dynamic compaction or vibrocompaction, because thawed ground will likely be loose and saturated. Application of another ground improvement technique is especially important in seismic areas to reduce the liquefaction potential of thawed areas.

12-3.4.1.2 Forced Ground Thawing.

Several methods are used to force ground thawing, including thaw points driven into the ground, thaw pipes placed in drilled holes, or heating mats placed on the ground surface. Construction planning must include consideration of dewatering that may be needed when the ground is thawed, as well as the potential for encountering site contamination. Clearing vegetation is also an effective method for thawing permafrost, but it may require several years before the site is thawed to sufficient depth for construction. This approach is limited to the Subarctic, where the air and permafrost temperatures are relatively warm.

12-3.4.1.3 Heating Probes.

Two F-35A aircraft hangar-facility projects designed and constructed by USACE at Eielson Air Force Base, Alaska, required initial ground thawing to mitigate potential differential settlement from discontinuous permafrost underlying the project sites. Ground thawing was accomplished using electric heating probes (0.75 in. diameter [19 mm]), wired to a 220 volt single-phase generator and installed within a 1.25 in. (32 mm) casing drilled to a final depth of 25 ft (7.6 m). The heating probes were placed on a 10 ft (3 m) grid pattern across the treatment area, with one thermistor string installed for every 12 heating probes to monitor the progress of permafrost thawing. In this case, electric heating probes (700°F [371°C] heating elements) were used instead of steam points to facilitate faster thawing and to avoid the introduction of water into the subgrade, which would complicate further site development. Well points were installed to extract thaw water and facilitate the circulation of heated water and thawing effect within the permafrost. The projects are in an area of high seismicity, with underlying soil strata that include thawed permafrost subject to seismic-induced liquefaction settlement. Accordingly, the sites were further improved by means of deep dynamic compaction (DDC).

12-3.4.2 Excavation and Replacement.

Excavation and replacement of thaw-susceptible soil ensures compaction and the long-term performance of the site. The availability of appropriate materials and suitable construction equipment will affect the economics and dictate the feasibility of this ground improvement method. Excavate in the spring when the ground is still frozen; however, depending on ground conditions, excavations may be difficult to perform or may require blasting. If excavations extend into summer, they must be dewatered so water does not pond in the excavation prior to backfilling. Well-trained quality assurance is needed to ensure excavation has reached the ice-poor to ice-free limits.

12-3.4.3 Thermosyphons.

12-3.4.3.1 Passive Cooling.

Passively cooled thermosyphons are used to maintain or reduce ground temperatures without the need for mechanical refrigeration systems.[3] Installations must be designed to provide adequate cooling capacity for site conditions, including understanding ground temperature and wind speeds at the site. Additional considerations are discussed in paragraph 8-5.5.4 and examples of thermosyphon installations are shown in paragraph A-10. Performance is related mainly to wind speed and finned condenser area, and it is important to place passively cooled thermosyphons to maximize their effectiveness and to group them in areas around a structure to avoid damage to the thermosyphons from snow removal or other maintenance activities. Include periodic monitoring and maintenance as part of integrity management and life-cycle planning.

Control of seepage and use of NFS materials is especially important when passive refrigeration, such as that discussed in paragraph 8-5.5.4, is installed as part of the foundation design to limit the potential for heave of the foundation elements as the ground refreezes. Ponded water should not be allowed to accumulate in excavations needed to install flat loop thermosyphon systems because this may result in excessive heaving beneath foundations.

12-3.4.3.2 Hybrid Systems.

There are also hybrid systems that incorporate an attachment that allows for use of a vapor compression refrigeration system to cool the condenser enough to activate the thermosyphon during every season. Further details can be obtained from the only licensed manufacturers in North America (in 2024): Arctic Foundations or Arctic Foundations Canada.

12-3.4.4 Active (Mechanical) Ground Freezing.

Active or mechanical ground freezing may be an option for some sites. This method is adaptable to many situations, provides relatively strong soil structures within a matter of months, and is easily reversible by applying heat. However, these systems have high energy requirements because they use circulating coolants that must be maintained at temperatures between −20°F (−29°C) and about −75°F (−59°C). For design and construction considerations, see Chapter 6 of *Frozen Ground Engineering,* by Andersland and Ladanyi. A case study, “Construction Ground Freezing—A Look at Modeled versus Measured Performance,” by Daggett et al., compares modeled to measured performance of mechanical ground freezing.

Another relatively simple approach to construction ground freezing involves blowing cold air into open pipe piles or along the face of excavations. This approach has been effective for enhancing freezeback around piles and temporarily cutting off the seepage of saline groundwater into open excavations during construction of utilidors in Utqiagvik.

[3] *Review of Thermosyphon Applications,* Wagner.

12-3.5 Methods of Site Improvement After Thawing.

Frozen ground that has been thawed will require site improvement using the same techniques as applied in temperate areas. These methods could include vibrocompaction, deep dynamic compaction (see paragraph 12-3.4.1) or other methods, such as wick drains or stone columns, to enhance consolidation. In seismically active areas such as Alaska, ground improvement may be required to provide stable foundation conditions for both permanent dead loads and earthquake-induced loads, to improve bearing capacity, to mitigate excess settlement that may occur, and to reduce the liquefaction potential. These ground improvement techniques are often proprietary to specialty contractors and may require an extra level of design analysis and specification development. Post improvement testing is required to demonstrate that the desired level of ground improvement has been achieved.

Two F-35A aircraft hangar-facility projects designed and constructed by USACE at Eielson Air Force Base, Alaska, required ground improvement by DDC after initial thawing of underlying discontinuous permafrost. DDC was performed to mitigate potential seismic-induced liquefaction settlement of the subgrade soils. The complete sequence of ground improvement consisted of (1) over-excavating near-surface soils subject to seasonal freeze and thaw; (2) thawing permafrost using electric heating probes; (3) preparing a stable excavation surface with several feet of classified fill; (4) performing DDC across the treatment area, extending 25 ft (7.6 m) beyond structural limits; and (5) after DDC, proof rolling the area with a large vibratory roller, with the addition of classified fill compacted in 12 in. (305 mm) lifts to 95% density per ASTM D1557, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))*. DDC was accomplished using a 16 ton (14.5 metric ton) tamper dropped from a height of 50 ft (15 m), producing 4 ft (1.2 m) craters on a 10 ft (3 m) grid pattern. Each DDC point was subject to four to eight drops, with some areas needing a second pass to achieve the required degree of improvement. Ground improvement was verified by performing pre-DDC and post-DDC geotechnical borings, measuring the level of soil densification through the increase in standard penetration blow counts (modified ASTM D1586 using the large diameter split spoon sampler). The required level of ground improvement was achieved to the maximum target depth of 40 ft (12 m). Alternative ground improvement methods (such as vibrocompaction and permeation grouts) and deep foundations (driven piles) were considered during the design phase. DDC combined with ground thawing was selected as the best approach, with respect to cost, local experience, and suitability, for the specific ground conditions.

12-4 CONCRETE AND GROUT UNDER FREEZING CONDITIONS.

Concrete or grout can be used for anchors and foundation elements. However, poured concrete requires careful mix design so the concrete has sufficient time to cure before freezing and because the concrete may include admixtures. The foundation may need to be protected from cold air temperatures or placed inside a tented structure during curing. For footings in remote locations, prefabricated footings that can be placed on a vessel for transport are often used instead of poured footings.

For further information on mix design and placement of concrete under freezing conditions, see the following publications:

- ACI 306R
- *Creep Behavior of Shallow Anchors in Ice-Rich Silt,* by Zhang et al.
- “Development of Innovative Antifreeze Grout Mortar for Anchor Applications in Cold Regions,” by Lin et al.
- *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost,* by Linell and Lobacz
- *Cold Region Structural Engineering,* by Eranti and Lee
- *Construction in Cold Regions, A Guide for Planners, Engineers, Contractors, and Managers,* by McFadden and Bennett

Refer to UFC 3-130-01 for requirements on placing concrete.

CHAPTER 13 PERFORMANCE MONITORING AND MAINTENANCE

13-1 GENERAL.

Well-designed and -implemented performance monitoring programs are used to inform decisions about maintenance activities that are necessary for preserving the original capital investment and performance of structures. Monitoring includes measuring ground temperatures in permafrost areas, measuring deformation for critical foundation components, and visual inspection, and is linked to baseline measurements, established performance criteria, and clear data recording standards.

Management of geotechnical monitoring data is an evolving area or practice without specific guidance used to help optimize operations and maintenance. It has most commonly been applied to linear infrastructure and can be relatively simple (such as documenting end-of-construction conditions and periodic monitoring) or can involve more extensive data acquisition and monitoring linked to risk and cost–benefit analyses. Detailed guidance related to geotechnical asset management for transportation projects can be found in *Geotechnical Asset Management for Transportation Agencies*, by the National Cooperative Highway Research Program, or a library of online resources found on the Ohio Department of Transportation website (https://www.transportation.ohio.gov/working/engineering/geotechnical/asset-management/asset-management#page=1).

13-1.1 Ground Temperature.

Ground temperature is one of the most important and commonly measured parameters for assessing the capacity and performance of foundation systems where frozen ground is present. A ground temperature monitoring system, consisting of temperature sensors installed at various locations and depths, provides early warning to managers and engineers about changing conditions that risk foundation damage.[1] Ground temperature in North America is typically measured using thermistor strings or digital temperature cables with known calibrations of output to temperature. Other methods of measuring ground temperature, such as thermocouples, may also be appropriate; consult with the geotechnical engineer of record for additional guidance. Ground temperature monitoring systems can be coupled with data loggers and installed at many locations. For remote installations, solar-powered systems with satellite uplinks may be used to provide real-time monitoring and analysis of data. Other techniques for measuring ground temperature are discussed in Chapter 3 of *Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground,* by Esch.

Ground temperature measurement is especially important for flat loop thermosyphon systems or active refrigeration systems, like those used in mainline refrigeration units along the Trans-Alaska Pipeline System. Because these systems are difficult or impossible to access, instrumentation must be installed at the time of construction and

[1] *Improving Design Methodologies and Assessment Tools for Building on Permafrost in a Warming Climate,* Bjella et al.

include redundant sensors. Regularly calibrate sensors because the data from many of the sensors on the market today will drift over time.

13-1.2 Settlement, Tilt, and Lateral Movement.

Settlement, tilt, and lateral movement of structural foundation elements are common measures of foundation performance. Settlement and tilt are determined by conventional optical survey measurements, although there are tilt meters and crack monitoring gauges that allow continuous measurement of these parameters. Gauges are used in temperate climates and are deployable for cold climate applications, provided they are also winterized.

Settlement can also be monitored using drone-based or ground-based lidar surveys and high-resolution remote sensing data, such as interferometric synthetic aperture radar, for large or remote sites. However, the accuracy of these surveys, especially those involving remote sensing, must be checked. Survey control may be needed to improve accuracy, and survey monuments will need to be designed to resist frost movement. Features included in these types of monuments are illustrated in Figure 5.1 of *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost,* by Linell and Lobacz. They require a casing around the survey marker that is filled with a media such as silicone oil or a wax-oil mixture. The marker must be anchored into permafrost deeper than the estimated depth of thawing anticipated over the life of the marker.

13-1.3 Groundwater.

Groundwater can be a significant factor in the stability of embankments or foundation systems. Conventional systems (such as open standpipes or pressure transducers) provide simple and effective measurements in areas of seasonal frost or below the base of permafrost. However, both systems will freeze, and pressure transducers are not well suited to long-term measurements in freezing conditions unless the system is winterized. Geophysical surveys like those discussed in UFC 3-130-02 are also commonly used to identify thawed areas and unfrozen zones within permafrost.

13-1.4 Visual Inspection.

Specific observations and the frequency of inspections will vary depending on the structure, but examples include noting the condition of thermosyphons, blocked airflow below elevated structures, fluids leaking from elevated structures, and out-of-level doors, windows, and floors. Other features worthy of notice during a visual inspection include cracks developing within structures and pavements; changes in grade, areas of subsidence, and tension cracks in the ground external to structures; differential movement and disturbance of utilities entering buildings; and evidence of site modifications that may pose future facility instability issues, such as removal of vegetation, which will increase the risk of thaw degradation.

13-2 MAINTENANCE OPERATIONS.

Well-planned and -implemented monitoring programs provide indications of developing stability problems before they affect the structure. Catastrophic acute foundation failures are rare, but chronic problems can occur in the Arctic and Subarctic due to inappropriate engineering or unforeseen site conditions in design and construction. Chronic problems related to thawing permafrost may not become apparent until well after construction, but ground temperature monitoring like that discussed in paragraph 13-1.1 can help prevent disastrous outcomes. Examples of this monitoring include identifying areas where ground temperatures are higher than desired due to heat inputs from the structure, identifying areas of the site with high local ground-ice contents, measuring lateral translation, and measuring settlement (either locally or area-wide) to make sure it is not excessive.

13-2.1 Operational Impacts to Consider.

Normal day-to-day facility activities can affect the thermal regime and the support capacity of foundations. Plowing snow away from structures maintains colder permafrost temperatures, avoids thawing of ground ice, and prevents the resulting localized thaw settlement and structure damage. If snow drifts are not cleared or if plowed snow is stockpiled, the insulating effect will change the local thermal regime and can warm up the underlying permafrost soils and, over time, trigger permafrost degradation that can affect the structure performance. Similarly, blowing snow into ditches adds insulation in these areas and contributes to ponding near the toe of embankments. Preparing an operations manual will provide guidance to the maintenance team over the long term, thus improving the performance of foundations.

13-2.2 Mitigation Measures.

Develop appropriate mitigation measures to address observed movement or foundation distress based on an understanding of the cold regions design principles and criteria provided in previous paragraphs. Examples of mitigation measures include the following:

- Adding additional ground cooling capacity to a facility.
- Redirecting drainage to eliminate the added heat loss and associated permafrost degradation caused by flowing water.
- Incorporating adjustable foundation elements.
- Changing the surface energy balance by managing vegetation.

This Page Intentionally Left Blank

APPENDIX A BEST PRACTICES

A-1 INTRODUCTION.

The Best Practices Appendix is considered to be guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned but may not be the only solution to meet the requirement. It identifies additional background information and practices for accomplishing the design of foundations for freezing and thawing conditions. The DoR is expected to review and interpret this guidance and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that are not discussed in the Unified Facilities Guide Specifications (UFGS) or UFC, the DoR must submit a list of the guidelines or requirements being used for the project, with sufficient documentation, to the Government Project Manager for review and approval prior to incorporation within the design.

A-2 CANADIAN EXPERIENCE.

Various guides and national standards have been developed for use in Canada, including some by the government of the Northwest Territories. These guides and standards contain performance guidelines, design data, preferred materials and methods, and logistical considerations developed from decades of experience with the design and construction of foundations in the Canadian north. Over time, certain products and approaches to constructing foundations have proven successful and have been adopted by design consultants and builders working in the Canadian north. These guidelines and standards should be reviewed as they document both failures and successes in foundation construction and durability in cold regions. Publications relevant to foundations in cold regions include the following:

- *National Standard of Canada CAN/BNQ 2501-500/2017: Geotechnical Site Investigations for Building Foundations in Permafrost Zones*, by the Bureau de Normalisation du Quebec
- Chapter 13 of the *Canadian Foundation Engineering Manual*, by the Canadian Geotechnical Society, for an alternative approach for estimating frost heave potential is to measure the segregation potential of the soil

A-3 OTHER CODES AND STANDARDS.

The effects of these various codes and standards will vary, as will the way specific requirements may need to be handled on a project. Extensive literature is published by sources in the U.S. (such as the American Petroleum Institute, International Code Council, International Conference of Building Officials) and by the National Research Council Canada and the European Union, but there is no prescriptive code requirement for foundation design in permafrost regions. Russia, however, has developed an extensive body of regulatory documents, which include a series of national building codes, standards, territorial building codes, and guiding regulations with specific design criteria for permafrost areas. Resident professionals who are familiar with the specific requirements in the project area are a valuable resource to consult during project planning to confirm local practice and avoid delays in project design approval and construction.

A-4 PLANNING AND DESIGN CONSIDERATIONS.

Military installations in cold regions may be self-contained or connected to existing public or industrial infrastructure. Where public or private infrastructure exists, specific standards and practices for construction may need to be followed. Other installations own, operate, and maintain their own facilities. For those installations, direction from the installation staff, often in the form of installation facilities standards (IFS), should be solicited and followed. New installations may benefit from the guidance used at existing military installations or local municipalities. Revegetation after construction should follow applicable IFS guidance and local requirements. IFSs are available on the WBDG at https://www.wbdg.org/airforce/ifs.

Modular construction, where an entire facility or a major component of a facility is preassembled and shipped via barge or sled to the point of use, has been used at oil field developments on the northern coast of Alaska. It is advantageous in these locations because the construction season is short and labor costs are relatively high. Barges can usually begin to arrive in Utqiagvik, Alaska, and the eastern Arctic around the first of September. This means the nonmodular construction materials must be shipped a year in advance and stockpiled for the next construction season. Facilities may also be built on-site using basic structural materials, or significant components (such as mechanical assemblies) may be preassembled at the point of manufacture. The approach adopted depends on logistical limitations specific to each site, and the use of modular construction needs to be discussed with the design team on a case-by-case basis. Prefabrication of foundation assemblies has been shown to be cost-effective in remote locations and locations with a high cost of labor.

A-5 CLIMATE CHANGE CONSIDERATIONS.

A-5.1 Intergovernmental Panel on Climate Change.

The IPCC provides a common source of information relating to emission scenarios, provides third-party reviews of models, and recommends approaches to documenting future climate projections. Periodically, the IPCC issues assessment reports summarizing the current state of climate science. The most current complete synthesis of information regarding climate change must be used in climate analyses. The IPCC does not run the models but acts as a clearinghouse for the distribution and sharing of the model forecasts.

In the IPCC Fifth Assessment Report (AR5), which consists of Working Group Reports and a Synthesis Report, potential scenarios for future climate are designated as RCPs, while in the IPCC Sixth Assessment Report (AR6), SSPs are used. Both sets of scenarios include a suffix that specifies the radiative forcing projected to occur by 2100. For example, SSP2-4.5 denotes a pathway that is characterized by climate change mitigation and adaptation options of SSP2, which would result in 4.5 watts per square meter of radiative forcing by 2100 (like RCP4.5). Compared to AR5, a wider range of scenarios are provided in AR6, covering an updated set of pathways by which future climate may unfold. The RCP and SSP scenarios for similar radiative forcing values provide comparable trajectories of future climate. For example, both SSP1-2.6 and RCP2.6 are characterized by sustainable development proceeding at a reasonably high pace. Similarly, both SSP5-8.5 and RCP8.5, which are commonly considered for work in Arctic areas, are characterized by high greenhouse gas emissions.

A-5.1.1 IPCC Fifth Assessment Report (AR5).

Documents from the AR5:

- *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Stocker et al.
- *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Field et al.
- *Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part B: Regional Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Barros et al.
- *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Edenhofer et al.
- *Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Pachauri et al

A-5.1.2 IPCC Sixth Assessment Report (AR6),

Documents from the AR6:

- *Climate Change 2021: The Physical Science Basis, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte et al.
- *Climate Change 2022: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner et al
- *Climate Change 2022: Mitigation of Climate Change, Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Shukla et al

A-5.2 Downscaling Climate Data and Sources.

A-5.2.1 Scenarios Network for Alaska + Arctic Planning (SNAP).

Downscaled climate data for the Arctic and Subarctic is available through the SNAP project at University of Alaska Fairbanks. The SNAP website (https://uaf-snap.org/climate-tools/) includes a collection of tools that use downscaled climate data to estimate projected changes in a variety of different climate variables and scenarios, such as those noted in paragraph A-5.1. The tools that follow can be found at the SNAP website:

- Community Climate Charts
- Precipitation Projections for Alaska Infrastructure
- Community Wind Data
- Arctic Environmental and Engineering Data + Design Support System (Arctic-EDS)

A-5.2.2 Climate Data Portals.

Climate data portals can provide climate projections that are readily accessible and provide regional or global coverage. Examples include the following:

- IPCC Interactive Atlas (https://interactive-atlas.ipcc.ch/)
- World Bank Climate Change Knowledge Portal (https://climateknowledgeportal.worldbank.org/)

These portals provide information for both AR5 and AR6. However, they may not provide enough information for design applications, which require higher resolution climate data (see paragraph A-5.2.3). The projections available from these portals can be used to understand how downscaled climate projections compare to regional or global projections and how downscaled projections from AR5 compare to projections from AR6. Climate data portals are often updated much faster than daily downscaled data and provide good summaries of the most recent projections.

A-5.2.3 Daily Downscaled Climate Data.

Daily downscaled climate projections can be downloaded from SNAP and from a variety of other sources at a daily resolution. One example is NASA's NEX-GDDP, which provides projections of total precipitation, wind speed, relative humidity, solar radiation, and mean, minimum, and maximum temperature for an ensemble of climate models and emissions scenarios.

A-6 CLIMATE AND CONTINUAL IMPROVEMENT.

USACE evaluated climate risk in the design process for shore protection at Utqiagvik, Alaska. First, a climate change dataset was developed to establish projected changes in air temperature over time using an ensemble of climate models and scenarios. Using this dataset, thermal analyses were conducted to assess the potential for an eroding permafrost slope to thaw, based on the planned construction and potential changes in future climate. This is an example of the first stage of the MAC process for assessing climate risks. Details of each stage of the MAC process are described below.

A-6.1 First Stage.

The initial stage of the MAC process involves the assessment of climate risks. For engineering foundation design, this includes establishing historical climate conditions and obtaining projections of future climate conditions for climate-related design parameters. Climate risk thresholds may then be established for when key climate parameters may affect the foundation designs. Depending on the projected changes, the uncertainty in these parameters, and the sensitivity of the foundation design, climate risks may be identified and ranked. These risks may depend on a given climate parameter meeting or exceeding a predefined value.

A-6.2 Second Stage.

In the second stage of the MAC process, adaptation options are developed to address the climate risks identified in the first stage. Adaptation pathways provide decision-making support on when to implement the adaptation options. For engineering foundation design, this may include adjusting the initial design to account for projected climate changes or developing provisional measures that can be phased into the project over time as climate risk thresholds are reached.

A-6.3 Third Stage.

The final stage of the MAC process involves monitoring and surveilling designs at climate risk thresholds established in the first stage. Given the level of uncertainty involved in future climate projections, this step acts to confirm the risks identified in the first stage and the adaptation options implemented in the second stage as new information becomes available. This information may include new on-site observations or updated climate projections. If climate risk thresholds are approached or met, the MAC process cycle may be repeated with this new information.

A-7 SLOPE GEOHAZARDS.

When selecting building sites or routes for linear infrastructure, it is important to remember that slopes in permafrost areas migrate downslope over time due to the force of gravity, depending on ground ice content, active layer moisture, and ground ice temperature. The slope movements constitute geohazards that must be considered when planning a project. Table A-1 lists some of the more common slope processes, the relative speed at which they occur, and related engineering issues. Figure A-1 through Figure A-5 show representative examples of some geohazards. Additional illustrations of permafrost features are found in the following:

- *Glossary of Permafrost and Related Ground-Ice Terms*, by Harris et al.
- *Permafrost, A Guide to Frozen Ground in Transition*, by Davis
- *The Periglacial Environment*, by French

- *Geocryology: Characteristics and Use of Frozen Ground and Permafrost Landforms*, by Harris et al

Table A-1 Slope Processes and Related Engineering Concerns

Speed of Process	Process	Description	Engineering Issues
Slow	Solifluction	• Geomorphic features produced by solifluction include uniform sheets of locally derived surficial materials and tongue-shaped lobes.[1] • Can occur on slopes as low as 3°.[2]	• Disturbing solifluction lobes, when or as they are thawed, can cause slides to occur. • Structures located on these lobes can move or be disturbed, including localized impact on piles.
	Creep	• Related primarily to the presence of ice within soil.	• Structures can move or be disturbed.
Intermediate to rapid	Frozen debris lobe	• Described in “Frozen Debris Lobe Morphology and Movement: An Overview of Eight Dynamic Features, Southern Brooks Range, Alaska” by Darrow et al.	• Structures can be displaced or disturbed. • Can result in severe structure damage, entire loss, or need to relocate.
	Thermo-erosion gullying	• See definition in paragraph B-3 • This process is occurring in the upland silts of interior Alaska.	• These features can cause sinkholes and instability, most commonly in horizontal structures.
Rapid	Active-layer detachment	• Common on colluvial slopes in areas of fine-grained, ice-rich deposits, where they occur as shallow slumps. • Occur more frequently during warm summers or following disturbance of the vegetation or ground surface by, for example, tundra or forest fires or engineering activity, when the depth of thaw is greater than normal.[3]	• Structures can move or be disturbed. • Detachment failures that expose massive ice or icy sediments can develop into retrogressive thaw slumps.
	Thaw slumping	• Geomorphic features produced by thaw slumping are retrogressive thaw slumps. These can be large features with an exposed face more than several meters high with a long crest length.	• Structures will likely move or be disturbed. • Can result in severe structure damage and entire loss.

1. *The Periglacial Environment*, French.
2. *Permafrost and Related Engineering Problems in Alaska*, Ferrians et al.
3. *Multi-Language Glossary of Permafrost and Related Ground-Ice Terms*, van Everdingen.

Figure A-1 Solifluction Lobes (Alaska Range)

Photo courtesy of R.G. Tart Jr., Golder Associates.

Figure A-2 Frozen Debris Lobe

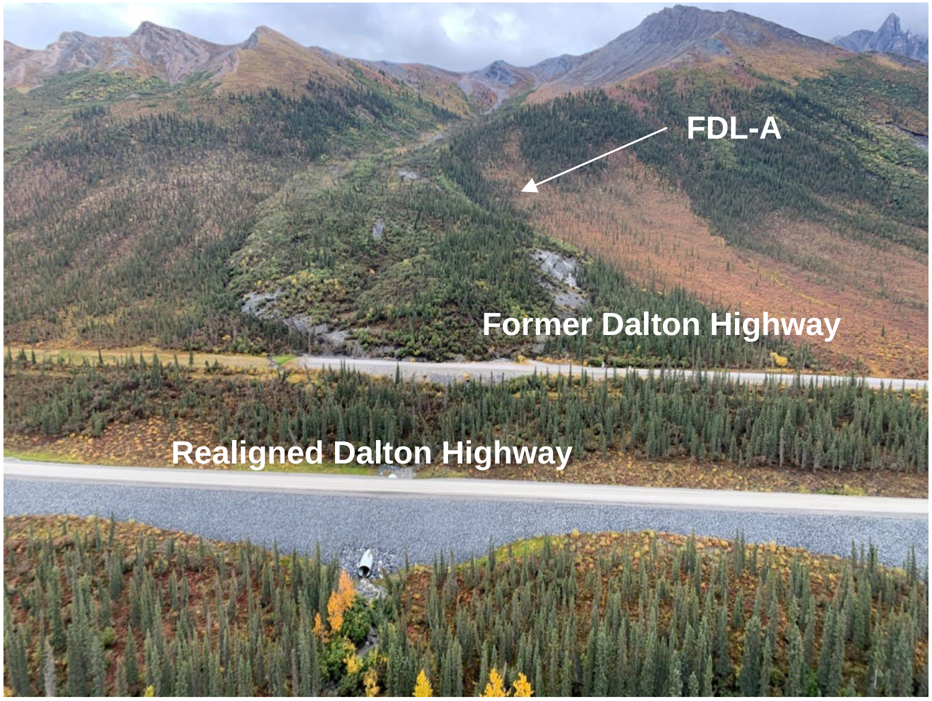


Photo courtesy of WSP USA.

Figure A-3 Connected Sinkholes Formed after Material Site Development (Dempster Highway, Canada)

Photo courtesy of WSP USA.

Figure A-4 Retrogressive Thaw Slump (Mackenzie River, Canada)

Photo courtesy of T. Krzewinski, WSP USA.

Figure A-5 Active Layer Detachment

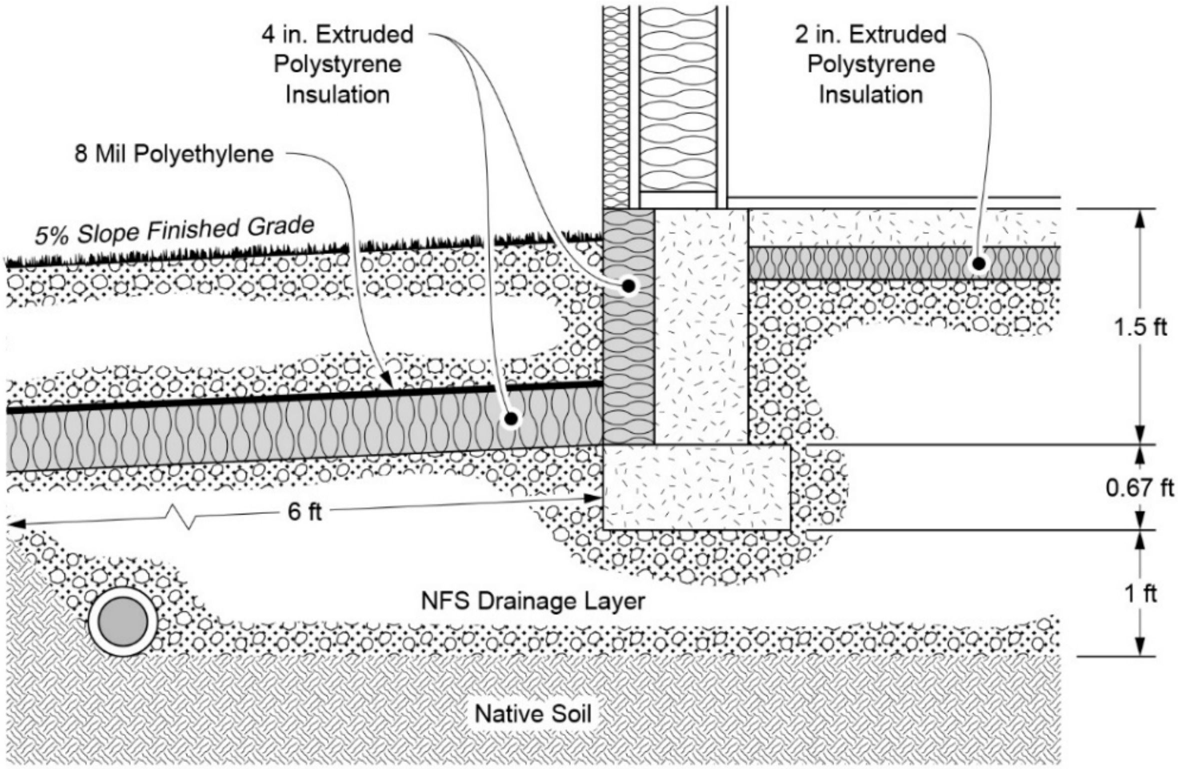
Photo courtesy of R.G. Tart Jr., Golder Associates.

A-8 FROST PROTECTION.

Frost effects on foundations are discussed in paragraphs 7-5 and 7-6. Frost effects include frost jacking due to frost heave in seasonally frozen ground, basal or upward thrust when soil beneath footings freezes and heaves, and lateral thrust on retaining walls due to freezing of the ground. General measures to mitigate frost effects on foundations include isolation of deep foundations within the freezing soil or deeper installation to provide sufficient uplift to resist frost heave forces, flanges to increase uplift resistance, use of NFS material to reduce capillary action and formation of ice within the freezing soil, and drainage to cut off water that may migrate to the freezing front and enhance formation of ice within the freezing soil. *Cold Region Structural Engineering,* by Eranti and Lee, provides further discussion.

Figure A-6 illustrates a frost-protected shallow foundation used in seasonal frost areas to mitigate formation of frost beneath footings though a combination of insulation and heat flow through the building foundation (see paragraph 7-5.3). The effects of floor insulation used to improve energy efficiency must be carefully considered if heat flow is being relied on to prevent frost formation and may require adjustment of design parameters.

Figure A-6 Example of Frost-Protected Shallow Foundation



Source: Reproduced from *Shallow Insulated Foundation at Galena, Alaska: A Case Study,* by Danyluk, Figure 4.

A-9 FOUNDATION OPTIONS.

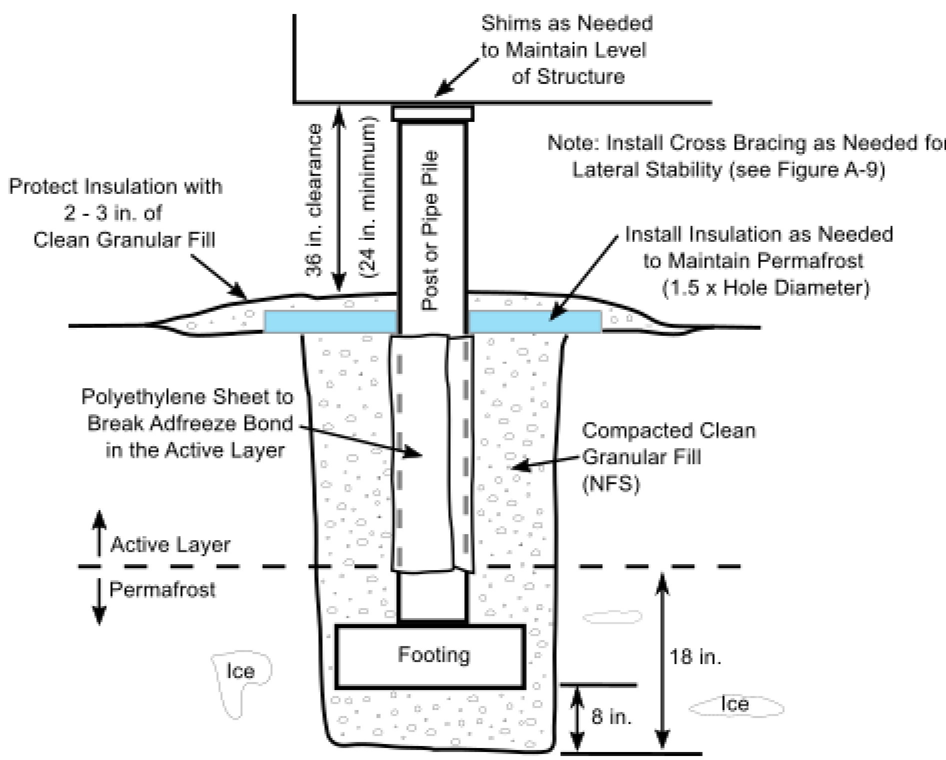
There are many options and design variations for shallow and deep foundations in Arctic and Subarctic areas, depending on site-specific conditions and facility requirements. Granular pads may be part of a building foundation subsystem or a foundation for horizontal structures. Pads should be constructed from NFS material, and they may incorporate passive or active cooling, insulation, ventilation, or some combination of these thermal techniques to mitigate heat flow from structures, maintain the existing thermal regime, and minimize frost heave potential. Table A-2 presents a partial list of foundation types, but options continue to evolve as new technologies are developed or environmental conditions dictate adaptations.

Table A-2 Partial List of Foundation Types

Shallow Foundation	Deep Foundation	Foundation Subsystem
• Spread footing • Post and pad • Raft foundation • Structural slab • Frost protected	• Slurry piles • Driven piles • Drilled (helical) piles • Adfreeze piles • Passively cooled piles (thermopile or thermosyphon) • End bearing piles • Shear piles • Micropiles • Vibe piles	• Granular pad • Insulated pad • Passively cooled (thermosyphon) pad • Ventilated pad (ducts, air cooled embankment) • Combination of the above

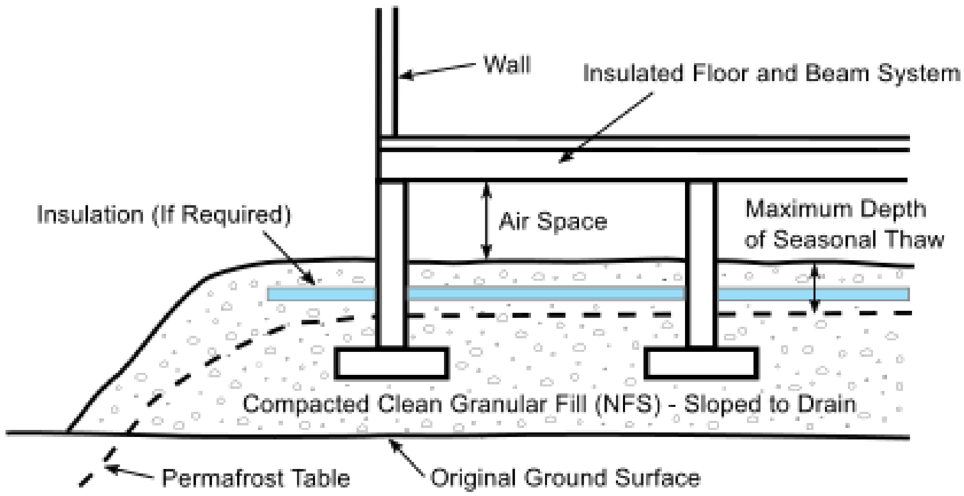
Examples of shallow foundations like those discussed in Chapter 8 are presented in Figure A-7 through Figure A-10 for conditions where permafrost is present. Figure A-8 and Figure A-9 also illustrate how the permafrost level can aggrade into thick foundations when climatic conditions are favorable.

Figure A-7 Example Footing in Shallow Permafrost



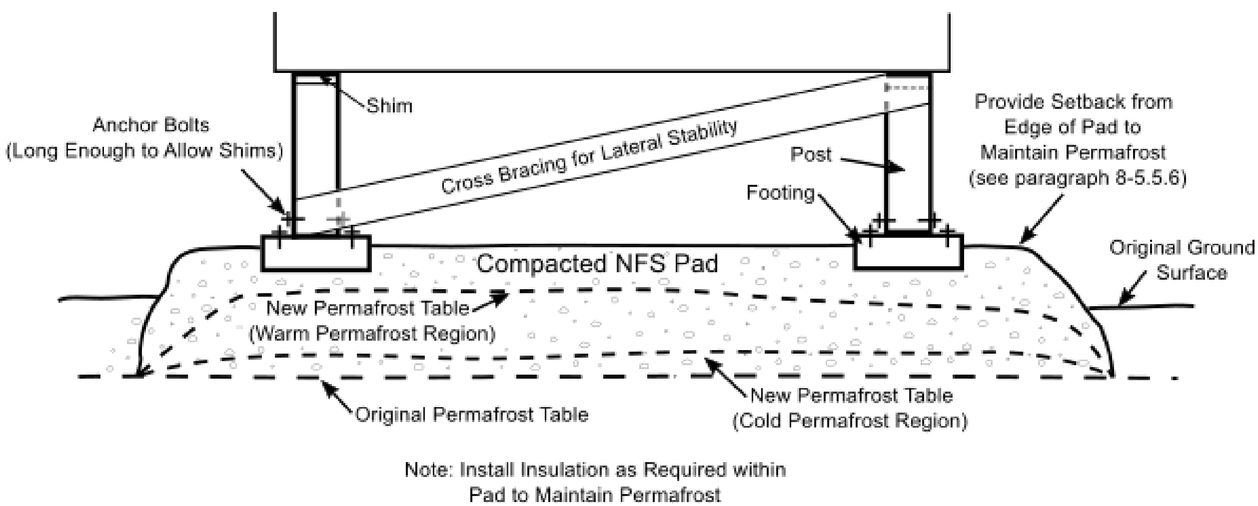
Source: *Design Manual for New Foundations on Permafrost,* Figure 3.9. Adapted with permission of the Cold Climate Research Center and the United States Permafrost Association.

Figure A-8 Example Footing in Insulated Pad Where Permafrost Level is Expected to Aggrade into the Pad



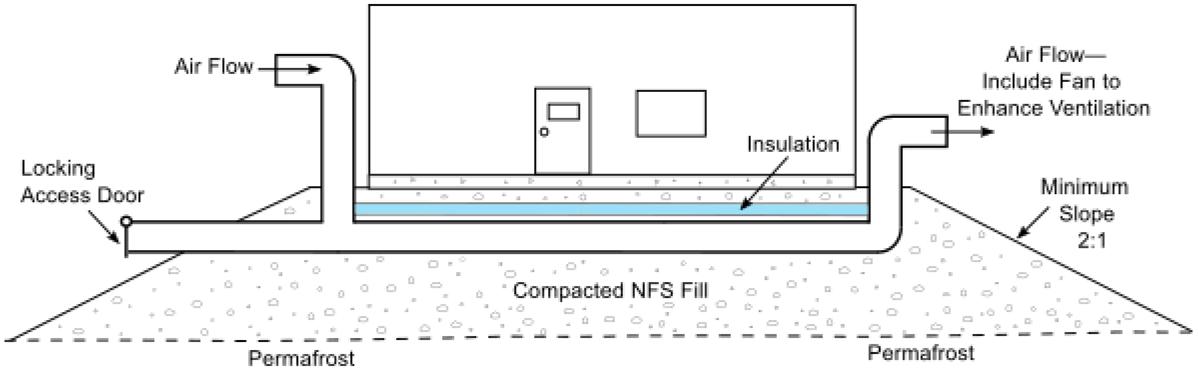
Source: *Permafrost Engineering Design and Construction,* by Johnston, Figure 7.16a. Adapted with the permission of John Wiley & Sons.

Figure A-9 Post and Pad Concept—Thick Fill



Source: *Design Manual for New Foundations on Permafrost,* Figure 3.12. Adapted with permission of the Cold Climate Research Center and the United States Permafrost Association.

Figure A-10 Example Air-Ducted Slab on Grade

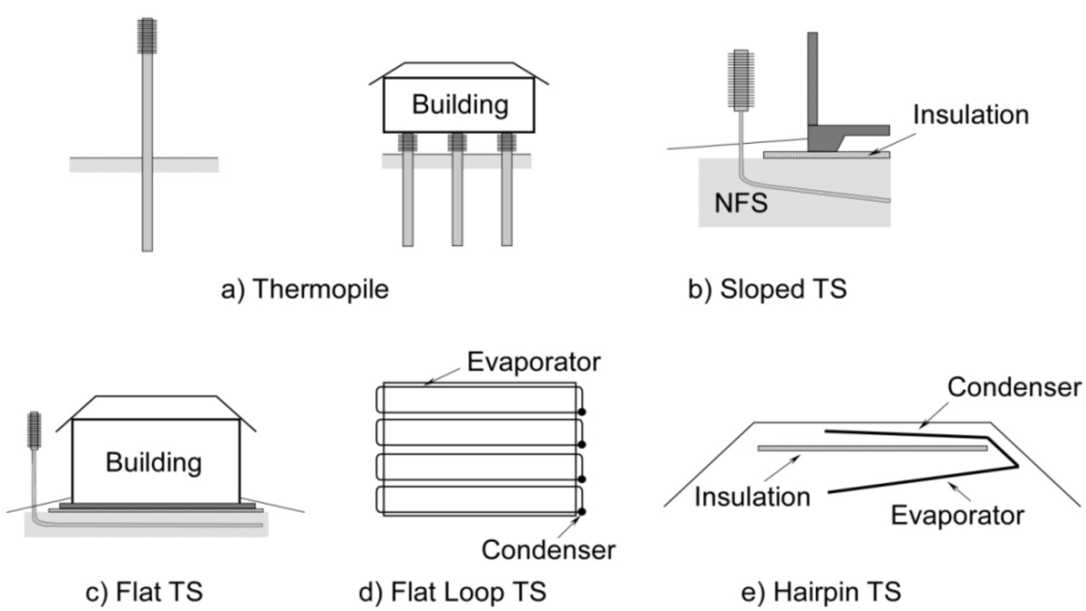


Source: Construction in Cold Regions, A Guide for Planners, Engineers, Contractors, and Managers, by McFadden and Bennett, Figure 4.5.7. Adapted with the permission of Wiley Books.

A-10 THERMOSYPHONS.

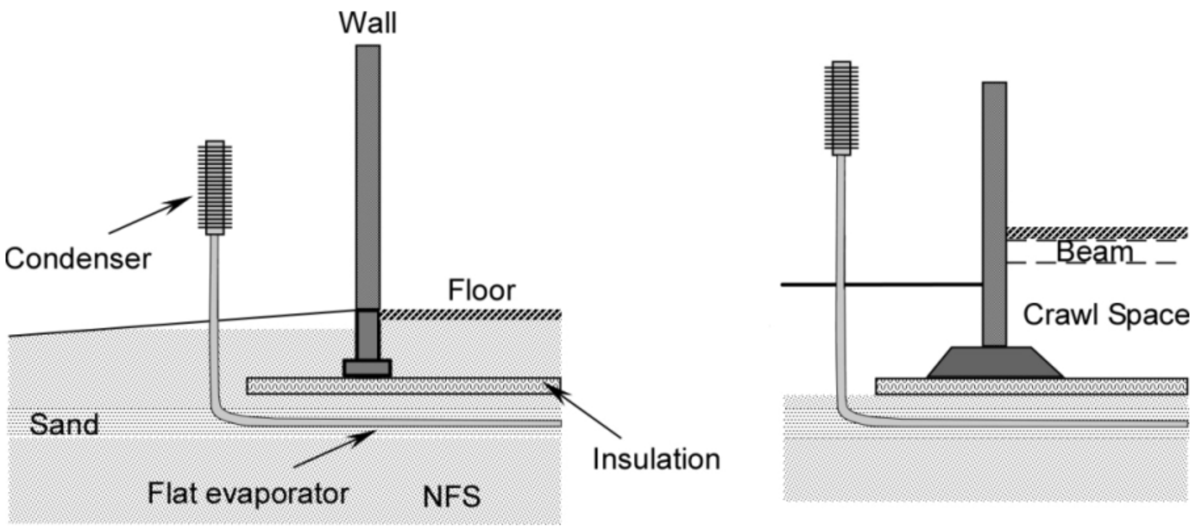
Thermosyphons like those discussed in paragraphs 8-5.5.4 and 9-3 are widely used to provide passive cooling of foundation systems in permafrost areas. They are used in both single pipe flat loop configurations, as discussed in *Review of Thermosyphon Applications,* by Wagner, and shown conceptually in Figure A-11 and Figure A-12. Vertical thermosyphons can be configured to fit within a pile or be installed adjacent to them, or a pile can be built as a thermosyphon. Hybrid thermosyphons are another configuration that uses a low-energy chiller below the condenser to activate the thermosyphon when the ambient air temperature is above freezing. Figure A-13 and Figure A-14 present representative thermosyphon applications.

Figure A-11 Typical Thermosyphon (TS) Applications



Source: Reproduced from *Review of Thermosyphon Applications,* by Wagner, Figure 5.

Figure A-12 Schematic of Shallow Foundation Using Thermosyphons to Refrigerate Granular Pad



Source: Reproduced from *Review of Thermosyphon Applications,* by Wagner, Figure 7.

Figure A-13 Flat Loop Thermosyphon Condensers Configured Adjacent to an Aircraft Hangar with Flat Loops Extending Beneath Building Footprint (Deadhorse, Alaska)

Photo Courtesy of WSP USA.

Figure A-14 Condensers (White) of Thermosyphons Configured within Foundation Piles (Goldstream Creek, Alaska)

Photo courtesy of WSP USA.

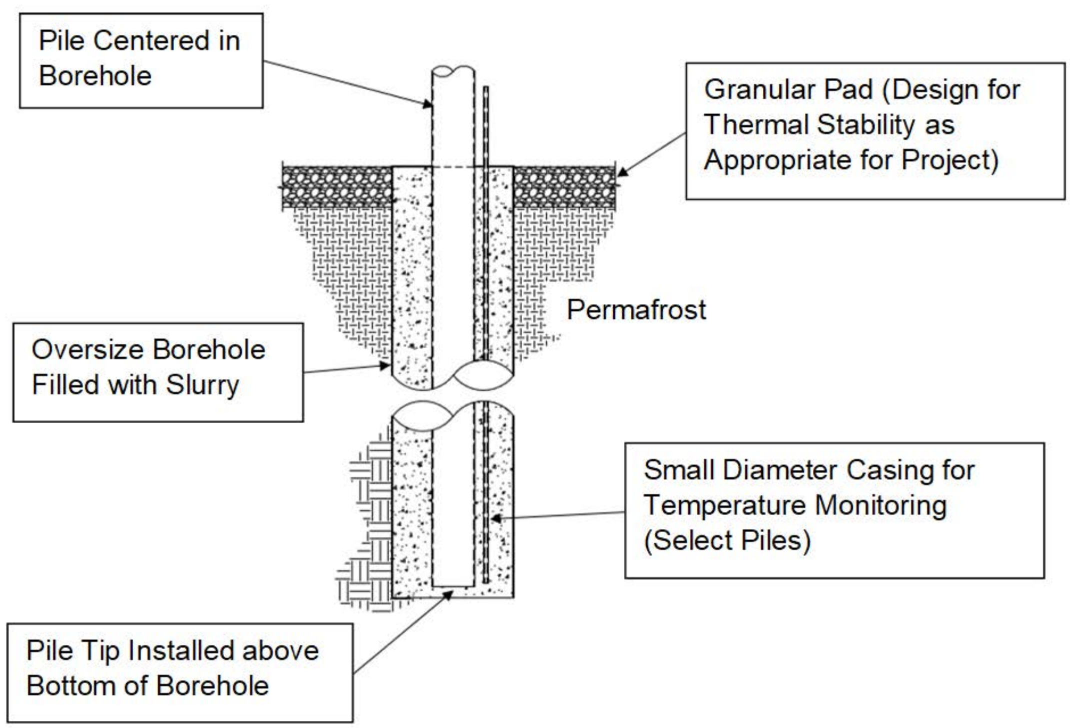
A-11 EXAMPLE PILE INSTALLATIONS.

As described in Chapter 9, piles can be configured in many ways, depending on specific foundation design criteria and structural support requirements. In North America (in 2024), steel piles are the most common type used for industrial applications, but timber piles were historically used extensively and may be encountered in existing facilities. Concrete piles are also used in permafrost areas, but to a lesser extent than steel piles. The designer should be familiar with local practices and the availability of pile materials.

A-11.1 Slurry Piles.

Figure A-15 illustrates a simple slurry pile installed in permafrost. This type of pile is generally supported by adfreeze between the pile and slurry, and the design for long-term compressive loads is typically controlled by the allowable creep rate defined in the foundation design criteria. Conventional adfreeze piles are installed with their tip above the bottom of the borehole as they typically do not include an end-bearing component. Additionally, adfreeze piles are often fixed-length with a prefabricated cap, so suspending them in the hole allows the cap to be precisely set. Many adfreeze piles are also installed open ended; and slurry at the base is preferable to icy cuttings. However, piles can bear on the bottom and be cut off to design elevation depending on details of the connection and other design requirements. For ice-poor conditions, other configurations may be appropriate, as indicated in Chapter 9.

Figure A-15 Example Slurry Pile



A-11.2 Pile Drilling.

Specialized drilling equipment like that shown in Figure A-16 may be required to advance oversize boreholes in permafrost.

Figure A-16 Example Drilling Oversize Borehole (North Slope, Alaska)

Photo courtesy of WSP USA.

A-11.3 Helical Piles.

The capacity and creep resistance of adfreeze piles may be increased by use of shear plates or a helical wrap like those shown in Figure A-17. Figure A-18 shows finished thermo-helix piles supporting a large, elevated structure. The thermo-helix piles are a thermopile with the addition of helical wrap. Helical piles like that shown in Figure A-19 may be an efficient option for some types of structures, especially when clearances are tight. The success of the installation depends on ground conditions and available equipment.

Figure A-17 Example Helical Shear Piles

Photo courtesy of Arctic Foundations.

Note: The coating at the top of the pile is to reduce solar radiation gain and provide corrosion protection in the active layer.

Figure A-18 Thermo-Helix Piles Supporting Elevated Structure (Kotzebue, Alaska)

Photo courtesy of Arctic Foundations.

Figure A-19 Example Helical Pile (Western Alaska)

Photo courtesy of WSP USA.

This Page Intentionally Left Blank

APPENDIX B GLOSSARY

B-1 INTRODUCTION.

The following acronyms and terms are used in this document and are specific to cold regions foundation engineering, design, and construction. UFC 3-130-01 provides a more comprehensive list of acronyms and terms for general cold regions engineering.

B-2 ACRONYMS.

1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
AR5	IPCC Fifth Assessment Report
AR6	IPCC Sixth Assessment Report
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BIA	Bilateral Infrastructure Agreements
BNQ	Bureau de Normalisation du Quebec
C	Celsius
DDC	Deep Dynamic Compaction
DoD	Department of Defense
DoR	Designer of Record
EM	Engineering Manual
EPS	Expanded Polystyrene
F	Fahrenheit
FGS	Final Governing Standards
FS	Factor of Safety
ft	Foot
ft^2	Square Foot
ft^3/s	Cubic Foot per Second

GCM	Global Climate Model
HNFA	Host Nation Funded Construction Agreements
IBC	*International Building Code*
in.	Inch
IPCC	Intergovernmental Panel on Climate Change
kg/m^3	Kilogram per Cubic Meter
km	Kilometer
kPa	Kilopascals
kph	Kilometer per Hour
lb/ft^3	Pound per Cubic Foot
m	Meter
m^2	Square Meter
m^3/s	Cubic Meter per Second
MAC	Mining Association of Canada
mi	Mile
mm	Millimeter
MPa	Megapascal
mph	Mile per Hour
NASA	National Aeronautics and Space Administration
NEX-GDDP	Earth Exchange Global Daily Downscaled Projections
NFS	Nonfrost-susceptible
OEBGD	*Overseas Environmental Baseline Guidance Document*
ppt	Part per Thousand
psi	Pound per Square Inch
RCP	Representative Concentration Pathway
SEI	Structural Engineering Institute

SNAP	Scenarios Network for Alaska + Arctic Planning
SOFA	Status of Forces Agreements
SSP	Shared socioeconomic pathway
UFC	Unified Facilities Criteria
USCS	Unified Soil Classification System
XPS	Extruded Polystyrene

B-3 DEFINITION OF TERMS.

Active layer detachment: A slope failure in which the thawed or thawing portion of the active layer detaches from the underlying frozen material.

Adfreeze: The process by which two objects adhere to each other via ice.

Aufeis: The type of ice that forms when water emerges from the ground under freezing conditions and is exposed to extremely cold air.

Basal heave: An upward normal force that acts on base, or bottom face, of shallow foundations or pile caps that bear within the frost depth.

Frozen debris lobe: Elongated, lobate permafrost features that mostly move through shear in zones near their bases.

Granular soil: Gravel, sand, or silt with little or no clay content.

Horizontal structures: Roads, airfields, and similar structures.

Longwave radiation: Electromagnetic thermal radiation emitted by Earth's surface, atmosphere, and clouds.

Multichannel analysis of surface waves: A seismic method that measures the shear-wave velocity distribution, which can be used to determine the depth to bedrock and shear strength or soil stability. This can be used in liquefaction studies, sinkhole mapping, fault mapping, and assessments of earthquake resilience.

Radiative forcing: The change in energy flux in the atmosphere caused by natural or anthropogenic factors of climate change as measured in watts per meter squared (W/m^2).

Sensible energy: The energy that causes a change in temperature of a substance without phase change. This is also the energy felt by humans as heat. It is the amount of energy needed to increase or decrease the temperature of a substance.

Shortwave radiation: Incoming ultraviolet, visible, and a limited portion of infrared energy from the sun.

Surface energy balance: Balance between all surface energy inputs and outputs at the surface over a given interval of time.

Talik: A perennially unfrozen zone below the active layer or within permafrost. Taliks may penetrate the permafrost (a "through talik") or be a zone between the active layer and the top of the permafrost.

Thaw degradation: Change in thermal state from frozen to thawed, usually accompanied by volume change in excess moisture from thawed ice structures.

Thaw points: Pipes that allow steam to be used to enhance thawing of permafrost.

Thaw-stable material: Frozen soil or rock that undergoes minimal volume change or strength loss when it thaws, such as clean granular soil or quarry rock without interstitial ice.

Thaw strain: The amount that frozen ground compresses upon thawing.

Thaw-unstable material: Frozen soil or rock with total ice content greater than its water content under normal consolidation conditions.[1] Also referred to as *thaw-sensitive* or *ice-rich*.[2] Thaw-unstable material will lose significant strength and settle when it thaws. An example of this material is fine-grained soil with a significant volume of interstitial ice. Rock also may be thaw unstable when fractured and containing significant ice within the rock structure.

Thermo-erosion gullying: Thawing permafrost can result in ground-ice erosion and sediment displacement (thermo-erosion), which can lead to permafrost tunneling and development of gully networks. A combination of mechanical erosion and gravitational processes results in soil subsidence and channel inclusions, resulting in a mixing of soil horizons and continued erosion of adjacent soils. Thermo-erosion gullies enlarge both retrogressively upslope and through deepening and widening of the initial incision.

Thermopile: A structural pile built to function as a thermosyphon.

Thermosyphon: A passive refrigeration device charged with a two-phase working fluid, such as carbon dioxide (CO_2) (in liquid and gaseous states), that uses natural convection to passively exchange heat between the ground and environment without a mechanical pump.

Transient layer: An ice-rich zone that acts as a thermal buffer to protect the underlying permafrost due to its relatively higher ice content and the significant heat needed to thaw this layer.

Trumpet curve: The envelope of ground temperature bounding all whiplash curves. The shape and limits of the trumpet curve may shift right or left depending on ground

[1] *Frozen Ground Engineering*, Andersland and Ladanyi.
[2] *Glossary of Permafrost and Related Ground-Ice Terms*, Harris et al.

temperature and with time at a given site in response to changes in ground temperature.

Vertical structures: Buildings, towers, and similar structures.

Whiplash curve: Ground temperature at a given moment; in aggregate, these form the trumpet curve.

This Page Intentionally Left Blank

APPENDIX C SUPPLEMENTAL RESOURCES

The following references are reliable sources for information related to foundations engineering and design. These sources provide direction for specific applications not addressed in this UFC or provide additional information to guide or aid the designer in the various phases of the design. This list is provided for the convenience of the designer and may not include references for all specific applications relevant to all projects. The designer is responsible for ensuring the design conforms to all criteria relevant to the project.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

LRFDBDS-9, *LRFD Bridge Design Specifications*, 9th edition

AMERICAN SOCIETY OF CIVIL ENGINEERS

https://ascelibrary.org

Conferences Series (With Proceedings)

Congress on Technical Advancement

International Conference on Cold Regions Engineering

International Symposium on Cold Regions Development (ISCORD)

Regional Conference on Permafrost (with the U.S. Permafrost Association)

Monographs and Specialty Publications

Arctic Coastal Processes and Slope Protection Design, A.C.T. Chen and C.B. Liedersdorf, Technical Council on Cold Regions Engineering Monograph, ASCE, Reston, VA, 1988

Cold Regions Construction, D.F. Jordan and G.N. McDonald (eds.), Technical Council on Cold Regions Engineering Monograph, ASCE, Reston, VA, 1983

Design for Ice Forces, S.R. Caldwell and R.D. Crissman (eds.), Technical Council on Cold Regions Engineering, ASCE, Reston, VA, 1983

Foundations in Permafrost and Seasonal Frost, A.F. Wuori and F.H. Sayles (eds.), Technical Council on Cold Regions Engineering, ASCE, Reston, VA, 1985

Freezing and Thawing of Soil-Water Systems, D.M. Anderson and P.J. Williams (eds.), Technical Council on Cold Regions Engineering Monograph, ASCE, Reston, VA, 1985

Frost Action in Soils: Fundamentals and Mitigation in a Changing Climate, S.A. Shoop (ed.), ASCE, Reston, VA, 2020

Frozen in Time: Permafrost and Engineering Problems, S.W. Muller (edited by H.M. French and F.E. Nelson), Technical Council on Cold Regions Engineering Monograph, ASCE, Reston, VA, 2008

Innovative Design and Construction for Foundations and Substructures Subject to Freezing and Frost, Geotechnical Special Publication No. 73, C.K. Tan (ed.), ASCE, Reston, VA, 1997

Permafrost Foundations: State of the Practice, Technical Council on Cold Regions Engineering Monograph, ASCE, Reston, VA, 2007

Research on Transportation Facilities in Cold Regions: Proceedings of a Session, O.B. Andersland and F.H. Sayles (eds.), Technical Council on Cold Regions Engineering, ASCE, Reston, VA, 1986

Roads and Airfields in Cold Regions, T.S. Vinson. J.W. Rooney, and W.H Haas (eds.), Technical Council on Cold Regions Engineering Monograph, ASCE, Reston, VA, 1996

Thermal Design Considerations in Frozen Ground Engineering, T.G. Krzewinski and R.G. Tart (eds.), Technical Council on Cold Regions Engineering Monograph, ASCE, Reston, VA, 1985

CANADIAN STANDARDS ASSOCIATION

https://www.csagroup.org/

CAN/CSA-S500-21, *Thermosyphon Foundations for Building in Permafrost Regions*, National Standard of Canada

CAN/CSA-S501-14, *Moderating the Effects of Permafrost Degradation on Existing Building Foundations*, National Standard of Canada

CAN/CSA-S503:20, *Community Drainage System Planning, Design, and Maintenance in Northern Communities*, National Standard of Canada

CSA PLUS 4011:19, *Technical Guide: Infrastructure in Permafrost: A Guideline for Climate Change Adaptation*, National Standard of Canada

INTERNATIONAL TECHNICAL ASSOCIATIONS AND CONFERENCES

Arctic Council, https://arctic-council.org

Arctic Technology Conference (ATC), Offshore Technology Conference (OTC), 2011, https://www.otcnet.org/

Canadian Permafrost Association, https://canadianpermafrostassociation.ca/

International Permafrost Association, https://www.permafrost.org/

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*

UFC 4-020-01, *DoD Security Engineering Facilities Planning Manual*

UFC 4-020-02, *DoD Security Engineering Facilities Design Manual*

UFC 4-021-02, *Electronic Security Systems*

OTHER REFERENCES

Comparative Analysis of the USSR Construction Codes and the US Army Technical Manual for Design of Foundations on Permafrost, CRREL Report 82-14, A.M. Fish, U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, NH, 1982

Design Manual for Stabilizing Foundations on Permafrost, Permafrost Technology Foundation, Cold Climate Housing Research Center, Fairbanks, AK, 2001, https://cchrc.org/media/DesignManualforStabilizingFoundationsonPermafrost.pdf

"The Effect of the Extent of Freezing on Seismic Velocities in Unconsolidated Permafrost," *Geophysics* 51: 1,285–1,290, R.W. Zimmerman and M.S. King, 1986

"Foundations in Permafrost of Northern Canada: Review of Geotechnical Considerations in Current Practice and Design Examples," *Geotechnics* 4: 285–308, J. Batista de Oliveira Libório Dourado , L. Deng, Y. Chen and Y-H Chui, 2024, https://doi.org/10.3390/geotechnics4010015

Geophysical Applications for Arctic/Subarctic Transportation Planning: *Final Report*, Project No. 410018, INE/AUTC 13.01, W.E. Schnabel, R. Fortier, M. Kanevskiy, J. Munk, Y. Shur, and E. Trochim, 2014

"Geotechnical Aspects of Northern Pipeline Design and Construction," in *Proceedings of the International Pipeline Conference, IPC,* J.M. Oswell, ASME, 2002, https://doi.org/10.1115/IPC2002-27327

Good Building Practice for Northern Facilities, Government of Northwest Territories, Fourth edition, 2021

"Numerical Modeling of Spatial Permafrost Dynamics in Alaska," in *Proceedings of the Ninth International Conference on Permafrost* 29: 1,125–1,130, S. Marchenko, V. Romanovsky, and G. Tipenko, Institute of Northern Engineering, University of Alaska Fairbanks, 2008

Opportunities to Use Remote Sensing in Understanding Permafrost and Related Ecological Characteristics: Report of a Workshop, National Research Council, Washington, DC, The National Academies Press, 2014, https://doi.org/10.17226/18711

Pipeline Geohazards: Planning, Design, Construction and Operations, M. Rizkalla and R. Read (eds.), ASME, New York, NY, 2019

Proceedings of the Third International Conference on Permafrost, Edmonton, Alberta, Canada, National Research Council of Canada, 10–13 Jul 1979

"Reviews and Syntheses: Changing Ecosystem Influences on Soil Thermal Regimes in Northern High-Latitude Permafrost Regions," *Biogeosciences* 15: 5,287–5,313, M.M. Loranty, B.W. Abbott, D. Blok, T.A. Douglas, H.E. Epstein, B.C. Forbes, B.M. Jones, A.L. Kholodov, H. Kropp, A. Malhotra, S.D. Mamet, I.H. Myers-Smith, S.M. Natali, J.A. O'Donnell, G.K. Phoenix, A.V. Rocha, O. Sonnentag, K.D. Tape, and D.A. Walke, 2018, https://doi.org/10.5194/bg-15-5287-2018

Revised Builder's Guide to Frost Protected Shallow Foundations, National Association of Home Builders Research Center, Upper Marlboro, MD, 2004

Suggested Method of Test for Some Viscoelastic Properties of Materials, Especially Frozen and Nonfrozen Soils, Under Vibratory Loads, Selected Technical Papers STP38549S, H.W. Stevens, ASTM, 1970

Thermokarst, Y. Shur and T.E. Osterkamp, Institute of Northern Engineering Report INE06.11, University of Alaska Fairbanks, 2007

APPENDIX D REFERENCES

AMERICAN CONCRETE INSTITUTE

ACI 306R, *Guide to Cold Weather Concreting*, https://www.concrete.org/Portals/0/Files/PDF/University/306R-16_excerpt.pdf

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

https://www.astm.org

ASTM D1557, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))*

ASTM D1586, *Standard Test Method for Standard Penetration Test and Split-Barrel Sampling of Soils*

ASTM D2216, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*

ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes*

ASTM D4083, *Standard Practice for Description of Frozen Soil (Visual-Manual Procedure)*

ASTM D4542, *Standard Test Methods for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer*

ASTM D5334, *Standard Test Method for Determination of Thermal Conductivity of Soil and Rock by Thermal Needle Probe Procedure*

ASTM D5520, *Standard Test Method for Laboratory Determination of Creep Properties of Frozen Soil Samples by Uniaxial Compression*

ASTM D5780, *Standard Test Methods for Individual Piles in Permafrost Under Static Axial Compressive Load*

ASTM D5918, *Standard Test Methods for Frost Heave and Thaw Weakening Susceptibility of Soils* (withdrawn 2022)

ASTM D7099, *Standard Terminology Relating to Frozen Soil and Rock*

ASTM D7263, *Standard Test Methods for Laboratory Determination of Density and Unit Weight of Soil Specimens*

ASTM D7300, *Standard Test Method for Laboratory Determination of Strength Properties of Frozen Soil at a Constant Rate of Strain*

ASTM D7400, *Standard Test Methods for Downhole Seismic Testing*

ASTM D7928, *Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*

ASTM D8295, *Standard Test Method for Determination of Shear Wave Velocity and Initial Shear Modulus in Soil Specimens Using Bender Elements.*

AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE)

https://ascelibrary.org

ASCE/SEI 7*, Minimum Design Loads and Associated Criteria for Buildings and Other Structures*

SEI/ASCE 32, *Design and Construction of Frost-Protected Shallow Foundations*

Cold Regions Hydrology and Hydraulics: An American Society of Civil Engineers Monograph, W.L. Ryan, and R.D. Crissman (eds.), ASCE, 1990

Cold Regions Pavement Engineering, G. Doré and H.K. Zubeck, ASCE and McGraw Hill, New York, NY, 2009

Cold Regions Utilities Monograph, Third edition*,* D.W. Smith (ed.), ASCE, 1996

Embankment Design and Construction in Cold Regions, E.G. Johnson (ed.), A. Phukan and W.H. Haas (co-eds.), Technical Council on Cold Regions Engineering, ASCE, 1988

Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground, Technical Council on Cold Regions Engineering Monograph, D.C. Esch (ed.), ASCE, 2004

DEPARTMENT OF DEFENSE

MIL-STD-810G, *Department of Defense Test Method Standard: Environmental Engineering Considerations and Laboratory Tests*, 2008, https://www.atec.army.mil/publications/Mil-Std-810G/MIL-STD-810G.pdf

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Vex, and P.M. Midgley (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013

Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R.

Mastrandrea, and L.L. White (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014

Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part B: Regional Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014

Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, O. Edenhofer, R. Pichs-Madruga, Y. Sokona, J.C. Minx, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, and T. Zwickel (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014

Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team, R.K. Pachauri, and L.A. Meyer (eds.), IPCC, Geneva, Switzerland, 2014

Climate Change 2021: The Physical Science Basis, Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, V. Masson-Delmotte, P Zhai, A. Pirani, S.L. Connors, C. Péan, Y. Chen, L. Goldfarb, M.I. Gomis, J.B.R. Matthews, S. Berger, M. Huang, O. Yelekçi, R. Yu, B. Zhou, E. Lonnoy, T.K. Maycock, T. Waterfield, K. Leitzell, and N. Caud (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2021

Climate Change 2022: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, H.-O. Pörtner, D.C. Roberts, M.M.B. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, 2022

Climate Change 2022: Mitigation of Climate Change, Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, P.R. Shukla, J. Skea, R. Slade, R. Fradera, M. Pathak, A. Al Khourdajie, M. Belkacemi, R. van Diemen, A. Hasija, G. Lisboa, S. Luz, J. Malley, D. McCollum, S. Some, and P. Vyas (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, 2022

Climate Change 2022: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team, H. Lee, and J. Romero (eds.), IPCC, Geneva, Switzerland, 2023

INTERNATIONAL CODE COUNCIL

https://ww.iccsafe.org

IBC, *International Building Code*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 1-200-01, *DoD Building Code*

UFC 2-100-01, *Installation Master Planning*

UFC 3-130-01, *Arctic and Subarctic Engineering*

UFC 3-130-02, *Arctic and Subarctic Site Selection and Development*

UFC 3-130-04, *Arctic and Subarctic Buildings*

UFC 3-130-05, *Arctic and Subarctic Utilities*

UFC 3-201-01, *Civil Engineering*

UFC 3-220-01, *Geotechnical Engineering*

UFC 3-220-04FA, *Backfill for Subsurface Structures*

UFC 3-220-05, *Dewatering and Groundwater Control*

UFC 3-220-08FA, *Engineering Use of Geotextiles*

UFC 3-220-10, *Soil Mechanics (DM 7.1)*

UFC 3-220-20, *Foundations and Earth Structures*

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*

UFC 3-260-02, *Pavement Design for Airfields*

UFC 3-301-01, *Structural Engineering*

UFC 3-301-02, *Design of Risk Category V Structures, National Strategic Military Assets*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

U.S. ARMY CORPS OF ENGINEERS

EM 1110-1-1804, *Geotechnical Investigations*

EM 1110-2-2906, *Design of Pile Foundations*

OTHER

"Active Freezing Techniques," *Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground,* 193–237, D.W. Mageau and D.F. Nixon (edited by D.C. Esch), ASCE, 2004

"The Adfreeze Strength Characteristics of Vibratory Driven Piles," in *ISCORD 2013: Planning for Sustainable Cold Regions*, T. Mayrberger, K. Braun, W.N. Scott, and J. Cologgi, ASCE 10th International Symposium on Cold Regions Development, 2013, https://doi.org/10.1061/9780784412978.005

"Adfreeze Strength of Model Piles in Frozen Soil Under Dynamic Loads," in *Proceedings, 7th International Conference on Permafrost,* 1,217–1,221, J. Zhang, Y. Zhu, and J. Zhang, Yellowknife, Canada, 1998

"Adjustable Foundation Design Development in Arctic Engineering," in *Permafrost Foundations: State of the Practice*, B. Borjesson and E.S. Clarke (eds.), ASCE Technical Council on Cold Regions Monograph, ASCE, Reston, VA, 2007

"Advances in Geophysical Methods for Permafrost Investigations," in *Permafrost and Periglacial Processes* 19(2): 157–178, C. Kneisel, C. Hauck, F. Richard, and B. Moorman, 2008

"Air-Ducted Hangar Foundations at Thule, Greenland," in *Proceedings, 63rd Canadian Geotechnical Conference & 6th Canadian Permafrost Conference,* 970–977, K. Bjella, GEO 2010, Calgary, Alberta, 2010

"Analysis of Laterally Loaded Piles Embedded in Layered Frozen Soil," *Journal of Geotech Engineering* 116 (7): 1,137–1,152, G.S. Crowther, 1990

"Analysis of Laterally Loaded Piles in Frozen Soils," in *GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering*, 215–224, Z. Yang, Q. Li, J. Horazdovsky, and E. Marx (edited by R.D. Hryciw, A. Athanasopoulos-Zekkos, and N. Yesiller), ASCE, Reston, VA, 2012, https://doi.org/10.1061/9780784412121.023

"ARRC Rail Alignment Improvements Birchwood, Alaska Railroad Design—Construction in Marginally Frozen Relic Ice and Soil," *Current Practices in Cold Regions Engineering*, T. Krzewinski, M.J. Wachholz, D. Miller, and G. Lotakis (edited by M. Davies and J.E. Zufelt), ASCE, Reston, VA, 2006, https://doi.org/10.1061/40836(210)27

"Aufeis Formation and Prevention," in *Cold Regions Hydrology and Hydraulics: An ASCE Monograph,* C.W. Slaughter (edited by W.L. Ryan and R.D. Crissman), ASCE, Reston, VA, 1990

"Aufeis Formation and Remediation," in *Cold Regions Engineering 2012: Sustainable Infrastructure Development in a Changing Cold Environment*, J. Zufelt and S. Daly (edited by B. Morse and G. Doré), ASCE, Reston, VA, 2012

Canadian Foundation Engineering Manual, Fifth edition, Canadian Geotechnical Society, Surrey, British Columbia, Canada, 2023

"Climate Tools," SNAP, https://uaf-snap.org/climate-tools/

Cold Region Structural Engineering, E. Eranti and G.C. Lee, McGraw Hill Higher Education, New York, NY, 1986

"Cold Regions Earthwork," *Cold Regions Construction: A State of the Practice Report*, R.G. Tart (edited by D.F. Jordan and G.N. McDonald), Technical Council on Cold Regions Engineering, ASCE, Reston, VA, 1983

"The Compressible Inclusion Function of EPS Geofoam," *Geotextiles and Geomembranes* 15: 77–120, J.S. Horvath, 1997, https://doi.org/10.1016/S0266-1144(97)00008-3

Construction in Cold Regions, A Guide for Planners, Engineers, Contractors, and Managers, T.T. McFadden and F.L. Bennett, John Wiley & Sons, Inc., New York, NY, 1991

"Construction Ground Freezing—A Look at Modeled versus Measured Performance," in *Cold Regions Engineering 2019,* A. Daggett, J. Thornley, E. Yarmak, J. Zarling, and S. Mehta (edited by J-P Bilodeau, D.F. Hadeau, D. Fortier, and D. Conciatori), ASCE, Reston, VA, 2019

"Construction—Wintertime Compaction and LNG Facilities in Fairbanks, Alaska," in *Cold Regions Engineering 2019,* D. Prusak, A.P. Daggett, J. Quakenbush, and J.D. Thornley (edited by J-P Bilodeau, D.F. Hadeau, D. Fortier, and D. Conciatori), ASCE, Reston, VA, 2019

"Creep and Strength Testing of Frozen Saline Fine-grained Soils," *Canadian Geotechnical Journal* 21 (3): 518–529, J. Nixon and G. Lem, 1984, https://doi.org/10.1139/t84-054

Creep Behavior of Shallow Anchors in Ice-Rich Silt, X. Zhang, L. Chen, C. Lin, and R. McHattie, Alaska Department of Transportation & Public Facilities and Alaska University Transportation Center, University of Alaska Fairbanks, 2013

Creep in Engineering Structures, J.A.H. Hult, Blaisdell Publishing Company, Waltham, MA, 1966

"Creep of a Strip Footing on Ice-rich Permafrost," in *Foundations in Permafrost and Seasonal Frost,* 29–51, F.H. Sayles (edited by A. Wuori and F.H. Sayles), Denver, Colorado, 1985

Creep of Frozen Soils, TR 190, F.H. Sayles, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, September 1968

Demonstration of an Artificial Frozen Barrier, ERDC/CRREL TR-12-12, A.M. Wagner and E. Yarmak, Jr., U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, November 2012

Description and Classification of Frozen Soils, TR 150, K.A. Linell and C.W. Kaplar, U.S. Army Cold Regions Engineering Laboratory, Hanover, NH, 1966

Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost, SR 80-34, K.A. Linell and E.F. Lobacz, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, 1980

"Design, Construction and Operation of an Insulated Ice Drilling Pad, North Slope, Alaska," in *Proceedings: Third International Specialty Conference, Cold Regions Engineering,* B. Hazen, D.L. Miller, M.J. Stanley, and W.S. Powell, ASCE, Reston, VA, 1994

Design Manual for New Foundations on Permafrost, Permafrost Technology Foundation, Cold Climate Housing Research Center, Fairbanks, AK, 2000, https://cchrc.org/media/DesignManualforNewFoundationsonPermafrost.pdf

"Design of Vertical and Laterally Loaded Piles in Saline Permafrost," in *Proceedings of the Third International Specialty Conference—Cold Regions Engineering*, 131–144, J.F. Nixon and R.J. Neukirchner, 1984

"Development of Innovative Antifreeze Grout Mortar for Anchor Applications in Cold Regions," *Transportation Research Record: Journal of the Transportation Research Board* 2508: 1–12, C. Lin, J. Liu, and X. Zhang, 2015, https://doi.org/10.3141/2508-01

"Displacement of Piles Under Dynamic Loads in Frozen Soils," in *Proceedings of the Fourth Canadian Permafrost Conference* (Roger J.E. Brown Memorial Volume), 555–559, V.R. Parameswaran (edited by H.M. French) Calgary, 1982

Driven Piles in Permafrost, State of the Art, D. Nottingham and A.B. Christopherson, Prepared for State of Alaska Department of Transportation and Public Facilities, Division of Planning and Programming, 1983 https://dot.alaska.gov/stwddes/research/assets/pdf/ak_rd_83_19.pdf

"Dynamic Load Effect on Settlement of Model Piles in Frozen Sand," in *International Conference on Permafrost, Proceedings* 5 (2): 1,165–1,170, D.L. Stelzer and O.B. Andersland, 1988

"Effect of Backfill Properties and Surface Treatment on the Capacity of Adfreeze Pipe Piles," *Canadian Geotechnical Journal* 26: 718–725, D.C. Sego and L.B. Smith, 1989

Effect of Dynamic Loads on Piles in Frozen Soils, V.R. Parameswaran, National Research Council Canada, 1984

"Effects of Seasonally Frozen Soil on the Seismic Behavior of Bridges," *Cold Regions Science and Technology* 54 (1): 44–53, F. Xiong and J.Z. Yang, 2008

"Eighteenth Canadian Geotechnical Colloquium: Limit States Design for Foundations, Part I: An Overview of the Foundation Design Process," *Canadian Geotechnical Journal* 33(6): 956–983, D.E. Becker, 1996, https://doi.org/10.1139/t96-124

"Eighteenth Canadian Geotechnical Colloquium: Limit States Design for Foundations, Part II: Development for the National Building Code of Canada," *Canadian Geotechnical Journal* 33 (6): 984–1007, D.E. Becker,1996 https://doi.org/10.1139/t96-125

"An Engineering Theory of Creep of Frozen Soils," *Canadian Geotechnical Journal* 9 (1): 63–80, B. Ladanyi, 1972, https://doi.org/10.1139/t72-005

"Estimating Thaw-Strain Settlement of Frozen Fill," *ASCE Journal of Cold Region Engineering* 6 (4): 152–159, G.S. Crowther,1992

"Estimating Thermal Conductivity of Pavement Granular Materials and Subgrade Soils," *Transportation Research Record* 1967 (1): 10–19, J. Côté and J-M. Konrad, 2006

"Evaluating Wind Extremes in CMIP5 Climate Models," *Climate Dynamics* 45: 441–453, D. Kumar, V. Mishra, and A.R. Ganguly, 2014

"Field Tests of Grouted Rod Anchors in Permafrost," *Canadian Geotechnical Journal* 9 (2): 176–194, G.H. Johnston and B. Ladanyi, 1972

"Foundations in Cold Regions," in *Foundation Engineering Handbook*, Chapter 19, A. Phukan (edited by H-Y Fang), Van Nostrand Reinhold, New York, NY, 1990

"Foundation Design for Frost Heave," in *Cold Regions Engineering 2009, Cold Regions Impact on Research, Design, and Construction*, H.G. Widianto, J. Owen, and J. Fente (edited by H.D. Mooers and J. Hinzmann, Jr.), ASCE, Reston, VA, 2009

Frost Action Predictive Techniques for Roads and Airfields, A Comprehensive Survey of Research Findings, CRREL Report 86-18, T.C. Johnson, R.L. Berg, E.J. Chamberlain, and D.M. Cole, U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, NH, December 1986

"Frost Heave and Thaw Settlement Estimation of a Frozen Ground," in *Proceedings, 15th Pan-American Conference on Soil Mechanics and Geotechnical Engineering*, G. Sinnathamby, H. Gustavsson, L. Korkiala-Tanttu, C. Perez Cervera, and M. Koskinen, 2015, http://doi.org/10.3233/978-1-61499-603-3-891

"Frost Heave Predictions for Alaskan Soils," in *Permafrost, Sixth International Conference Proceedings*, B. Hazen, J.F. Nixon, C.E. Heuer, J.B. Caldwell, and E.L. Brudie, Beijing, China, 5–9 July 1993

Frost Protected Shallow Foundations (FPSF) for Interior Alaska Freezing Indices Between 4,000 and 8,000 Degree-Fahrenheit-Days: A Research Report, P.V. Perreault, Prepared for Cold Climate Research Center, 2008

Frost Susceptibility of Soil: Review of Index Tests, CRREL Monograph 81-2, E.J. Chamberlain, U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, NH, 1981

"Frozen and Unfrozen Shear Wave Velocity Seismic Site Classification of Fairbanks, Alaska," *Journal of Cold Regions Engineering* 26 (3): 118–145, B.R. Cox, C.M. Wood, and K. Hazirbaba, 2012

"Frozen Debris Lobe Morphology and Movement: An Overview of Eight Dynamic Features, Southern Brooks Range, Alaska," *The Crysophere* 10 (3): 977–993, M.M. Darrow, N.L. Gyswyt, J.M. Simpson, R.P. Daanen, and T.D. Hubbard, 2016

Frozen Ground Engineering, Second edition, O.B. Andersland and B. Ladanyi, John Wiley & Sons, Inc. in cooperation with American Society of Civil Engineers Press, Hoboken, NJ, 2004

Frozen Ground Engineering, A. Phukan, Prentice-Hall, Inc., Englewood Cliff, NJ, 1985

"A Generalized Thermal Conductivity Model for Soils and Construction Materials," *Canadian Geotechnical Journal* 42 (2): 443–458, J. Côté and J-M. Konrad, 2005

Geocryology: Characteristics and Use of Frozen Ground and Permafrost Landforms, S.A. Harris, A. Brouchkov, and C. Guodong, CRC Press/Balkema, Schipholweg, The Netherlands, 2018

"Geographical Coverage," Arctic Monitoring & Assessment Programme, www.amap.no/about/geographical-coverage

Geotechnical Asset Management for Transportation Agencies, Volumes 1 and 2, Research Report 903, National Cooperative Highway Research Program (NCHRP), The National Academies Press, Washington, DC, 2019

Geotechnical Engineering for Cold Regions, O.B. Andersland and D. Anderson, McGraw-Hill, New York, NY, 1978

"Geotechnical Thermal Analysis," In *Embankment Design and Construction in Cold Regions,* J.P. Zarling and W.A. Braley (edited by E.G. Johnson, A. Phukan, and W.H. Haas), 35–92, Technical Council on Cold Regions Engineering, ASCE, Reston, VA, 1988

Glossary of Permafrost and Related Ground-Ice Terms, Technical Memorandum No. 142, S.A. Harris, H.M. French, J.A. Heginbottom, G.H. Johnston, B. Ladanyi, D.C. Sego, and R.O. van Everdingen, National Research Council of Canada (NRC Canada), 1988

"Ground Ice in the Upper Permafrost of the Beaufort Sea Coast of Alaska," *Cold Regions Science and Technology* 85: 56–70, M. Kanevskiy, Y. Shur, M.T. Jorgenson, C.-L. Ping, G.J. Michaelson, D. Fortier, E. Stephani, M. Dillon, and V. Tumskoy, 2013

"Ground Temperatures and Permafrost Warming from Forest to Tundra, Tuktoyaktuk Coastlands and Anderson Plain, NWT, Canada," *Permafrost and Periglacial Processes* 28: 543–551, S.V. Kokelj, M.J. Palmer, T.C. Lantz, and C.R. Burn, 2017

Guide on Climate Change Adaptation for the Mining Sector, Prepared by Golder Associates, Mining Association of Canada (MAC), June 2021

Guide to a Field Description of Permafrost for Engineering Purposes, Technical Memorandum 79 (NRC 7576), J. Pihlainen and G.H. Johnston, National Research Council of Canada, Associate Committee on Soil and Snow Mechanics, 1963

Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions, Transportation Association of Canada, 2010

Guidelines for Estimation of Shear Wave Velocity Profiles, PEER Report 2012/08, B.R. Wair, J.T. Dejong, and T. Shantz, Earthquake Engineering Research Center, 2012

Handbook for the Design of Bases and Foundations of Buildings and Other Structures on Permafrost, Technical Translation TT1865, S.S. Vyalov and G.V. Porkhaev (eds.), National Research Council Canada, 1976

Heat Transfer in Cold Climates, V.J. Lunardini, Van Nostrand Reinhold Company, New York, NY, 1981

Improving Design Methodologies and Assessment Tools for Building on Permafrost in a Warming Climate, ERDC/CRREL TR-20-13, K.L. Bjella, Y. Shur, M. Kanevskiy, P. Duvoy, B. Grunau, J. Best, S. Bourne, and R. Affleck, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2020

"The Influence of Cryostructure on the Creep Behavior of Ice-Rich Permafrost," *Cold Regions Science and Technology* 79–80: 43–52, M.T. Bray, 2012

"In Situ Creep Properties in Ice-rich Permafrost Soil," *Canadian Geotechnical Journal* 23 (4): 504–514, K.W. Savigny and N.R. Morgenstern, 1986, https://doi.org/10.1139/t86-080

"Interface Shear Strength Characteristics of Steel Piles in Frozen Clay Under Varying Exposure Temperature," *Soils and Foundations* 59: 2,110–2,124, A.A. Aldaeef and M.T. Rayhani, 2019

"Laboratory and Field Performance of High Alumina Cement-Based Grout for Piling in Permafrost," *Canadian Journal of Civil Engineering* (20): 100–106, K.W. Biggar, D.C. Sego, and M.M. Noel, 1993

Landslides: Investigation and Mitigation, Special Report 247, A.K. Turner and R.L. Schuster (eds.), Transportation Research Board (TRB), National Academy Press, Washington, DC, 1996

"Lateral Pile Analysis Frozen Strength Criteria," *Journal of Cold Regions Engineering,* 29 (2), S. Crowther, 2014, https://doi.org/10.1061/(ASCE)CR.1943-5495.0000078

"Marginal Permafrost, a Foundation Material in Transition," In *Permafrost Foundations: State of the Practice,* M. Musial and G.E. Wyman (edited by E.S. Clarke), ASCE Technical Council on Cold Regions Monograph, ASCE, Reston, VA, 2007

"The Measurement of Compressional and Shear Wave Velocities in Permafrost: A Comparison of Three Seismic Methods," in *Proceedings of the Tenth International Conference on Permafrost*, Volume 1: 45–48, W. Black, E. Bashaw, J. Drage, and R. Kmack, 2012

Mechanical Properties of Frozen Soils, Selected Technical Paper 1568-EB, H. Zubeck and Z. Yang (eds.), ASTM, 2013

"Monitored Thermal Performance of Varying Embankment Thickness on Permafrost Foundations," in *Cold Regions Engineering 2019,* E.M.B. De Guzman, M. Alfaro, L.U. Arneson, and G. Doré (edited by J-P Bilodeau, D.F. Hadeau, D. Fortier, and D. Conciatori), ASCE, Reston, VA, 2019

Multi-Language Glossary of Permafrost and Related Ground-Ice Terms, R.O. van Everdingen (ed.), International Permafrost Association, University of Calgary, Calgary, Alberta, 2005

National Assessment of Shoreline Change—Historical Shoreline Change Along the North Coast of Alaska, U.S.—Canadian Border to Icy Cape, USGS Open File Report 2015-1048, A.E. Gibbs and B.M. Richmond, U.S. Department of Interior, U.S. Geological Survey, Washington, DC, 2015

National Standard of Canada CAN/BNQ 2501-500/2017: Geotechnical Site Investigations for Building Foundations in Permafrost Zones, Bureau de Normalisation du Quebec (BNQ), approved by Standards Council of Canada, 2017

"Passive Techniques for Ground Temperature Control," in *Thermal Analysis, Construction, and Monitoring Methods for Frozen Ground*, 77–165, E.L. Long and J.P Zarling (edited by D.C. Esch), ASCE, Reston, VA, 2004

The Periglacial Environment, Third edition, H.M. French, John Wiley & Sons, Chichester, UK, 2007

"Permafrost Dynamics at the Fairbanks Permafrost Experimental Station Near Fairbanks, Alaska," in *Proceedings of the Ninth International Conference on Permafrost,* 373–378, T.A. Douglas, M.T. Jorgenson, M. Kanevskiy, V.E. Romanovsky, Y.L. Shur, and K. Yoshikawa (edited by D. Kane, D. Hinkel, and K. Hinkel), 2008

Permafrost, A Guide to Frozen Ground in Transition, T.N. Davis, University of Alaska Press, Fairbanks, Alaska, 2001

Permafrost and Related Engineering Problems in Alaska, Geological Survey Professional Paper 678, O.J. Ferrians, R. Kachadoorian, and G.W. Greene, U.S. Government Printing Office, Washington, DC, 1969

"Permafrost and Terrain Conditions at Northern Drilling-Mud Sumps: Impacts of Vegetation and Climate Change and the Management Implications," *Cold Regions Science and Technology* 64 (2010): 46–56, S.V. Kokelj, D. Riseborough, R. Coutts, and J.C.N. Kanigan, 2010

Permafrost Engineering Design and Construction, G.H. Johnston (ed.), John Wiley & Sons Canada, Toronto, Ontario, 1981

"Permafrost of Northern Alaska," in *Proceedings, Twenty-first International Offshore and Polar Engineering Conference (ISOPE11)*, 1,179–1,186, M. Kanevskiy, Y. Shur, M.T. Jorgenson, C.-L. Ping, D. Fortier, E. Stephani, and M. Dillon, 2011

"Permafrost Thaw and Ground Settlement Considering Long-Term Climate Impact in Northern Alaska," *Journal of Infrastructure Preservation and Resilience* 2: 8, Z.J. Yang, K.C. Lee, and H. Liu, 2021, https://doi.org/10.1186/s43065-021-00025-2

"Pile Construction Practices in Arctic Regions State-of-the-Art," in *Cold Regions Construction*, D. Nottingham, A.B. Christopherson, and J.L. Larson (edited by D.F. Jordan and G.N. McDonald), Technical Council on Cold Regions Engineering Monograph, ASCE, New York, NY, 1983

"Pile Design in Permafrost," *Canadian Geotechnical Journal* 18 (3): 357–370, J.S. Weaver and N.R. Morgenstern, 1981, https://doi.org/10.1139/t81-043

Pile Foundations in Engineering Practice, S. Prakash and H. D. Sharma, John Wiley & Sons, Inc., New York, NY, 1990

"Procedure for Determining the Segregation Potential of Freezing Soils," *ASTM Geotechnical Testing Journal* 10 (2): 51–58, J-M. Konrad, 1987

"Recent Developments in Thermosyphon Technology," in *Proceedings, Cold Region Engineering: Cold Regions Impacts on Transportation and Infrastructure,* E. Yarmak, Jr., and E.L. Long, 2012, https://doi.org/10.1061/40621(254)56

"The Response (1958–1997) of Permafrost and Near-Ground Temperatures to Forest Fire, Takhini River Valley, Southern Yukon Territory," *Canadian Journal of Earth Sciences* 35 (2):184–198, C.R. Burn, 1998

"A Reversal in Global Terrestrial Stilling and Its Implications for Wind Energy Production," *Nature Climate Change* 9: 979–985, Z. Zeng, A.D. Ziegler, T. Searchinger, L. Yang, A. Chen, K. Ju, S. Piao, L.Z.X. Li, P. Ciais, D. Chen, J. Liu, C.

Azorin-Molina, A. Chappell, D. Medvigy, and E.F. Wood, 2019, https://doi.org/10.1038/s41558-019-0622-6

Review of Thermosyphon Applications, ERDC/CRREL TR-14-1, A.M. Wagner, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2014

Rheological Properties and Bearing Capacity of Frozen Soils, SPIRE TL 74, S.S. Vailov, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, 1965

Roads and Airfields Constructed on Permafrost: A Synthesis of Practice, B. Connor, D.J. Goering, M. Kanevskiy, E. Trochim, K.L. Bjella, and R.L. McHattie, University of Alaska Fairbanks Institute of Northern Engineering, Fairbanks, Alaska, 2020

“Russia and North American Approaches of Pile Design in Relation to Frost Action,” in *Proceedings of 7th International Permafrost Conference,* 803–809, B. Nidowicz and Y. Shur, 1998

“Salt Concentration Effects on Strength of Frozen Soils,” in *Proceedings of the Third International Symposium on Ground Freezing*, Special Report 82-16, N. Ogata, M. Yasuda, and T. Kataoka, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH, 1982

“The Settlement of Model Piles in Frozen Soil Under Dynamic Loading,” *Science in China* (series D) 29 (special issue 1): 27–33, J. Zhang, Y. Zhu, and J. Zhang, 1998

Shallow Insulated Foundation at Galena, Alaska: A Case Study, Special Report 97-7, L.S. Danyluk, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH, 1997

“Shear Strength in the Zone of Freezing in Saline Soils,” *ASCE Conference–Arctic ’85,* E.J. Chamberlain, 25–27 March 1985

“Some Considerations Regarding the Design of Two-Phase Liquid/Vapor Convection Type Passive Refrigeration Systems,” Presentation at the Fourth International Conference on Permafrost, E. Yarmak, Jr., and E.L. Long, Fairbanks, AK, 1983

“Strength of Frozen Saline Soils,” *Canadian Geotechnical Journal* 32 (2): 336–354, E.G. Hivon and D.C. Sego, 2011, https://doi.org/10.1139/t95-034

“Structure and Properties of Ice-rich Permafrost Near Anchorage, Alaska,” *Cold Regions Science and Technology* 93: 1–11, M. Kanevskiy, Y. Shur, T. Krzewinski, and M. Dillon, 2013

Thaw Stabilization of Roadway Embankments Constructed Over Permafrost Areas, Report No. FHWA-AK-RD-87-20, J.P. Zarling and W.A. Braley, Federal Highway Administration, Washington, DC, 1988

"Thaw Strain Data and Thaw Settlement Predictions for Alaskan Soils," in *Proceedings, 4th International Conference on Permafrost* 4: 912–917, R.A. Nelson, U. Luscher, J.W. Rooney, and A.A. Stramler, Fairbanks, AK, 18–22 July 1983

"Thermal Conductivity of Base-Course Materials," *Canadian Geotechnical Journal* 42 (1), 61–78, J. Côté and J-M. Konrad, 2005.

Thermal Conductivity of Soils, O. Johansen, Ph.D. dissertation, Norwegian University of Science and Technology, 1975

"Thermal Conductivity of Some Ice-Rich Permafrost Soils," *Canadian Geotechnical Journal* 12 (3): 413–424, W.A. Slusarchuk and G.H. Watson, 1975, https://doi.org/10.1139/t75-045

"Thermal Design Considerations for Raised Structures on Permafrost," *Journal of Cold Regions Engineering* 29 (1), J.M Oswell and J.F. Nixon, ASCE, 2014, https://doi.org/10.1061/(ASCE)CR.1943-5495.0000075

"Thermal Properties of Soils," Bulletin No. 28, Vol. LII, No. 21, M.S. Kersten, University of Minnesota Institute of Technology Engineering Experiment Station, 1949 https://hdl.handle.net/11299/124271

"The Thermal Properties of Soils in Cold Regions," *Cold Regions Science and Technology* 5 (1): 67–75, O.T. Farouki, 1981

"Thermal Stabilization of Embankments Built on Thaw-Sensitive Permafrost," *Journal of Cold Regions Engineering* 35 (3), X. Kong and G. Doré, 2021, https://doi.org/10.1061/(ASCE)CR.1943-5495.0000256

"Thermosyphon Applications in Cold Climates," in *Proceedings, Fourth International Symposium on Thermal Engineering and Science for Cold Climates*, 24–35, J.P. Zarling (edited by V.J. Lunardini and S.L. Bowen), 1993

"Thread Bar Pile for Permafrost," in *Proceedings of 5th Canadian Permafrost Conference, Collection Nordicana, Permafrost–Canada*, 341–348, I. Holubec, 1990

"Time-Dependent Displacement Behaviour of Model Adfreeze and Grouted Piles in Saline Frozen Soils," *Canadian Geotechnical Journal* 31: 395–406, K. Biggar and D.C. Sego, 1994

"The Transient Layer: Implication for Geocryology and Climate-Change Science," *Permafrost and Periglacial Processes* 16: 5–17, Y. Shur, K.M. Hinkel, and F.E. Nelson, 2005

"Transportation, Preparation, and Storage of Freezing Soil Samples for Laboratory Testing," in *Soil Specimen Preparation for Laboratory Testing*, ASTM Special Technical Publication 599, 88–112, T. Baker (edited by D. Sangrey and R. Mitchell), ASTM International, West Conshohocken, PA, 1976, https://doi.org/10.1520/STP39077S

"Uniaxial Compressive Strength of Frozen Silt Under Constant Deformation Rates," *Cold Regions Science and Technology* 9 (1): 3–15, Z. Yuanlin and D.L. Carbee, 1984

"The Upper Horizon of Permafrost Soils," in *Proceedings of the 5th International Conference* on *Permafrost* 1: 867–871, Y.L. Shur (edited by K. Senneset), Tapir Publishers, Trondheim, Norway, 1988

Vibration Amplitudes in the Inuvik Powerhouse, DBR Paper No. 1283, G. Pernica, V.R. Parameswaran, and G.H. Johnston, National Research Council of Canada Division of Building Research, 1985

UFC 3-130-04
16 January 2025

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC BUILDINGS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC BUILDINGS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes UFC 3-130-07, dated 16 January 2004.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website http://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

THOMAS P. SMITH, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

S. KEITH HAMILTON, P.E., SES
Chief Engineer and Assistant Commander
Planning, Design and Construction
Naval Facilities Engineering Systems Command

THOMAS P. BROWN, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MARK S. SINDER, SES
Deputy Assistant Secretary of Defense
(Infrastructure Modernization and Resilience)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

The field of Arctic and Subarctic engineering, also known as cold regions engineering, covers a wide range of multidisciplinary topics and principles. Unique issues exist in the planning, design, construction, and operation of infrastructure and facilities in Arctic and Subarctic regions. Among them are permafrost, seasonal ground frost heave and thaw settlement, extreme low temperatures, high wind loads, heavy snow loads, and remote construction sites. Additionally, the implications of the rapidly changing climate in Arctic and Subarctic regions exacerbate these unique challenges.

The Unified Facilities Criteria (UFC) Arctic and Subarctic series includes five volumes that summarize relevant information and the most feasible approaches and solutions for planning, design, construction, and maintenance of infrastructure and facilities in the Arctic and Subarctic areas of the globe.

1-2 REISSUES AND CANCELS.

This document supersedes and cancels inactivated UFC 3-130-07, 16 January 2004.

1-3 PURPOSE AND SCOPE.

The Arctic and Subarctic UFC series provides technical guidance and available technical requirements for planning, design, construction, and maintenance of DoD facilities worldwide for all service elements in Arctic and Subarctic environments. These guidance and technical requirements are based on the International Building Code (IBC) and the requirements in UFC 1-200-01. The UFC 3-130 series covers many aspects of Arctic and Subarctic engineering with the specific exception pavements, which is incorporated into the UFC 3-250 and 3-260 series as discussed in UFC 3-130-01, paragraph 1-6.3. In addition to this volume, there are four other series volumes:

- UFC 3-130-01, *Arctic and Subarctic Engineering*. UFC 3-130-01 serves as an introduction to the Arctic and Subarctic UFC series.
- UFC 3-130-02, *Arctic and Subarctic Site Assessment and Selection*. UFC 3-130-02 provides applicability and technical guidance for geotechnical site assessment for the Arctic and Subarctic environment conditions.
- UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*. UFC 3-130-03 includes horizontal and vertical foundations, considerations affecting foundation design, and construction and monitoring of facilities in the Arctic and Subarctic areas.

- UFC 3-130-05, *Arctic and Subarctic Utilities*. UFC 3-130-05 provides criteria and guidance for the design of utility systems for military facilities in Arctic and Subarctic regions.

This UFC provides criteria and guidance for the planning, design, and construction of DoD-owned facilities in Arctic and Subarctic regions. Only criteria and guidance unique to cold regions (the Arctic and Subarctic) are provided. The Arctic and Subarctic regions present unique challenges in every aspect of facility planning, design, construction, operation, and maintenance. Refer to UFC 3-130-01 for background and general criteria for Arctic and Subarctic engineering. This UFC references the fundamental building design and construction requirements from UFC 1-200-01, and the associated core UFCs and the UFCs referenced therein. It adapts those criteria for Arctic and Subarctic conditions, and transitions activities from completed Installation Master Planning, Area Development Plans, or other planning products described in UFC 2-100-01.

1-4 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, for those geographic locations in Arctic and Subarctic regions worldwide.

1-5 GENERAL BUILDING REQUIREMENTS.

This UFC is an integrated part of the Arctic and Subarctic UFC 3-130 series. Use the other documents of this series in conjunction with this UFC to address construction aspects unique to cold regions. See UFC 3-130-01, Chapter 2 for the definitions of Arctic and Subarctic.

Often, conventional construction practices are acceptable in Arctic and Subarctic regions with appropriate modification to account for extreme cold temperatures, frost heaving soils, and permafrost areas. This UFC modifies and supplements the criteria found in the core UFCs. Utility provider’s or Installation specific requirements must be considered.

1-6 LEVEL OF CONSTRUCTION.

See UFC 1-200-01, paragraph 1-3.2, for the definitions of permanent construction, temporary construction, and facilities in support of military operations.

1-7 CYBERSECURITY.

Facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-8 BEST PRACTICES.

Appendix A contains guidance rather than requirements. It communicates proven facility solutions, systems, and lessons learned, but these are not the only solutions that meet requirements. It identifies additional background information and practices for accomplishing building design and construction. The Designer of Record (DoR) must review and interpret this guidance and apply the information according to the needs of the project. If a Best Practices document guideline differs from a UFC, the UFC requirements take precedence. For Best Practice guidelines not discussed in a UFC, the DoR must submit to the Government Project Manager a list of the guidelines or requirements being used for the project with documentation sufficient for review and approval prior to completing the design.

1-9 GLOSSARY.

Appendix B contains acronyms, abbreviations, and terms specific to this document. UFC 3-130-01 provides additional terms commonly used in cold regions engineering.

1-10 REFERENCES.

Appendix C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

This Page Intentionally Left Blank

CHAPTER 2 DESIGN CONSIDERATIONS

2-1 ENVIRONMENTAL FACTORS AND CONSIDERATIONS.

The Arctic and Subarctic environment affects most stages of building design, construction, operation, and maintenance. UFC 3-130-01 and UFC 3-130-02 cover the important environmental considerations for the configuration and orientation of individual structures in Arctic and Subarctic locations. Reference UFC 3-130-03 for criteria and guidance on ground conditions, the presence of permafrost, or seasonally frozen and thawing soils as needed for building design.

[C] 2-1 The interior building environment is usually drastically different from ambient Arctic and Subarctic conditions, placing severe stresses on building components. Rapid deterioration and costly maintenance are inevitable unless these stresses are carefully considered during planning, material selection, and throughout construction. In addition to designing for occupant comfort, building design must account for hazardous conditions, such as poor visibility caused by whiteout conditions, fog, or darkness, coupled with high winds, blowing snow, and low temperatures. It is essential to minimize personnel encounters with the environment.

2-2 ENVIRONMENTAL SEVERITY AND HUMID LOCATIONS.

Comply with UFC 3-101-01 and associated references therein, such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE) *Cold-Climate Buildings Design Guide* and ASHRAE *Handbook—Fundamentals*, for appropriate climate design values. See also UFC 3-400-02.

[C] 2-2 Knowledge of individual site conditions is important for developing effective facility designs. The winter months in Arctic and Subarctic locations exhibit the greatest range and severity of conditions on the planet.

This Page Intentionally Left Blank

CHAPTER 3 ARCHITECTURAL

3-1 GENERAL.

Comply with UFC 1-200-01 and UFC 3-101-01 and associated references therein for architectural considerations. See Appendix A for guidance on Architectural Best Practices.

[C] 3-1 Consider issues related to snow and ice early in the design process. Special designs and construction techniques are required for buildings, primarily due to prolonged and extreme low temperatures, snow, wind, seasonally frozen and thawed ground, permafrost ground conditions, and special transportation, equipment, and maintenance requirements. Designers must provide a functional building while considering the factors required to provide an environment that meets the total needs of the occupants, contributes to high morale and productivity, and is energy efficient and sustainable.

3-2 BUILDING ORIENTATION.

Refer to UFC 3-101-01, Appendix A, for general guidance on building orientation.

[C] 3-2 Snow and ice significantly affect the design, operation, and maintenance of buildings and the safety of the building's occupants. Building orientation, building geometry, and climatic conditions are factors in snow shedding (snow sliding) off roofs, snow drifting, and drainage.

3-2.1 Snow Drifting.

Comply with UFC 3-301-01 criteria on snow loads, to address snow drifting potential. See Appendix A for guidance on Best Practices to reduce issues from snow drifting for buildings. Properly seal penetrations through the building envelope.

[C] 3-2.1 Snowdrift accumulations can have severe implications for occupant health and safety, such as when emergency equipment access is blocked or building egress is obstructed in an emergency.

3-2.2 Snow and Ice Creeping, Sliding, and Falling from Roofs.

To prevent falling snow and ice from blocking entrances, locate building access at the gable ends or control with the use of dormers and canopies. Refer to the *Site-Specific Case Studies for Determining Ground Snow Loads in the United States,* by Buska et al., to address this and other related design issues.

Refer to the Cold Regions Research and Engineering Laboratory (CRREL) Sliding Snow Calculator Summary Sheet and Sliding Snow Calculator tool (https://www.erdc.usace.army.mil/Portals/55/docs/CEERD-RV/CEERD-RR-H/BuildingTechnology/Tools/Sliding%20Snow%20Calculator.xls) to estimate the potential zone impacted by snow and ice shedding from roofs.

3-2.3 Local Site Conditions.

Observe site-specific conditions during winter site visits for indicators of potential snow-drifting problems. Aerial photographs also provide valuable information. Consult historical weather records to determine the intensity, direction, variability, and frequency of storms. Refer to Appendix A to estimate snow transport directions and volumes, which are useful for site planning with a snow transport analysis.

> [C] 3-2.3 The primary factors facilitating snow transport and influencing potential drift locations are high winds and dominant wind directions. Snow-drifting conditions are highly variable, even at nearby sites, and are affected by topography, vegetation, surrounding buildings, and so on, even when the locations are not separated by large distances.

3-3 PREFABRICATED STRUCTURES.

Prefabricated systems must be specifically designed for extreme cold climates—most off the shelf prefabricated options currently available may fail in the Arctic and Subarctic. The design factors that govern the selection of primary systems and backup systems are system reliability, ease of access for regular operation or to conduct maintenance, system simplicity, and cost. See Appendix A for further information.

3-4 BUILDING ENVELOPE.

The building's exterior envelope must provide a continuous barrier to air infiltration, a layer of insulation, and a vapor retarder around heated spaces. Maintain the continuous air barrier and air-vapor barrier at penetrations, windows, doors, and around elements of the structural system. Design thermal breaks in locations with little resistance to heat loss, such as between metal framing and the outside air. Comply with UFC 3-101-01, Appendix A, and associated references therein. Refer to ASHRAE *Cold-Climate Buildings Design Guide* for specific building-envelope considerations for Arctic and Subarctic climates.

> [C] 3-4 It is critical to control the transfer of heat and infiltration of air and moisture through the individual components of walls, ceilings, roofs, and floors and to maintain a continuous barrier at their transitions.

3-4.1 Heat.

Reduce heat loss and maximize energy efficiency. Provide insulation with effective R-values in foundations, walls, ceilings, roofs, and elevated floors to meet the minimum requirements of applicable energy codes. Install insulation carefully, completely filling the spaces between wall framings, door frames, and window frames to provide continuous insulation and minimize cold air penetration and infiltration. In exterior walls avoid gaps, uninsulated gaps can create air currents. For above-grade floor systems where the under-building surface is exposed to the ambient air temperature, for example in a building on a pile foundation, insulate floors in a manner that is similar to that used for exterior walls.

[C] 3-4.1 Different insulation R-values are appropriate for different geographic locations, depending on the severity of the thermal conditions, and for above- and below-grade walls.

3-4.1.1 Insulation.

Install insulation in walls, ceilings, roofs, floors, and elevated floors to regulate thermal transfer between interior and exterior surfaces according to the specific requirements of the application. Exterior foundation walls must have properly designed perimeter insulation board extending from the top of the footing to the bottom of the floor slab. Depending on the wall construction, the insulation may be on the exterior or interior face of the wall. Design insulation to meet fire protection requirements, flame spread and smoke development rating requirements, and to comply with UFC 3-600-01.

3-4.1.2 Thermal Bridging.

Design for thermal breaks to avoid problems such as below-freezing temperatures on warmer interior surfaces, at the connections, and at places of contact between the interior and exterior surfaces. On the cold portions of interior sheathing, add thermal breaks to reduce condensation and mold growth.

[C] 3-4.1.2 Thermal bridging is the conduction of heat between two areas of high thermal conductivity where there is little resistance. This phenomenon is observed in construction materials such as metal, masonry, wood, and concrete, which exhibit higher thermal conductivity compared to insulation materials. While wood-frame construction has lower thermal conductivity and fewer issues with frost buildup, it is also subject to issues of thermal bridging, shrinkage and water damage.

3-4.2 Air.

Use a well-sealed and continuous air barrier to control air leakage into and out of the building envelope, including walls and floors. The wall assemblies must be designed to minimize both moisture intrusion and air infiltration. In accordance with ASHRAE guidelines, it is imperative that wall assemblies integrate well-designed vapor and air barriers to regulate the movement of air and moisture. These barriers play a crucial role in preventing exterior air infiltration while facilitating the escape of interior moisture, ensuring an optimal balance in moisture control within building structures. Comply with the air barrier requirements of UFC 3-101-01, and the references therein.

> [C] 3-4.2 Air leakage is a significant issue for buildings located in Arctic and Subarctic regions; however, appropriate mechanical ventilation needs to be addressed during the design process.

3-4.3 Moisture.

Moisture from exterior and interior sources, and vapor ladened indoor air, can become trapped in the insulated cavity between the vapor retarder and the exterior surface material. The building envelope must be designed to limit moisture intrusion into these cavities as much as possible. Take extra precautions when dealing with transitions and penetrations in walls, floors, and ceilings. These areas are critical for minimizing the movement of air and moisture. Provide vapor relief if needed to avoid trapping moisture that can freeze within the building envelope and build up ice, leading to deterioration of the insulation material and rendering it ineffective. Refer to UFC 3-101-01, ASHRAE *Cold-Climate Building Design Guide,* and *Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates*, by Zhivov. During winter in the far north, some facilities require humidification due to low air humidity and the low relative humidity associated with heated structures. Humidifying facilities in cold climates is often problematic and requires careful design.

3-4.3.1 Vapor Retarder.

Exterior wall systems require a layer that retards the infiltration of interior moisture into the insulation. A Class I or II vapor retarder (such as 6-milimeter polyethene sheeting) is required by the International Building Code for the Arctic and Subarctic climate zones. Use vapor retarders on or near the warm interior side of the building envelope. Vapor retarders must extend below slabs on grade, and along crawlspace walls and floors. See Appendix A for further information.

3-4.3.2 Ventilation.

Design ventilation to prevent trapping moisture or provide relief to allow moisture to escape. Ventilate the space between the roof insulation and the roof finish to maintain the integrity of the insulation and the roof structure and help prevent ice dams and water leakage. See Appendix A for further information.

3-4.3.3 Condensation.

Controlling condensation in Arctic and Subarctic regions requires a complete and continuous vapor retarder on the warm side of the exterior enclosure of the building; insulation to maintain the interior surfaces and the vapor retarder at a temperature warmer than the dew point; and a vapor-permeable exterior surface of the building enclosure (for a roof, this may require ventilation). Where a facility requires or there is high humidity within a building, such as in medical facilities or water-treatment plants, exercise special care to control air leakage and prevent condensate from forming on or within cold walls, windows, and ceilings. Make provisions to avoid water dripping onto personnel and critical equipment. Allow no condensate to drip on floors, particularly in front of doors that open to the outside.

[C] 3-4.3.3 Satisfactory building-envelope design requires balancing three factors—vapor retarder, insulation, and vapor dissipation.

3-4.4 Daylighting.

Window design must consider the range of available daylight hours throughout the year and its effect on energy use and efficiency. Comply with UFC 3-101-01, paragraph 3-7.1, and include design considerations for snowdrift previously discussed in paragraph 3-2.1. See Appendix A for further information.

3-5 ROOFS.

Comply with UFC 3-110-03 and applicable paragraphs of UFC 3-600-01. Keep roof geometry simple. Complex roof geometries and configurations create problems if they contain valleys, dormers, ice dams, or other features that restrict or block ventilation. Minimize the adverse effects of snow and ice on roofs. Design roof systems to prevent ice damming and excessive snow accumulation. Increase roof pitches, use low friction materials, or site buildings to avoid areas of low wind where blowing snow may accumulate. Roof system designs must be able to withstand ice and snow removal activities. For further guidance, see:

- “Minimizing the Adverse Effects of Snow and Ice on Roofs,” by Buska and Tobiasson;
- “Electric Heating Systems for Combating Icing Problems on Metal Roofs,” by Buska et al.;
- “Guidelines for Ventilating Attics and Cathedral Ceilings to Avoid Icings at their Eaves,” by Tobiasson et al.;
- “Roof Ventilation to Prevent Problematic Icings at Eaves,” by Buska et al.,
- “Standing Seam Metal Roofing Systems in Cold Regions,” by Tobiasson and Buska; and
- “Snow Guards for Metal Roofs,” by Tobiasson et al.

Ventilated roofs need careful design consideration in non-wood framed structures due to thermal bridging, condensation, and other issues noted paragraph 3-4. A ‘hot roof’ system may be used in conjunction with a low sloped roof for non-wood framed structures but must be carefully designed as the roofing materials and insulation need to be compatible. Avoid large roof steps as lower roofs must be designed for snow drift loading and this additional load can be significant with large roofs and high ground snow loads. Pitched roofs require consideration of unbalanced snow loads. Steep roofs with slippery surfaces, such as standing seam metal roofing, pose a sliding snow hazard at entrances and usually require snow guards (also called “snow stops”) or some other mechanism to help restrain sliding snow. Restrained snow adds to roofing down drag forces that must be considered for roofing attachment. Specify pre-engineered metal building (PEMB) roof systems for more collateral loading assuming another roof system will need to be installed over the original roof system in the future. Extreme changes in temperature at Arctic and Subarctic sites result in large roof panel expansions that tend to work open typical PEMB roof panel attachment fastener locations causing roof leaks. This can be mitigated by using an insulated metal panel standing seam roofing system instead of PEMB standard panels. Protect roof stacks and vents from sliding snow on sloped roofs with slippery surfaces.

[C] 3-5 Address roof design and drainage issues early in the design process. Problems are avoided, and more functional designs developed, when snow and ice issues are considered as the building design evolves. Both low-slope and steep-slope roof designs are commonly used in cold regions. Metal, conventional built-up, and protected-membrane roofs perform satisfactorily if properly constructed.

3-5.1 Drainage for Low-Sloped Roofs.

Comply with UFC 3-110-03. Heat trace roof drains to keep drains functional during freezing weather.

[C] 3-5.1 On low-sloped roofs, secondary roof drainage, such as scuppers, that drain to cold eaves can become blocked by ice formation and build-up and create ponding that increases the potential for leaks and possible roof collapse. Problems commonly occur at scuppers placed along a raised edge.

3-5.2 Gutters.

In Arctic and Subarctic regions, where snow slides off slippery roofs, gutters are not recommended. For low roofs featuring asphalt shingles and areas with lower slopes, incorporate gutters to manage moisture and reduce icicle formation. Integrate heating elements, such as heat tape, into the design of the gutter systems and extend along the entire length of the gutter system, including downspouts.

3-6 FENESTRATION DESIGN.

Comply with UFC 3-101-01. Window design must consider features to avoid condensation and frost buildup. Use higher performing windows with insulated frames including thermal breaks and insulated glazing units to prevent condensation and frost build up in the cold temperatures.

3-7 SEALANTS.

Sealant compounds normally used in temperate regions do not perform satisfactorily in cold regions. Select sealant materials that remain flexible and provide permanent cohesion and adhesion in extremely low ambient air temperatures to seal joints of precast concrete panels, metal roofing, around window and door frames, and in similar transitions.

[C] 3-7 The extreme variation between low and high summer and winter temperatures causes common sealant compounds to become brittle and lose their cohesion and adhesion.

3-8 EXTERIOR DOORS.

3-8.1 Exterior Personnel Doors.

Provide vestibules, or arctic entrances, near high-humidity areas in buildings and in buildings located in windy areas. An arctic entrance is a vestibule used in Arctic and Subarctic locations to shut out cold air, high wind, or drifting snow after the exterior door closes and before the inside door is opened. Use exterior doors that open inward to preclude being blocked by drifting snow and possibly damaged by high winds. A door that swings inward permits burrowing out when blocked, although it violates the fire code for certain occupancies and functions. Separately evaluate each inward-swinging-door requirement in terms of risk, alternate exits, and other factors related to occupant safety. See Appendix A for further guidance on arctic entrances.

Because of high winds and extreme cold, doors located on the prevailing windward side of the building require special protection (windscreen or baffle) in addition to arctic entrances. Provide wind screens, baffles, or heavy bumper stops mounted on steel posts to protect the doors and hinges from damage and to prevent injury. Insulate and weather-strip both doors and frames to provide an integral thermal break. Where drifting snow is not a problem, follow standard codes for exit doors. Exclusive use of insulated metal or composite doors and frames is highly recommended. For buildings that support child development or other youth programs, provide a protected warming area for patrons to await transportation.

[C] 3-8.1 Exterior personnel doors are normally free from frost buildup unless there is high humidity within the building. Typical high-humidity areas include laundry, showers, kitchen areas in mess halls, dormitories, and indoor swimming pools. For exterior use, metal and composite doors and frames are sturdier, look better longer, are better insulated, and retain their shape better than wooden doors and frames.

3-8.2 Accessibility.

Cover exterior access ramps for accessibility. Otherwise, designs for accessibility must conform to current criteria. See Appendix A for further information.

3-8.3 Overhead Doors.

On shop and warehouse buildings with large doors, use insulated sectional overhead doors. Separate the outside and inside panels with a thermal break. Provide seals at the head, jambs, the sill, and between sections. Individual sections and the entire door assembly must withstand design wind loads. Doors can operate manually or electrically, depending on their location and function. Do not use metal rollup doors in exterior walls. Do not slope floors to the door because melted snow will freeze at the doorsill and hinder the door operation.

[C] 3-8.3 When using electric operators, an important safety feature to incorporate is an automatic safety edge that stops or reverses the door's downward motion when the bottom edge strikes an object.

3-9 FINISHED FLOOR ELEVATION.

In Arctic and Subarctic areas, establish the minimum floor elevation 6 in. (150 mm) to 12 in. (300 mm) above the exterior finish grade to eliminate the possibility of water backing into the building during thaw periods. In extremely flat terrain and where snow drifting is anticipated, the higher elevation is justified. Provide a stoop at exterior doorways other than emergency exits. Construct the stoop to avoid frost heaving by placing additional non-frost susceptible fill material under stoop and anchoring or doweling the stoop to the main foundation wall. A 6 in. (150 mm) step may be an ABA code violation depending on egress points. Ventilated floors or floors in buildings sited on permafrost are not subject to this requirement.

3-10 EXTERIOR LANDINGS, STAIRS, AND RAILINGS.

For elevated walking surfaces on exterior landings and stairs, use materials with serrated open grating to prevent ice and snow accumulating on horizontal surfaces. Interior or enclosed stairways are preferable. Separately support or hinge exterior stairs and landings from the building or cantilever them from the building to allow for movement from frost heave. If differential heave is anticipated, isolate large landing structures or docks from the main structure. Proper foundation treatment may minimize differential movement between warm and cold structures. Refer to UFC 3-130-03 for foundation design.

3-11 INTERIOR FINISHING.

Ensure there are acceptable tolerances for movement and consider that the structure may not always be warm in the interior and may undergo periods of cold soaking during mothballing or prolonged power or mechanical outages. See Appendix A for further information.

3-12 BUILDING RETROGRADE OR MOTHBALLING.

Mothballing or retrograding Arctic and Subarctic buildings involves using strategic measures to protect structures during extended periods of inactivity, typically due to seasonal shutdowns or temporary closures. Key considerations for effective mothballing include comprehensive winterization efforts, ensuring protection against extreme cold temperatures. This involves conducting insulation checks, sealing gaps, and safeguarding plumbing systems from freezing. Additional measures encompass the implementation of a controlled heating system to maintain an adequate temperature within the building, preventing issues like frozen pipes and ensuring the interior environment remains within acceptable limits. Proper ventilation is essential to prevent moisture buildup, condensation, and mold growth, while sealing openings and entry points helps keep out pests. Managing moisture using absorbent materials or dehumidifiers is crucial, as is safeguarding the electrical system and implementing security measures. The drain traps must also be considered as they may need to be filled with propylene glycol or other fluids.

[C] 3-12 Conducting a thorough inspection of the building envelope, preserving equipment according to manufacturer guidelines, and developing a comprehensive mothballing plan with detailed procedures are integral components of the mothballing action. Establish an emergency response plan, adhering to local regulations, and implementing regular monitoring practices, especially before and after extreme weather conditions. In no case is it recommended to totally remove heat from a previously heated structure. These actions help to preserve the integrity of Arctic and Subarctic buildings during periods of inactivity.

This Page Intentionally Left Blank

CHAPTER 4 STRUCTURAL

4-1 GENERAL.

Structural designs for buildings situated in Arctic and Subarctic regions present unique challenges. Unlike more temperate locations, these areas experience compounded challenges arising from distinctive design loads and extensive seasonal climate variations. Comply with UFC 1-200-01 and UFC 3-301-01 and associated references therein. For structures designated as Risk Category V, comply with UFC 3-301-02 and the references therein.

4-2 DESIGN LOADS.

Refer to UFC 3-301-01, Chapters 2 and 3, and UFC 3-301-02, Chapter 2, for design requirements. There are several sources of design load information available. UFC 3-301-01 describes the Structural Load Data Tool (SLDT), hosted on the Whole Building Design Guide website https://www.wbdg.org/ar/tools/sldrt, that provides structural load information for wind, snow, frost penetration, and seismic data for DoD Installations within the U.S. and its territories. The American Society of Civil Engineers (ASCE) ASCE 7 Hazard Tool (https://asce7hazardtool.online/) provides load information for flood, ice, rain, seismic, snow, tornado, and wind for U.S. locations not included in the SLDT. Alaska-specific snow-load data are available from the Structural Engineers Association of Alaska website https://seaak.net/alaska-snow-loads. Ground snow load case studies may be needed for site-specific locations in the U.S. that are not included in published maps due to extreme local variations in snow loads. Use the methodology in *Site-Specific Case Studies for Determining Ground Snow Loads in the United States,* by Buska et al., and the accompanying spreadsheet-based calculator, Snow Load Case Studies (https://erdc-library.erdc.dren.mil/jspui/handle/11681/37574). At locations where load data is lacking, use the best locally available criteria with the approval of the Authority Having Jurisdiction (AHJ).

4-3 MATERIALS.

Common structural materials, such as concrete, wood, and steel, are successfully used in Arctic and Subarctic areas in conditioned (heated) structures with few problems. Comply with UFC 3-301-01 Best Practices for additional information on using these materials in Arctic and Subarctic areas. In non-conditioned (unheated) structures, thermal expansion/contraction must be considered. Comply with American Concrete Institute (ACI) ACI 318 concrete durability requirements for exposure. When using concrete as a building material, additional construction measures are required when ambient temperatures fall below 40°F (4.4°C) to ensure timely strength development and prevent damage due to freezing at early placement ages. These measures may include enclosing and heating the concrete placement, insulation of formwork, or use of accelerating admixtures, solely or in combination. The ACI 306R *Guide to Cold Weather Concreting* provides recommendations for the use of these measures in varying cold weather conditions. Consider low temperature steels with high-notch toughness where structural steel is exposed in arctic conditions. Design with proper joints to account for thermal expansion/contraction.

4-4 FOUNDATIONS.

Comply with UFC 3-130-03. UFC 3-130-03 provides a complete discussion of foundations for freezing and thawing conditions.

.

CHAPTER 5 MECHANICAL

5-1 GENERAL.

Comply with UFC 1-200-01, UFC 3-401-01, and the government criteria referenced therein. Standardize components whenever possible to reduce the necessary inventory of repair materials. Employ redundant or backup heating options that reduce risk to other systems and personnel.

[C] 5.1 While the design and operation of mechanical systems in Arctic and Subarctic regions share similarities with those in the northern regions of the continental U.S., it is crucial to note that extended periods of exceptionally low temperatures and high wind conditions in the Arctic and Subarctic can lead to failures in systems that typically function effectively in more moderate climates. Therefore, mechanical system design for cold regions must be simple, robust, and utilize Arctic-type technical changes and economic considerations. Operation and maintenance considerations are crucial because isolated Arctic sites may lack expert technical assistance.

5-2 PLUMBING.

5-2.1 General Design Requirements.

Comply with UFC 3-130-05 for cold regions utilities requirements to include various types of piping and utilities connections.

[C] 5-2.1 Designing plumbing systems for Arctic and Subarctic regions requires careful consideration of extreme weather conditions, freezing temperatures, and the unique challenges posed by the environment. Some considerations are, insulation, heating pipes, below frost level installation of utilities, and decoupling frost zone penetrations both thermally and mechanically. Thermal decoupling is achieved using thermal breaks and insulation, while mechanical decoupling involves employing flexible joints, slip connections, isolation pads, and other methods.

5-2.1.1 Energy Efficiency and Water Conservation.

Comply with UFC 1-200-01, UFC 3-420-01, and the criteria referenced therein.

[C] 5-2.1.1 Where adequate water supplies are available and normal sewage systems can be installed interior plumbing facilities vary little from those used in temperate climates. However, water is not always readily available. In areas with permafrost, it is difficult to treat and dispose of sewage.

5-2.1.2 Reliability.

To prevent potential freezing in sewage pipes and systems, collect small waste flows and discharge them in slugs rather than allowing the sewage to trickle by gravity within the lines.

5-2.1.3 Piping Arrangement.

Avoid locating plumbing on the exterior walls. Buildings in permafrost areas that are elevated above ground on a piling system expose the area under the floor to cold arctic air. Protect underfloor piping from freezing. See Appendix A for further guidance.

5-2.1.4 Siting.

Do not divert drainage from roof and floor drains into the sewage treatment systems because this increases the volume of sewage requiring treatment and is frequently a violation of applicable plumbing or public health codes. Dispose of sewage (black water) separately from excess surface moisture (snow, ice, or water) runoff. Dry wells located below the depth of seasonal frost may be used in Subarctic regions that are permafrost free and have free-draining soils. Prevent dry wells or connecting drains from freezing with regular monitoring and maintenance to clean out and inspect for the buildup of silt, leaves, or other debris. Avoid frozen conditions that cause wells to back up water toward the roof and create leaks within the building. Install roof drain lines that discharge through an exterior wall onto a splash block and into a concrete trench covered by a grate to carry water away from the building and minimize ice formation on paved surfaces. In shops, install floor or trench drains to collect and carry away melted snow brought in on vehicles; drains, traps, and piping must be kept clear of blockages created by the considerable amounts of mud, gravel, sticks, and vegetation carried in on vehicles. Provide baskets, strainers, and sand and oil traps to keep drains operational. Frozen oil traps become inoperable. Heating is required to keep these traps operational. Alternately, install traps inside buildings. Make sure drains and piping are located such that there is no impact to the building foundation if a thaw bulb is created.

5-2.2 Supplemental International Plumbing Code (IPC) Technical Criteria.

The IPC lays out the general plumbing code, below are considerations for Arctic and Subarctic regions for specific use cases.

5-2.2.1 Food Waste Disposer.

Garbage disposals are generally not installed in Arctic and Subarctic locations at small, remote Installations where sewage treatment and disposal are particularly difficult. Grease traps become inoperable when water within them freezes. To keep these traps operational, they must be either heated or installed inside the building.

[C] 5-2.2.1 If disposals are installed, consider grease removal. Grease may congeal and clog cold sewer lines and may also create operation and maintenance problems at the sewage treatment facility. Oversized exterior grease traps require frequent cleaning. The normal foodstuffs that are run through a garbage disposal tend to reduce the life of a septic system drain field or leach pit.

5-2.2.2 Water Storage Tanks.

Water storage tanks may need to be heated to avoid freezing. Conduct appropriate thermal analysis to determine if this applies to a specific case.

5-2.2.3 Exterior Faucets or Hose Bibs.

Avoid frozen hose bibs by use of a valve on the supply zone inside the heated space that can be turned off in the winter. In this case drain the hose bib and leave open for the winter. Alternatively, frost-proof faucets or hose bibs can be installed to minimize the risk of freezing. Provide adequate drainage paths from exterior hose bibs so that the building foundation is not impacted by excess water.

[C] 5-2.2.3 Frost-proof faucets are designed to drain water away from the remote valve when turned off, preventing water from standing in the exposed portion of hose bib.

5-3 FACILITY HVAC SYSTEMS.

5-3.1 General.

Comply with UFC 3-401-01 and UFC 3-410-01. Minimize cold floors and downdrafts from windows by using adequate floor insulation and locating heating units below windows.

[C] 5-3.1 A reliable and easy-to-maintain heating system is extremely important for personnel comfort and safety. Remote locations, severe climatic conditions, and short daylight hours tend to confine personnel to the site and are the primary reasons for maintaining a good physical environment. While constant circulating heat systems usually provide more uniform room temperatures, it is important to evaluate available information before selecting a system.

5-3.2 Ventilation.

Comply with UFC 3-410-01. Utilize heat recovery ventilation systems to minimize the impact of ventilation on the heating load of the building. Ventilation systems require designs that temper incoming cold air so as not freeze equipment that can cause failures.

[C] 5-3.2 The fresh air requirements for ventilation are principally the same as those in temperate climates. Avoid issues resulting from inadequate or improper ventilation-system design during the design process.

5-3.2.1 Freezing of Heating Coils in Ventilation Units.

Provide a low limit thermostat control in the air discharge from the coil to stop the fan and close the outside air dampers when air temperatures drop to about 35°F (2°C), such as during a power outage. Refer to UFC 3-410-01 for further freeze protection criteria. Prevent air stratification in the mixing box by bringing warm air in at the bottom and cold air in at the top. Refer to UFC 3-410-01 for further ventilation criteria, and Appendix A of this UFC for Best Practice guidance.

5-3.2.2 Outside Air Openings.

See Chapter 3 of this document, UFC 3-410-01, Appendix B, and the ASHRAE *Cold-Climate Buildings Design Guide*.

[C] 5-3.2.2 High winds, blowing snow, rain, damage from falling ice, and the need for screens cause problems with outside air openings used for air ventilation intake and exhaust.

5-3.2.3 Frosting of Filters in Ventilation Systems.

Because fresh air intakes, including filter banks, are generally under negative pressure, seal openings and penetrations that permit more humid air to enter the intake duct or filter bank. Several methods to correct this issue are possible. One method is to install a preheat coil ahead of the filter to heat the air to 30°F (−1°C), but that coil can plug with dirt, lint, and other material during normal summer operation. To obtain the best results, use heat recovery ventilators or energy recovery ventilators, frost resistant filters, or increase the airflow to minimize icing. Refer to UFC 3-410-01, Appendix B.

[C] 5-3.2.3 Icing and frost closure occur when saturated freezing air, usually below −20°F (−29°C), is brought in through a filter. The same problem can occur when fresh air intakes are too close to the exhaust openings and plumbing vents. . Icing and thawing cause throwaway-type filters to get wet, collapse, and jam the face and bypass dampers within a relatively short duration.

5-3.2.4 Insulation of Ducts and Pipes Handling Cold Air.

Provide insulation for pipes and ducts subjected to cold air and seal at the vapor retarder penetration, as described in Chapter 3.

5-3.3 Humidification.

The need to address and control variations in humidity is discussed in Chapter 3. During winter a building may need humidification to be comfortable for habitation. The system must be balanced between humidification and the need to control condensation in the structure.

5-3.4 Condensation.

Maintain an adequate difference between the dew point and the temperature to avoid condensation. Refer to paragraph 3-4.3 for moisture within the building envelope, and to UFC 3-410-01 for heating and cooling load calculations.

[C] 5-3.4 Condensation can cause interior damage when excessive levels of humidity are maintained within the building. Condensation can freeze on the vapor barrier if it is too cold and over repeated cycles.

5-3.5 Low-Temperature Lubricants.

Fans or other moving equipment mounted on a building's exterior or located within unheated portions of the building must be capable of operating at the lowest recorded ambient temperature. Use special low-temperature lubricants. Require manufacturers to guarantee their equipment under the extreme weather conditions expected at the site.

[C] 5-3.5 Many bearings and races may be coated in materials that have incompatible thermal conductivities and expansions. In a cold and dry condition, they may fail exponentially faster.

5-4 HEATING CONCERNS.

Minimize cold floors and downdrafts from windows by using adequate floor insulation and locating heating units below windows. While constantly circulating heat systems usually provide more uniform room temperatures, it is important to evaluate available information before selecting a system. Further design criteria for various types of heating systems are discussed in detail in paragraphs 5-4.1 through 5-4.8. The advantages or disadvantages of each system when used in the arctic environment are noted. Comply with UFC 3-410-01 and the references therein on the selection and design of appropriate heating systems.

[C] 5-4 A satisfactory, reliable, and easy-to-maintain heating system is extremely important for personnel comfort. Remote locations, severe climatic conditions, and short daylight hours tend to confine personnel to the site and are the primary reasons for maintaining a good physical environment.

5-4.1 Freezing of Water and Steam Systems.

Comply with UFC 3-410-01. Guard against system freezing by protecting heating lines and equipment. Properly protect hot water lines located in exterior walls. Constant circulation delays water freezing in the pipes if a boiler, furnace, or heat exchanger stops working. Where automatic room temperature control is not provided, personnel may open windows to provide necessary control, and lines may freeze when the room is left unattended. For this reason, provide individual room thermostat controls. In garages or hangars, interlock unit heaters installed within 20 ft of doors with those doors so that the fans on the unit heaters shut off when the doors open. When fans are left running, cold outside air is blown over the coil, frequently causing the coil to freeze. Install a temperature alarm system in each remote, unoccupied building to alert maintenance personnel when the building interior temperature approaches freezing.

5-4.2 Shop and Hangar Heating.

Comply with UFC 3-410-01, paragraph 3-6. To address Arctic and Subarctic heating challenges in large buildings, several issues must be considered. These include the frequent opening of large doors, the presence of high ceilings, and the imperative for swift heat recovery. It is essential to appropriately size and select projection-type heaters, ensuring their efficiency in managing the vast spaces. Installing snow melting systems beneath hangar doors and ramps helps mitigate ice and snow accumulation, ensuring the doors remain operational. Additionally, incorporating radiant floor heating alongside the standard heating system enhances overall warmth. To minimize heat loss, focus on reducing air infiltration through strategic measures such as well-designed doors, effective weather stripping, and minimizing the use of operable windows. Factor estimates for infiltration into comprehensive heat loss calculations, emphasizing the need for meticulous data and calculations to optimize heating systems in these expansive structures.

5-4.3 Heating Control.

Generally, provide automatic controls for heating and ventilating systems. Provide manual control systems to preclude complete shutdown if automatic controls fail. Consider night temperature setback wherever practical. Heating coils require adequate controls to protect them against freezing. Keep control systems simple because expert maintenance is often not available.

5-4.4 Cooling Water and Recharge Wells.

Cool the water supply and use recharge wells where outside temperatures are too high to cool electronic equipment during summer months. During winter months, discharging wastewater in recharging wells, rather than on the ground surface, can effectively reduce ice fog and glaciation. Reducing ice fog is especially important near airfields. Well water in Subarctic regions typically does not exceed 39°F (4°C).

5-4.5 Fuel Oil Piping and Storage.

Comply with UFC 3-410-01. Fuel oils used in cold regions must comply with proper grading. When used in areas where low temperatures prevail, consider special heating and insulation of fuel lines. When commercial diesel fuels with a higher pour point are used, heating may be required for the system to function properly. Lines may be increased one pipe size; however, larger-diameter pipes reduce velocity and cause sluggish operation. It is not advisable to bury exterior fuel oil tanks in permafrost areas because the supply and return connections are extremely vulnerable to breakage when settlement occurs. Aboveground tanks, however, are exposed to lower temperatures, and a protective shelter may be required. When installing aboveground tanks that are higher in elevation than the burner unit, install a vacuum relief on the fuel oil supply line. Double-wall construction or containment is required for fuel tanks.

5-4.6 Air Elimination.

Provide systems for positive air removal and for draining the piping and equipment.

[C] 5-4.6 Eliminating air in a hot water heating system can be a problem in every climate. It is more critical in Arctic regions because of the need for continuous operation.

5-4.7 Piping in Hot Water Heating Systems.

Maintain positive flows in piping systems unless using an antifreeze-filled system. Antifreeze systems are preferred; however, they do lower the thermal conductivity of the working fluid. Avoid feeding numerous parallel zones from one circulating pump. If parallel zones must be used, provide accessible balancing control, indicating devices, and a manual bypass to allow operation during maintenance.

[C] 5-4.7 An improperly piped system may perform satisfactorily in a temperate zone, but the same system may cause heating problems when exposed to extreme Arctic conditions. Careful design minimizes these problems. Parallel zones are difficult to balance, and eliminating air from the many circuits is difficult. Flow can easily stop in one zone because of poor air elimination. A freeze-up may result, which, when concealed, is extremely difficult to correct.

5-4.8 Design Considerations for Simple, Effective Mechanical Systems.

Ensure adequate space in the mechanical room and around equipment to facilitate inside maintenance during cold weather. Arrange piping connections and space to permit the removal of coils, tube bundles, and filters. Provide ready access to maintain motors, automatic controls, dampers, traps, and so on. Provide systems subject to interior condensation with drain valves to drain moisture annually. Simple mechanical systems that can be serviced by inexperienced maintenance personnel are required.

[C] 5-4.8. Inaccessibility is one of the most frequent problems encountered by maintenance personnel, especially when repairs must be made immediately to reduce system outages; fast repairs require sufficient maintenance space. Sites may be in remote areas where experienced personnel and ready sources of spare parts are not available. In specifications for heating and plumbing piping, emphasize the need to keep dirt and gravel out of piping during construction. Alert inspectors to assure compliance. After years of operation, military bases in Arctic regions are still plagued with stoppages and restrictions from gravel remaining in glycol-grid snow melting systems. Gravel and other debris have also caused stoppages in steam heating and plumbing systems many years after entering service.

5-5 COMPRESSED AIR SYSTEMS.

Colder outdoor air contains less moisture than warmer inside air. Include removal of the excess water vapor in the design of compressed air systems. Use low temperature exterior air as the air source for large compressors because it requires less water removal from the system. Reference UFC 3-401-01, paragraphs on Compressed Air Systems.

[C] 5-5 This applies to instrument air and compressed air systems in shops and hangars where water vapor, if not removed, can freeze and cause the system to quit functioning. Pneumatic control systems require dry air to function properly.

5-6 REFRIGERATION SYSTEMS FOR COLD STORAGE FACILITIES.

Standard refrigeration design for cold storage or air conditioning can be used effectively and must comply with UFC 3-410-01.

CHAPTER 6 ELECTRICAL

6-1 GENERAL.

Standard electrical system design criteria are suitable for buildings in Arctic and Subarctic regions because buildings are heated. However, some special consideration must be addressed. Comply with UFC 1-200-01, UFC 3-501-01, and the UFCs and government criteria referenced therein.

6-2 GROUNDING.

Comply with UFC 3-501-01; UFC 3-550-01; and UFC 3-130-05, paragraph 11-2. UFC 3-130-05 paragraphs 11-2 and A-11.2 provide additional information and resources on electrical grounding.

> [C] 6-2 It is difficult to obtain an effective electrical ground in Arctic and Subarctic regions because of soil and climatic conditions. Grounding is not difficult during summer months but is a problem during the winter if the ground electrode is completely enclosed in frozen soil and cannot achieve an effective ground. In frozen conditions the grounding method may include multiple grounding rods, grounding mats, or grounding wells.

6-3 EXTERIOR LIGHTING AND CONTROLS.

Comply with UFC 3-501-01 and UFC 3-550-01. Exterior wiring and lighting must be rated to −40°F (−40°C). Ensure NEC compliant circuit wiring and protection are provided for heat trace cables used for heating liquid carrying pipes exposed to cold temperature as indicated in Chapter 5.

> [C] 6-3 It's important to emphasize that considerations regarding the temperature rating of wiring, particularly related to the insulation material, extend beyond just exterior lighting and controls. This applies to exterior wiring, whether for power, communications, signaling, etc., installed in low-temperature environments. The challenge arises during installation or movement of wires in cold conditions. In such instances, certain insulation materials may become brittle, making them susceptible to cracking when force is applied, leading to potential damage. This concern is mitigated when wiring is installed within or above the insulation's temperature rating, and post-installation, the wires remain static within the protective raceway.

6-4 EXTERIOR DISTRIBUTION SYSTEMS.

Comply with UFC 3-501-01 and UFC 3-550-01. Where damage from snowplows is likely, elevate utility pedestals that are near roads, typically about 3 ft (1 m) above grade. Provide exterior vehicle electrical plug-ins for parking areas as required by parking practices.

Seal raceways transiting from outdoors to indoors in accordance with NEC requirement for sealing raceways exposed to different temperatures.

6-4.1 Exterior Enclosures.

Use heated enclosures for outdoor-mounted equipment and devices susceptible to adverse effects from cold temperatures. This includes LCD displays, backup batteries in electronic equipment, and mechanisms vulnerable to seizing due to lubricant hardening or freezing.

Utilize specialized Arctic enclosures for outdoor equipment and devices susceptible to adverse impacts from snow, ice, and sleet. This is particularly relevant for devices like cameras and satellite dish antennas, ensuring their functionality despite challenging weather conditions.

[C] 6-4.1 Additionally, heated enclosures prevent moisture buildup from condensation and address concerns like fogging on lenses, especially in outdoor cameras.

6-5 INTERIOR DISTRIBUTION SYSTEMS.

6-5.1 Service Entrance.

Comply with UFC 3-501-01 and UFC 3-520-01. Install the overhead service entrance on the gable end of the building, as explained in Chapter 3. Within a building, locate service entrance equipment in a readily accessible area to allow for quick power disconnection in case of an emergency. Provide one service disconnect for each facility. Provide climate-control for electrical rooms.

For underground services in cold regions employ liquid-tight flexible metallic conduit for the exterior riser conduit leading into the meter base. This mitigates concerns related to frost heaving, which could potentially elevate rigid metal conduit, risking the displacement of the meter from its mounting.

6-5.2 Generators.

Comply with UFC 3-501-01 and UFC 3-540-01*.* Power interruptions, outages, and reliability must be considered. Generator backup power is needed when extreme winter conditions cause issues with power (a life and safety concern) and increase the danger of building freeze-up if power is disrupted for a significant period. For cases of power fluctuations and interruptions, protect sensitive equipment from potential damage.

Use manufacturer recommended Arctic options for generators such as jacket water heaters (preheats the generator coolant), battery heaters, and fuel heaters (this helps the generator during cold startup). The use of generator space heaters maintains the air around the generator at a suitable temperature to prevent moisture buildup due to condensation.

6-5.3 Corrosion Control.

Comply with UFC 3-570-01. In some Subarctic regions, corrosive conditions caused by wind-driven rain, snow, and salt spray are so severe that vault space must be provided inside buildings for transformers and associated service equipment. See Appendix A for further information.

6-5.4 Lightning Protection and Static Electricity.

Comply with UFC 3-575-01. Lightning protection is needed during the summer months. Provide humidity control and use low-static floor coverings in interior spaces to mitigate static electricity.

[C] 6-5.4 During the winter months, static electricity is a significant problem due to low humidity.

6-5.5 Communications.

Comply with UFC 3-580-01. Terminal blocks are routinely installed on the exterior of residences. These must be protected from moisture intrusion and able to withstand the extreme temperature ranges.

This Page Intentionally Left Blank

CHAPTER 7 FIRE PROTECTION

7-1 GENERAL.

Fire protection is critical in Arctic and Subarctic regions. Evaluate the isolation and climate conditions of each site to determine the extent of required fire protection facilities. Principally at isolated sites, guard against fire hazards because the loss of facilities and materials during extreme low temperatures constitutes a major threat to survival. Evaluate the fire hazard at each site by considering the distance to other facilities and the availability and reliability of alternate forms of shelter and transportation. Evaluate each building in terms of the effects of local winds and temperatures on firefighting capability and on survivors. Strong winds can occur for extended periods of time, causing fires to spread rapidly and be difficult to control. Comply with UFC 1-200-01, UFC 3-600-01, and UFC 3-130-05.

7-2 FIRE PROTECTION ENGINEERING SERVICES.

Consult experienced fire protection engineers at the Installation or Command level with expertise in Arctic and Subarctic conditions to develop comprehensive and effective fire protection strategies that address the specific challenges of these environments.

> [C] 7-2 Fire protection involves a holistic approach that encompasses design, materials, systems, and emergency response planning tailored to the unique conditions of the Arctic and Subarctic.

7-2.1 Water Supplies for Fire Protection.

Comply with UFC 3-230-01 for developing water sources and distribution. Applicable fire protection engineering services must comply with local standards and practices.

7-2.2 Water Storage Tank Vents.

Take preventative measures to avoid ice buildup blocking tank vents on facility water storage tanks. Where heavy ice buildup is expected, such as in coastal locations include special protection for tank vents. Alternately, provide protection by venting tanks into the pump house and omitting an exterior vent. The facility storage tank must either have the capacity to store several months’ supply of domestic water, in addition to reserve water for firefighting, or be dedicated solely for firefighting.

> [C] 7-2.2 Driving winds have blocked 6 in. (152 mm) vents, and the vacuum resulting from water drawdown can cause a tank to collapse.

7-3 FIRE PROTECTION SYSTEMS.

7-3.1.1 All-Weather Ground Access.

In Arctic and Subarctic regions, locate fire room access doors on the gable end of the building to prevent snow and ice buildup.

7-3.1.2 Fire Department Connection.

Locate exterior fire department connections on the gable end of the building to avoid snow and ice buildup. To eliminate freeze potential, install a ball drip assembly on the supply low point (more than one may be required) and route to an interior drain.

7-3.1.3 Exterior Antennas.

To prevent snow and ice buildup, mount antennas on the gable end of the building exterior. For a pitched roof, mount each transmitter antenna on the gable end on the face of the eave closest to the fire department or mass notification central station location. Mount each antenna a minimum of 6 in. (152 mm) above the roofline and secure it, using nuts and bolts, to withstand the wind load. It is unacceptable to secure the mounting bracket into the building exterior with screws. Proper installation and operation of each antenna is required for the correct frequency and transmission. Each antenna cable must have a lightning arrester installed inline in a weather-proof box, and each assembly must be properly grounded per the manufacturer’s specifications. Show antenna locations on each floor.

7-3.1.4 Valves.

In Arctic and Subarctic locations, use street valves and then a primary shut-off valve inside buildings, as permitted by NFPA 24, a National Fire Protection Association regulation. Ensure that recirculation and heating systems are working properly to avoid issues. The use of post-indicating valves is not recommended in Arctic or Subarctic climates because they create a thermal bridging issue.

7-3.1.5 Facility On-Site Water Storage.

Heat and insulate water storage tanks exposed to extremely low temperatures with continuous water circulation. Heating techniques include circulating tank water through a heat exchanger or using a flow-through type electric heater.

> [C] 7-3.1.5 Water storage from surface sources may be inaccessible during the winter months due to ice formation, and underground water sources may be unavailable.

7-3.1.6 Fire Pumps.

The use and maintenance of fire pumps in Arctic and Subarctic regions involve special considerations due to the extreme cold temperatures and challenging environmental conditions. Some key factors to consider for fire pumps in these regions, cold weather start-up, enclosure and insulation, heated enclosures, fuel considerations, battery heating, emergency power sources, snow management, and materials and corrosion resistance.

7-3.1.6.1 Fire Pump Room.

To protect against freezing, do not locate fire pumps, jockey pumps, or sensing lines near an exterior door. Provide an acceptable method to continuously monitor the sensing lines within the fire pump room to maintain a minimum temperature of 68°F (20°C).

7-3.1.6.2 Drainage Piping.

In cold climates, include drainage systems in fire protection rooms. To mitigate the risk of freezing and potential blockages, implement freeze protection measures for drains. This can involve the installation of insulation or heating elements as preventive measures.

7-3.1.6.3 Discharge to Exterior.

Locate main drains and auxiliary drains within 2 ft (0.6 m) of grade and not less than a 10 ft (3 m) distance from both the exterior doors and the fire department connection.

7-3.1.7 Fire Pump Controllers.

To protect against freezing, do not locate fire pump controllers or jockey pump controllers near an exterior door. Within the fire pump room, provide an acceptable method for continuously monitoring the controllers to maintain a minimum temperature of 68°F (20°C).

7-3.1.8 Fire Alarm and Mass Notification System Installation.

In Arctic and Subarctic regions, locate or install lines of communication, fire alarm and mass notification panels, transceivers and releasing panels or annunciators inside the building. Do not locate or install these devices in an artic entryway or vestibule. The interior of the building provides better access to and climate control for these systems.

7-3.1.9 Fire Suppression System Testing.

Water recirculation systems used for freeze protection, and other connected systems, must be tested at the same hydrostatic pressure as required for the sprinkler system. Apply this same hydrostatic pressure when testing other systems connected to the sprinkler system, except the incoming domestic water. Pumps on the recirculation system must also be rated for both the working and static pressure of the sprinkler system. To prevent freezing, the domestic lines and fire-suppression line may be combined.

7-3.1.10 Automatic Sprinkler Systems.

Protect wet pipe systems from freezing by providing heat trace for sprinklers under overhead doors. Supply heat trace and insulation for wet pipe sprinkler lines that must cross a hangar. The heat trace must be Underwriters Laboratory (UL) listed or FM Approved for sprinkler systems. The heat trace may need to be on a dedicated breaker in an emergency panel, though this depends on various factors, including local electrical codes, the specific requirements of the heat trace system, and the overall electrical design of the facility. It is essential to consult with a qualified electrician or an electrical engineer who is familiar with local codes and regulations to determine the specific requirements. Provide sprinklers in maintenance vestibules where air-handling units (AHU) are located. Dry sprinklers are also an option for spaces where freezing may occur. Dry sprinklers can be used with a wet system or as a standalone system.

7-3.1.11 Arctic Vestibules.

Provide dry sprinklers in arctic vestibules.

7-3.1.12 Standpipe Systems.

To mitigate the risk of freezing in multi-story buildings, incorporate a standpipe in a heated location for water lines connected to fire trucks exposed to freezing temperatures. This design approach enhances the resilience of the firefighting system in colder conditions.

7-3.1.13 Fire Alarm Systems.

Freeze-protection monitoring guards against lines freezing. Connect fire protection life safety equipment to the Fire Alarm Reporting System. Include freeze-protection monitoring on the fire alarm reporting system when monitoring the incoming water line. The freeze-protection connection to the fire alarm reporting system monitors the proper operation of the main fire protection water line must include, at a minimum, low-temperature alarms, circulation pumps, and no-flow conditions.

To protect against freezing, the fire alarm system must monitor heat trace breakers for sprinkler systems and hydrant systems. Provide a low-temperature alarm near the sprinkler riser in every high-expansion foam room and in sprinkler riser locations. Upon activation of the low-temperature alarm, a supervisory signal must be sent to the fire department. Low-temperature alarms must also be provided in rooftop AHU enclosures with maintenance vestibules that are provided with sprinkler protection. Low-temperature devices must be mounted within 18 in. (457 mm) of the lowest point in the room and must be coordinated with the District Fire Protection Engineer (FPE) for location. For rooms with pits, coordinate with the District FPE for location.

APPENDIX A BEST PRACTICES

A-1 INTRODUCTION.

The Best Practices Appendix contains guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned. However, these recommendations are not the only viable solutions.

A-2 CANADIAN EXPERIENCE.

The Canadian Arctic covers over 40% of Canada's land mass. Canada has extensive experience with cold regions engineering and infrastructure. The documents provided by the Government of Canda on the Codes Canada website (https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada) provide valuable guidance for cold regions engineering and construction on a variety of topics.

A-3 SNOW DRIFTING.

The accumulation of blowing snow causes snow drifts. Snow accumulates on buildings in areas of aerodynamic shade created by roof design. Inadequate separation between structures causes intersecting drifts. A single storm can quickly create large drifts on and around structures and block access to utility systems that are necessary for maintenance or repairs and can quickly bury items, such as construction materials, that are stored outside. Snowdrifts often cover doorways. Drifting snow may enter buildings in a variety of ways. For example, it is difficult to tightly seal doors on a building's upwind face to prevent snow infiltration. Dry, windblown snow can enter small cracks in doorways, windows, or louvers that are intended for ventilation.

A-3.1 Snowdrift Indicators.

High winds, rather than the prevailing wind direction, better indicate the direction of drifting snow and where snow drifts will form. The quantity of snow transported by wind is roughly proportional to the 4th power of wind speed. This causes high winds to disproportionately transport more snow than either moderate or low winds.

Determine the transport direction from the orientation of drifts, onsite visits, or aerial or satellite images taken during the winter. Late-winter observations give the best indication of the average transport direction. To determine the drift location and building orientation, use the windward direction and wind orientation based on dominate wind transport directions rather than the prevailing wind direction alone. Lacking direct observations of drift orientation for a snow transport analysis, use meteorological data to estimate transport directions and volumes for site planning. Refer to "Blowing Snow Transport Analysis for Estimating Drift Orientation and Severity," by Haehnel, and *Design Guidelines for the Control of Blowing and Drifting Snow,* by Tabler, for additional information on snow transport analysis.

A-3.2 Problems Due to Snow Drifting.

The list that follows contains additional guidelines and concerns about snow drifting for building design:

- Poorly oriented generator intakes can be become blocked, and ice can coat, or snow can block, warm exhaust stacks and vent pipes.
- Large snowdrifts can accumulate on low roofs and in other areas of aerodynamic shade.
- In permafrost areas, snow infiltration in ventilated foundations can be a serious problem.
- Material and equipment must not be stored adjacent to or under buildings elevated above permafrost because doing so can cause snow drifts that allow soil warming in winter.

A-3.3 Solutions to Snow Drifting Problems.

While drifting patterns are difficult to predict, following the guidelines listed here minimizes problems:

- Place utility distribution systems within or below elevated walkways to facilitate repairs. Walkways placed on grade tend to aggravate snow drifting problems.
- Use trees, shrubs, snow fences, or other obstructions to precipitate snow before it reaches the site proper. Where storms may come from every direction, provide protection for every quadrant.
- Place major roads parallel to the dominant snow transport direction. This may differ from the prevailing wind direction.
- Do not locate roads directly upwind or downwind of large obstructions. Where possible, maintain 100 ft (30 m) upwind and 200 ft (61 m) downwind clearances.
- Locate parking lots alongside roads to function as buffer zones. Do not place parking lots among buildings. Expect additional snow accumulation around parked vehicles and provide ample room for snow storage away from roads and on the downwind end of the lot. Because curbed islands hinder snow removal operations, they are rarely suitable.
- Place parking aprons alongside, not upwind or downwind of, hangers and garages.
- Orient surface structures with their longest side parallel to the winter snow transport direction. Winter storm winds and snow transport may come from a different direction than prevailing summer or winter winds.

- Locate doors along the sides of the building facing toward the upwind end. Doors on the downwind end of the structure may be rapidly blocked by drifting snow; those on the upwind face are difficult to seal. Though main entrances and exits need to open out, it is advisable to have at least one alternate set of doors that open inward for use if drifting snow blocks the main doors. Establish and maintain clear pathways from the building interior to these alternate exits.
- Orient large garage doors parallel to the dominant snow transport direction, even if this results in a building orientation that is perpendicular to the wind. Adjust this orientation slightly to assure that the doors are not in the lee of the upwind corner of the building.
- Place structures in rows perpendicular to the wind. Allow ample space (such as a minimum of two times the width of the snow removal equipment) between buildings to permit effective snow removal. Place each row of structures downwind from the preceding row, either abutting the windward structure or spaced at least the length of the building in the windward direction from the preceding row.
- Provide snow dumping areas to eliminate large piles or windrows of snow in the camp area. Piles and windrows are obstructions that increase future snow removal requirements.
- Avoid decorative earthen berms around buildings and in parking lots. Berms can cause additional snow accumulation problems and interfere with snow removal operations, disrupt building access for maintenance and fire protection, and create moisture problems at the foundation wall.
- For AT/FP structures they may need to be placed further from buildings and have dedicated paths for snow removal and water drainage.
- For buildings on a permafrost foundation system such as thermopiles, elevate the building adequately to allow free flow of air under the building and avoid snowdrift buildup around condensers.

A-4 SNOW AND ICE CREEPING, SLIDING, AND FALLING FROM ROOFS.

In Arctic and Subarctic climates, anticipate that snow and ice will creep, slide, and fall from roofs; this situation can cause significant property damage and injure, or even kill, pedestrians. This is particularly the case with roofs that drain to cold eaves and for steep roof slopes and slippery surfaces. Snow and ice sliding off pitched metal roofs can damage property and injure people as far as 20 to 30 ft (6 to 9 m) away from two-story facilities. Snow sliding off these roofs can block vehicle access to and from critical facilities.

A-5 LOCAL CONSTRUCTION METHODS, MATERIALS, AND SKILLS.

Generally, in Arctic and Subarctic regions, construction methods, materials, and skills are major factors tied to overall project cost. Maximum factory prefabrication is an economical solution to reduce on-site construction, especially given the short construction season, but the benefits of prefabrication must be weighed against higher handling and shipping costs, the risk of damage and breakage during transport, and the effect of shipping delays. Scheduling work so that construction of the outer building shell is completed during mild weather and interior work is completed during severe weather expedites completion, reduces costs, and eliminates many problems. Many materials used in standard temperate construction are used in Arctic and Subarctic locations; however, their availability and transportability are significant concerns. A shortage of skilled labor can cause higher costs.

A-6 BUILDING ENVELOPE.

A-6.1 Vapor Retarder.

A well-constructed and continuous vapor retarder can significantly control air leakage. During installation, exercise care to ensure that joints, corners, and penetrations of the vapor retarder are completely sealed with properly specified mastic or sealants. Create detailed designs and provide careful supervision during construction to obtain maximum retarder continuity between the walls and roof.

A-6.2 Ventilation.

Moisture can become trapped in the insulated cavity between the vapor retarder and the exterior surface material. Given sufficiently low temperature conditions, this trapped moisture can freeze and, over time and with successive moisture trapping and freezing, create ice within the insulated cavity that melts when temperatures warm, deteriorating the insulation material.

An air gap exterior to the envelope insulation, but behind the exterior finish, helps to keep the insulation dry, and does not reduce the insulation value of the envelope. A small air gap behind the wall finish material (also called a rain screen) can also help dry out the wall in the event of bulk water intrusion and offers some drying if vapor enters the wall cavities.

A-6.3 Daylighting.

The positive effects of introducing daylight into interior spaces to improve productivity and the wellbeing of the occupants is well documented. During the three months in midwinter when the sun is at its lowest angle and shines for only a few hours each day, little natural illumination is available through windows. Conversely, during the summer months, there is continuous daylight. Low sun angles during both the fall and spring seasons increase light entering the building and contribute to increased heat gain and glare.

A-7 ARCTIC ENTRANCES.

Where practical, depress the floor and provide grating and a pan to allow snow and water removal from footwear. Provide mats or carpets at the inside door of the arctic entrance to collect snow and dirt at the entry and prevent slippery floor surfaces. Use a canopy over the entrance to protect personnel from falling icicles and dripping water. Protect exterior walkways from falling ice and snow and from water that may freeze, causing a safety hazard.

A-8 INTERIOR FINISHING.

For structures located in Arctic and Subarctic regions, considerations for thermal expansion and contraction, and structural movement due to asymmetrical high wind and snow loading, are crucial when choosing joining methods for interior finishing work. Structures move to some degree throughout the seasons, and the typical tight tolerances for finish work are not appropriate. This is particularly relevant when large areas of sheet products are installed and finish-joined at the seams, both on walls and ceilings. For gypsum board, cracks will propagate along vertical and horizontal finish seams, and diagonally from door and window openings in walls. This is also very important where different materials meet, or where materials meet orthogonal to each other, such as drywall-to-steel ceiling joints, doorways, penetrating beams, and other interfaces in concrete and various finishes where movement and tight finish tolerance induce finish material cracking, especially originating at corners of openings (window and doors).

A-9 HVAC SYSTEMS.

"Best Practices for HVAC, Plumbing, and Heat Supply in Arctic Climates," by Winfiled et al., discusses common HVAC system approaches used in Arctic climate. This paper describes best practice examples of robust and reliable systems with the emphasis on system redundancy, durability, and functionality

A-10 MECHANICAL SYSTEMS MAINTAINABILITY.

System reliability, ease of access for regular operation or maintenance, system simplicity, and cost are governing factors when selecting primary and backup systems. Carefully select backup and emergency systems to account for an outage to prevent issues with freezing under harsh environmental conditions because this poses a danger to station personnel. To address high maintenance costs, consider whether a high initial cost is outweighed by decreased maintenance costs, resulting in a lower total life cycle cost. Maintenance costs may be high due to high local wages, scarce skilled local labor, the need to provide room and board at remote locations, decreased worker and machine efficiency due to environmental conditions, the length and cost of communications and resupply channels, and the difficulties, costs, and risks in shipping materials and equipment. These issues are critical in the event of an emergency.

A-11 PLUMBING PIPE ARRANGEMENT.

A special enclosed and heated crawl space immediately below the ground floor elevation is an option in Arctic and Subarctic building design. The floor can be constructed with removable insulated panels. Run piping, including hot and cold water, heating lines, and waste piping, in this protected space. Tightly seal the area to avoid air infiltration. The benefits of this approach include ready access for maintenance, easy replacement, and a buffer zone to warm the floor above. Another approach places the utility lines underneath the building within insulated enclosures and protecting pipes with heat to prevent freezing. Heat may be applied by wrapping a heat cable in a spiral pattern around the pipe under the insulation layer; installing an immersion cable within the pipe containing the liquid; installing heat cables in small-diameter conduits attached either directly to, or in close proximity to, the carrier pipe under the insulation layer; or preheating the liquid prior to entering the pipeline.

A-12 FREEZING OF HEATING COILS IN VENTILATION UNITS.

Whenever flow of the heating medium within a coil is modulated and coils are subjected to outside air, they are vulnerable to freezing. Circulating an antifreeze solution can avoid freezing while allowing the system to operate at low temperatures. Recirculating air that reheats return air and mixes it with outside air has been successfully used in Arctic and Subarctic regions. Air stratification can occur when warm return air and cold air are improperly mixed before going through the heating coil. An air-to-air heat recovery coil system is useful in locations such as maintenance shops or fuel storage areas where only outside air and exhaust are used for ventilation and the incoming outside air is preheated prior to entering the fan and heating coil assembly.

A-13 CORROSION CONTROL FOR INTERIOR ELECTRICAL SYSTEMS.

Corrosion slows as temperatures fall below freezing. Consider this fact when installing cathodic protection because anodes installed in frozen earth do not protect a heated structure. For an unheated structure, the required cathodic protection current drops significantly and could result in overprotection if the current is not adjusted. Corrosion from the earth is mild when structures require freeze protection. Wind-blown salts in marine environments are so corrosive that summer months provide enough warmth for substantial corrosion.

APPENDIX B GLOSSARY

B-1 ACRONYMS.

AFCEC	Air Force Civil Engineer Center
AHJ	Authority Having Jurisdiction
AHU	Air-handling unit
ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIA	Bilateral Infrastructure Agreements
cm	Centimeter
CCR	Criteria Change Request
CDC	Child development center
CRREL	Cold Regions Research and Engineering Laboratory
°C	Degrees Celsius
°F	Degrees Fahrenheit
DoR	Designer of Record
ft	Feet
FPE	Fire Protection Engineer
HNFA	Host Nation Funded Construction Agreements
HQUSACE	Headquarters, U.S. Army Corps of Engineers
in.	Inches
m	Meter
mm	Millimeters
NAVFAC	Naval Facilities Engineering Systems Command
NFPA	National Fire Protection Association

SLDT	Structural Load Data Tool
SOFA	Status of Forces Agreements
TRB	Transportation Research Board
UFC	Unified Facilities Criteria

B-2 DEFINITION OF TERMS.

UFC 3-130-01, Appendix B, provides a list of general terms for Arctic and Subarctic engineering. This appendix includes terms specific to UFC 3-130-04.

Aerodynamic shade: An area protected from wind and strong air movement. An area of relatively calm conditions conducive to the settling of snow.

Arctic entrance: A type of vestibule. The exterior door of the vestibule is closed to shut out the cold air, high wind, or drifting snow before the inside door is opened to enter the building.

Downwind: In the direction that the wind is blowing.

Ice dam: An ice buildup on building eaves that occurs when snow melted by escaping building heat flows to the eaves and freezes when air temperature drops below 32°F (0°C).

Ice fog: Results when a dew point air temperature below 32°F (0°C) meets an available supply of moisture. Ice fog can seriously impair visibility for extended periods.

R-value: A material's ability to resist heat flow. Otherwise known as *thermal resistance*.

Snow fences: Lath-type fences designed to stop windblown snow and protect a downwind facility from snowdrifts.

Snow transport (Q): The mass of snow transported by the wind over a specified time and width across the wind within the first 16 ft (5 m) above the surface, per meter of width across the wind.

Thermal break: An area of low thermal conductivity between two areas of higher thermal conductivity. The opposite of a thermal bridge.

Thermal bridge: An area of high thermal conductivity between two areas of high thermal conductivity. An example is a through-metal connection in a building envelope component.

Upwind: In the direction from which the wind is blowing.

Whiteout: An optical phenomenon occurring in the Arctic and Subarctic regions in which the snow-covered ground blends with a uniformly white sky, blotting out shadows, clouds, horizon, and so on, and destroying all sense of depth, direction, or distance.

This Page Intentionally Left Blank

APPENDIX C REFERENCES

AMERICAN CONCRETE INSTITUTE (ACI)

https://www.concrete.org

ACI 306R, *Guide to Cold Weather Concreting*

ACI 318, *Building Code Requirements for Structural Concrete and Commentary*

AMERICAN SOCIETY OF CIVIL ENGINEERS

https://www.asce.org

ASCE 7 HAZARD TOOL, https://asce7hazardtool.online/

"Blowing Snow Transport Analysis for Estimating Drift Orientation and Severity," *Journal of Cold Regions Engineering* 33 (2), R.B. Haehnel, 2019, https://doi.org/10.1061/(ASCE)CR.1943-5495.0000184

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS (ASHRAE)

https://www.ashrae.org/

ASHRAE, *Cold-Climate Buildings Design Guide*, Atlanta, GA

ASHRAE *Handbook–Fundamentals*, Atlanta, GA

NATIONAL FIRE PROTECTION ASSOCIATION

https://www.nfpa.org/

NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 1-200-01, *DoD Building Code*

UFC 1-201-01, *Non-Permanent DoD Facilities in Support of Military Operations*

UFC 2-100-01, *Installation Master Planning*

UFC 3-101-01, *Architecture*

UFC 3-110-03, *Roofing*

UFC 3-130-01, *Arctic and Subarctic Engineering*

UFC 3-130-02, *Arctic and Subarctic Site Assessment and Selection*

UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*

UFC 3-130-05, *Arctic and Subarctic Utilities*

UFC 3-230-01, *Water Storage, Distribution, and Treatment*

UFC 3-301-01, *Structural Engineering*

UFC 3-301-02, *Design of Risk Category V Structures, National Strategic Military Assets*

UFC 3-400-02, *Design: Engineering Weather Data*

UFC 3-401-01, *Mechanical Engineering*

UFC 3-410-01, *Heating, Ventilating, and Air Conditioning Systems*

UFC 3-420-01, *Plumbing Systems*

UFC 3-501-01, *Electrical Engineering*

UFC 3-520-01, *Interior Electrical Systems*

UFC 3-530-01, *Interior and Exterior Lighting Systems*

UFC 3-540-01, *Engine-Driven Generator Systems for Prime and Standby Power Applications*

UFC 3-550-01, *Exterior Electrical Power Distribution*

UFC 3-570-01, *Cathodic Protection*

UFC 3-575-01, *Lightning and Static Electricity Protection Systems*

UFC 3-580-01, *Telecommunications Interior Infrastructure Planning and Design*

UFC 3-600-01, *Fire Protection Engineering for Facilities*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

OTHER REFERENCES

"Best Practices for HVAC, Plumbing, and Heat Supply in Arctic Climates," *ASHRAE Transactions*, 127 (1), E.C. Winfield, R.J. Rader, A.M. Zhivov, T.A. Adams, A. Dyrelund, C. Fredeen, O. Gudmundsson and B. Goering, 2021, https://annex73.iea-ebc.org/Data/Sites/4/media/papers/VC-21-007_Preprint.pdf

CODES CANADA, https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada

Design Guidelines for the Control of Blowing and Drifting Snow, SHRP-H-318, R.D. Tabler, Strategic Highway Research Program: National Research Council, Washington, D.C.,1994

"Electric Heating Systems for Combating Icing Problems on Metal Roofs" in *Proceedings 4th International Symposium on Roofing Technology*, J. Buska, W. Tobiasson, A. Greatorex, and W. Fyall, National Roofing Contractors Association, 1997

Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates, A. Zhivov (ed.), ASHRAE, Peachtree Corners, GA, 2021

"Guidelines for Ventilating Attics and Cathedral Ceilings to Avoid Icings at their Eaves," in *Proceedings Performance of Exterior Envelopes of Whole Buildings VIII*, W. Tobiasson, J. Buska, and A. Greatorex, ASHRAE, 2001

"Minimizing the Adverse Effects of Snow and Ice on Roofs" in *Proceedings International Conference on Building Envelope Systems and Technologies*, J. Buska and W. Tobiasson, Institute for Research in Construction (IRC), 2001

"Roof Ventilation to Prevent Problematic Icings at Eaves," in *Proceedings Performance of Exterior Envelopes of Whole Buildings*, VIII, J. Buska, W. Tobiasson, A. Greatorex, Toronto, Canada, Jun 1998, https://www.aivc.org/sites/default/files/airbase_11883.pdf

Site-Specific Case Studies for Determining Ground Snow Loads in the United States, ERDC/CRREL SR-20-1, J.S. Buska, A. Greatorex, and W. Tobiasson, U.S. Army Engineer Research and Development Center, Cold Regions Research Engineering Laboratory, Hanover, NH, 2020, https://erdc-library.erdc.dren.mil/jspui/handle/11681/37574

Sliding Snow Calculator, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH, 2009, https://www.erdc.usace.army.mil/Portals/55/docs/CEERD-RV/CEERD-RR-H/BuildingTechnology/Tools/Sliding%20Snow%20Calculator.xls

"Snow Guards for Metal Roofs," in *Proceedings 8th Conference on Cold Regions Engineering*, W. Tobiasson, J. Buska, and A. Greatorex, ASCE, 1996

"Standing Seam Metal Roofing Systems in Cold Regions," in *Proceedings 10th Conference on Roofing Technology*, W. Tobiasson, and J. Buska, National Roofing Contractors Association, 1993

STRUCTURAL ENGINEERS ASSOCIATION OF ALASKA, https://seaak.net/alaska-snow-loads

UFC 3-130-05
16 January 2025

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC UTILITIES

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC UTILITIES

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes UFC 3-130-05, dated 16 January 2004.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website http://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

THOMAS P. SMITH, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

S. KEITH HAMILTON, P.E., SES
Chief Engineer and Assistant Commander
Planning, Design and Construction
Naval Facilities Engineering Systems Command

THOMAS P. BROWN, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MARK S. SINDER, SES
Deputy Assistant Secretary of Defense
(Infrastructure Modernization and Resilience)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

FIGURES

TABLES

This Page Intentionally Left Blank

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

The field of Arctic and Subarctic engineering, also known as cold regions engineering, covers a wide range of multidisciplinary topics and principles. Unique issues exist in the planning, design, construction, and operation of infrastructure and facilities in Arctic and Subarctic regions. Among them are permafrost, seasonal ground frost heave and thaw settlement, extreme low temperatures, high wind loads, heavy snow loads, and remote construction sites. Additionally, the implications of the rapidly changing climate in Arctic and Subarctic regions exacerbate these unique challenges.

The Unified Facilities Criteria (UFC) Arctic and Subarctic series includes five volumes that summarize relevant information and the most feasible approaches and solutions for planning, design, construction, and maintenance of infrastructure and facilities in the Arctic and Subarctic areas of the globe.

1-2 NEED FOR SPECIAL APPROACHES.

Unique problems exist in the planning, design, construction, and operation of water, wastewater, and energy utility systems in Arctic and Subarctic regions. Among them are permafrost, seasonal ground freezing and thawing with its associated frost heave and thaw settlement, extreme low temperatures, and often, remoteness of the construction site. The degree of influence of these factors varies significantly over these regions as they include vast geographical territory. Many components of conventional or temperate climate utilities can be used in cold regions. However, no conventional component should be used without careful analysis of the effects of cold stress on their operation and durability. Analysis should assume that the system will freeze. As a result, all systems should incorporate a plan for the recovery of a frozen component or system.

"Environmental Engineering Failures in Alaska," by Schubert et al., provides case histories of utility failures in Alaska that illustrate the potentially catastrophic nature of utilities systems designed and operated without consideration of the extreme conditions in which they were installed. In some cases, failure resulted in abandonment of the structure or system; in other cases, repair or change in operation was able to correct the design shortcomings. In all cases, the cost of these failures was significant in social (interruption of service), environmental, and monetary terms.

1-3 REISSUES AND CANCELS.

This document supersedes and cancels inactivated UFC 3-130-05, dated 16 January 2004.

1-4 PURPOSE AND SCOPE.

The Arctic and Subarctic UFC series provides technical guidance and available technical requirements for planning, design, construction, and maintenance of DoD facilities worldwide for all Service elements in Arctic and Subarctic environments. These guidance and technical requirements are based on the International Building Code (IBC) and the requirements in UFC 1-200-01. The UFC 3-130 series covers many aspects of Arctic and Subarctic engineering with the specific exception of pavements, which is incorporated into the UFC 3-250 and 3-260 series as discussed in UFC 3-130-01, paragraph 1-6.3. In addition to this volume, there are four other series volumes:

- UFC 3-130-01, *Arctic and Subarctic Engineering*. UFC 3-130-01 serves as an introduction to the Arctic and Subarctic UFC series.
- UFC 3-130-02, *Arctic and Subarctic Site Assessment and Selection*. UFC 3-130-02 provides applicability and technical guidance for geotechnical site assessment for the Arctic and Subarctic environment conditions.
- UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*. UFC 3-130-03 includes horizontal and vertical foundations, considerations affecting foundation design, and construction and monitoring of facilities in the Arctic and Subarctic areas.
- UFC 3-130-04, *Arctic and Subarctic Buildings*. UFC 3-130-04 includes building design in the Arctic and Subarctic areas.

This UFC provides criteria and guidance for the planning, design, and construction of utility systems for DoD facilities in Arctic and Subarctic regions. Only criteria and guidance unique to cold regions (the Arctic and Subarctic) are provided. Topics covered include water supply; wastewater collection, treatment, and disposal; fire protection; utility distribution systems; and the thermal calculation techniques needed for their cold regions design. These minimum technical requirements are determined by UFC 1-200-01. Where other statutory or regulatory requirements are referenced, the more stringent requirement must be met.

Specific discussion of centralized heating plants and their distribution systems, either steam or hot water, are beyond the scope of this UFC. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) *District Heating Guide* and *Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates* provide excellent references for this topic. Topics such as equipment redundancy and fault detection found in the *Resilient Thermal Energy Systems Design in Cold and Arctic Climates* are applicable to noncentralized systems also. Requirements for distribution pipelines carrying natural gas, manufactured gas, or Liquefied Petroleum Gas (LPG) in its vapor phase, that are installed on DoD owned property, from the point of delivery by the gas supplier to the points of connection to the buildings' fuel gas piping, are provided in UFC 3-430-05. As with water and wastewater piping, the thermal considerations for these pipelines are critical in cold regions. Chilled or warmed pipelines may affect frost heave and thaw settlement in such a way as to be catastrophic to the structural integrity of these systems. Further discussion can be found in resources listed in Appendix B.

1-5 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, for those geographic locations in Arctic and Subarctic regions worldwide.

1-6 GENERAL BUILDING REQUIREMENTS.

This UFC is an integrated part of the Arctic and Subarctic UFC 3-130 series. Use the other documents of this series in conjunction with this UFC to address construction aspects unique to cold regions. See UFC 3-130-01, Chapter 2 for the definitions of Arctic and Subarctic.

Often, conventional construction practices are acceptable in Arctic and Subarctic regions with appropriate modification to account for extreme cold temperatures, frost heaving soils, and permafrost areas. This UFC modifies and supplements the criteria found in the core UFCs. Utility provider’s or Installation specific requirements must be considered.

1-7 CYBERSECURITY.

All facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-8 COMMENTARY.

Because of the unique aspects of cold regions engineering, commentary has been added to the chapters. This commentary speaks to elements that are unique to cold regions applications. Section designations for such commentary are preceded by a “[C]” and the commentary narrative is highlighted with light gray.

1-9 BEST PRACTICES.

In cold regions engineering planning, design, and construction, much of the state of the practice is not codified. Lessons learned and the experiences of the Installation engineering staff are invaluable and may help avoid potentially costly and catastrophic infrastructure failures. Appendix A, Best Practices, provides guidance for accomplishing certain utilities design and engineering services in extreme Arctic and Subarctic environments. The Designer of Record (DoR) must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any UFC, the UFC takes precedence. For Best Practices guidelines not discussed in a UFC, the DoR must submit a list of the guidelines or requirements being used for the project to the Government Project Manager with documentation sufficient for review and approval prior to completing the design.

1-10 GLOSSARY.

Appendix D contains acronyms and abbreviations. See UFC 3-130-01 for definitions of general cold regions engineering terms.

1-11 SUPPLEMENTAL RESOURCES.

Appendix B provides a list of reliable sources for information on subjects related to cold regions engineering, design, and construction. These resources are valuable tools to the civil engineer for additional information on topics pertinent to and affiliated with construction of utility systems in Arctic and Subarctic regions.

1-12 REFERENCES.

Appendix E contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 PLANNING AND DESIGN

2-1 GENERAL.

Engineering decisions for the planning, design, construction, and maintenance of infrastructure in Arctic and Subarctic regions are based not only on applicable federal, state, and local codes, but also the expertise of engineers or practitioners with experience in dealing with the unique conditions provided by the extreme environment these regions experience. It is the intent of this UFC, and the Arctic and Subarctic UFC series, is to provide requirements and guidance to prevent significant missteps in the planning, design, and construction of cold regions infrastructure. Consultation with experienced engineers at the Command, District, and Installation level is required to ensure technologies and practices that are unsuitable for this environment, or a specific location, are not proposed. This UFC provides indicators of potential problem areas that may require unique engineering solutions outside the realm of those seen in temperate region or standard construction practices.

2-2 ENVIRONMENTAL CONDITIONS IN THE ARCTIC AND SUBARCTIC.

The planning, design, construction, and maintenance of utility systems are all affected by the special environmental conditions found in the Arctic and Subarctic. These conditions include adverse temperatures, extreme temperature variations, wind, humidity, and snow; high costs; remoteness of locations; limited availability of construction materials and labor; need for fuel additives, synthetic lubricants, oils, and greases for construction equipment; thermal stresses; and seasonal ground freezing, frost heaving, and permafrost.

2-2.1 Temperature.

[C] 2-2.1 The low temperatures prevailing in the cold regions are the most critical environmental factor. The intensity of the cold is important, but equally critical is the duration of the cold period. Mean annual air temperatures in the Northern Hemisphere are presented in UFC 3-130-01. Air temperatures in Arctic locations vary from highs of 80°F (27°C) in summer to lows of −75°F (−59°C) in winter. Interior locations away from the tempering effects of oceans or large water bodies tend to have the greatest extremes. Sub-zero temperatures can persist for months, and it is not uncommon for air temperatures to remain below −30°F (−34°C) for a week or more at many locations in Alaska.

2-2.2 Wind and Related Factors.

The combination of wind and low temperatures results in very large heat losses from exposed facilities and presents hazards for personnel. Blowing and drifting snow can create major construction and operational problems even when the total precipitation is low. The location and layout of utility systems and access points for operation and maintenance must be given careful consideration during planning and design to avoid problems with drifting snow.

[C] 2-2.2 Mean annual wind speeds for most Arctic and Subarctic locations are usually about 5 to 10 miles per hour (mph) (8 to 16 kilometers per hour [kph]) in the interior and 10 to 20 mph (16 to 32 kph) at coastal locations. During a 1972 extreme storm event, Thule, Greenland reported wind speeds in excess of 200 mph (322 kph).

2-2.3 Humidity.

Humidity is a critical factor in enclosed spaces, and both high and low extremes may be experienced in arctic situations. Since natural humidity is extremely low due to the low winter temperatures, humidifiers may be desirable in personnel spaces in order to maintain humidity at about 30 percent. Very high humidity is experienced in pump stations and enclosed treatment works, and thus, condensation may occur on cold surfaces causing damage and inconvenience. Corrosion under insulation is one example of the resulting damage, as are the potential negative effects of high humidity on wood (Type V) construction.

2-2.4 Permafrost.

The presence of frozen soil critically impacts the structural considerations for cold regions design and construction, potentially affecting the ability of the ground to support infrastructure loads. Therefore, the presence of permafrost, or perennially frozen ground, is typically a major design consideration. Figure 2-1 in UFC 3-130-01 illustrates the approximate distribution of permafrost in the Northern Hemisphere. In the zone of continuous permafrost, frozen ground is absent only at a few widely scattered locations such as at the bottoms of lakes and rivers. In the discontinuous zone, permafrost is found intermittently. Permafrost and seasonal frost are discussed in more detail in UFC 3-130-01.

2-3 PLANNING CONSIDERATIONS.

In the Arctic and Subarctic, utility systems are usually the costliest component in construction of military Installations. The layout of an Installation is often controlled by the type of distribution and collection systems selected for the utilities network. As a result, planning for a new Installation or the addition of new facilities on an existing Installation in the Arctic and Subarctic must include consideration of utilities at a very early stage to ensure overall cost effectiveness. Use UFC 3-201-01 for preliminary site analysis and evaluation of existing conditions such as geotechnical site investigation, environmental considerations, surveying, and topographic surveying. Use UFC 3-130-02 for site analysis topics specific to cold regions. Review the existing utility maps and Installation planning documents with Installation personnel to develop population estimates and plans for new service areas. Address Installation specific design preferences and standards with responsible engineering and operations personnel as part of the system design analysis.

DoD Installations in Arctic and Subarctic regions vary significantly by size, mission, and remoteness. Engineering design decisions for Installations manned by unaccompanied military, civilian, and contractor personnel may differ from those made for Installations where the tour of duty is accompanied, and family housing is provided on the Installation. In Figure 2-1 high voltage, insulated electrical lines on pipeline sleepers are placed directly on the ground at Thule Air Base, Greenland. Thule Air Base assignments are unaccompanied, limiting Installation access to DoD service members, civilians, and contractors. These ground surface electrical lines would likely be unacceptable for both safety and aesthetic reasons on less remote Installations where family members are present. The Installation, District, or Command engineering personnel must be involved in project planning and throughout the design process to ensure appropriate facilities to meet the locality mission are constructed.

Figure 2-1 Unprotected Insulated Power Lines at Thule Air Base, Greenland

2-3.2 Useful Life.

The harsh operating conditions for utility systems and equipment in cold regions reduces their useful life. Table 2-1 presents typical useful lives for some utilities components in the Arctic and Subarctic.

[C] 2-3.2 Equipment that must operate throughout the winter are particularly critical. Pumps and their controls, required to maintain pipe flow, are examples of critical equipment.

Table 2-1 Approximate Useful Life of Utility System Components in Cold Regions

Component	Useful Life (years)
Wells	30
Pumps and controls	5
Storage tanks	40
Water distribution lines	40
Meters	10
Valves	10
Sewage collection lines	30
Lift stations (not pumps)	30
Buildings	30
Paint (exterior)	10
Service connections	10–15
Trucks	4
Tracked vehicles	2–3
Backhoe (occasional use)	6–10
Compressors	5

2-3.3 Construction Methods.

The three basic construction techniques used are modular, stick built or in-place construction, and prefabricated. The method selected depends on site conditions and transportation facilities available. The normal construction season varies from two to three months along Alaska's Arctic coast to six to eight months in southern areas of Alaska.

2-3.4 Installation Layout.

Consult UFC 2-100-01 for guidelines to Installation planning and infrastructure layout and UFC 3-130-04 for issues specific to cold regions. For existing Installations, consult the Installation Development Plan (IDP), or other Installation planning documents.

2-3.4.1 Utility Networks.

The critical planning decisions for utility networks are (1) whether the pipes should be above or below ground, and (2) whether the pipes should be installed as individual units or combined with other utility services in a utilidor. Heat loss is directly proportional to the difference between the inside and outside temperatures. An aboveground utilidor or pipeline is directly exposed to extreme weather conditions and therefore has a much higher maximum rate of heat loss (and therefore shorter time to freeze) compared to a similar pipeline buried just below the ground surface. In general, adopt belowground installation wherever possible. Pipes buried in permafrost or in the seasonal frost zone must not only be protected from freezing but must also resist the structural effects of heaving in the seasonal frost zone and potential thawing of the permafrost. Additionally, thermal considerations must be concerned with not only protecting the pipe from freezing, but also protecting the permafrost from thawing. The terrain is relatively flat in much of the Arctic, and maintenance of the necessary grades for gravity sewers in either the aboveground or buried mode is difficult. Use pump stations, or pressure or vacuum sewer systems, to overcome these constraints. The decision to combine multiple utility services in a utilidor is determined by a variety of factors. Benefits may be derived both during construction and maintenance, and the combined systems may be easier to protect from freezing. However, utilidors are generally larger structures and more expensive to build. The thermal contribution of multiple pipes in a single space, and their possible interaction, must be considered. Thermal considerations for above and belowground utility installation are covered in detail in Chapter 12 and utilidors are discussed further in Chapter 9.

[C] 2-3.4.1 Aboveground utility systems offer easier access for maintenance and repair and are cheaper to build where site conditions are poor. However, there are disadvantages. They are susceptible to vandalism and traffic damage, disrupt pedestrian and vehicle traffic patterns, and create snow removal problems. Belowground systems allow for more normal Installation layout, however pipe breaks and leaks in belowground pipes are harder to detect and locate, particularly in frozen ground.

2-3.4.2 Network Layout.

Utility network layout is dependent on the source and termination of each component of the system. Utilities may be provided from off Installation by local utility companies. Other Installations have centralized heating or power plants; water source, treatment, and storage facilities; and wastewater treatment facilities all on-site. Service lines from utility mains to individual buildings are the main source of freezing problems. Site buildings as close to the mains as possible with service lines 60 ft (18.3 m) or less in length. Do not design Installation layouts with dead-end streets unless a pipe connection can be made to an adjacent street for the circulating water system. Locate the largest consumers of water at the extremities of the distribution system if possible.

[C] 2-3.4.2 It is typical practice in temperate climates to bury most utility lines in the streets. However, there are thermal disadvantages to this practice in cold regions since clearing the roads of snow will allow greater frost penetration. Burying water and sewer mains in the front or back yards of dwellings, and in open areas where snow will not be removed, maintains warmer ground and pipe temperatures.

2-4 DESIGN.

Use UFC 3-201-01 for topics such as site development, grading, and storm drainage systems. Use UFC 1-200-02 for energy and sustainability.

2-4.1 Design Criteria.

Design utility systems to meet all applicable regulations and requirements of federal, state, and local governments, or overseas equivalent.

2-4.2 Approvals and Permits.

See UFC 3-130-01, paragraph 1-13, for the general approval and permit processes for Arctic and Subarctic construction. For new potable water supply systems, extensions to new areas, rehabilitation, or replacement of existing potable water supply systems, coordinate with the Safe Drinking Water Act primacy agency, as applicable, to determine primacy agency requirements. For new or rehabilitated sanitary sewer systems or facilities such as service extensions, domestic wastewater treatment, or industrial wastewater treatment, coordinate with the applicable primacy agency to determine permitting requirements.

2-5 EQUIPMENT.

For remote Arctic Installations, the initial cost of most utility equipment is not as important as its reliability. Redundant or split systems allow extended operation with a single unit failure for equipment such as boilers. Standby units for critical equipment are essential and are particularly important for emergency power and for heating systems. A large inventory of critical spare parts is recommended and standardization of equipment to reduce the parts inventory will prove economical.

2-6 ALARM SYSTEMS.

Provide alarms and safeguards, such as low water temperature alarms, low flow alarms, and low or high voltage alarms to warn operators of any pending problems. Incorporate instrumentation and monitoring into utility systems and facilities to allow for safe and efficient operation. All critical utility facilities must have instrumentation, monitoring, alarm, and notification systems to indicate critical conditions that would result in:

- cessation of essential service (for example, monitor flow, temperature, and pressure); or
- damage to facilities (for example, monitor for fire and low temperature).

Further discussion is given in paragraphs 3-6.4, 5-2.6, and 7-4.4. Paragraph 10-5 discusses integration of utility alarm instrumentation with the Installation central alarm system.

2-7 REVEGETATION.

Revegetate areas excavated and backfilled for utility systems to prevent erosion. Request planting criteria from the Installation, District, or Command environmental staff.

[C] 2-7 Locations may have significantly different grass, tree, and shrub species lists. The preferred or acceptable planting season may also vary by location.

This Page Intentionally Left Blank

CHAPTER 3 WATER SOURCE DEVELOPMENT

3-1 GENERAL.

The water requirements and design capacity factors for domestic, fire, and other functional uses are specified in UFC 3-230 series. Per UFC 3-230-01, unless otherwise directed by the Government Project Manager, use nearby public potable water systems. However, if that is not practical, sources must be developed on the Installation. Both ground and surface waters are available in the Arctic and Subarctic, but the environmental conditions require special approaches for their development. In addition, ice and snow are sometimes used for water supply augmentation or as emergency or standby sources.

3-2 ENVIRONMENTAL CONSTRAINTS.

In most of the Arctic and Subarctic, precipitation is light, terrain is relatively flat, and runoff is concentrated in the short period during ice breakup. There are many small, shallow lakes, ponds, and numerous rivers and streams. Ice cover varies according to local conditions but generally lasts from 6 to 10 months and approaches 6 ft (1.8 m) in depth in small quiescent water bodies (see Appendix C, Example 1 for procedures to estimate thickness of ice formation). Hydrologic data for these regions are scarce, so it is difficult to predict reliable yields. Because permafrost is essentially impermeable, there is little direct recharge of most aquifers. Any penetration of the permafrost for exploration or for well development requires special engineering consideration and is costly.

3-3 SURFACE WATERS.

Many shallow lakes and small streams freeze completely in the winter, eliminating them temporarily as a water source. Some Installations pump water from such sources in the summer months to store for a winter supply. Larger streams and deep lakes can have liquid remaining beneath the ice, but the volume available is limited since there is no contribution from precipitation in the winter. The large quantity of ice and snow results in major annual flows occurring during the spring breakup. Hydrographs for Arctic rivers in the U.S. are available from the United States Geological Service (USGS) website https://waterdata.usgs.gov/nwis.

3-3.1 Rivers.

The volume of flow is low in the winter for Arctic and Subarctic rivers, but water quality is excellent since sediment transport from glacial sources is minimal and surface runoff recharges do not occur. Winter water temperatures are very low (33°F [0.6°C]), which creates difficulties for treatment, and intakes can clog due to formation of frazil ice. Floating ice during freeze-up and breakup periods can damage or destroy intake structures. Some facilities remove intake structures and rely on water from temporary storage locations during these periods. Development of intake galleries or wells in the stream bottom mitigates ice problems, but it is difficult to locate the permanent channel in alluvial and braided streams. The summer flows are higher in volume than winter flows, but they are poorer in quality, containing sediments which may be difficult to remove. These sediments are primarily glacial silts and are almost colloidal in size.

3-3.2 Lakes.

Deep lakes are a reliable, continuous source of water. The quality of any liquid beneath the ice in a shallow lake or pond is typically poor. Impurities, such as most salts, are rejected from the freezing water, making the ice relatively pure but concentrating the impurities in the remaining liquid. A survey is required to identify lakes and ponds that may freeze deeply enough to create this condition. Chapter 12 discusses the thermal aspects of such an analysis.

3-3.3 Saline Waters.

Distillation or reverse osmosis is used to treat saline or brackish waters; these procedures are costly and energy intensive. Avoid such sources except as the last resort.

3-3.4 Augmentation.

In the Arctic, most of the annual precipitation is in the form of snow. Although total precipitation is low, advantage can be taken of windy conditions to induce snow drifting at selected locations. Collection of the melting snow augments the summer water supply. ASCE *Cold Regions Utilities Monograph,* Section 5.2.1, provides more information.

[C] 3-3.4 Snow fences were used to induce drifting in the watershed of the Utqiagvik, Alaska water reservoir. It was shown that at least 800 gallons (3000 liters) of water were collected for every linear foot of 5-ft-high (1.5-m) snow fence that was installed, with the fences about 250 ft (76 m) apart.

3-4 GROUNDWATER.

Groundwater can be a more reliable water source than surface supplies. It is usually available on a year-round basis and is more consistent in its temperature and mineral quality than surface sources. Very shallow groundwaters are unsuited for potable water supplies without extensive treatment and the yield is limited. Subpermafrost groundwater or permafrost zones thawed by large rivers and lakes are the most reliable sources. Subpermafrost wells are technically feasible when the permafrost extends to a depth of a few hundred feet or less, and they have been successfully used in central Alaska. Costs for drilling and maintenance of such wells are high. The water must be protected from freezing, and the permafrost must be maintained in a frozen condition. This requires special well casings or grouting methods and unique operational methods. Subpermafrost water is generally deficient in dissolved oxygen and can also contain high concentrations of dissolved iron and manganese salts. Hardness is also common. Dissolved organics can create serious treatment problems because of interactions with the dissolved iron and the color imparted to the water. The most reliable and economical groundwater sources in the Arctic and Subarctic are in the thawed zones adjacent to large rivers and lakes. Most of the rivers are braided streams and have shifted their channels many times. The former stream channels may still be underlain by thawed material and represent a potential water source depending on the type of soils involved.

3-5 OTHER WATER SOURCES.

Consider snow, ice, and direct catchment of rainfall as potential water sources for augmentation or emergency supplies and for small facilities, temporary facilities, or facilities in support of military operations with a design life of five years or less. The natural quality of these sources is good, but a stockpile of snow or ice can be easily contaminated. Large volumes of snow are required to produce even small quantities of water and the costs for harvesting and melting are high. It is estimated that 4 to 5 ft^3 (0.11 to 0.14 m^3) of snow is required for every 5 gallons (19 liters) of water produced, and to melt this volume of snow would require about a pint of diesel fuel for the snow melting equipment. Brackish and saline ponds have been improved in quality by pumping out the concentrated brines that remain under the ice near the end of the winter and allowing fresh spring runoff to recharge the pond. If repeated several times the procedure allows the use of an initially unacceptable water source.

3-6 STRUCTURES.

Structures range from wells and their appurtenances, to simple temporary intakes placed on the river ice, to complex dam structures located on permafrost. The complete structural design of any of these is beyond the scope of this UFC (UFC 3-130-03 discusses embankment construction on permafrost). It is the intent of this section to point out those features that may require special attention in the cold regions. ASCE *Cold Regions Utilities Monograph,* Section 5.4, provides additional considerations in design of these structures.

3-6.1 River Intakes.

A permanent intake structure is usually employed for large-scale permanent military facilities in the Arctic. Structural damage from moving ice in the spring and in the fall is the major concern.

3-6.1.1 Temporary Intakes.

Temporary intakes are less expensive and are removed from the river during spring ice breakup; and storage is relied on as the water supply. This approach is suitable for small populations. A temporary intake consists of a pump and simple shelter.

3-6.1.2 Permanent Intakes.

Numerous arrangements and configurations for permanent intake structures have been designed. Special features of these designs include insulation, heat tracing in the wet well and in the intake line, and a recirculating line from the facilities served. Dual intakes are recommended to ensure reliability. Continuous water circulation is then used to prevent freezing. Frazil ice can be a serious problem for intakes during the freeze-up period. Frazil ice occurs as small crystals in flowing water slightly below 32°F (0°C) in temperature. It will adhere to and accumulate on any submerged object it contacts. Water intakes, trash racks and similar structures can become completely choked by frazil ice in a few hours. It can be avoided by locating the intake in a long, calm reach of the river where surface ice will occur before the water becomes supercooled. The surface ice cover then prevents rapid heat loss and precludes frazil ice formation. Heating the intake and bar screens to about 33°F (0.6°C) prevents formation of frazil ice. This can be done electrically or by back pumping hot water or steam.

3-6.2 Infiltration Galleries.

Infiltration galleries remove the structure from risk of ice damage and thereby offer advantages over direct intakes. The gallery is placed in thawed material in the stream bed or adjacent to it. The yield will depend on the type of soil present. Importation of coarse-textured material is necessary for gallery construction in fine-textured silty and clayey soils. Both electrical and steam lines have been used in galleries to prevent freezing. Steam lines are usually placed on the upper surface of the intake laterals and on a second level about 1.5 ft (0.5 m) above that. The heating elements or steam lines are not normally operated continuously but are used only in emergencies to restore a frozen or partially frozen system.

3-6.3 Wells.

See UFC 3-230-02, for basic procedures for water well design. The special concern for subpermafrost wells is not to allow thawing of the permafrost during drilling or operation of the well. The former may require either compressed air or nontoxic drilling muds or fluids with rotary drilling procedures. Avoidance of permafrost thawing during well operation may require multiple casings so that cold air can circulate in the annular spaces. Concurrent with protection of the permafrost is the necessity of maintaining the water in an unfrozen state, which requires heat addition for an intermittently used system. Artesian flow, from subpermafrost aquifers, may also cause issues for wells, especially on valley floors and at the bottom of hill slopes. In *Geologic Hazards of the Fairbanks Area: Alaska Division of Geological & Geophysical Surveys Special Report 15,* Péwé discusses this phenomenon and several cases of uncontrolled flow through and around the well casings in the Fairbanks area.

In nonpermafrost conditions, design wells for frost heave protection in the surface soils. Casings must be designed to prevent the bonding between the frozen soil and the pipe and thereby eliminate heave damage.

3-6.4 Pumping Stations.

Pumphouses provide shelter for pumping equipment controls, boilers, treatment equipment, and maintenance personnel who must operate and service the facility. The structural design depends on the requirements of each location and must be considered individually. The type of equipment housed within the shelter also depends on the individual system and may vary from a simple pump to a complex system with HVAC, standby power, and alarm systems to alert operators of malfunction. Any system must provide the degree of redundancy and other safeguards required by the nature of the operation and location. ASCE *Cold Regions Utilities Monograph,* Section 5.4.4, provides more information.

Alarms should include, but are not limited to, the following:

- no return flow
- low/no return pressure
- low/critical low return temperature
- high supply/fire flow
- high supply temperature
- pump trouble
- heating system or HVAC trouble
- Fire Flow Trouble

Consult Installation, District, or Command engineering and operations staff for specific requirements.

This Page Intentionally Left Blank

CHAPTER 4 WATER TREATMENT

4-1 GENERAL.

See UFC 3-230-01, for the basic requirements, criteria, and procedures for water treatment systems for military facilities. This chapter discuss only those aspects unique to the Arctic and Subarctic. There are three major process concerns: the low temperature of the raw water, removal of glacial silt from surface sources and removal of dissolved minerals, and organics from surface or groundwater sources.

4-2 TEMPERATURE EFFECTS.

The temperature of surface water sources during winter will be at or very near 32°F (0°C), while groundwater sources in permafrost regions may be a few degrees warmer and maintain that level year-round. The water must be preheated to at least 40 to 50°F (4 to 10°C), or the unit processes must be designed for low temperature operation. The effect of low temperatures on equipment operations must also be evaluated during facility design. ASCE *Cold Regions Utilities Monograph,* Section 6, provides further guidance.

4-3 LOW TEMPERATURE TREATMENT.

Almost all physical, chemical, and biological processes used in water treatment are sensitive to temperature either through viscosity effects or as an influence on reaction rates. This must be considered for mixing, sedimentation, filtration, and disinfection. See the ASCE *Cold Regions Utilities Monograph,* Section 6.3, for further details.

As of 2015, there is no longer separate guidance for fluoridation in cold climates. See the UFC 3-230 series for specific requirements for military Installations.

4-4 REMOVAL OF MINERALS AND ORGANICS.

[C] 4-4 Ion exchange water softening is commonly used at smaller Installations with hard water. Lime-soda softening is frequently used when the water is both turbid and has a high hardness. Dissolved iron is common in cold regions groundwater. Aeration or chemical oxidation with chlorine have been successful for precipitation of elemental iron. Iron can foul zeolite and greensand ion exchange resin systems unless they are appropriately designed. If the groundwater has excessively high iron, precipitation is likely a better way to remove the iron, and then use greensand as a polishing measure for any remaining iron. However, iron/organic complexes are present in many cold regions groundwaters. Ozone has been shown to be effective in treating such water. Ozone and carbon adsorption are very effective for color and organics removal.

4-5 TREATMENT OF BRACKISH AND SALINE WATERS.

Distillation, reverse osmosis and freezing have all been used in cold regions to reduce saline concentrations to potable levels. See the ASCE *Cold Regions Utilities Monograph,* Section 6.3.11, for further details.

CHAPTER 5 WATER STORAGE

5-1 GENERAL.

Basic criteria for determination of capacity requirements, design, and construction of water storage facilities can be found in UFC 3-230-01. This chapter discusses only those aspects unique to the Arctic and Subarctic. Water is provided for domestic, industrial, and fire protection services. A design study to determine specific water needs must be undertaken for each new facility so that cost-effective designs for water supply, water storage, and wastewater systems can be ensured.

[C] 5-1 The requirements for water will typically be lower at remote facilities in the Arctic and Subarctic than at similar operations in the temperate zone due to conservation and lower external water needs. The water needs will vary with the type of facility, so general criteria are not possible.

5-2 WATER TANKS.

Structural design of water storage tanks generally follows temperate regions practice. Considerations specific to Arctic and Subarctic construction include insulation, thermal conditions, foundation design (see UFC 3-130-03), and the need to prevent ice damage. Ice buildup, either inside or on the exterior of the tank, due to leakage, may pose serious structural and safety risks. ASCE *Cold Regions Utilities Monograph,* Section 7.5, provides additional details on water tank design.

5-2.1 Tank Materials.

Construction materials for water tanks in cold regions include wood, steel, and concrete. In Alaska, welded steel tanks are the most commonly used. Tank insulation materials include polystyrene or polyurethane boards, or sprayed-on polyurethane. Concrete tanks have been used where aggregate is available and the foundation conditions permit slab construction. Insulate concrete tanks, or cover with earth, to reduce heat losses. Evaluate seismic conditions prior to selection of a rigid concrete tank. Welded steel tanks are more cost effective for high-risk seismic areas.

[C] 5-2.1 Wood stave tanks are constructed with prefabricated pieces that can be shipped relatively easily to any remote site. Leakage is a problem with intermittent or fill-and-draw operations since the joints can open slightly if the wood is allowed to dry.

5-2.2 Corrosion Protection.

Paint steel water tanks in accordance with applicable standards provided in UFC 3-230-01. When selecting paints, the in-service temperature range must include normal and possible extremes. Strictly follow manufacturers' recommendations regarding acceptable temperature limits for the application of these paints to avoid premature failure. Cathodic protection is also required.

[C] 5-2.2 The cost of sandblasting and liner replacement is very high in remote locations so the type of coating initially selected must be of high quality and properly applied.

5-2.3 Insulation.

Common tank insulation materials are earth cover (soil), polyurethane or polystyrene board, or sprayed on polyurethane materials. Selection is affected by factors including moisture exposure, attachment options, and cost, among other considerations. Moisture-resistant layers of insulation materials must be installed in contact with the tank at inaccessible locations since moisture from leaks, condensation, rain, or groundwater can drastically reduce the insulating effect. Insulation applied aboveground requires protection against accidental mechanical damage, vandalism, birds and animals, and weather. Aluminum or steel cladding provides a good barrier against weather and mechanical damage. Insulation materials are further discussed in paragraph 12-7.

[C] 5-2.3 Tanks may also be enclosed with a protective shell. Such an exterior shell is either constructed against the tank or a walkway provided between the tank and the exterior wall. The air gap and the wind protection will reduce heat losses, and this heat loss can be further reduced by installing insulation. Near-hydrophobic plastic foam insulations are readily available and commonly used. Polyurethane can be obtained as either prefabricated boards or foamed in place by spraying directly onto the tank. The latter has been the more common approach in Alaska.

5-2.4 Tank Design.

Design water storage tanks to prevent the formation of ice in the tank under all foreseeable circumstances, and tanks must be completely drainable. Surface icing can be avoided by maintaining the water temperature above 39°F (4°C) and ensuring continuous circulation. Double-wall, testable heat exchangers are recommended for sanitary purposes.

[C] 5-2.4 Floating ice in the tank can destroy interior appurtenances, and ice formed on the walls can collapse and cause structural failure or punctures in the tank bottom. In some cases, the return line of a circulating water distribution system is discharged to the storage tank to promote circulation and maintain temperatures. In other cases, a small amount of water is withdrawn, heated with a boiler or heat exchanger, and pumped back into the tank.

5-2.5 Appurtenances.

Locate breather vents on the inside of the tank and vent into an attached pump house or building rather than directly to the outside. Install overflow piping inside the tank or protect it with insulation and heat tracing if placed on the exterior.

[C] 5-2.5 Locating vents as discussed prevents ice from forming in an exposed vent due to condensation, which would cause a vacuum to form in the tank as water is withdrawn and, possibly, the tank to collapse.

5-2.6 Instrumentation.

Instrumentation includes water level indicators, with high- and low-level alarms, and thermal probes at various levels for control and alarm. Air temperature above the water surface is likely to be of interest. Since ice can damage float type water level indicators, a pressure type transducer is recommended. External lighting may improve security and an internal light may assist inspection. Thermal monitoring of permafrost foundation soils may be part of the overall project.

5-2.7 Thermal Considerations.

Whenever practical, tanks must be buried or covered with soil to reduce the effect of low air temperature. Avoid elevated tanks unless they are absolutely necessary for the water distribution system since they expose the greatest surface area to the worst climatic conditions. Insulate all exposed tank surfaces and pipe risers for elevated tanks. Thermal calculations are necessary to size heating systems when they are used to replace heat losses or to heat the water for distribution. The unit capacity of a heat exchanger or boiler must be equal to the maximum rate of heat loss. Water circulation within the tank or boiler heating are common for tanks with intermittent flow and refill.

5-2.8 Tank Foundations.

Foundation considerations for tanks are like those for other Arctic and Subarctic structures and are covered in UFC 3-130-03.

[C] 5-2.8 Foundation design for tanks is complicated by the very high loads imposed by the stored water and the need to keep the water in the unfrozen state. The unfrozen water is a heat source that can have an adverse effect on the underlying permafrost and must be considered during design for a tank on grade.

5-3 EARTH RESERVIORS.

Construct earth embankments for water reservoirs in accordance with UFC 3-130-03. A liner is necessary within the embankment, or to seal the entire reservoir, when permeable soils are present or used for construction. Ice formation, and its effect on the function of the reservoir, must be considered. ASCE *Cold Regions Utilities Monograph,* Section 7.3, provides more detail.

[C] 5-3 Water impoundments for domestic and industrial water supply and for hydropower have been successfully constructed in the Arctic and Subarctic. The most likely configuration for military facilities is an earthen embankment to either increase the storage capacity of an existing lake or stream or to impound water in a natural drainage swale.

CHAPTER 6 WATER DISTRIBUTION

6-1 GENERAL.

See UFC 3-230-01 for the basic criteria for design and construction of water distribution systems. This chapter presents information that is unique to the Arctic or Subarctic. Pressurized pipe distribution systems are used for exterior utilities and interior plumbing in most military facilities in the cold regions. An exception might be small, remote facilities separated from the main distribution network. If individual wells are not feasible, then vehicle delivery of water would be necessary. Truck delivery systems are common at remote civilian communities in Alaska, Canada, and Greenland. The location of pipe distribution systems and whether they should be buried, aboveground, or in a utilidor are discussed in Chapters 2, 8, and 9.

6-2 RECIRCULATION SYSTEMS.

6-2.1 Single Loop.

6-2.1.1 General.

Single pipe recirculation, or loop, systems are recommended for Arctic conditions. As shown in Figure 6-1, a single loop system consists of one uninterrupted loop originating at a recirculation facility and returning to that point without any branch loops. This layout eliminates dead-ends and related freezing problems and requires the minimum amount of piping as compared to other circulation methods. A simple, positive control of distribution is possible with flow and temperature indicators on the return lines at the recirculation facility. Typically, water pressure is regulated at the water recirculation facility. Manual and automatic control valves are frequently used, along with variable speed pumps to maintain pressure. Pipe network design uses the same procedures used for standard water systems. The return line does not have to be of the same size as the delivery pipe because of withdrawals in the network. If possible, locate mains at the rear of buildings or in areas not cleared of snow, rather than in the streets.

6-2.1.2 Water Temperatures.

Normally, water is pumped out at 39 to 45°F (4 to 7°C) and returns at 33 to 39°F (0.5 to 4°C). Where the mainline provides fire protection, NFPA 24 Chapter 7-5.2.2 requires water to be maintained above 40º F (4.4°C) for freeze protection, when exposed to freezing conditions. Otherwise, two scenarios exist:

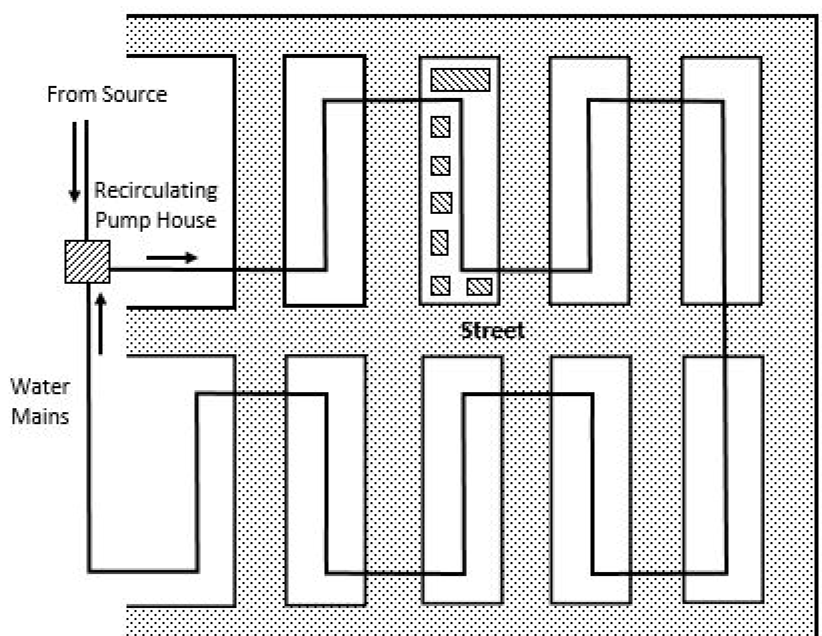
- Seasonally frozen ground with insulation/insulated pipe or pipes buried outside of the active layer—a minimum return temperature of 35°F (2°C) is suggested. Supply temperatures may vary by system parameters, but 5 to 10°F (9 to 18°C) above the minimum return temperate is common.
- Permafrost and above grade—suggest keeping the minimum return temperature at 40°F (4.5°C) if it is a circulating system. Return water may pick up heat on the way back to the recirculation building and can mask

lower temperatures realized in the field. Supply water temperature may be 5 to 15°F (9 to 29°C) above this setting to keep the return temperatures above the minimum.

Supply water temperature may be controlled by the source water (such as a tank or reservoir), which could cause higher temperatures than the recommended limits for part of the year. Water temperatures may need to be kept low to prevent thawing of permafrost soils in order to maintain stable foundation conditions. Return flow, temperature, and pressure monitoring are as essential as monitoring supply and heat addition.

[C] 6-2.1 Single loop mains also prevent water quality impairment because of low disinfectant residual and formation of disinfection byproducts which may occur in dead-ends. The use of circulating mains also allows for compliance sampling to occur at the point of return, generally in the water recirculation facilities, effectively centralizing operations, and daily compliance sampling. Fire water flow can be supplied through both the supply and return lines if required to meet hydrant or sprinkler flow requirements. In many cases, using both the supply and returns for fire flows can reduce the water main size as compared to using only the supply main.

Figure 6-1 Layout and Location of Mains for Single Pipe Recirculation



6-2.2 Branch Loops.

Branch loops use small bore piping take-offs with circulation pumps pumping around a full-bore check valve. This allows for flow monitoring and alarming but adds complexity and requires operational balancing. There are some requirements worth noting since the use of check valves affects fire flow. For example, circulated hangar loops should be pushed, not pulled. Branch loops also require more decentralized monitoring by operators. In Alaska, more complex distributions systems require more operator training/higher certifications to operate (State of Alaska 18 AAC 74.120).

6-3 ALTERNATIVE SYSTEMS.

Several types of alternate systems have been used historically. Three are discussed briefly here. ASCE *Cold Regions Utilities Monograph*, Section 8.6.3, provides more detail on these systems.

6-3.1 Conventional—No Recirculation Systems

For conventional water pipe mains with no recirculation high-volume consumers are placed at the ends of the main lines to ensure continuous flow. Return loops are therefore unnecessary. Sizing of the pipe network and other design details follow conventional practice. In Alaska, more complex distributions systems require more operator training/higher certifications to operate (State of Alaska 18 AAC 74.120).

> [C] 6-3.1 Single pipe no recirculation systems, such as branch systems, are possible but require careful planning in the initial site layout for military Installations.

6-3.2 Dual-pipe Pressure Differential Systems

Dual-pipe systems are complex, and the control mechanisms tend to be elaborate as varying consumption in different locations can result in stationary water in certain areas at certain times. For these reasons, they are no longer commonly installed.

> [C] 6-3.2 Dual-pipe pressure differential systems rely on a large diameter supply line and a small diameter return line with a pressure differential between them. The return line is sized to maintain the desired flow in the system. For typical service connections from a dual system, the service lines tap from the main and return to the smaller diameter return line. The pressure differential between the delivery and the return line must be sufficient to induce circulation in the service loop.

6-3.3 Summer Line Systems

[C] 6-3.3 Some facilities have utilized seasonal transmission mains to convey the water from a summer source to storage tanks. Drain or blow out these lines each fall to reduce potential for freeze damage and properly disinfect them at the beginning of each use season.

6-4 SERVICE LINES.

The design of service lines must prevent freezing of the contained water but must also consider the effects of permafrost thawing, frost heaving and differential settlements between the pipes and the building. The minimum depth of burial, to be below the frost depth, varies depending on the specific location and its temperature conditions. Circulation in these service connections is the recommended method to prevent freezing. Insulation with heat tape is also commonly installed as a backup. The two most common methods for circulation are either a small pump inside the building or the use of pitorifices. Backup freeze protection is usually provided by a thermostatically controlled electrical heat tracer. If copper pipe is used for the service lines, an electrical connection between the two service pipes at the main allows electrical resistance thawing from within the building as a second backup system. See Appendix A, paragraph A-7.1, for references that provide example schematics of service lines and minimum depth of burial for various locations.

6-5 MATERIALS.

Select pipe materials in conformance with UFC 3-230-01; the UFGS, such as UFGS 33 11 00; and the standards listed therein. Standards listed in the UFC and UFGS may provide specific cold weather requirements (for example, ASTM F2620).

Materials must be selected to meet specific site conditions and soil characteristics. Consider freeze tolerance and thermal expansion of pipe material according to pipe location and flow temperatures. The discussion that follows is intended to give some indication of the performance of these materials in the Arctic and Subarctic. Note that though no longer approved for installation, asbestos cement pipes may be encountered in existing systems. ASCE *Cold Regions Utilities Monograph*, Appendix A, provides more information and discussion on piping material options.

6-5.1 Copper.

Copper pipe selected must be rated for utility service, typically Type K. Copper should have only conditional use, consult Installation, District or Command engineering and operations staff. Install copper pipe in continuous runs where joints are minimized or eliminated, unless installed in a controlled space such as utilidor box with access points at each joint or in seasonally frozen ground. Isolation for corrosion potential may be required. Copper may be coated to meet this need.

[C] 6-5.1 Copper pipe is commonly used for service lines because it can be thawed by using electrical resistance, while plastic pipes cannot be thawed in this manner.

6-5.2 Ductile Iron.

Ductile iron pipe can take some shock loadings and is slightly flexible. It is a heavy, durable pipe often used in rocky areas or where adequate pipe bedding materials are not available. Ductile iron pipe is generally available in 18–20 ft (5.5–6.1 m) lengths, which may offer easier shipping and construction logistics than longer steel pipe. It can be thawed with electrical resistance.

Ductile iron has poor corrosion resistance, and lining is necessary. Corrosion protection is required in corrosive soils such as magnesium anodes and pipe bonds. Consider isolation if used above grade. Some ductile iron pipe installations may warrant specialty coatings for corrosion protection.

6-5.3 Steel Pipe.

Steel pipe is less commonly used in Alaska. Expansion and contraction, including necessary thrust anchors, as well as the differential expansion and contraction between a steel pipe and rigid heat tracing components or insulation attached to the pipe, must be considered. Corrosion protection is required in corrosive soils such as magnesium anodes and pipe bonds. Consider isolation if used above grade. Some steel pipe installations may warrant specialty coatings for corrosion protection.

[C] 6-5.3 Steel pipe is lighter, more flexible, and more corrosion resistant than ductile iron. Continuously welded steel pipe has been used to obtain maximum span between piles. It can also be thawed using electrical resistance.

6-5.4 High Density Polyethylene (HDPE).

High Density Polyethylene (HDPE) is recommended for Arctic Installations. Typically, HDPE water pipe is pre-insulated and then covered with a polyethylene, aluminum or steel jacket as discussed in paragraph 6-5.7. Joints must be leak-free and have the same or higher strength than the pipe, and either butt-fusion or electrofusion joints should be considered. Insulate field joints and cover with heat shrink couplings. Consider thermal expansion and contraction when using HDPE pipe owing to its high coefficient of expansion. Heat trace systems are recommended when freeze protection is warranted, see paragraph 6-7.1.

[C] 6-5.4 HDPE pipe is very flexible and impact resistant, with a high coefficient of expansion and contraction, high corrosion resistance, and a smooth interior, but it cannot be threaded. Butt-fused polyethylene pipe has been used extensively in Canada for water and sewer mains. The most common use has been in buried systems, and experience has shown that the pipe and contained water can freeze solid without breaking the line.

6-5.5 Polyvinyl Chloride (PVC).

PVC is not recommended for use where there is a chance of the pipe being exposed to freezing conditions. Heat trace systems are recommended when freeze protection is warranted, see paragraph 6-7.1. Conditional use of PVC pipe for certain applications may be considered such as:

- Burial—seasonal frozen soils only, and pipe must be located below maximum season frost in snow cleared soil plus factor of safety or protected by designed insulation (insulation canopy or factory installed pre-insulated and jacketed pipe).
- Above grade—insulated and heat traced locations only.

Joint types should be solvent weld or bell and spigot. PVC pipe is at higher risk for shipment damage or loss.

[C] 6-5.5 PVC can be threaded, is corrosion resistant and has a smooth interior but is not as flexible as polyethylene. It may become brittle and rupture if pipe and contents freeze.

6-5.6 Concrete.

Concrete pipes may be considered. Reinforced concrete is usually used for large transmission lines. Concrete pipe is at higher risk for shipment damage or loss.

6-5.7 Pre-Insulated Pipe.

Pre-insulated pipe units are composed of an inner-core pipe, insulation, and outer jacket, heat tracing may be provided for freeze protection. The pipe materials described above, with the exception of concrete, are typically insulated with high density urethane foam at the factory and covered with either a steel, HDPE, or aluminum jacket, depending on the final conditions of exposure in the field. The jacketing protects the insulation from moisture and mechanical damage. Prefabricated pipe units are shipped to the job site with preformed half shells of urethane insulation for the joints. Heat shrink sleeves or special tape is used to complete the field joint when HDPE is used as the outer jacket. Pipe insulation, such as spray foam, maybe done on-site, but cost and quality control must be considered. Factory prefabrication usually ensures better quality insulation. Exceptions are appurtenances, such as hydrants, where foamed-in-place urethanes are commonly employed. Design calculations to determine insulation thickness and insulation materials are described in Chapter 12. ASCE *Cold Regions Utilities Monograph*, Section A.6, provides more information and an expanded discussion on pre-insulated pipes.

6-6 APPURTENANCES.

On a typical water distribution system, these include hydrants and valves. ASCE *Cold Regions Utilities Monograph,* Section 8.8, provides additional considerations for design of these structures.

6-6.1 Hydrants.

Hydrants must be dry-barrel type conforming to AWWA C502. Hydrants installed on an aboveground water main must have an insulated hydrant box specially designed and fabricated to fit the equipment to be used at the specific location. Insulate the hydrant barrel and wrap the hydrants in polyethylene sheeting prior to backfill to prevent frost heave damage; hydrants that are insulated and jacketed with a polyurea coating do not need polyethylene sheeting wrap for frost jacking. After use, during the winter months or when ambient air temperatures at the hydrant location drop below freezing at any point during the day, the hydrant must be pumped out since frozen ground conditions may prevent self-draining. Alternate freeze protections such as secondary heat tracing or food grade propylene glycol protection are options if hydrants cannot be reliably drained or pumped out. In-ground or buried hydrants on airfields require special consideration to prevent freezing and maintain service. Consult Installation, District or Command engineering and operations staff. See Appendix A, paragraph A-7.4, for references that provide example schematics of hydrants.

For a buried water main, install hydrants directly on the main to minimize the possibility of freezing, with a frost-isolating gasket between the hydrant barrel and the tee into the main. Isolating valves are typically put in the main or both sides of the tee to allow for hydrant repair or replacement. The vertical riser from the main to the hydrant base should be as short as possible, limited to the tee's branch length plus the height of a flange connected to it, and freeze protected so that heat conducted from the water flowing in the main can keep the hydrant from freezing. If laterals are used, their length must be minimized. Dead-end segments at hydrants run the risk of water quality issues without regular operator flushing programs. Typically, the maximum dead-end leg length is 10 ft (3 m) to prevent freezing for systems that rely on depth of bury rather than a recirculation system. Consider installing heat trace if secondary freeze protection is required. ASCE *Cold Regions Utilities Monograph,* Section 8.8.1, provides additional considerations for design of these structures.

[C] 6-6.1 Water main alignment can be selected to minimize or eliminate dead-end legs to hydrants, by placing the hydrant tee in the flow path of the main, with the hydrant directly above the tee. This will eliminate any horizontal piping but may require additional mainline fittings to accomplish.

6-6.2 Valves.

The riser stem for buried valves is insulated in a manner similar to that described above for hydrants. Nonrising stem-gate valves are most practical for buried or completely insulated locations.

6-7 BACKUP FREEZE PROTECTION AND THAWING.

Backup freeze protection is provided by reserve systems to either prevent freezing if circulation stops in the lines or to thaw the system if freezing occurs. The procedures apply to both main lines and service piping, and wastewater systems. They include heat tracing to prevent freezing, and various methods to thaw systems. ASCE *Cold Regions Utilities Monograph,* Section 8.9 and Appendix D, provide additional information for heat tracing and thawing of frozen systems.

6-7.1 Heat Trace Systems.

A heat trace system is the standard backup used in most piped water distribution systems. Constant monitoring is required on such electrical systems if they are to perform as intended. Easy replacement of heat trace lines should be a standard feature of any system. For under insulation heat trace systems self-regulating heat trace designs are the preferred solution. With these systems, end of line illuminated terminations provides easy verification that the system is functioning and are preferred where a simple monitoring method is required. Some heat trace can generate higher temperatures than HDPE and PVC can withstand; however, pre-insulated HDPE piping is available with the appropriate heat trace pre-installed in channels under the insulation.

> [C] 6-7.1 If the controlling thermostats are not working properly or the sensors are in the wrong location, either too much electric energy will be expended at great cost, or the heat trace will fail to do its job when required. If the heat trace is in a channel or tube, it is typically easy to replace by exposing both ends. When it is placed under the insulation and applied directly to the pipe, replacement is very difficult.

6-7.2 Steam or Hot Water Thawing.

Steam or hot water thawing systems can be used with most types of pipe materials but are not recommended for plastic pipes which could melt or be damaged.

> [C] 6-7.2 These systems use a source of steam or hot water introduced under pressure into the frozen pipe via a suitable hose or tube to thaw out the pipe. Units specifically designed for this purpose are available commercially.

6-7.3 Service Line Thawing.

[C] 6-7.3 Small-diameter service lines of any material may be thawed by pushing a flexible 0.5 inch (1.27 cm) or smaller plastic tube into the frozen pipe while pumping warm water into the tube. Water pressure can be obtained from a nearby building, either directly or by connecting to the building plumbing. A conventional hand pump filled with warm water can also be used. Commercial units produce a pulsating stream of water to pump warm water through a tube attached to the frozen pipe by a special fitting to ease installation and reduce spillage.

6-7.4 Electrical Resistance Thawing.

ASCE *Cold Regions Utilities Monograph,* Section D.3 provides additional discussion.

[C] 6-7.4 Historically, the thawing of metal pipes using electricity was fairly common, and equipment specifically designed for this purpose is available commercially. This method is still in use in some rural areas, but not typically on larger military Installations. Caution must be exercised to prevent electrical or fire mishaps.

This Page Intentionally Left Blank

CHAPTER 7 WASTEWATER COLLECTION

7-1 GENERAL.

See UFC 3-240-01 for the basic criteria for design of wastewater collection or sanitary sewer systems for military facilities. The unique aspects of design and construction of these systems in cold regions are discussed in this section. In addition, some further detail is included on the use of pressure and vacuum sewers since the flat terrain and permafrost may make it difficult to design a conventional gravity sewer system in the Arctic. Combined utility systems, or utilidors, are covered in Chapter 8. Table 7-1 compares the characteristics of gravity, vacuum, and pressure systems for use in cold regions. Vehicle hauling of water and wastewater is still used at some remote sites, but generally, military facilities are serviced by piped collection systems. Normally, a conventional gravity sewer system has the lowest life cycle cost and should be used whenever practicable. Gravity systems have an additional advantage over pressure systems in that they seldom flow full. As a result, gravity pipes are less likely to break if freezing occurs.

Table 7-1 Characteristics of Wastewater Collection Systems

Type	Soil Conditions	Desirable Topography	Economics	Other
Gravity	Nonfrost-susceptible or slightly frost-susceptible with gravel backfill	Gently sloping to prevent deep cuts or lift stations	Initial construction costs high, but operational costs low unless aboveground or lift stations used	Low maintenance; must have adequate grade; larger diameter pipes required; flushing of low-use lines may be required
Vacuum	Most useful for poor soils or bedrock conditions; can be used with any soil type	Level or gently sloping	Initial construction costs moderately high; operational costs moderately high	Low water use requirement; traps every 300 ft; must have central holding tank for each 30 to 50 services with additional pumps to pump waste to treatment facilities; can separate gray and black water; uses small pipes; no exfiltration
Pressure	Most useful for frost susceptible or bedrock soils; can be used with any soil type	Level to hilly topography	Initial construction costs moderate; operational costs moderately high	Low water use, if low water use fixtures are installed; number of services not limited; no infiltration; uses small pipes

7-2 DESIGN CONSIDERATIONS.

As described in Chapter 2, the location of the pipe, above or below ground, is critical to satisfactory performance. An aboveground location with the piping installed on piles may be necessary because of soil conditions. However, the grades necessary for gravity flow are difficult to maintain with aboveground sewers. Aboveground sewers also hinder transportation, block surface drainage and snow removal, have high heat losses, and are more susceptible to vandalism.

[C] 7-2 The operation and maintenance costs for aboveground systems are about three times higher than those for similar systems buried underground. Aboveground construction costs for a single pipe depend on the foundations required. If the pipe can be laid directly on the surface, construction costs may be 20 to 40 percent of that required for the same pipe installed on piling.

7-2.1 Sewage Temperatures.

Domestic wastewater from dormitories, dining halls, and family housing on military installations in the cold regions will range from 50 to 60°F (10 to 16°C) at the source. Wastewater from facilities not having hot water heaters can be as low as 35°F (2°C). The temperature of wastewater in utilidors (Chapter 8) can be increased if steam or hot water lines are also included in the utility package. However, if temperatures are too high, hydrogen sulfide may form, requiring hydrogen peroxide injection. The thermal design of the sewer piping (Chapter 12) must include these wastewater temperatures for cost-effectiveness. Do not admit storm water to sewers in cold regions.

[C] 7-2.1 Storm water lowers the temperature of the wastewater and increases the cost of pumping, treatment, and disposal.

7-2.2 Pipe Materials.

Select materials sewer systems in accordance with the criteria given in UFC 3-240-01 and UFGS 33 30 00. Chapter 6, paragraph 6-5 discusses the cold climate aspects of these materials.

7-3 APPURTENANCES.

Appurtenances include manholes, cleanouts, building or service connections, and flushing siphons.

7-3.1 Manholes.

Manholes or access holes require protection from frost heaving because of uplift forces on the sides or under the structures. Polyethylene sheeting around the outside of the manhole can prevent bonding of the soil to the structure and thereby reduce damage from frost heaving. Insulate manholes around the outside, and appropriately treat the insulation to prevent moisture damage. Provide an insulated cover over the wastewater chamber to further reduce heat loss. A firm foundation is essential to prevent settlement and may require either installation of pilings under the manhole or over excavation and backfill with nonfrost susceptible soil (sand and gravel). If a poured-in-place concrete invert is used in the manhole and permafrost is at a relatively shallow depth, place the concrete on insulation board to reduce the downward heat losses. Space of manholes in accordance with UFC 3-240-01. Solid manhole covers are required to prevent entry of surface water. Any electrical device in a manhole must be electrically rated as well as be sealed should a manhole be flooded—this may include thermostatic controls or heat tracing.

[C] 7-3.1 Manholes provide multidirectional access for sewer maintenance, but confined space is required for access. Manhole flow channels may either be traditional open channels or closed piped through the manhole.

7-3.2 Cleanouts.

Cleanouts are typically used in building connections and, in some cases, are installed in place of manholes as described in UFC 3-240-01. Like manholes, they require protection from frost heave uplift forces. Wrapping polyethylene sheeting around the outside of the cleanout riser and the use of non-frost susceptible backfill soils can prevent bonding of the soil to the riser and thereby reduce damage from frost heaving.

[C] 7-3.2 Cleanouts provide above grade access to sewer mains for inspection and obstruction clearing without the need for confined space access and significantly less capital cost to install. Cleanouts are directional for access, one direction, unless a bidirectional cleanout is installed. They are typically provided at large changes in sewer direction and at intervals along a main or service. The same thermal design considerations are needed to prevent transmitting cold into the sewer main, but supplemental heating may not be needed for all installations.

7-3.3 Siphons.

Avoid sewers subject to low flows and velocities, if possible, in the system design since a trickle flow may result in gradual freezing and ice build-up in the pipe. If such sewers are necessary, then a pump station or a flushing siphon must be included. These must be designed to discharge a slug of relatively warm water into the system. If there is insufficient wastewater available to operate the siphon frequently enough to avoid freezing, it may be necessary to add water, with proper precautions taken to prohibit cross connections.

7-3.4 Building Connections.

Building connections for gravity sewer systems in cold regions may be through either the wall or floor of the building. Special attention to prevent freezing of water and wastewater connections and separation or damage because of differential settlement is required, especially for buildings with ventilated spaces beneath the structure. For floor penetrations, avoid bringing the riser up into the building less than 5 ft (1.5 m) from any exterior wall to prevent freezing.

[C] 7-3.4 Wall penetrations are more flexible than the floor penetrations and will permit more differential settlement without damage to the sewer line.

7-4 PUMP STATIONS.

The basic hydraulic design of pumping stations must be in accordance with UFC 3-240-01. Special requirements and concerns for use in cold regions are discussed below. See ASCE *Cold Regions Utilities Monograph,* Section 9.7, for further discussion.

7-4.1 Insulation.

Insulate the outside of the station structure with at least 3 inches (7.6 cm) of urethane or polystyrene, with an outer covering to protect the insulation from moisture. Place insulation beneath the station when permafrost is present at a shallow depth to prevent settling because of ground thaw. Polyethylene sheeting or other bond breakers are required to reduce frost jacking in the active layer. If thawing and settling under the station are anticipated, pile foundations extending well into permafrost may be required. All stations must be attached to concrete base slabs to provide sufficient weight to overcome the buoyancy of the station. Pressure couplings or flexible connections are required for the inlet and outlet pipes to prevent station differential movement from breaking the lines.

7-4.2 Condensation.

A prefabricated, below-grade pumping station must not be installed without immediately placing the heater and dehumidifier into operation. Condensation caused by the surrounding cold earth could corrode the controls and electrical equipment before the system is put into service.

7-4.3 Multiple Units.

Duplicate all critical components, such as pumps and compressors, in pump stations serving base infrastructure where service disruption is unacceptable. Stations must have at least two pumps for redundancy with each pump capable of providing at least 2/3 of required capacity of the pump, lift station, or systems it serves. A single pump may be used for a wastewater pumping station serving extremely low flows, such as a remote gate house, when justification is provided to and approved by the Installation engineering staff.

Where possible, maintain replacement equipment on the shelf for backup. If not possible, service kits need to be stored on-site to repair equipment. Electrical components such as motor starters are often overlooked and should be included in backups.

7-4.4 Alarms.

Provide alarms in accordance with the requirements of UFC 3-240-01. In addition, set alarms to warn of freezing temperatures in the station and to warn of sump pump malfunctions. Alarms must be annunciated as required in UFC 3-240-01. Consult Installation, District or Command engineering and operations staff for specific requirements.

Alarms should include, but are not limited to, the following:

- high or critical high level
- low or critical low level
- low wastewater temperature
- pump trouble
- water in motor (if pump is equipped with sensor)
- heating system or HVAC trouble
- atmosphere detection or gas detector alarm

7-4.5 Standby Power.

Because of the dangers of freezing associated with extremely low temperatures, provide standby power facilities for each major pump station. Where multiple pump installations are required, as discussed in paragraph 7-4.3, it is implicit that the site is more critical in nature and requires backup power or contingency for portable backup power connection. Otherwise, consult the Installation engineering staff to evaluate the need for standby power for smaller pump stations depending on the nature of the collection area.

7-4.6 Maintenance.

Extend all entrance manholes sufficiently above the ground surface to be above any flooding or snow drifts. Supply all pump stations with devices for measuring flow rates. Corrosion protection must be provided in accordance with UFC 3-240-01. Sacrificial anode type systems do not work well when the ground surrounding the anode or pump station is frozen.

7-4.7 Force Mains.

Force mains are pressure lines into which the sewage pumps discharge. They must comply with all temperate region standards required in UFC 3-240-01. Design force mains to have scour velocities during pumping (2.5 to 3.5 ft per second [0.76 to 1.1 m per second]) and to drain between pumping cycles. This can be accomplished by an electrically operated ball valve in the line to allow drainage back into the wet well between pump cycles. If this is not possible, the line must be placed in a heated utilidor, or heat traced. Another option would be to time the pumping cycle so that wastes stay in the line for a calculated period, and to size the wet well at the pump station to hold at least the volume of the force main.

[C] 7-4.7 Consideration may be given to increasing the flowrate or reducing pipe size. Doubling velocity through the pipe approximates the same flowrate through the pipe with a single pipe diameter reduction. This would not change the heat flux to the pipe appreciably, but it halves the contact time a slug of wastewater is in contact with the pipeline for the perceived purpose of freeze protection. The designer needs to determine which is more important: transferring heat to the force main pipe system to maintain a thawed condition or minimizing the resident time of wastewater in the main.

7-5 PRESSURE SEWERS.

The hydraulic design of pressure sewer systems is not unique to the cold regions, use criteria found in UFC 3-240-01. Design the pressure piping to drain by gravity to a low point or sump in case the system must be shut down in the winter. The grinder pump units, holding tanks, and septic tanks must have a firm foundation and must be protected from frost heaving as discussed previously for manholes (paragraph 7-3.1). Water conservation measures in each of the buildings served are required to reduce the costs of equipment and energy for pumping.

[C] 7-5 The main advantage of pressure sewers is that specific grades need not be maintained throughout the system. Typically, grinder pump units are used so that smaller diameter pipes can be installed without the risk of clogging. Grinder pumps may be installed in each building or in a holding tank serving several buildings. An alternative to grinder pumps is to install a two-compartment septic tank with a conventional submersible pump in the second compartment.

7-6 VACUUM SEWERS.

Vacuum sewers do not depend on a specific grade for successful operation. They operate at a vacuum of 8–10 psi (55–69 kPa), and so are limited to an elevation difference of 15 to 20 ft (4.6 to 6.1 m) within the system. The hydraulic design is not unique to the cold regions. The concept depends on providing traps in the system to maintain a vacuum. Since these traps are full of water for extended periods, they must be insulated, heated, or both, for extreme low temperature conditions. The traps should also be drainable under emergency situations.

CHAPTER 8 WASTEWATER TREATMENT

8-1 GENERAL.

See UFC 3-240-01 for basic design criteria for domestic wastewater treatment systems. UFC 3-240-01, paragraph A-6.6, also includes special considerations for cold and Arctic locations outside the U.S. This chapter provides additional information and requirements on those aspects unique to cold regions and presents general design criteria for treatment systems most commonly used in the Arctic and Subarctic. More detailed information is provided by ASCE *Cold Regions Utilities Monograph*, Section 10. *Prevention of Freezing and Other Cold Weather Problems at Wastewater Treatment Faculties* provides design information and case studies on the prevention of freezing and other issues for cold regions wastewater treatment facilities.

8-2 WASTEWATER CHARACTERISTICS.

Wastewater characteristics in the cold regions are generally different from those in temperate regions with respect to quantity, quality, and temperature. The total quantity of wastewater discharged at military Installations in cold regions tends to be very close to the quantity supplied for potable water use since there is little external or industrial use, storm water is usually excluded, and groundwater infiltration is not a factor in the newer insulated and tightly sealed pipe systems. As a result, wastewater in the Arctic and Subarctic tends to be more domestic in nature and higher in strength than at comparable facilities elsewhere.

8-2.1 Quantity.

Determine design flows by a specific analysis of the Installation. The population equivalents and capacity factors presented in UFC 3-240-01 tend to overestimate the volume of flow to be expected at remote Installations in the Arctic and Subarctic with small populations. This may result in operational problems with some biological treatment units. Selection of less sensitive processes or use of two smaller units in parallel avoids the problem if the design cannot be determined by actual flows.

8-2.2 Quality.

The mass of pollutants in cold region wastewaters is comparable to that in other locations, but the concentration will generally be higher because of lower water usage rates.

8-2.3 Temperature.

The wastewater temperature at many cold region facilities tends to be at least 50°F (10°C) owing to transmission in insulated and sometimes heated lines. Consider the heat available in this incoming wastewater during process design.

8-2.4 Flow Variations.

The diurnal flow pattern at military Installations tends to be the same regardless of climate.

8-3 UNIT OPERATIONS.

Practically all the basic unit operations used in wastewater treatment are affected by temperature through liquid viscosity changes or changes in chemical reaction rates. An analysis during the early stages of design is required to predict the thermal status of major components in the treatment system. If wastewater temperatures above 50°F (10°C) are expected and the entire system is to be housed in a heated building, then conventional practice as defined in the UFC 3-240-1 must be used. If temperatures below 50°F (10°C) are expected or significant temperature changes are allowed to occur within the system, then adjustments are necessary for the design of the unit operations. ASCE *Cold Regions Utilities Monograph,* Section 10.4.2, provides additional information on design adjustments required for mixing, sedimentation, filtration, gas transfer, and adsorption and chemical reaction operations for wastewater treatment facilities in the Arctic and Subarctic.

8-4 UNIT PROCESSES.

Unit processes include preliminary treatment, primary treatment, and a variety of biological or chemical processes for secondary treatment. All are subject to temperature influences on their performance. ASCE *Cold Regions Utilities Monograph,* Section 10.4.3, provides additional information.

8-4.1 Preliminary Treatment.

Preliminary treatment commonly includes screening, grit and scum removal and grinding, or comminution. Conventional equipment can be used, and basic design criteria must be in accordance with UFC 3-240-1 with appropriate adjustments in grit chamber detention time for the projected operating temperatures. Construct protective, insulated shelters over trash racks, bar screens, and grit chambers to avoid icing problems in the winter. Where structures are unheated, condensation and icing may occur on the inner surfaces of exterior walls. In these instances, select materials and coatings accordingly, and locate controls on dry interior walls or in another remote location.

8-4.2 Primary Treatment.

Adjust the design detention time of primary clarifiers for the projected operating temperatures. In general, design tanks in the conventional manner as buried or partially buried structures. However, the presence of shallow permafrost, particularly ice-rich, fine textured soils, requires aboveground tanks or special foundations (see UFC 3-130-03). Temporary covers for heat retention purposes are recommended for winter operation of buried or exposed tanks in the Arctic and Subarctic. Tanks above grade also require sidewall insulation or enclosure in a protective structure.

Mechanical measures for primary treatment are also commercially available, such as microscreens and rotating belt filters. These technologies have been used in indoor wastewater treatment applications for years and can achieve primary treatment in about 1/10th the footprint of a conventional gravity settling basin. These systems require a heated, insulated building.

8-4.3 Secondary Treatment

In cold regions where mechanical treatment is used, the biological treatment systems deployed are often similar to warm weather processes, with additional insulation or housed entirely inside of a heated building. Packaged treatment systems are commercially available and must be housed in appropriately insulated and climate-controlled buildings. Certification may be required for the operators of these systems.

Biological systems for secondary treatment that have been successfully used in cold climates include lagoons or ponds, both facultative and aerated, several activated sludge variations and attached growth systems. Each has special requirements for successful cold regions performance.

[C] 8-4.3 In general, biological alternatives using outdoor lagoons require a large footprint, but will have minimal operations and maintenance needs and offer moderately good effluent quality. Biological treatment using indoor systems require a much smaller footprint; will have higher operations, maintenance, and electrical power needs, with the associated costs; and provide superior effluent quality.

8-4.3.1 Lagoons.

8-4.3.1.1 Facultative.

The treatment performance of facultative lagoons during winter is greatly reduced by low temperatures and by ice and snow cover, with removal rates roughly comparable to those of primary treatment alone. Total retention of wastewater during winter months may be required with controlled discharge commencing in late spring and in early fall. Standard construction techniques can be used except where permafrost is present. Fine textured, ice-rich permafrost must be avoided if possible since thawing can result in failure or at least require frequent repair of dikes and berms. Lagoons may be installed in permafrost that is physically stable after thawing. Additional design and construction information is provided in ASCE *Cold Regions Utilities Monograph*, Section 10.4.3.

[C] 8-4.3.1.1 Where sufficient land area and suitable soil conditions exist, facultative lagoons are the most economical alternative in the cold regions because of their low construction cost and simplicity of operation.

8-4.3.1.2 Aerated.

Partially mixed aerated lagoons, also called facultative-aerated ponds, have been used successfully in cold regions. Basic process design criteria are similar to those of temperate regions. Additional design and construction information is provided in ASCE *Cold Regions Utilities Monograph*, Section 10.4.3.

[C] 8-4.3.1.2 Aerated lagoons require less land area but more energy and more operational attention than facultative lagoons.

8-4.3.2 Treatment Plants.

8-4.3.2.1 Activated Sludge Systems.

Activated sludge systems that have been successfully used in cold regions include conventional and pure-oxygen activated sludge, contact stabilization, and extended aeration concepts in both package plants and oxidation ditches. Basic design criteria for these processes must be in accordance with UFC 3-240-1. When the system is enclosed and incoming wastewater temperatures exceed 50°F (10°C), basic design criteria apply. Special measures are necessary only when incoming wastewaters are below 50°F (10°C) or if a significant temperature drop is expected within the system. All the biological reaction rates involved are temperature sensitive and must be adjusted using Equation 8-1.

Equation 8-1. Biological Reaction Rate Coefficient

$$k_T = k_{20}\theta^{(T-20)}$$

Where:
k_T = reaction rate coefficient at the temperature T
k_{20} = reaction rate at 20°C (68°F)
θ = temperature coefficient
T = temperature in °C

Use the θ values given in Table 8-1 in Equation 8-1 to adjust the reaction rate for the design wastewater temperature. Additional design and construction information is provided in ASCE *Cold Regions Utilities Monograph,* Section 10.4.3.

8-4.3.2.2 Attached Growth Systems.

These include trickling filters, rotating biological discs, and other devices with plastic, rock, or wooden media. Effective treatment depends on maintaining a thin film of liquid over the media. These units are susceptible to freezing and must therefore be enclosed in a protective structure. Use criteria from UFC 3-240-01 for design, along with the temperature coefficients given in Table 8-1. The need for additional heat in the protective structure depends on the temperature of incoming wastewater and on the degree of treatment required. Additional design and construction information is provided in ASCE *Cold Regions Utilities Monograph,* Section 10.4.3.

Table 8-1 Temperature Coefficients for Biological Treatment

Process	θ	**Temperature Range (°F)**
Oxidation pond	1.072–1.085	37–95
Facultative lagoon	1.06–1.18	39–86
Anaerobic lagoon	1.08–1.10	41–86
Aerated lagoon	1.026–1.058	36–86
Activated sludge	1.00–1.041	39–113
Extended aeration	1.037	50–86
Trickling filter (conventional)	1.035	50–95
Biofilter (plastic media)	1.018	–
Rotating disc		
Direct filter recirculation	1.009	50–86
Final effluent recirculation	1.009	55+
Final effluent recirculation	1.032	40–55

8-5 SLUDGE MANAGEMENT.

Large-scale, conventional treatment facilities and those operating in a heated environment can be expected to produce sludge at rates similar to those of conventional temperate zone practice. Thickening, digestion, and dewatering of sludge all follow temperate zone practice in accordance with UFC 3-240-01.

8-5.1 Freeze-thaw Dewatering.

Sludge from water or wastewater treatment operations can be flooded onto conventional open sand drying beds in layers and allowed to freeze. It is important to avoid rewetting the sludge once it has been freeze-thawed by providing a roof overhead or physically moving the solids around after they have been frozen.

8-5.1.1 Depth of Sludge.

Calculate the depth of sludge that can be frozen (or thawed) with Equation 8-2.

Equation 8-2. Application Depth of Frozen Sludge

$$X = m_s(I_A)^{1/2}$$

Where:
X = depth of sludge that can be frozen (inches)
m_s = proportionality coefficient for sludge, use 0.6 for sludge concentrations in range of 0–7% solids (higher concentrations are difficult to spread on bed) (°F-days)$^{-1/2}$
I_A = Air freezing (or thawing) index (°F-days)—use warmest winter of record for freezing calculations

Sludge with an undrainable jelly-like consistency will dewater immediately upon thawing and then have a granular consistency. Solids concentrations of 20–25 percent immediately after thawing are typical and after a few more weeks of drying will approach 50 percent.

8-5.1.2 Repeated Applications.

The total depth of sludge that can be frozen is also related to the depth of frost penetration that will occur in a particular location. Repeated applications in thin layers are recommended to ensure that each layer freezes completely. Use Equation 8-3 to estimate the potential total depth of sludge that could be frozen (applied in 3-inch [7.6-cm] layers) if the maximum depth of frost penetration for a site is known.

Equation 8-3. Potential Total Depth of Frozen Sludge

$$\Sigma X = 1.76(f_p) - 40$$

Where:
ΣX = total depth of sludge that could be frozen in 3-inch (7.6-cm) layers (inches)
f_P = maximum depth of frost penetration for area (inches)

[C] 8-5.1 At most facilities it is not be cost effective to depend entirely on freezing since this would require sludge storage during the warmer months. The optimum design to avoid storage determines the amount of material that can be frozen and then thawed by early summer so that the beds can be used in the conventional drying mode for the balance of the warm season.

8-5.2 Sludge Disposal.

Landfills or land application of sludge are the most appropriate techniques for disposal in cold regions. Temporary sludge storage will be necessary where winter conditions or frozen ground prevents surface application or landfill operations. Disposal must be in accordance with local environmental regulations.

8-6 OUTFALLS.

Outfall structures require special consideration to prevent freezing of the effluent and to prevent structural damage from ice in the receiving waters. In some cases, these problems can be avoided by designing for seasonal discharge. However, an unused outfall is still exposed to damage by ice in the winter and during spring thaw. Insulate and heat-trace exposed outfall piping. The thermal design must be in accordance with Chapter 12. A submerged outfall is recommended wherever possible. However, in shallow streams the pipe must be protected from ice scour that can occur during spring break-up. If possible, install the pipe underground with the outlet completely submerged in water and below the maximum penetration depth of winter ice. If these conditions cannot be satisfied an elevated outfall is required. Design the support piling in accordance with UFC 3-130-03 to resist the uplift forces generated by a floating ice sheet. This is particularly critical at coastal locations with significant tidal action. It is usually not practical to design simple pile supports to resist the lateral forces from ice movements during spring break up. Use break-away couplings to prevent complete destruction of the outfall structure. Design elevated outfalls, in general, to discharge on top of the ice since an open water surface cannot always be maintained. Most of the effluent will then freeze and form a large mound of ice as the winter progresses.

8-7 ALTERNATIVES TO TREATMENT AND DISPOSAL.

At many remote Installations that have small populations or with intermittent usage, it may not be cost effective or technically feasible to construct one of the treatment or disposal options discussed above. Consider small-scale on-site systems that may be feasible for these situations. Conventional septic tanks and soil absorption systems have been used throughout Alaska with mixed results. Sludge accumulates at high rates in septic tanks in low temperature soils. Annual sludge removal is required to avoid clogging problems in the adsorption field. Design procedures are similar to conventional practice for these systems. Insulation of the septic tank is desirable and recommended for intermittently operated systems. Where feasible, deep seepage pits are preferred over conventional absorption fields because of their greater thermal efficiency. In locations where in-ground disposal is not practical or feasible, vault storage and truck haul may be required.

This Page Intentionally Left Blank

CHAPTER 9 UTILIDORS

9-1 GENERAL

A utilidor is a structure that contains multiple utility systems such as water, sanitary sewer, fuel oil, gas, electrical power, communications, and central heating in various combinations or, in some cases, all together. The term is often applied to aboveground insulated water and wastewater piping as well. They are commonly used at military Installations and civilian communities in the North American Arctic. Utilidors may be constructed above- or belowground, or at ground level, and range in size from a simple insulated conduit to a walk-through passageway. Their size and shape are determined by considering the number and sizes of the pipes they will contain, their location relative to the ground surface, and the ease of access desired for maintenance or repairs. A 1981 survey of Fort Wainwright, Alaska reported approximately 200 configurations of utilidors with sizes ranging from 1 ft by 1 ft to 7 ft by 9 ft (30 cm by 30 cm to 2 m by 3 m), and pipe sizes varying from 1 inch to 24 inch (2.54 cm to 61 cm) in diameter.[1] The ASCE *Cold Regions Utilities Monograph,* Section 11, provides additional discussion of utilidors and their design considerations.

9-2 DESIGN CONSIDERATIONS.

Use Chapter 12 procedures for the thermal design of utilidors. Design foundations in accordance with UFC 3-130-3. Both designs should consider the types of utilities to be included. The inclusion of power, telephone, and gas lines, along with water and sewer pipes in a utilidor is common, but the overall utilidor design must account for the interactions between these components. Locate the heat sources for freeze protection near the bottom of large utilidors, if possible, to ensure distribution of heat.

The installation of pipe identification markers or stenciling is recommended within manholes. Flanged elbows or pipes must be large enough to insert cleaning or thawing equipment. Standard fittings or smaller pipes do not provide adequate access in both directions. Figure 9-1 illustrates cross sections of two typical utilidors. Utilidors may be prefabricated. When transport methods permit, prefabrication of the major utilidor components is recommended to reduce construction costs in the field.

[C] 9.2 The inclusion of central heating lines in utilidors is often beneficial. Their heat losses are usually great enough to protect the water and sewage pipes from freezing, but the utilidor is most often larger to provide continuous easy access to steam and condensate lines, and therefore, construction costs will increase. Problems also occur because this heat source operates all or most of the year. In the summer, undesirably high domestic water supply temperatures may result because of exposure to the excess heat (>80°F [>27°C]). Thermal stratification can cause freezing of the lower pipes in large utilidors even when the average air temperature is above freezing.

[1] *Losses from the Fort Wainwright Heat Distribution System*, Phetteplace et al.

9-2.1 Materials.

It is critically important to calculate thermal expansion and contraction of the various types of piping material within the utilidor. Unlike buried pipes, pipes located in a utilidor can experience a large temperature range throughout the year, especially if steam or condensate piping are not operational year-round. Expansion joints or flexible couplings may be required to prevent a rupture, major leak, or pipe anchor failure.

9-2.2 Insulation.

Separate insulation of domestic water lines is recommended to maintain acceptable cold-water temperatures for domestic use, and to prevent condensation and pipe corrosion. Do not install insulation on the hydrant lateral piping between the water main connection and the riser penetration through the utilidor roof.

9-2.3 Water and Sewer Line Proximity.

For Installations in the state of Alaska, placement of water and sewer lines (including sump drain lines) within a single utilidor requires a waiver from the State of Alaska, Department of Environmental Conservation (ADEC) under *Standard 18 AAC 80, Drinking Water.* This is a part of the standard permitting process in the state of Alaska (Section 2-3.2). When both water and sewage lines are exposed in the same utilidor, the sewer access cleanouts must be sealed to prevent cross contamination.

9-3 MOLD.

Utilidors are kept warm for water and sewer utility piping. They are normally dry unless a leak or infiltration has occurred. Consider low point drains or positive ventilation in walk-through passages. For box or pipe utilidors use closed cell insulation with a moisture barrier to keep moisture out of the foam. Polyureas or plastic resist mold formation if they are clean and free of dirt or other materials.

[C] 9.3 Mold growth is inhibited by keeping utilidors clean and disinfected.

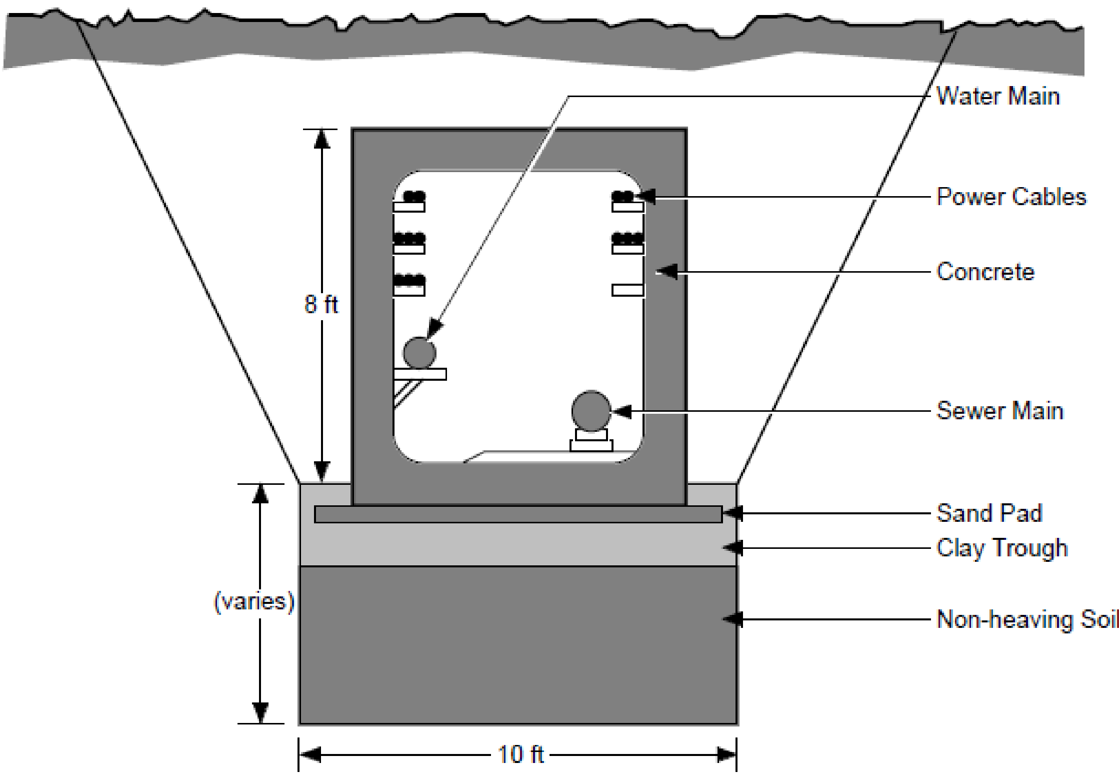
9-4 MAINTENANCE CONSIDERATIONS.

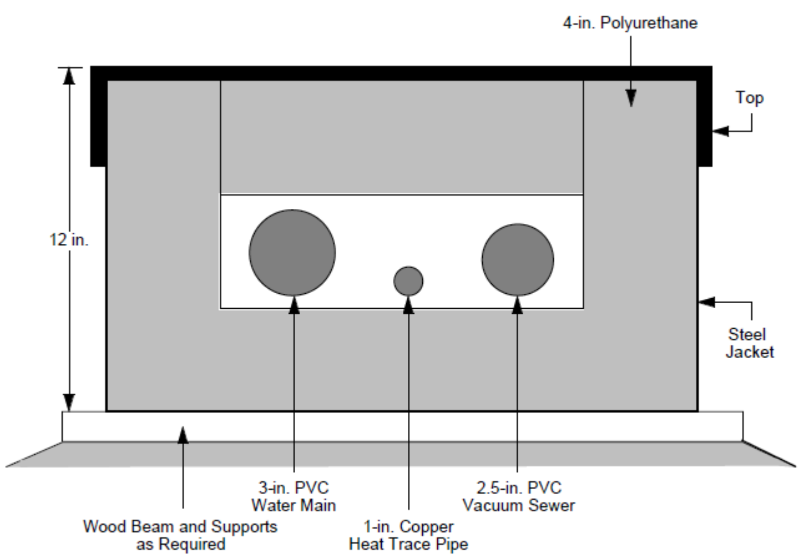
Maintenance and inspection should be determined by construction materials and the following:

- Above grade or at grade—If operators perform daily service rounds, the system should be observed during those activities. General conditions should be inspected and documented monthly. Program maintenance based on surface finish conditions and corrosion observations. Base mechanical equipment maintenance on manufacturer’s recommendations.
- Buried—If the utilidor is a walk-through passage, operators should review conditions during daily rounds and perform monthly inspections. Pipe or

box systems are difficult to access. Buried utilities should be inspected and cleaned during any maintenance activity.

Figure 9-1 Example Cross Sections of Utilidors Constructed in the Arctic[2]





[2] *Two-Dimensional Analysis of Natural Convection and Radiation in Utilidors,* Richmond.

This Page Intentionally Left Blank

CHAPTER 10 FIRE PROTECTION

10-1 GENERAL.

Use UFC 3-600-01 for fire protection requirements. The ASCE *Cold Regions Utilities Monograph*, Section 15, provides additional information.

10-2 HYDRANTS.

Cold regions hydrant features were discussed in paragraph 6-6.1. Hydrants must be accessible and operable at all times regardless of frost depth, snow cover, and temperature.

10-3 TRUCK SYSTEMS.

Where winter operation in the Arctic requires tank trucks on standby, provide heated garages and a freeze-protected water point with a pumping capability of at least 350 to 500 gallons per minute (1,325 to 1,900 liters per minute) for refilling the tank trucks if hydrants are not available.

[C] 10-3 Historically, motorized fire pumping apparatus with booster tanks and hoses provided protection for remote buildings not serviced by the water distribution system or sprinklers within the facility.

10-4 FIRE PROTECTION SYSTEMS.

Fire protection systems are covered in Chapter 9 of UFC 3-600-01. The use of post-indicating valves on the main lines coming into buildings is not recommended as they act as a thermal bridge to the water lines. Street valves are permitted. Locate the primary shutoff valve inside the building in a room accessible from the exterior per National Fire Protection Association (NFPA) 24. A minimum 1-hour fire rating is required unless otherwise approved by the Installation, District or Command engineering and operations staff.

[C] 10-4 If recirculation and heating systems are used, this may not be an issue.

Foaming equipment will not function at optimum levels in air temperatures below –15°F (–26°C) since aspiration of the foam is not complete. Standard carbon dioxide fire extinguishers will also not function properly at below-freezing temperatures. Dry chemical extinguishers have been used successfully and range in size from hand-held units to large dolly-mounted units containing about 350 pounds (160 kilograms) of chemical. Per paragraph 9-16 of UFC 3-600-01, installation of a new Halon 1301 systems is prohibited except by special approval of Service Signature Authority.

10-5 ALARM SYSTEMS.

Design central alarm systems in accordance with UFC 3-600-01. For Installations with direct digital control (DDC), see UFC 3-410-02. Monitoring and alarm systems must be compatible with the Installation reporting system. Transmit all signals to the fire department and other central alarm centers where appropriate action can be initiated.

[C] 10-5 In many cases, it is advantageous to integrate the systems with other utility system sensors for protection of the water distribution network and sewage transmission lines (see Chapter 6 and Chapter 7).

CHAPTER 11 POWER DISTRIBUTION AND COMMUNICATION SYSTEMS

11-1 GENERAL CONSIDERATIONS.

With a few exceptions, the basic design requirements for wire and cable networks for power transmission and communication systems are not unique to the cold regions. Use UFC 3-501-01, UFC 3-550-01, and the regulatory and industry standards adopted therein, for design of these systems. Power distribution and communication systems must also comply with any specific requirements of the Installation or, for privatized systems, the utility contractor. Special attention is needed to ensure proper grounding in permafrost areas, to maintain stability of towers, poles, guy wires and anchors, and for direct burial of cables.

11-2 GROUNDING.

Soils in both seasonal frost and permafrost areas may not provide acceptable grounding conditions owing to the high electrical resistivity of frozen ground—up to several orders of magnitude higher than that of unfrozen soil. This may require finding areas where soils are less likely to freeze or where the seasonal frost zone or permafrost layer is thinnest and installing ground rods or piles in the warmer soils. *Electrical Grounding in Cold Regions*, by Henry, discusses this further. In some permafrost locations all the facilities are tied together, including electrical wiring; petroleum, oil, and lubricant (POL) piping metal building; POL storage tanks; water and sewer lines; and so on, to form one large grid network. This network is then connected to a water well casing that penetrates the permafrost layer and results in an acceptable ground. If no well casing exists, the grid system is connected to a ground rod that does not penetrate the permafrost. This provides a common floating ground with everything at the same electrical potential. This is an acceptable approach as long as everything is bonded to that common ground. Another possibility is to place a grounding cable grid into a nearby lake or other body of water that does not freeze. The ASCE *Cold Regions Utilities Monograph*, Section 17.5.3, provides additional information on the grounding. All grounding measures must comply with UFC 3-550-01.

11-3 UNDERGROUND SYSTEMS.

Power and communication networks have been successfully installed in the utilidor systems described in Chapter 8. However, some Installations do not install electrical distribution systems within utilidors. Directly burying cables in frost-susceptible soils within the active layer must be carefully considered. Place buried conduits or ducts in nonfrost susceptible backfill materials. Otherwise, place a gravel or other nonfrost-susceptible material pad on the existing ground surface and bury the cables in this new pad if a buried system is required. The gravel pad may also serve as a road or walkway.

Buried cables, or conduit, connected to a wall mounted cabinet may rip the cabinet off the wall because of conduit jacking. Similarly, direct buried cables terminating in a post mounted termination cabinet can be pulled out of their terminations as a result of the post and cabinet being subjected to long term jacking. If jacking conditions are present, provide sufficient cable or flexible conduit slack to permit cable movement and prevent cabinet damage.

[C] 11-3 The freezing and expansion of soils in the active layer may result in structural failure of cables or severe mechanical damage. Oil industry facilities near the Arctic Ocean use direct burial single phase armored cables instead of conductors in conduit for below grade construction.

11-4 AERIAL SYSTEMS.

Ice buildup is a problem for aerial cables, particularly in coastal locations. Preventative measures have included the use of a steel conductor to increase tensile strength and to allow resistance thawing. The major engineering problem with aerial systems in the cold regions is the stability of the supporting towers or poles. The practical effect of frost heave on towers and poles is an upward force to the unit that may result in overstress and mechanical failure or in differential vertical movement between components. It is necessary to design towers and poles to resist these upward forces, or to allow the units to float up and down with the expansion and contraction caused by heaving of the active layer, or to replace the frost-susceptible soils with clean gravel. In many cases, the utility pole will move up due to the heaving forces but cannot return to its original position because of the flow of soil into the void. The net effect is an annual increment of upward movement that will eventually jack the pole out of the ground.

[C] 11-4 The upper soil layer, known as the active zone, goes through a freezing and thawing cycle on an annual basis. In the spring, this zone may go through several freezing cycles because of warm days and cold nights. This freezing causes significant soil expansion, or frost heave, depending on the soil type and moisture content. The expansion is very significant with fine-textured silty soils when a source of unfrozen water is available. Further details on frost heave can be found in UFC 3-130-3.

11-4.1 Poles.

As mentioned in paragraph 11-4, a very strong bond can develop between the frozen soil and the surface of an imbedded power pole. This bond, if developed in the active layer with frost-susceptible soils, will lift the pole out of the ground. This phenomenon is called frost jacking. Wooden poles are commonly used for both power and communications systems. Two measures are commonly taken for permanent construction where permafrost is relatively close (3–5 ft [0.9–1.5 m]) to the surface;

- The pole is sufficiently embedded in permafrost so that the bond developed in that zone can resist the uplift forces due to heaving in the active layer.

- The active zone portion of the hole is backfilled with nonfrost-susceptible materials, or this portion of the pole is wrapped with a 10-mil polyethylene sleeve to prevent development of a bond.

Set poles to a minimum depth of 10 percent of the aboveground height plus another 4 ft (1.2 m) into the permafrost (ASCE *Cold Regions Utilities Monograph,* Section 17.5.3). For example, a 50 ft (15 m) aboveground height would require 9 ft (2.7 m) of embedment. However, this depth may need to be increased to fully prevent frost jacking. Holes for these poles or support piles are made with a drill or soil auger and are made slightly larger (3–4 inch [8–10 cm]) than the diameter of the pole. A slurry of native soil or sand with water is then placed around the pole to the top of the permafrost. This construction is often done in the winter when the active layer is also frozen to allow easier access with minimal environmental disturbance. Rock-filled cribs are used where permafrost is very deep, the rock is very shallow, or for temporary facilities or facilities in support of military operations with a design life of five years or less.

11-4.2 Towers.

Typical designs for tower foundations are gravel pads with footings constructed on frost-susceptible soils or gravel backfill with footings in frost-susceptible soil. Foundations are discussed in UFC 3-130-3.

[C] 11-4.2 Above-surface gravel pads provide some surcharge for resistance to heaving forces, but some vertical movement is likely. At the end of the thaw period, the pad will settle to its original position. The anchors for guyed towers provide the major resistance to uplift and provide lateral stability. If the footings for towers are placed in the frost-susceptible material, they will be moved upward during the heaving phase, but as described in paragraph 11-4.1, the footing will not then settle back to its original position when seasonal thawing is complete. A progressive failure will result because the footing will be moved upward another increment each year until the resistance to overturning is insufficient.

11-4.3 Anchors.

Design anchors for tower guy wires in accordance with UFC 3-130-3. Both grouted and ungrouted anchor types used in temperate climates may also work in areas of seasonal frost or permafrost. However, the embedment depth must be such that the anchor can withstand frost jacking forces within the active layer as well as the design guy line loading. Manufacturers' ratings for design capacities of commercially available earth anchors may be reduced by 75% if placed in thawed soil above the permafrost layer.[1] Install anchors into the permafrost when it exists and is shallow. The active layer

[1] *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost*, Linell and Lobacz.

dynamics will cause loose guy lines unless anchors are firmly installed into the permafrost and below long-term warming thaw depth.

An additional major concern is progressive movement, or creep, of anchors embedded in ice-rich permafrost with temperatures just below the freezing point. Make provisions for adjusting the tension of guy lines in both summer and winter, since the pole, tower, or structure being guyed and anchored may experience heave or settlement quite different from that of the anchors.[2]

11-5 SPECIAL CONSIDERATIONS.

The following other special considerations relate to construction of electrical distribution systems in the cold regions because of responses to low temperatures or other environmental factors:

- Nylon-jacketed conductors (type THWN), when used at low ambient temperatures, tend to experience separation of the insulation from the jacket.
- Molded case circuit breakers and stored potential switches are not always dependable at extremely low temperatures. Consider the alternative use of fuses, if approved by Installation engineering personnel, or supplemental heat provided to raise the ambient temperature of the equipment enclosure.
- Low temperature, special alloy steel is frequently used for transformers, circuit breakers and other exterior electrical distribution apparatus.
- At some Installations, such as Thule Air Force Base (AFB), electric and communication conductors are installed on the ground surface supported by sleepers, as shown in Figure 2-1. Timber sleepers are typically 4 inch by 4 inch by 24 inch (10 cm by 10 cm by 61 cm), and generally spaced 10 to 15 ft (3 to 4.6 m) apart. Conductors are clamped to the sleepers. All the conductors are insulated and armored to protect personnel. This method avoids issues with icing and wind damage and keeps costs low. This type of installation is not recommended on facilities with accompanied personnel, because of potential hazard to children.

[2] Ibid.

CHAPTER 12 THERMAL CONSIDERATIONS

12-1 GENERAL CONSIDERATIONS.

The thermal aspects of utility system designs are among the most critical elements for cold regions systems. The potential problems are failure of pipes due to freezing of water, thaw settlement or heaving of foundation soils, thermal strains and the associated stresses, the cost-effective selection of materials and insulation thicknesses, and economical operation of the system. This chapter presents criteria for the most critical thermal calculations that might be required for design of pipes, utility structures, and appurtenances. Example problems of the use of the thermal consideration equations are given in Appendix C.

EPA-600/8-79-027, Section 15.10; ASCE *Cold Regions Utilities Monograph*, Section 4.7; and Chapter 6, “Heat Transfer Calculations for Piping Systems,” of the ASHRAE *District Heating Guide* provide additional discussion and example problems.

12-2 FREEZING OF PIPES AND TANKS.

Damage or failure occurs due to the expansion of water changing to ice. The hydrostatic pressure on the still-unfrozen liquid can reach several hundred atmospheres, and it is this pressure, not the contact of the ice, which typically causes pipe failure. Prevention of freezing is accomplished via the most cost-effective combination of insulation, heat trace, circulation, and other measures. Insulation alone does not necessarily prevent freezing; it reduces the rate of heat loss and extends the freeze-up time. Small diameter service connections may have a freeze-up time measured in minutes or a few hours. These are the most vulnerable portions of the system and will usually freeze first. Thawing capability is mandatory for these small diameter pipes.

[C] 12-2 There are some methods of insulating (such as foam board) that allow capture of ground heat, such as those employed at Joint Base Elmendorf-Richardson. These systems are sufficient on their own to prevent freezing. References listed in paragraph A-8 discuss these methods.

12-3 THAWING OF FROZEN PIPES.

Remote electrical thawing methods that can be incorporated in the original design include skin effect, impedance, and various resistance wire and commercial heating cable systems. Frozen wells have been thawed by applying a low voltage from a transformer to a copper wire located inside the riser. Once a small annulus is melted, the flow can be restarted, and it will thaw the remaining ice. Chapter 6 discusses thawing of frozen pipes.

12-4 HEAT LOSS FROM PIPES.

The total heat loss and the freeze-up time are dependent on the ambient and internal temperatures in the pipe system. Aboveground piping systems must be designed for the lowest expected air temperatures, which range from –40 to –75°F (–40 to –59°C). These extreme surface temperatures are attenuated by burial, depending on the thermal properties of the soil. Frost penetration is greatest in rock or bare, dry soils. A snow cover typically reduces the depth of frost penetration by an amount equal to the snow depth. Locating utility lines away from snowplowed surfaces takes advantage of this potential.

[C] 12-4 For example, the air temperature at the surface might have an annual variation of 150°F (66°C). At a depth of 6 ft (2 m), the temperature may vary slightly with the season, and at 30 ft (9 m), seasonal temperature fluctuations are negligible. There is also a time lag involved with frost penetration so that maximum depth of frost penetration will occur long after the extreme winter temperatures. At a depth of 6 ft (2 m) the lag time may be one to five months after the onset of freezing conditions at the surface. The specific time depends on soil properties and moisture conditions.

12-4.1 Direct Burial.

Water and sewer mains are typically buried below the maximum depth of seasonal frost. In cold regions, the frost penetration is often greater than the common pipe burial depths of 6 to 10 ft (1.8 to 3 m) and may be 20 ft (6 m) or more in exposed dry soil or rock. Deep frost penetration, high groundwater, hilly terrain, rock, or other factors make it more practical and economical to install all or portions of the utility system within the frost zone. In these cases, the degree of freeze protection necessary depends on the ground temperatures at the pipe depth. Where pipes are only intermittently or periodically within frost, such as during a particularly cold winter or at a more temperate location, conventional bare pipes may be adequate, provided a minimum flow can be maintained by circulation, bleeding, or consumption. Frost-proof appurtenances, appropriate monitoring and alarms, stable backfill, and some heating may also be necessary. Provide continuous monitoring of any system buried above the seasonal frost depth to alert for malfunction. Heat loss and freeze danger are significantly reduced by insulating the pipes. Insulated pipes may be installed in shallower trenches or within berms at ground surface. In these cases, the minimum depth of cover would be 1.5 to 3 ft (0.5 to 1 m) for exposed ground surfaces. Greater depths are necessary if heavy surface traffic is expected. For long pipelines which are trenched, installed in frozen soils, and which rely on the soil bond to overcome expansion forces, initial warm up of the pipes after construction may result in upheaval buckling of pipeline if backfill material is not allowed sufficient time to consolidate and secure the pipe in the trench.

12-4.2 Insulation Barrier for Buried Pipes.

Buried pipes within seasonal frost can also be protected by placing a layer of insulation board, usually polystyrene, above the pipe. This method, using bare pipes and fittings and board insulation, is often less expensive (for materials) than use of prefabricated insulated pipe; however, the construction cost will be higher, and the effectiveness of the insulation is lower than direct insulation on the pipes. The board method has been used where the soils underlying the pipe are frost-susceptible, since frost penetration beneath the pipes can be prevented by the insulation board. The necessary thickness and width of the board increases for shallower pipes and deeper frost penetration. The relative economics, compared to that for insulated pipes, is improved when pipes are placed in a common trench under insulation board and when warm sewer or central heating lines are included. Generally, the insulation should be a minimum of 4 ft (1.2 m) wide for a single pipe, and the thickness is determined by the proposed depth of burial and the expected or calculated frost penetration. The heat loss and trench width may be reduced by placing the insulation in an inverted U on both the top and sides of the pipe. Example 3 in Appendix C illustrates frost penetration calculations beneath an insulation board.

[C] 12-4.2 In terms of reducing frost penetration, 2 inches (5 cm) of polystyrene foam insulation (k = 0.02 Btu/hr·ft·°F [0.035 W/m °C]) is roughly equivalent to 4 ft (1.2 m) of sand or silt or 3 ft (0.9 m) of clay cover over the pipe.

12-4.3 Deep Burial.

Deeper pipes will experience less extreme ambient temperatures, lower maximum rates of heat loss, and a longer safety factor time against freezing. However, pipes installed in permafrost require freeze-protection all year.

12-5 PHYSICAL METHODS FOR REDUCING HEAT LOSS.

The primary physical method of reducing heat loss is insulation. It is impractical to prevent ground moisture, humidity, or water from pipe failures from reaching the insulation, and since moisture content is a key factor in determining the thermal performance of insulations, use only near-hydrophobic insulations. Even these insulations usually require some physical and moisture protection. Consideration corrosion resistant external coatings of pipe segments or factory applied insulation which is bonded to the pipe surface and forms a water impervious barrier. Assure pipes are protected from moisture entry at joints, connections, and other features where moisture may come in contact with pipe materials.

12-5.1 Amount of Insulation.

Perform an economic analysis to balance heating and insulation costs to determine the minimum amount of insulation that is required. Include factors such as the freeze-up time, the maximum rate of heat loss, and practical dimensional considerations. Heat loss estimates for pipe systems must consider exposed sections of pipes, joints and appurtenances, and thermal breaks such as at pipe anchors. To ensure safe design, the thermal resistance around appurtenances must be 1.5 times that required around adjacent pipe sections. Where insulation is applied to relatively complex equipment features that require frequent maintenance or access, a removable insulated blanket may prove cost effective.

[C] 12-5.1 For example, a 5-inch (13-cm) gate valve has a surface area equivalent to 3 ft (1 m) of bare pipe. If this valve were left exposed, it would lose as much heat as about 200 ft (61 m) of 5-inch (13-cm) pipe insulated with 2 inches (5 cm) of polyurethane insulation, and freezing would occur at the valve first.

12-5.2 Location of Insulation.

The amount of heat loss from a single pipe or multiple pipe system is reduced by minimizing exposed surface area. Minimizing the surface area also requires less insulation. This is especially important for aboveground pipes, facilities, and appurtenances where insulation is most effective when it is placed directly around the source of heat. For a single pipe, insulation is best applied in an annulus directly around the pipe. Where there is an air space, for example between an insulated pipe and a jacket or casing, the thermal resistance of the air space may be quite significant and must be considered. For the same total volume of insulation, it is more effective to group several pipes in a single insulated conduit or small utilidor than to separately insulate each pipe. The ASCE *Cold Regions Utilities Monograph*, Section 4.5, and Chapter 6, “Heat Transfer Calculations for Piping Systems,” of the ASHRAE *District Heating Guide* provide additional discussion and example problems.

12-6 HEAT LOSS REPLACEMENT.

If ambient temperatures are below 32°F (0°C), freezing will eventually occur in the pipe unless the cold fluid is replaced by warmer fluid, or heat is added to the fluid. Heat can be added either at point sources, such as pump stations, or continuously along the length of the pipe with heat tracing. Friction generated by the fluid moving through the pipe may also generate heat, but it is negligible at typical flow velocities.

12-6.1 Fluid Replacement.

Freezing will not occur if the liquid residence time in the pipeline is less than the time necessary for it to cool to the freezing point. The quantity and temperature of the replacement water must be sufficient, and the flow must be reliable. Operation without additional heating is restricted to situations where relatively warm water supplies, such as groundwater, are used or where the flow rate is reliable and high, such as in some water supply pipelines or mains. Recirculation will maintain a flow and a uniform temperature within the system and prevent premature freezing at locations with lower-than-average ambient temperatures or at poorly insulated sections. However, the water temperature will still decline unless warmer water is added, or the recirculating water is heated.

[C] 12-6.1 Bleeding of water has been used historically to maintain or enhance the flow in service lines, dead-ends, and intermittent flowing pipelines, but the wasting of large quantities of water is inefficient, costly, and results in water supply and wastewater treatment problems.

12-6.2 Point Sources of Heat.

Water may be heated at the source, treatment plant, pumping stations, along the pipeline, or within distribution systems as required. There must also be sufficient flow within the piping system to distribute the heat. If the normal water demand is too low or is intermittent, then bleeding or recirculation is necessary. Maintain a minimum water temperature within the piping system by increasing either the flow rate or the input water temperature while keeping the other parameters constant or by adjusting them simultaneously. Higher velocities must be balanced with the electrical energy requirements for pumping and are not usually practical for large diameter mains. The ASCE *Cold Regions Utilities Monograph*, Section 4.4.2, provides additional information.

12-6.3 Heat Tracing.

Replacement of heat losses and maintenance of minimum temperature can also be accomplished with pipe heat tracing systems. Circulation of warm air has been used in large, open utilidors, but the most common heat tracing systems use either separate fluid or electrical lines as the heat source.

12-6.3.1 Fluid Heat Tracing.

For pipe heat tracing, fluids generally between 175°F and 200°F (79°C and 93°C) are much simpler to use than either steam or higher temperature water. The ASCE *Cold Regions Utilities Monograph*, Section 4.4.3, provides additional information.

12-6.3.2 Electric Heat Tracing.

Electric heat tracing systems are relatively easily installed and controlled. They can be installed continuously on water and sewer pipelines or only at freeze-susceptible locations, such as road crossings, service connections, or at appurtenances such as fire hydrants. A variety of electric heat tracing systems and products are available from a number of manufacturers. Exterior heat tracing on pre-insulated pipe is commonly installed within a raceway channel or conduit attached to the pipe surface, which facilitates fabrication, installation, removal, and replacement. Plastic pipes, insulation, and the electric heat tracing system itself must be protected from overheating unless the self-limiting heating cable is used. To provide freeze protection, automatic control systems must activate the electric heat tracing system at a set point above 32°F (0°C) to provide some lead time and allow for variances in the temperature detection sensitivity of the thermostat and sensor. To provide economical operation, the controls also cut off the power supply when heating is not required. The sensors must be located with care to provide proper control, freeze-protection, and prevent the waste of energy. They should be located where the lowest pipe temperatures within the section being controlled are expected, such as at exposed windswept areas or shallow buried sections. The ASCE *Cold Regions Utilities Monograph*, Section 4.4.4, provides additional information.

12-6.4 Pipe Friction.

Friction heating is negligible for smooth pipes with fluid velocities less than 6 ft per second (1.8 m per second), which is about the desirable upper limit for flow in pipes. At high velocities, frictional heat is significant, but deliberately increasing velocity for this purpose is an inefficient method of heating since the energy is supplied by pumping. The equations for frictional heat input are presented in Figure 12-1.

12-7 INSULATION MATERIALS.

Insulation materials include, but are not limited to, polyurethane foam, extruded polystyrene board, fiberglass, molded calcium silicate, and molded polyisocyanurate. Insulation can be installed in the form of boards or may be factory applied on the pipe with appropriate jacketing. Factory insulated pipe may also include heat tracing or channels for heat tracing installation. The insulation materials selected must be in accordance with the criteria given in applicable UFGS, such as UFGS 23 07 00. The ASHRAE *District Heating Guide* provides additional information on insulation types and thermal properties, including obsolete insulation materials that may be found on renovation projects.

For design purposes, the structural and thermal properties for the worst conditions must be used. These conditions occur after aging, compaction, saturation, and freeze-thaw cycles. Other selection considerations are ease of installation, vapor transmission, burning characteristics, and susceptibility to damage by vandals, animals, chemicals, and the environment. The insulating value of a material depends more or less directly on the volume of entrapped gas in the material. If the material becomes wet and the voids filled with water, the insulating properties are lost since the thermal resistance of air is about 25 times that of water and 100 times that of ice. In the past, the lack of a near-hydrophobic insulation made the design of piping in moist environments very difficult and is a major reason for the development of aboveground utilidors.

12-8 THERMAL CALCULATIONS.

The analytical thermal equations presented in this section use a number of simplifying approximations. The user must determine their applicability to specific problems and consider the various models and a range of values for physical and temperature conditions. This chapter’s equations include time-independent steady-state heat flow procedures as well as calculations to determine ground temperature and the depth of freezing and thawing. The symbols used for this chapter’s figures are defined in Table 12-1. The thermal conductivity values of common materials are given in Table 12-2. Solutions to utility system example problems are given in Appendix C to illustrate the methods involved.

12-8.1 Steady-State Pipeline Heat Loss.

Steady-state calculations include typical cases for bare and insulated pipes, and single and multiple pipes in above- and belowground configurations. These methods are presented in Figure 12-1, 12-2, 12-3 and 12-4.

- Figure 12-1 presents equations for estimating the temperature drop (or gain) along a pipeline system. In addition, simple procedures to determine freeze-up times under no-flow conditions are included.
- Figure 12-2 presents equations for estimating heat flow from above-surface pipes. The pipe configurations include bare pipe, an insulated pipe, a single pipe in an insulated box, and a utilidor carrying multiple pipes. In each case, some of the major approximations, in addition to the implied time-independent steady-state assumptions, are indicated. Some comments intended to facilitate application of equations are also included. Where applicable, procedures are given for relevant thermal resistance, rates of heat flow and insulation thicknesses.
- Figure 12-3 presents equations for estimating heat flow from buried pipes. The pipe configurations include a bare pipe with no thaw, a bare pipe with a thaw zone, an insulated pipe with no thaw, and an insulated pipe with a thaw zone. In addition, equations are included to estimate the dimension of the thaw zone.
- Figure 12-4 presents equations for estimating the thermal resistance of typical applications of pipe insulation and utilidor insulation.
- Steady-state thermal influences in isotropic, homogenous soils can be summed, and geometric modifications and approximations can be made to the basic steady-state equations. For example, a layered soil can be represented by an effective soil thickness with the same total thermal resistance as the layered soil.
- When pipes are buried below the area influenced by short-term air temperature fluctuations, the ground temperatures around the pipeline resemble a slowly changing series of steady-state conditions.[1] The heat loss from deeply buried pipes can be calculated from steady-state equations for a cylinder of material around a pipe if the fluid temperature and the soil temperature at a known distance from the pipe are measured, and the soil and insulation thermal conductivities are known. Heat loss from deep pipes can also be estimated by replacing the ground surface temperature in the steady-state equations with the undisturbed ground temperature at the pipe depth.[2] Calculate heat loss from a buried pipe over a time period from the heating index during that period. ASCE *Cold Regions Utilities Monograph*, Section 4.6, provides additional discussion.

[1] *Underground Utility Lines*, Prokhaer.
[2] "Water Supply Systems for Frozen Ground," Janson.

Table 12-1 List of Symbols used in Thermal Calculations shown in Figures 12-1 through 12-4

Variable		Subscript	
A	thaw factor [Figure 12-3]	A	air [Figures 12-1 and 12-2]
a	height of insulation (ft) [Figure 12-4]	C	conduit [Figure 12-2]
b	width of insulation (ft) [Figure 12-4]	D	design [Figure 12-1]
c	equation variable (ft) [Figure 12-3]	E	exterior casing (of utilidor) [Figure 12-2]
C	volumetric heat capacity (Btu/ft3 °F) [Figure 12-1]	f	friction [Figure 12-1]
d	insulation thickness (ft) [Figures 12-2 and 12-4]	f	freezing or frozen [Figure 12-3]
δ	effective thickness of fictitious soil layer (ft) [Figure 12-4]	F	freeze [Figure 12-1]
D	scaling parameter (ft) [Figure 12-1]	G	ground (surface) [Figure 12-3]
f	friction head loss (ft/ft) [Figure 12-1]	I	Insulation [Figures 12-2–12-4]
F	friction heat constant, 0.2515 Btu/ft4 [Figure 12-1]	j	denotes pipe number [Figure 12-2]
h	thermal film or convective heat coefficient [Figures 12-2 and 12-4]	L	refers to thermal lining (of utilidor) [Figure 12-2]
k	thermal conductivity (Btu/h ft °F) [Figures 12-1–12-4]	P	pipe [Figures 12-2–12-4]
l	length (ft) [Figure 12-1]	S	soil [Figures 12-3 and 12-4]
L	volumetric latent heat (Btu/ft3) [Figure 12-1]	SF	safety factor [Figure 12-1]
N	equation variable [Figure 12-2]	t	thawed, thawing [Figure 12-3]
p	separation between pipes (ft) [Figure 12-4]	U	utilidor [Figure 12-2]
P	perimeter (mean) (ft) [Figure 12-2]	W	water (fluid) within a pipe [Figures 12-1 and 12-2]
q	fluid flow rate (ft3/s) [Figure 12-1]	Z	refers to zone of thaw [Figure 12-3]
Q	rate of heat loss per unit longitudinal length (Btu/ft h) [Figures 12-1 and 12-2]	0	(zero) refers to freezing point of water [Figures 12-1–12-4]
r	radius (ft) [Figures 12-1–12-4]	1, 2	input fluid, output fluid [Figure 12-1]; layers [Figure 12-4]; Pipes [Figure 12-4]
R	thermal resistance of unit longitudinal length (h ft °F/Btu) [Figures 12-1–12-4]		
s	offset of cylindrical insulation (ft) [Figure 12-4]		
S	equation variable [Figure 12-4]		
t	time (unit varies) [Figure 12-1]		
T	temperature (°F) [Figures 12-1–12-3]		
W	wind function [Figure 12-2]		
v	fluid mean velocity (ft/h) [Figure 12-1]		
V	wind velocity (mph) [Figure 12-2]		
x	depth [Figure 12-3]		

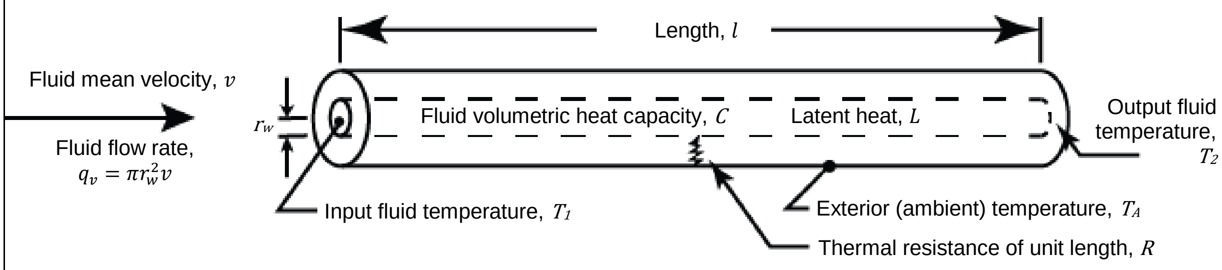
Table 12-2 Thermal Conductivities of Common Materials[1]

Material	Unit Weight (dry) lb/ft^3	Specific Heat Capacity Btu/lb-°F	Thermal Conductivity Btu/ft·h·°F
Air, no convection (32°F)		0.24	0.014
Air film, outside, 15 mph wind (per air film)			0.50
Air film, outside (per air film)			0.14
Polyurethane foam	2	0.4	0.014
Polystyrene foam	0.19	0.3	0.020
Rock wool, glass wool	3.4	0.2	0.023
Snow, new, loose	5.3	0.5	0.05
Snow, on ground	19	0.5	0.13
Snow, drifted and compacted	31	0.5	0.4
Ice at –40°F	56	0.5	1.54
Ice at 32°F	56	0.5	1.28
Water at 32°F	62.4	1.0	0.34
Peat, dry	16	0.5	0.04
Peat, thawed, 80% moisture	16	0.32	0.08
Peat, frozen, 80% ice	16	0.22	1.0
Peat, pressed, moist	71	0.4	0.40
Clay, dry	106	0.22	0.5
Clay, thawed, saturated (20%)	106	0.42	1.0
Clay, frozen, saturated (20%)	106	0.32	1.2
Sand, dry	125	0.19	0.06
Sand, thawed, saturated (10%)	125	0.29	1.9
Sand, frozen, saturated (10%)	125	0.24	2.4
Rock, typical	156	0.20	1.3
Wood, plywood, dry	37	0.65	0.10
Wood, fir, or pine, dry	31	0.6	0.07
Wood, maple, or oak, dry	44	0.5	0.10
Insulating concrete (varies)	12 to 94		0.04 to 0.35
Concrete	156	0.16	1.0
Asphalt	156		0.42
Polyethylene, high density	59	0.54	0.21
PVC	87	0.25	0.11
Wood stave (varies)	–		0.15
Steel	486	0.12	25
Ductile iron	468		30
Aluminum	169	0.21	115
Copper	550	0.1	220

[1] Values are representative of materials, but most materials have variable properties.

Figure 12-1 Temperature Drop and Freeze-Up Time in Pipes (After "Calculation of Heat Loss in Pipes," by Thornton)

Heat Loss and Temperature Drop in a Fluid Flowing through a Pipe	**Freeze-Up Time for a Full Pipe Under No-Flow Conditions (v = 0)**



Comments: The above is a schematic. R and T_A appearing in these equations can be replaced by the thermal resistance and corresponding exterior temperature for any shape or configuration.

D = scaling parameter $= \pi r_w^2 vCR$

Calculate T_1 or T_2, given R, T_1 or T_2, T_A

$$T_1 = T_A + (T_2 - T_A)/\exp(-l/D)$$

$$\cong T_A + (T_2 - T_A)/(1 + l/D), \text{ if } \frac{l}{D} \leq 0.1$$

$$T_2 = T_A + (T_1 - T_A)\exp(-l/D)$$

Calculate R, given T_1, T_2, T_A

$$R = l/\pi r_W^2 vC \ln[T_2 - T_A/T_1 - T_A]$$

Calculate v, given T_1, T_2, T_A, R

$$v = l/\pi r_W^2 RC \ln[T_2 - T_1/T_1 - T_A]$$

Calculate heat loss (Q), given T_1 or T_2, T_A, v, R

$$Q = D/R\,(T_1 - T_A)[1 - \exp(-l/D)]$$

$$\cong (\tfrac{l}{R})(T_1 - T_A) \text{ for } l/D \leq 0.1$$

$$= D/R(T_2 - T_A)[\exp(l/D) - 1]$$

Calculate Friction Heating (Q_f), given v, f

$$Q_f = F r_W^2 v f$$

Freeze-up Times, given R, T_1, T_A

Assume that thermal resistance of the ice, as it forms, and the heat capacity of the pipe and insulation are negligible.

Design Time (Recommended)

t_D= Time for the fluid temperature to drop to the freezing point.

$$t_D = \pi r_W^2 RC \ln\left[\frac{T_1 - T_A}{T_O - T_A}\right]$$

Safety Factor Time

t_{SF}= Time for the fluid to drop to the nucleation temperature. Same as t_D but with T_0 replaced by 27°F

Complete Freezing Time

t_F= Time for the fluid at freezing point, 32°F, to completely freeze solid.

$$t_F = \pi r_W^2 RL/(T_O - T_A)$$

Figure 12-2 Steady-State Thermal Equations for Above-Surface Pipes (After "Calculation of Heat Loss in Pipes")

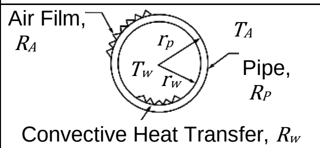
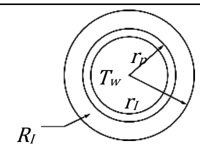
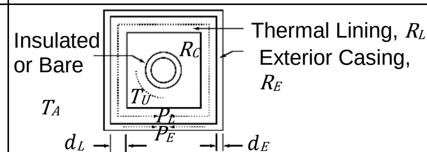
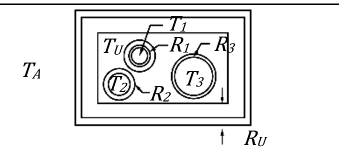
	(a) Bare Pipe	(b) Insulated Pipe	(c) Single Pipe in Utilidor	(d) Multiple Pipes in Utilidor
Sketch				
Assumptions	Thin-walled pipe ($r_p \leq 2r_W$). R_W is negligible, $R_P \leq R_A$.	All thermal resistances but that of the insulation are neglected.	Convection ensures the temperature inside the utilidor, T_U is uniform. Utilidor air spaces are neglected.	Same as (c).
Thermal Resistance	$R_P = \frac{\ln(r_P/r_W)}{2\pi k_P}$ $R_A = 1/2\pi r_P h_A$ $h_A = N\left(\frac{T_W - T_A}{r_P}\right)^{0.25} W(V)$ $N = 0.23\ Btu/h\,ft\,°F$ $W(V) = \sqrt{12.5V + 1}$ for V in mph $R_C = R_P + R_A$	$R_C = R_I = \frac{\ln(r_I/r_P)}{2\pi k_I}$	Calculate R_C the thermal resistance of the interior conduit by using (b) if insulated or using (a) if bare and replacing T_A in the formula for h_A by an estimate for $T_U (\leq T_W)$. $R_L = d_L/P_L k_L$ $R_E = d_E/P_E k_E$ $R_U = R_L + R_E$ $R = R_C + R_U$ $T_U = \frac{(T_W/R_C) + (T_A/R_U)}{(1/R_C) + (1/R_U)}$ If bare pipe, solution is found by iteration of T_U.	Calculate R for each pipe as in (c) to get R_J Where: $J = 1, 2, 3 \ldots$ Calculate R_U as in (c). $T_U = \frac{\sum_J (T_J/R_J) + (T_A/R_U)}{\sum_J (1/R_J) + (1/R_U)}$ If bare pipes, solution is found by iteration of T_U.
Rate of Heat Loss	$Q = (T_W - T_A)/R_C$	$Q = (T_W - T_A)/R_I$	$Q = (T_W - T_A)/R$	$Q_J = (T_J - T_U)/R_J$ (per pipe) $Q = \sum_J Q_J = (T_U - T_A)/R_U$
Insulation Thickness (given Q)	N/A	$r_I - r_P$ $= r_P\left\{exp\left[\frac{2\pi k_1 (T_W - T_A)}{Q}\right] - 1\right\}$ $= \pi k_I (T_W - T_A) Q$ if $r_I \leq 2r_p$	Obtain R_E and R_C as above $d_L = R_L k_L [\frac{(T_W - T_A)}{Q} - R_E - R_C]$ If bare interior pipe, iterate T_U, R_C and hence d_L.	Given acceptable Q_J, calculate R_J as above and evaluate $T_U = T_J - R_J Q_J$ for each pipe for which Q_J is known. Using the maximum T_U found, calculate new Q_J as above. Using these Q_J and the same T_U, evaluate $d_L = P_L k_L [\frac{T_U - T_A}{\sum Q_J} - R_E]$ If bare pipes, iterate T_U, R_J and hence d_L.
Comments	Often, for metal pipes, R_P may be neglected. If R_P is significant, the expression above h_A will generate an overestimate of Q. If $T_A > T_W$ switch T_A and T_W in the expression for h_A.	The neglected thermal resistances given in (a) may be included if desired. Estimate a value for the insulation surface temperature and calculate h_A and R_A, iterate.	The value of h_A, and hence R_A, is insensitive to the choice of T_U, and so one iteration of T_U is usually sufficient. Often R_E may be neglected. A similar calculation may be performed for pipes and utilidors of different cross section.	Same as (c). If one pipe dominates the heat loss process, (c) may be used to estimate T_U. It is wise to consider the heat loss from the various pipes if certain other pipes cease to function.

Figure 12-3 Steady-State Thermal Equations for Below-Surface Pipes (After “Calculation of Heat Loss in Pipes”)

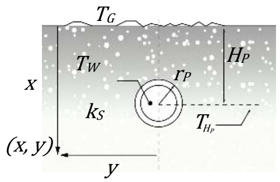
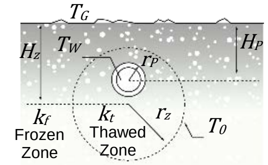
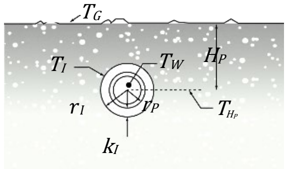
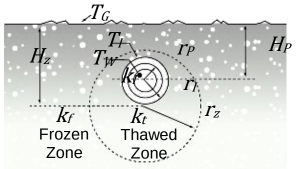
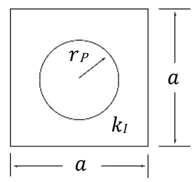
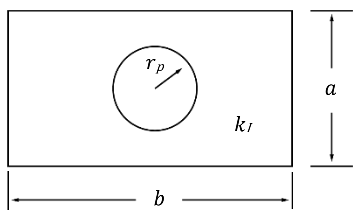
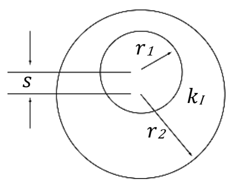
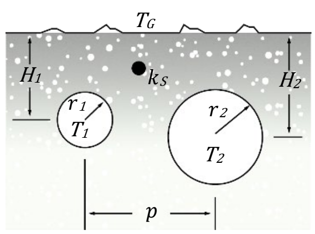
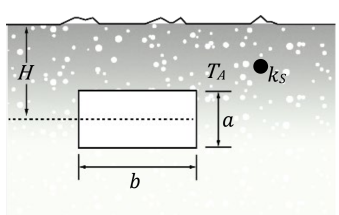
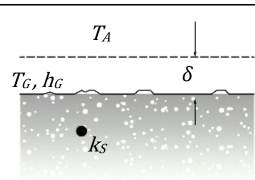
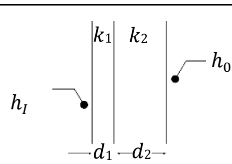
	(a) Bare, No Thaw	(b) Bare, with Thaw Zone	(c) Insulated, No Thaw	(d) Insulated, with Thaw Zone
Sketch				
Assumptions	Neglect all thermal resistances except that of the soil.	Same as (a), but accounting for the different conductivities of thawed and frozen soil.	Neglecting all thermal resistances except those of the soil and insulation. Outer surface of insulation assumed to be isothermal. $r_I - r_P \ll H_P$.	Same as (c) but accounting for the different thermal conductivities of thawed and frozen soil.
Thermal Resistance and Thaw Zone Parameters	$R_S = \frac{\text{arccosh}(\frac{H_P}{r_P})}{2\pi k_S}$ $= \frac{ln\left\{\left(\frac{H_P}{r_P}\right) + \left[\left(\frac{H_P}{r_P}\right)^2 - 1\right]^{1/2}\right\}}{2\pi k_S}$ $\cong \frac{\ln(2H_P/r_P)}{2\pi k_S}$ if $H_P \geq 2r_P$	$T'_W = \frac{k_t}{k_f}(T_W - T_O) + T_0$ $T' = \frac{(T_O - T_G)}{(T'_W - T_G)}$ $c = \sqrt{H_P^2 - r_P^2}$ $A = T'\,\text{arccosh}(\frac{H_P}{r_P})$ $H_Z = c\coth A \quad r_Z = c\,\text{csch}\,A$ R_t, R_f, and R_S (= $R_t + R_f$) as given in (d), but with r_t replaced by r_P	R_1 as given in Figure 12-2 (b), R_S as given in (a), but with r_P replaced by r_I. $T_I = T_W - \frac{R_I(T_W - T_G)}{R_S + R_I}$ For known T_W, T_G, and R_S, the minimum thermal resistance to prevent thaw, R'_1, (such as $T_I = T_O$) is given by: $R'_1 = \frac{T_W - T_O}{T_O - T_G} R_S$	R_I as given in Figure 12-2 (b) T'_W, T', c, H_Z, r_Z and R'_S as in (b) but with r_P replaced by r_I and using: $A = T'[\text{arccosh}(H_P/r_P) + 2\pi k_t R_I]$ $T_I = T_W - \frac{R_I(T'_W - T_G)}{R'_S + (k_t/k_f)R_I}$ Also, $R_t = \frac{[\text{arccosh}(H_P/r_I) - \text{arccosh}(H_Z/r_Z)]}{2\pi k_t}$ $R_f = \text{arccosh}(H_Z/r_Z)/2\pi k_t$ $R_S = R_f + R_t$
Rate of Heat Loss	$Q = \frac{T_W - T_G}{R_S}$	$Q = \frac{T'_W - T_G}{R'_S}$ Where: $R'_S = \frac{\text{arcosh}(H_P/r_P)}{2\pi k_f}$	$Q = \frac{T_W - T_G}{R_I + R_S}$	$Q = \frac{T'_W - T_G}{R'_S + (k_t/k_f)R_I}$
Insulation Thickness	N/A	N/A	For no thawing outside the insulation the minimum insulation thickness is given by: $r_I - r_P = r_P[\exp(2\pi k_I R'_I) - 1]$	$R_I = [(A/T') + \text{arccosh}(H_P/r_I)]/2\pi k_t$ $r_I - r_P$ as in (c) but with R'_I replaced by R_I from above.
Comments	For calculations of heat loss when there is a temperature gradient in the soil and $H_P > 2r_P$, T_G may be replaced by T_{H_P}, the undisturbed ground temperature at the pipe axis depth. For an upper limit on heat loss, use $k_S = k_f$, otherwise use $k_S = (k_f + k_t)/2$.	The thawed zone is a circle in cross section.	May be used to approximate (d) if $k_t \cong k_f$ and/or $r_Z \cong r_I$, and thaw zone parameters are not required. Use $k_S = k_f$ or $k_S = (k_f + k_t)/2$ as in (a).	Often the above expressions for R_t, R_f and R_S are not required.

Figure 12-4 Steady-State Thermal Resistance of Various Shapes and Bodies (After *Fundamentals in Heat Transfer* and EPA-600/8-79-027)

<table>
<tr><th>Condition</th><th>Sketch</th><th>Thermal resistance</th></tr>
<tr><td>Square insulation</td><td></td><td>$$R = \frac{1}{2\pi k_I}\ln 1.08\frac{a}{2r_P}$$</td></tr>
<tr><td>Rectangular insulation</td><td></td><td>$$R = \frac{1}{2\pi k_I}\ln(\frac{4a}{\pi r_P} - 2S)$$
<table>
<tr><th>b/a</th><th>S</th><th>b/a</th><th>S</th><th>b/a</th><th>S</th></tr>
<tr><td>1.00</td><td>0.08290</td><td>2.00</td><td>0.00373</td><td>4.00</td><td>6.97×10^{-6}</td></tr>
<tr><td>1.25</td><td>0.03963</td><td>2.25</td><td>0.00170</td><td>5.00</td><td>3.01×10^{-7}</td></tr>
<tr><td>1.50</td><td>0.01781</td><td>2.50</td><td>0.00078</td><td>⋮</td><td>⋮</td></tr>
<tr><td>1.75</td><td>0.00816</td><td>3.00</td><td>0.00016</td><td>∞</td><td>0</td></tr>
</table></td></tr>
<tr><td>Eccentric cylindrical insulation</td><td></td><td>$$R = \frac{1}{2\pi k_I}\ln\frac{\sqrt{(r_2+r_1)^2-s^2}+\sqrt{(r_2-r_1)^2-s^2}}{\sqrt{(r_2+r_1)^2-s^2}-\sqrt{(r_2-r_1)^2-s^2}}$$
$$= \frac{1}{2\pi k_I} arccosh\frac{r_1^2+r_2^2-s^2}{2r_1r_2}$$</td></tr>
<tr><td>Two buried pipes</td><td></td><td>Where: $H_1 \geq 3r_1$, $H_2 \geq 3r_2$ and $p \geq 3(r_1 + r_2)$
$$R_{1-2} = \frac{1}{2\pi k_S}\cdot\frac{\ln\frac{2H_1}{r_1}\cdot\ln\frac{2H_2}{r_2} - \left[\ln\sqrt{\frac{(h_1+h_2)^2+p^2}{(h_1-h_2)^2+p^2}}\right]^2}{\ln\frac{2H_2}{r_2} - \left[\left(\frac{T_2-T_G}{T_1-T_G}\right)\ln\sqrt{\frac{(h_1+h_2)^2+p^2}{(h_1-h_2)^2+p^2}}\right]}$$</td></tr>
<tr><td>Buried rectangular duct</td><td></td><td>$$R = \frac{1}{k_S(5.7+\frac{b}{2a})}\ln\frac{3.5H}{b^{0.25}\,a^{0.75}}$$</td></tr>
<tr><td>Surface thermal resistance</td><td></td><td>Surface thermal resistance between the ground surface and air can be approximated by adding a fictitious soil layer with an effective thickness equal to:
$$\delta = \frac{k_S}{h_G}$$
For further soil thermal resistance calculations this thickness is simply added to the actual burial depth of the pipe.</td></tr>
<tr><td>Composite wall</td><td></td><td>$$R = \frac{1}{h_I}+\frac{1}{h_O}+\frac{d_1}{k_1}+\frac{d_2}{k_2}$$</td></tr>
</table>

12-8.2 Depth of Freezing and Thawing

Obtain the depth of freezing or thawing of soil, and the ice thickness on water bodies, by field measurements when possible. If required, they can be estimated using one of the many analytical solutions available. Because of the assumptions necessary in these analytical solutions, such as assuming a step change in surface temperature or neglecting the soil temperature changes, they generally overestimate the maximum freezing isotherm depths for the given conditions and are, therefore, conservative for engineering applications.

12-8.2.1 Basic Analytical Solution Form.

Analytical solutions are generally Neumann- or Stefan-based equations which have the basic form:

Equation 12-1. Depth of Freezing or Thawing (Stefan Solution, Empirical Coefficients)

$$X = m\left(I_g\right)^{1/2}$$

Where:
X = depth of freezing or thawing (ft)
m = coefficient of proportionality (ice thickness $\boldsymbol{m}$-factor)
I_g = ground surface freezing (I_f) or thawing (I_t) index (°F-days)

12-8.2.2 Specific Solutions.

Equations 12-2 through 12-5 incorporate various assumptions that are useful for specific conditions:

- Equation 12-2 is the Stefan solution for a homogeneous material with a step change in surface temperature (see Appendix C, Example 1). Equation 12-2 is identical to Equation 12-1 except 12-1 uses empirical coefficients and 12-2 uses the values of the physical properties. Equation 12-2 overestimates the depth of freezing as a result.
- Equation 12-3 is a two-layer modification of the Stefan equation and is useful for calculations involving snow cover, a gravel pad, or a board of thermal insulation, in which the surface layer has no latent heat (see Appendix C, Example 2 and Example 3.
- Equation 12-4 is a close approximation of the Neumann solution when the ground temperatures are near freezing.
- Equation 12-5, the modified Berggren equation, is perhaps the most commonly used approach for determining thermal responses of soils. When the soil has a high moisture content the correction coefficient λ

approaches unity and the equation is identical to the Stefan approach (Equation 12-2).

- In climates where the mean annual temperature is near or below freezing, the thermal ratio approaches zero and the λ coefficient is greater than 0.9. In very dry soils, the soil warming or cooling can be significant, and should be included.

Equation 12-2. Depth of Freezing or Thawing (Stefan Solution)

$$X = \left(\frac{2kI_g}{L}\right)^{1/2}$$

Equation 12-3. Depth of Freezing or Thawing (Stefan Solution, Two-Layer)

$$X = \left(\left(\frac{k_2}{k_1}d_1\right)^2 + \frac{2k_2I_g - \frac{d_1^2L_1}{2k_1}}{L_2}\right)^{1/2} - \left(\frac{k_2}{k_1} - 1\right)d_1$$

Equation 12-4. Depth of Freezing or Thawing (Neumann Solution Approximation)

$$X = \left(\frac{2kI_g}{L}\right)^{1/2}\left(1 - \frac{CI_g}{8Lt}\right)$$

Equation 12-5. Depth of Freezing or Thawing (Modified Berggren Solution)

$$X = \lambda\left(\frac{2kI_g}{L}\right)^{1/2}$$

Where:

k = *thermal conductivity of the material above the freezing isotherm (Btu/hr·ft·°F). Subscripts f and t refer to freezing and thawing, and subscripts 1 and 2 refer to the surface layer and the underlying material (all symbols are also defined in Table 12-1).*

L = *volumetric latent heat of the material undergoing phase change (Btu/ft^3). For water L = (144 Btu/lb)(62.4 pcf) = 8986 Btu/f^3*

C = *volumetric heat capacity of the material above the freezing isotherm.*

For thawed soil: $C_t = \gamma\,[C_{mS} + C_{mW}(w/100)]$

For frozen soil: $C_f = \gamma\,[C_{mS} + C_{mi}\,(w/100)]$

γ = *dry unit weight of soil (pcf)*

C_{mS} = *mass heat capacity of mineral matter in soil; assume a value of 0.2 Btu/lb*

C_{mW} = *mass heat capacity of water = 1.0 Btu/lb*

C_{mi} = *mass heat capacity of ice, assumed value of 0.5 Btu/lb*

w = *moisture content of soil (%)*
T_m = *mean annual site temperature (°F)*
t = *freezing or thawing period, consistent units*
T_0 = *freezing point, 32°F for water*
d = *thickness of layer of material (ft)*
λ = *a correction coefficient which takes into consideration the effect of temperature change in the soil and primarily accounts for the volumetric specific heat effects. It is a function of two parameters, the thermal ratio (a) and the fusion parameter (μ) that are calculated using Equation 12-6 and Equation 12-7. λ is determined from Figure 12-5.*

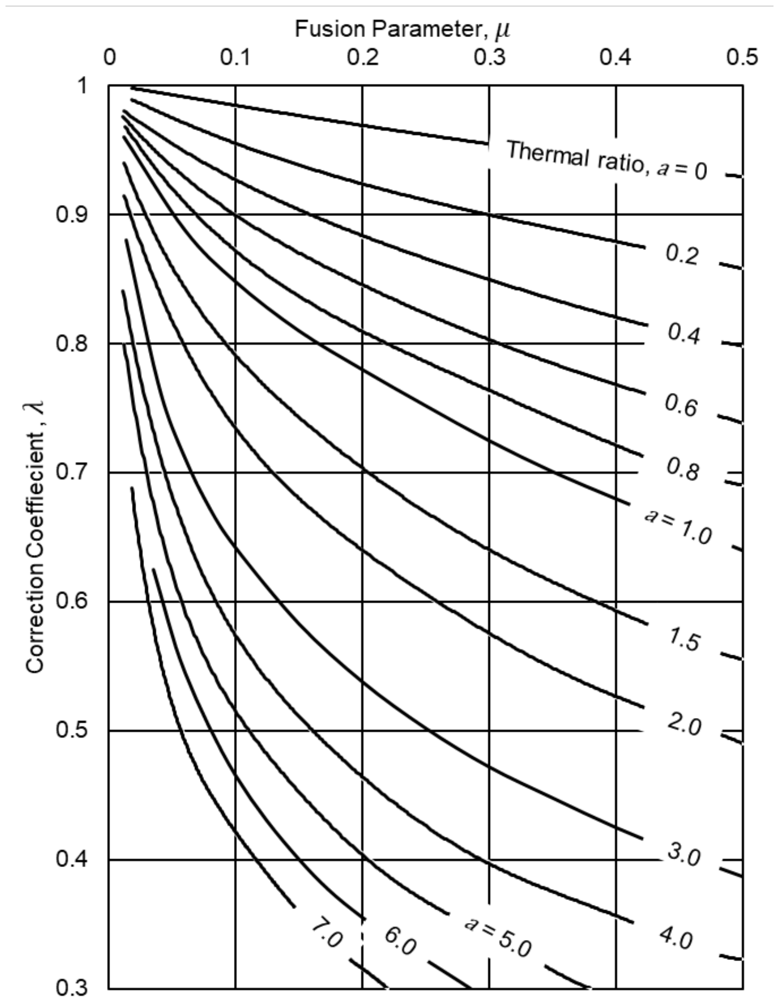
Equation 12-6. Thermal Ratio (*a*)

$$\mathrm{a} = \frac{(T_m - T_0)}{T_m} = \frac{(T_m - T_0)t}{I_g}$$

Equation 12-7. Fusion Parameter (*μ*)

$$\mu = \frac{CI_g}{Lt}$$

Figure 12-5 Correction Coefficient λ for use in Berggren Equation



12-8.2.3 Multi-layered Soil Systems.

Solve multilayered soil systems by determining that portion of the surface freezing or thawing index required to penetrate each layer. The sum of the thicknesses of the frozen or thawed layers, whose indices equal the total index, is equal to the depth of freeze or thaw. The partial freezing or thawing index to penetrate the n^{th} layer is calculated by Equation 12-8.

Equation 12-8. Partial Freezing or Thawing Index

$$I_n = \frac{L_n d_n}{\lambda^2} \sum_{1}^{n-1} \left(R + \frac{R_n}{2} \right)$$

Where:
I_n = *the partial freezing or thawing index required to penetrate the n^{th} layer (°F·hr)*
L_n = *volumetric latent heat in the n^{th} layer (Btu/ft^3)*
d_n = *thickness of the n^{th} layer (ft)*
λ = *the coefficient based on the weighted average values for µ down to and including the n^{th} layer*
$\sum_1^{n-1}\left(R + \frac{R_n}{2}\right)$ = *the sum of the thermal resistances of the layers above the n^{th} layer*
R_n = d_n/k_n, *the thermal resistance to the n^{th} layer (h ft °F/Btu)*

The solution for multilayered systems is facilitated by tabular arrangement of the intermediate values. The penetration into the last layer must be solved by trial and error to match the total freezing or thawing index at the site. It is necessary to determine the temperature condition at the ground surface to determine subsurface thermal effects, including the depth of freezing and thawing. Since air temperatures are readily available, but surface temperatures are not, a correlation factor which combines the effects of radiation with convective and conductive heat exchange at the air-ground surface is used:

Equation 12-9. Ground Surface Freezing or Thawing Index

$$I_g = nI_A$$

Where:
I_A = *air freezing or thawing index*
n = *n-factor, ratio of the surface and air temperature indices*

The n-factor is very significant in analytical ground thermal considerations. It is surface and site specific, highly variable, and usually estimated from published observations such as the values listed in Table 12-3.

12-8.2.4 Ice Thickness.

Estimate ice thickness on water bodies from the previous depth of freezing equations or from Equation 12-1 with the m values in Table 12-4 (see Appendix C, Example 1). Snow cover has a significant insulating effect and can significantly reduce the maximum ice thickness (see Appendix C, Example 2). The ice formation can be greater than calculated if the weight of snow or the lowering of the water level causes cracks in the ice and water overflows onto the surface. This water is drawn into the snow, and the mixture refreezes and bonds to the original ice.

Table 12-3 Typical Values of the n-factor of Air Temperature with Surface Temperature of Various Materials

Surface	n-factors		
	Thawing	Freezing	
Snow	—	1.0	General application
Pavement free of snow and ice	—	0.9	General application
Sand and gravel	2.0	0.9	General application
Turf	1.0	0.5	General application
Spruce	0.35 to 0.53	0.55 to 0.9	Thompson, Manitoba
Spruce trees, brush	0.37 to 0.41	0.28	Fairbanks, Alaska
Above site, cleared, moss surface	0.73 to 0.78	0.25	Fairbanks, Alaska
Stripped, mineral soil surface	1.72 to 1.26	0.33	Fairbanks, Alaska
Spruce	0.76	—	Inuvik, Northwest Territories (NWT)
Willows	0.82	—	Inuvik, NWT
Weeds	0.86	—	Inuvik, NWT
Gravel fill slope	1.38	0.7	Fairbanks, Alaska
Gravel road	1.99	—	Fairbanks, Alaska
Concrete road	2.03	—	Fairbanks, Alaska
Asphalt road	1.74 to 2.70	—	Fairbanks, Alaska
White painted surface	0.76 to 1.25	—	Fairbanks, Alaska
Peat bales on road	1.44 to 2.28	—	Fairbanks, Alaska
Dark gravel	1.15 to 1.73	—	Fairbanks, Alaska

Table 12-4 Example m-factors for Ice Thickness

m-factor inch /(°F-days)$^{1/2}$	Conditions
0.90–0.95	Practical maximum for ice not covered with snow
0.8	Windy lakes with no snow
0.7–0.8	Medium-sized lakes with moderate snow cover
0.6–0.65	Rivers with moderate flow
0.4–0.5	River with snow
0.2–0.4	Small river with rapid flow

This Page Intentionally Left Blank

APPENDIX A BEST PRACTICES

A-1 INTRODUCTION.

The Best Practices Appendix is considered to be guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned, but may not be the only solution to meet the requirement. It identifies additional background information and practices for accomplishing utilities design and construction in the Arctic and Subarctic. The DoR must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any UFC, the UFC takes precedence. For Best Practices guidelines not discussed in a UFC, the DoR must submit a list of the guidelines or requirements being used for the project to the Government Project Manager with documentation sufficient for review and approval prior to completing the design.

A-2 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide (WBDG) provides additional information and discussion on practice and facility design, including a holistic approach to integrated design of facilities. The WBDG provides access to all Construction Criteria Base criteria, standards and codes for the DoD Military Departments, and other agencies. These standards include UFC, UFGS, Performance Technical Specifications, design manuals, and specifications. For approved government employees, it also provides access to nongovernment standards.

A-3 CANADIAN EXPERIENCE.

The Government of the Northwest Territories (GNWT) *Good Engineering Practice for Northern Water and Sewer Systems* contains performance guidelines, preferred materials and methods, and logistical considerations developed from decades of Canadian experience with the design and construction of water and sewer systems in the far north. Over time, certain products and approaches to constructing water and sewer systems have proven successful and have been adopted by design consultants and builders working in the Northwest Territories. These guidelines should be reviewed as they document both failures and successes in cold regions utilities construction and durability.

A-4 PLANNING AND DESIGN CONSIDERATIONS.

Military Installations in cold regions may have their own heating or power plants, water source and treatment facilities, and wastewater treatment facilities. Alternatively, Installations may be connected to local utility providers. Virtually all Installations have existing overhead and underground distribution systems that have been in service for many years. Utility systems at some Installations are provided by public utility companies or have been privatized. Work for these systems must follow the standards of the utility owner or current utility contractor. Other Installations still own, operate, and maintain their utility systems. For those Installations, direction from the Installation staff, often in the form of Installation Facilities Standards (IFS), should be solicited and followed. IFS are available on the WBDG website at https://wbdg.org/airforce/ifs. New Installations may benefit from the guidance used at existing military Installations or local municipalities if differing design conditions are considered, especially climatic conditions. Revegetation after construction should follow IFS guidance and local requirements, such as Eielson AFB *Design Guidelines 04—Establishing Vegetation.*

Modular construction, where the entire facility or a major component is preassembled and shipped via barge to the point of use, has been used at oil field developments on the northern coast of Alaska. It is advantageous in these locations since large barges can be used, the construction season is short, and labor is very expensive. Barges can usually begin to arrive in Utiqiagvik (formerly Barrow), Alaska and the Eastern Arctic around the first of September. This means the nonmodular construction materials must be shipped a year in advance and stockpiled for the next construction season. The stick-built approach, where all fabrication is done on-site, and the prefabrication approach, where some components are preassembled at the point of manufacture, are more common at interior locations where transport is limited to air or small rivers. Prefabrication of insulating piping units has been shown to be cost effective for remote locations.

A-5 WATER SOURCE DEVELOPMENT.

The ADEC Standard 18 AAC 80 *Drinking Water* provides additional guidance for water wells. ADEC is the utilities permitting authority for the State of Alaska and all military Installations therein.

A-6 WATER TREATMENT.

See ADEC 18 AAC 80 *Drinking Water* standard.

UFC 3-230 series provides additional water treatment Best Practices. ADEC 18 AAC 80 *Drinking Water* is the regulatory standard document for water systems in Alaska.

A-7 WATER STORAGE AND DISTRIBUTION.

A-7.1 GENERAL.

UFC 3-230-01 provides general Best Practices for water storage and distribution. ADEC 18 AAC 80 *Drinking Water* is the regulatory standard for water systems in Alaska. Local municipalities and utility companies also publish standards that include minimum burial depth at specific locations, lists of materials that have performed well in their jurisdiction, and example detail drawings of pipes and appurtenances. Examples of such documentation are as follows:

- Anchorage Water and Wastewater Utility, *Design and Construction Practices Manual*

- Utility Services of Alaska, *Standards of Design and Construction* (Fairbanks, AK)
- City of North Pole, *Utility Standards of Construction*
- City of North Pole, *Service Line Requirements for Water and Wastewater—Commercial and Residential Structures*
- Doyon Utilities, *Water, Wastewater, Steam, & Utilidor Systems* (Fort Wainwright and Fort Greely)
- Doyon Utilities, *Division 60 Water Distribution Systems* (Joint Base Elmendorf-Richardson)

A-7.2 MATERIALS.

Unless otherwise approved by the Installation, Command, or District engineering staff, direct bury waterlines should be HDPE as this material can typically survive freeze expansion without rupturing.

A-7.3 MAINS.

Locating mains in the rear of buildings or in areas that retain their snow cover provides greater thermal protection, results in less risk of damage to manholes and other appurtenances, and allows shorter, less costly service connections to the buildings. There are special advantages to this approach for barracks and family housing areas where large numbers of similar structures tend to be laid out in a regular pattern.

A-7.4 HYDRANTS.

Comply with any specific requirements of the Installation, or for privatized systems, the utility contractor. It is best to avoid any kind of nonemergency operation of hydrants during the winter months.

A-8 WASTEWATER COLLECTION AND TREATMENT.

UFC 3-240-01 provides Best Practices for wastewater collection and treatment; paragraph A-6.6 provides guidance specific to cold regions. ADEC 18 AAC 72 *Wastewater Disposal* is the regulatory standards document for wastewater systems in Alaska, including required minimum separation distances between water and sewer mains (including manholes) and the criteria for obtaining a waiver if the required separation distances cannot be achieved. Local municipalities and utility companies also publish standards that include lists of material that have performed well in their jurisdiction, and example detail drawings of pipes and appurtenances. Contractors for Installations with privatized utilities system, or the Installation itself, may have specific design standards that must also be considered. Examples of such documentation are as follows:

- Anchorage Water and Wastewater Utility, *Design and Construction Practices Manual*
- Utility Services of Alaska, *Standards of Design and Construction* (Fairbanks, AK)
- City of North Pole, *Utility Standards of Construction*
- City of North Pole, *Service Line Requirements for Water and Wastewater—Commercial and Residential Structures*
- Doyon Utilities, *Water, Wastewater, Steam, & Utilidor Systems* (Fort Wainwright and Fort Greely)
- Doyon Utilities, *Division 50 Wastewater Collection Systems* (Joint Base Elmendorf-Richardson)

"Chatfield Wastewater Treatment Facility Improvements: A Design and Operational Review, Focused on Cold Weather Issues," by Wedin, provides a discussion of wastewater treatment facilities issues specific to cold regions operations.

A-9 UTILIDORS.

ADEC is the permitting authority for utilidors in the State of Alaska, and all utilidor designs must comply with ADEC standards or have an appropriate waiver. Follow the Eielson AFB *Design Guidelines 10—Utilidors*, generated by the 354th Civil Engineer Squadron, Operations Engineering Flight (354 CES/CEO), where applicable. Privatized utilities systems may have specific design standards that must be considered. An example of this would be Doyon Utilities, *Water, Wastewater, Steam, & Utilidor Systems.*

A-10 FIRE PROTECTION.

Follow Installation guidance such as the Eielson AFB *Design Guidelines 17—Fire Alarm Systems Standards* and Eielson AFB *Design Guidelines 71—Fire Protection* where applicable.

A-11 POWER DISTRIBUTION AND COMMUNICATIONS SYSTEMS.

A-11.1 GENERAL

Follow UFC 3-530-01 for exterior lighting, such as street and parking lot lighting.

Follow the Eielson AFB *Design Guidelines 14—Electrical Standards*, where applicable. Privatized utilities systems may have specific design standards that must be considered. An example of this would be Doyon Utilities, *Electrical System.*

A-11.2 GROUNDING

The GNWT *Good Building Practice for Northern Facilities* provides the following recommendations, in their order of preference, for obtaining the best possible electrical grounding in cold regions:

1. Exothermic (cad) weld to a minimum of four steel pipe piles
2. Minimum 9.5 mm (3/8 inch) bolts (copper, bronze, or brass) tapped and threaded to a minimum of four steel pipe piles

   Rationale: The large surface area of a steel pile or foundation system that is in contact with the ground can provide the best ground possible in northern areas. Cad welding provides a permanent connection.

3. A minimum of three steel rod electrodes
4. Ufer ground (concrete incased electrode)
5. Plate electrodes
6. Municipal piped water system

GNWT suggests the use of additives where obtaining low ground resistance is critical and standard methods are insufficient. GNWT notes: “Additives will degrade over time, reducing the effectiveness of the grounding system, however they may be warranted in some situations.” Additionally, they recommend designers avoid using dissimilar metals to protect from galvanic action, which may occur under certain soil conditions. All grounding measures must comply with UFC 3-550-01.

A-12 UTILITIES ENGINEERING RELATED GUIDANCE.

The following documents provide guidance on the specific topics indicated.

INSTALLATION GUIDELINES

Eielson Air Force Base (AFB) *Design Guidelines 04—Establishing Vegetation*, 354 CES/CEO

Eielson AFB *Design Guidelines 10—Utilidors*, 354 CES/CEO

Eielson AFB *Design Guidelines 14—Electrical Standards*, 354 CES/CEO

Eielson AFB *Design Guidelines 17—Fire Alarm Systems*, 354 CES/CEO

Eielson AFB *Design Guidelines 18—Utility Metering Requirements*, 354 CES/CEO

Eielson AFB *Design Guidelines 71—Fire Protection*, 354 CES/CEO

INSTALLATION FACILITIES STANDARDS (IFS), https://wbdg.org/airforce/ifs

MUNICIPAL

Anchorage Water and Wastewater Utility, Design and Construction Practices Manual, https://www.awwu.biz/about-us/reliable-infrastructure/design-and-construction-practices-manual

City of North Pole, *Service Line Standards for Water and Wastewater—Commercial and Residential Structures,* Stantec Consulting Services, Inc., https://www.northpolealaska.com/utilities/page/utility-construction-standards

City of North Pole, *Utility Standard of Construction for Extensions to the North Pole Utility*, PDC Inc. Engineers, https://www.northpolealaska.com/utilities/page/utility-construction-standards

Utility Services of Alaska, *Standards of Design and Construction,* http://www.akwater.com/construction_standards.shtml

NATIONAL FIRE PROTECTION ASSOCIATION

https://www.nfpa.org

NFPA 24, *Standard for the Installation of Private Fire Service Mains and their Appurtenances*

STATE OF ALASKA

https://dec.alaska.gov/commish/regulations/

State of Alaska, ADEC, Standard 18 AAC 80, *Drinking Water*

State of Alaska, ADEC, Standard 18 AAC 72, *Wastewater Disposal*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 3-530-01, *Interior and Exterior Lighting Systems and Controls*

UFC 3-550-01, *Exterior Electrical Power Distribution*

UTILITY COMPANIES

To request copies of the following documents, go to: https://www.doyonutilities.com/dustandards

Doyon Utilities LLC, *Division 50 Wastewater Collection Systems, Joint Base Elmendorf-Richardson Stand Construction Specification and Details*

Doyon Utilities LLC, *Division 60 Water Distribution Systems, Joint Base Elmendorf-Richardson Stand Construction Specification and Details*

Doyon Utilities LLC, *Electrical System, Design and Construction Standards, Fort Wainwright, Fort Greely & Joint Base Elmendorf-Richardson*

Doyon Utilities LLC, *Water, Wastewater, Steam, & Utilidor Systems, 2021 Design and Construction Standards, Fort Wainwright, and Fort Greely*

OTHER

"Chatfield Wastewater Treatment Facility Improvements: A Design and Operational Review, Focused on Cold Weather Issues," *ASCE Cold Regions Engineering 2009: Cold Regions Impacts on Research, Design and Construction*, T.M. Wedin, ASCE, 2012, https://doi.org/10.1061/41072(359)57

Good Building Practice for Northern Facilities, Government of the Northwest Territories (GNWT), Yellowknife, NT, Canada

Good Engineering Practice for Northern Water and Sewer Systems, GNWT, Yellowknife, NT, Canada

This Page Intentionally Left Blank

APPENDIX B SUPPLEMENTAL RESOURCES

The following references are reliable sources for information related to utilities planning, design, and construction in the Arctic and Subarctic. These sources provide direction for specific applications not addressed in this UFC or provide additional information to guide or aid the designer in the various phases of the design. This list is provided for the convenience of the designer and may not include references for all specific applications relevant to all projects. The designer is responsible for ensuring the design conforms to all criteria relevant to the project.

AMERICAN SOCIETY OF CIVIL ENGINEERS

"Analytical Methods for Ground Thermal Regime Calculations," *Thermal Design Considerations in Frozen Ground Engineering,* T.G. Krzewinski (Ed.), ASCE, New York, NY, 1985

COLD REGIONS ENGINEERING (ASCE Cold Regions Engineering Division), https://www.asce.org/communities/institutes-and-technical-groups/cold-regions-engineering/

Journal of Cold Regions Engineering, https://ascelibrary.org/journal/jcrgei

"Section Three - Geotechnical Thermal Analysis," *Embankment Design and Construction in Cold Regions.* E.G. Johnson (ed.), ASCE, New York, NY, 1988

AMERICAN SOCEITY OF MECHANICAL ENGINEERS

https://www.asme.org/

"Geotechnical Aspects of Northern Pipeline Design and Construction," In *Proceedings of the 2002 4th International Pipeline Conference,* J.M. Oswell, ASME, Calgary, Alberta, Canada, 29 September–3 October 2002

Pipeline Geohazards: Planning, Design, Construction and Operations, M. Rizkalla and R. Read (eds.), ASME Press, New York, NY, 2019

ENVIRONMENTAL PROTECTION AGENCY

EPA-600/8-79-027, Cold Climate Utilities Delivery Design Manual

OTHER

CSA Z662:19, *Oil and Gas Pipeline Systems*, Canadian Standards Association

This Page Intentionally Left Blank

APPENDIX C EXAMPLE PROBLEMS

Appendix C gives example problems. EPA-600/8-79-027, Section 15.10 and the ASCE *Cold Regions Utilities Monograph*, Section 4.7 provide additional example problems.

C-1 EXAMPLE 1

Estimate the ice thickness on a water reservoir with no snow cover when the annual air freezing index (I_g) is 3000°F-days.

Use Equation 12-1:

$$X = m\left(I_g\right)^{1/2}$$

From Table 12-4: m = 0.80 inch/(°F-days)$^{1/2}$

X = 0.80(3000)^{½} = 43.82 inches = 3.65 ft

The Equation 12-2 can also be used. However, Equation 12-1 uses empirical values from observations, and Equation 12-2 uses only the values of the physical properties of water. It is expected that Equation 12-2 overestimates the ice thickness compared to Equation 12-1.

$$X = \left(\frac{2kI_g}{L}\right)^{1/2}$$

Where:

k = thermal conductivity of material above the freezing isotherm, ice in this case, so from Table 12-2:

k_{ice} = 1.28 Btu/ft hr °F

L = volumetric latent heat of material undergoing phase change, in this case water, so:

Latent heat of water at 32°F = 144 Btu/lb

Density of water at 32°F = 62.4 lb/ft^3

L = (144 Btu/lb)(62.4 lb/ft^3) = 8985.6 Btu/ft^3

I_g = (3000°F-days)(24 hr/day) = 72,000°F hr

Solving for the practical maximum ice thickness:

$$X = \left(\frac{2(1.28 Btu/ft\ hr\ °F)(72{,}000\ °F\ hr)}{8986\ Btu/ft^3}\right)^{1/2} = 4.5 \text{ ft}$$

C-2 EXAMPLE 2

Estimate the ice thickness on the reservoir in Example 1 when there is an 8-inch snow cover on top of the ice and I_g is 3000°F-days.

From Equation 12-1, and Table 12-4:

$$X = m(I_g)^{1/2}$$

$$X = 0.7(3000)^{1/2} = 38 \text{ inch} = 3.2 \text{ ft}$$

Or use the Stefan equation (Equation 12-2) for a two-layer soil system:

$$X = \left(\left(\frac{k_2}{k_1}d_1\right)^2 + \frac{2k_2 I_g - \frac{d_1^2 L_1}{2k_1}}{L_2}\right)^{1/2} - (\frac{k_2}{k_1} - 1)d_1$$

The first layer is snow, d_1 = 8 inch = 0.667 ft, assumed to be drifted and compact. From Table 12-2, k_1 = 0.4 Btu/ft hr °F. Since no phase change occurs in the snow, L_1 = 0.

For Ice: k_2 = 1.28 Btu/ft hr °F

L_2 = (144)(62.4) = 8986 Btu/ft^3

$$X = \left(\left(\left(\frac{1.28}{0.4}\right)(0.667)\right)^2 + \frac{2(1.28)(3000)(24)}{8986}\right)^{1/2} - (\frac{1.28}{0.4} - 1)(0.667)$$

$= (4.55 + 20.5)^{1/2} - 1.47 = 3.5$ ft (includes the 8 inch snow)

C-3 EXAMPLE 3

The Equation 12-3 can be used to estimate the depth of frost penetration beneath a gravel pad or an insulation board. The L_1 in either case would be zero. The L_2 in this example would be the latent heat of fusion for the soil and would be dependent on the moisture content in the soil.

Assume: sandy soil, dry density 125 pcf, moisture content 6%, and a freezing index (I_g) of 3000°F-days.

Find depth of frost penetration under 3-inch thick polystyrene board. From Table 12-2:

k_1 = 0.020 Btu/ft °F hr (for polystyrene)

k_2 = 1.0 Btu/ft °F hr (for sand), and thus
d_1 = 3/12 = 0.25 ft

The moisture content in the soil = (0.06)(125 pcf) = 7.5 lb water/ft^3 soil.

Latent heat of water = 144 Btu/lb

L_2 = (144 Btu/lb)(7.5 lb/ft^3) = 1080 Btu/ft^3 of soil

L_1 = 0

$$X = \left(\left(\frac{k_2}{k_1}d_1\right)^2 + \frac{2k_2 I_g}{L_2}\right)^{1/2} - (\frac{k_2}{k_1} - 1)d_1$$

$$X = \left(\left(\frac{1.00}{0.02}(0.25)\right)^2 + \frac{2(1.00)(3000)(24)}{1080}\right)^{1/2} - (\frac{1.00}{0.020} - 1)(0.25)$$

$$X = (156 + 133)^{1/2} = 4.75 \text{ ft}$$

The depth of frost penetration would be 11.5 ft in the same soil, under the same conditions, if the insulation board were not in place.

C-4 EXAMPLE 4

Determine the rate of heat loss per linear foot of aboveground pipe from a 5-inch interior diameter (wall thickness ½ inch) plastic pipe encased in 2-inch thick polyurethane insulation. Water inside the pipe is maintained at 40°F, ambient air temperature is −40°F, and wind speed is 15 mph. Thermal conductivity of pipe material (k_P) is 0.208 Btu/°F ft hr and thermal conductivity of the insulation material (k_I) is 0.0133 Btu/°F ft hr.

Use equations from columns (a) and (b) of Figure 12-2:

Thermal resistance of pipe $R_P = \frac{ln(r_P/r_W)}{2\pi k_P}$

Inside pipe radius = r_w = 2.5 inch

Outside pipe radius = r_P = 2.5 + 0.5 = 3.0 inch

$$R_P = \frac{ln(3.0 - 2.5)}{2(3.14)0.208} = \frac{0.182}{1.307}$$

R_P = 0.139 hr ft °F/Btu

Thermal resistance of insulation: $R_I = \frac{ln(r_I/r_P)}{2\pi k_I}$

Outside pipe radius, r_P = 3 inch

Insulation radius, r_I = 5 inch

$$R_I = \frac{ln(5/3)}{2(3.14)0.0133}$$

= 6.115 hr ft °F/Btu

The total resistance of the pipe, R_C, is found as

$R_C = R_I + R_p$ = (6.115 + 0.139) = 6.254 hr ft °F/Btu

To determine the thermal resistance of the air film (R_A) it is necessary to estimate the surface heat transfer coefficient (h_a). From Figure 12-2 column (a):

$$h_A = N\left(\frac{T_S - T_A}{r_S}\right)^{0.25} W(V)$$

Where T_s is the outer surface temperature of the insulated pipe. (Note that in Figure 12-2 column (a) it was assumed that the thermal resistance of the pipe wall was negligible so that $T_s = T_w$. In the present case the pipe is insulated, and that assumption cannot hold.) From Figure 12-2 column (a), N = 0.23 and $W(V) = (12.5V + 1)^{1/2}$ where V is the wind speed (mph):

$$W(V) = ((12.5)(15)+1)^{1/2} = 13.73$$

In this case, R_P is to the outer surface of the insulation, 5 inches or 0.417 ft. For the first iteration one must assume a surface temperature (Ts). This is close to air temperature. Assuming Ts is −39°F, then:

$$h_a = 0.23\left(\frac{-39-(-40)}{0.417}\right)^{0.25} (13.73)$$

= 3.930 Btu/hr °F ft

Then, to calculate thermal resistance of air film:

$$R_A = \frac{1}{2(\pi)r_p h_a}$$

$$\mathrm{R_A} = \frac{1}{2(3.14)(0.417)(3.930)} = 0.0971 \text{ hr ft °F/Btu}$$

Then, check the assumed air film temperature:

$$T_S = T_A + (T_W - T_A)(\frac{R_A}{R_A + R_I + R_P})$$

$$T_S = -40 + (40 - (-40))(\frac{0.0971}{0.0971 + 6.116 + 0.1396})$$

= -40 + (80)(0.0153)

= −38.78°F (versus assumed −39.0°F, which is close enough).

If the values did not check, it would be necessary to repeat the calculation with another assumed T_S until a reasonable check is attained. The combined thermal resistance (R_C) is:

$$R_C = R_A + R_I + R_P$$

= 0.0971 + 6.116 + 0.139 = 6.352 hr ft °F/Btu

The rate of heat loss (Q) is:

$$Q = \frac{(T_W + T_A)}{R_C}$$

$$Q = \frac{(40 + (-40))}{6.352}$$

= 12.59 Btu/hr linear ft of pipe.

C-5 EXAMPLE 5

Compare the heat losses for the water pipe in Example 4 if installed at Utqiagvik, Alaska, aboveground or at a depth of 4 ft. Assume the minimum air temperature is −58°F, and the minimum mean daily soil temperature at a depth of 4 ft is 1.4°F. The thermal conductivity of the soil is 1.2 Btu/ft hr °F.

(1) Aboveground installation. Assume a 5-inch interior diameter plastic pipe with 2 inches of polyurethane insulation:

R_C = 6.254 hr ft °F/Btu (from Example 4).

The water inside the pipe will be maintained at 40°F so that the maximum rate of heat loss:

$$Q = \frac{(T_W - T_A)}{R_C}$$

$$Q = \frac{(40 - (-58))}{6.254}$$

= 15.5 Btu/hr linear ft of pipe.

(2) *Buried installation*. Assume that the top of the pipe is 4 ft below the surface, and the radius to the outer surface is 5 inches (0.416 ft). The depth to center of the pipe H_P is 4.416 ft, and the radius of pipe r_P is 0.416 ft, therefore the condition H_p is greater than $2r_p$ is true. So, from Figure 12-3 column (a), the thermal resistance of the soil (R_S) is:

$$R_S = \frac{ln(2\,H_P/r_P)}{2\pi k_S}$$

$$R_S = \frac{ln[2(4.416/0.416)]}{2(3.14)(1.2)}$$

= 0.405 hr ft °F/Btu

The air film is not a factor for a buried pipe of this type, so the combined resistance R_C equals:

$R_c = R_P + R_I + R_S$

= 0.1396 + 6.116 + 0.405
(R_P and R_I from the previous example)

= 6.661 hr ft °F/Btu

So, the heat loss Q equals: $Q = \frac{(T_W - T_G)}{R_C}$

T_G in this case is soil temperature 1.4°F

$$Q = \frac{(40 - 1.4)}{6.661}$$

= 5.79 Btu/hr linear ft of pipe.

This is about one-third the heat loss rate calculated for an above

ground installation in the same location. The responsible factor is the attenuation of the extreme surface temperature at the 4-ft depth.

C-6 EXAMPLE 6

Determine the mean size of the thaw zone and the average rate of heat loss from a 6-inch steel pipe buried 4 ft below the surface in a clay soil, where the soil thermal conductivities are as follows: k_t (thawed) = 0.60 Btu/hr ft °F, and k_f (frozen) = 1.0 Btu/hr ft °F. Mean soil temperature at the ground surface is 27.5°F, and the water in the pipe is maintained at 45 °F. (See Figure 12-3 column (b) for schematic, symbols, and equations). A bare steel pipe has negligible thermal resistance, so:

R_P = 0

Outer pipe radius r_P = 6 inch/(2)(12) = 0.25 ft

Depth to center of pipe H_P = 4.0 ft

$$T'_W = \frac{k_t}{k_f}(T_W - T_0) + T_0$$

Where:

T_W = water temperature inside pipe

T_0 = soil temperature at interface of the thawed zone

= 32°F

$$T'_W = \frac{0.6}{1.0}(45 - 32) + 32 = 39.8\ °\mathrm{F}$$

$$T' = \frac{T_0 - T_G}{T'_W - T_G}$$

T_G = temperature at ground surface

$$T' = \frac{32 - 27.5}{39.8 - 27.5} = \frac{4.5}{12.3} = 0.366\ °\mathrm{F}$$

Depth to center of thawed zone, H_Z = *(c)(coth A)*

Radius of thawed zone, r_Z = *(c)(csch A)*

$$c = (H_P^2 - r_P^2)^{1/2} = (4^2 - 0.25^2)^{1/2} = 3.99\ \mathrm{ft}$$

$$A = T' \operatorname{arcosh}(H_P / r_P)$$

If $H_P \geq 2r_P$

$$A \cong T' \ln(2H_P / r_P) = (0.366)(3.466) = 1.268$$

H_Z = *(3.99)(coth 1.268)* = (3.99)(1.172) = 4.68 ft

r_Z = *(3.99)(csch 1.268)* = (3.99)(0.5215) = 2.08 ft

The thaw zone, under steady state conditions, will be a cylinder of soil enclosing and parallel to the pipe. The radius of this zone will be 2.08 ft, and the axis will be about 5.2 inches below the bottom of the pipe:

The axis = $H_Z - (H_P + r_P)$ = 4.68 − 4.25 = 0.43 ft = 5.2 inches below pipe

The heat loss (Q) from this pipe would be:

$$Q = \frac{T'_W - T_G}{R'_S}$$

$$R'_S = \frac{\text{arcosh}(H_P/r_P)}{2\pi k_f}$$

If $H_P \geq 2r_P$:

$$R'_S = \frac{\ln(2\,H_P/r_P)}{2\pi k_f}$$

$$R'_S = \frac{\ln[2(4.0/0.25)]}{2(3.14)(1.0)} = 0.552 \text{ hr ft °F/Btu}$$

$$Q = \frac{(39.8 - 27.5)}{0.552} = 22.3\ \frac{\text{Btu}}{\text{hr}}\text{LF of pipe}$$

C-7 EXAMPLE 7

Determine the design time, the safety factor time and the complete freezing time for the pipe designed in Example 4 if the water stopped flowing. From Example 4, assume a 5-inch interior diameter plastic pipe with 2-inches of polyurethane insulation, constructed aboveground. The temperature of the water flowing into the pipe (T_1) is 40°F, the ambient air temperature (T_A) is −40°F, and the wind speed is15 mph. Use equations from Figure 12-1.

Design time equals the time for water in pipe to drop to freezing temperature (32°F); see Figure 12-2 for definition of terms.

$$t_D = \pi r_W^2 RC \, ln\left[\frac{T_1 - T_A}{T_0 - T_A}\right]$$

$$t_D = (3.14)(0.2080)^2(6.306)(62.4)\, ln\left[\frac{40-(-40)}{32-(-40)}\right] = 5.6 \text{ hr}$$

Safety factor time equals the time for water in the pipe to reach nucleation temperature for ice formation. Assume 27°F.

Substitute 27°F for T_2 in previous equation:

$$T_{SF} = (3.14)(0.208)^2(6.306)(62.4)\, ln\left[\frac{40-(-40)}{27-(-40)}\right] = 9.5 \text{ hr}$$

Complete freezing time equals the time for water at 32°F in pipe to freeze completely solid.

$$T_F = \frac{\pi r_W^2 RL}{T_0 - T_A}$$

Where:

L = volumetric latent heat of water

= (144 Btu/lb)(62.4 lb/ft^3)

= 8986 Btu/ft^3

Other factors are as defined above.

Therefore:

$$T_F = \frac{(3.14)\pi(0.208)^2(6.306)(8986)}{32-(-40)} = 107 \text{ hrs}$$

This Page Intentionally Left Blank

APPENDIX D GLOSSARY

D-1 ACRONYMS

ADEC	Alaska Department of Environmental Conservation
AFB	Air Force Base
AFCEC	Air Force Civil Engineer Center
ASCE	American Society of Civil Engineers
BIA	Bilateral Infrastructure Agreements
Btu	British thermal unit
C	Celsius
cm	Centimeter
CCR	Criteria Change Request
DoR	Designer of Record
DDC	Direct Digital Control
F	Fahrenheit
ft	Feet
FGS	Final Governing Standards
GNWT	Government of the Northwest Territories
HQUSACE	Headquarters, US Army Corps of Engineers
HDPE	High Density Polyethylene
HNFA	Host Nation Funded Construction Agreements
hr	Hour
IFS	Installation Facility Standard
kPa	Kilopascal
m	Meter
mph	Miles per hour

NAVFAC	Naval Facilities Engineering Systems Command
OEBGD	Overseas Environmental Baseline Guidance Document
POL	Petroleum, oil, and lubricant
PVC	Polyvinyl Chloride
pcf	Pounds per cubic ft
psi	Pound per square inch
s	Seconds
SOFA	Status of Forces Agreements
UFC	Unified Facilities Criteria
W	Watt
WBDG	Whole Building Design Guide

APPENDIX E REFERENCES

AMERICAN SOCIETY OF CIVIL ENGINEERS

https://ascelibrary.org

Cold Regions Utilities Monograph, https://doi.org/10.1061/9780784401927

AMERICAN SOCIETY OF HEATING, REFRIGERATION AND AIR-CONDITIONING ENGINEERS

https://www.ashrae.org/

District Heating Guide

Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates, A. Zhivov (ed.)

AMERICAN SOCIETY FOR TESTING AND MATERIALS

https://www.astm.org

ASTM F2620, *Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings*

AMERICAN WATER WORKS ASSOCIATION

https://www.awwa.org/

*AWWA C5*02*, Dry-Barrel Fire Hydrants*

INTERNATIONAL CODE COUNCIL

http://www.iccsafe.org/

International Building Code

STATE OF ALASKA

https://dec.alaska.gov/commish/regulations/

Standard 18 AAC 72, *Wastewater Treatment and Disposal, ADEC*

Standard 18 AAC 74, *Water and Wastewater Operator Certification and Training, ADEC*

Standard 18 AAC 80, *Drinking Wat*er, ADEC

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

Consult active UFCs for all aspects of design, including but not limited to:

UFC 1-200-01, *DoD Building Code*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 2-100-01, *Installation Master Planning*

UFC 3-130-01, *Arctic and Subarctic Engineering*

UFC 3-130-02, *Arctic and Subarctic Site Assessment and Selection*

UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*

UFC 3-130-04, *Arctic and Subarctic Buildings*

UFC 3-201-01, *Civil Engineering*

UFC 3-230-01, *Water Storage, Distribution, and Treatment*

UFC 3-230-02, *Operation and Maintenance: Water Supply Systems*

UFC 3-240-01, *Wastewater Collection and Treatment*

UFC 3-410-02, *Direct Digital Control for HVAC and Other Building Control Systems*

UFC 3-430-05, *Natural Gas and Liquified Petroleum Gas (LPG) Distribution Pipelines*

UFC 3-501-01, *Electrical Engineering*

UFC 3-550-01, *Exterior Electrical Power Distribution*

UFC 3-600-01, *Fire Protection Engineering for Facilities*

UFC 3-410-01, *Heating, Ventilating, and Air Conditioning Systems*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

UNIFIED FACILITIES GUIDE SPECIFICATIONS

https://www.wbdg.org/dod/ufgs

UFGS 23 07 00, *Thermal Insulation for Mechanical Systems*

UFGS 33 11 00, *Water Utility Distribution Piping*

UFGS 33 30 00, *Sanitary Sewerage*

UNITED STATES GEOLOGICAL SERVICE

https://waterdata.usgs.gov/nwis

USGS, *Water Data for the Nation*

OTHER

"Calculation of Heat Loss from Pipes," *Utilities Delivery in Arctic Regions*, Report No. EPS 3-WP-77-1, D.E. Thornton, Environmental Protection Service, Environment Canada, Edmonton, Alberta, 1977

Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost, K.A. Linell and E.F. Lobacz, Special Report 80-34, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, 1980

Electrical Grounding in Cold Regions, Cold Regions Technical Digest No. 87-1, K. Henry, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, 1987

"Environmental Engineering Failures in Alaska," *ASCE Cold Regions Engineering 2009. The 14th Conference on Cold Regions Engineering*, D.H. Schubert J.A. Crum, J. Olofsson, G.V. Jones, L.A. Woolard, and A. Ronimus, Duluth, MN, 31 Aug–2 Sep 2009

Fundamentals of Heat Transfer, S.S. Kutateladze, Harper & Row, New York, NY, 1963.

Geologic Hazards of the Fairbanks Area: Alaska Division of Geological & Geophysical Surveys Special Report 15, T.L. Péwé, 1982

Losses from the Fort Wainwright Heat Distribution System, Special Report 81-14, G.L. Phetteplace, W. Willey, and M.A. Novick, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, 1981

Prevention of Freezing and Other Cold Weather Problems at Wastewater Treatment Faculties, Special Report 85-11, S.C. Reed, D.S. Pottle, W.B. Moeller, C.R. Ott, R. Peirent, and E.L. Niedringhaus, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, 1985

Two-Dimensional Analysis of Natural Convection and Radiation in Utilidors, CRREL Report 99-7, P. Richmond, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, 1999

Underground Utility Lines, Technical Translation TT-1221, G.V. Prokhaer, National Research Council, Ottawa, Ontario, 1959

Water Supply Systems in Frozen Ground, L.R. Janson, in *Proceedings International Permafrost Conference,* 403–433, National Academy of Science, Washington, D.C., 1966

UFC 3-190-06
1 March 2021

UNIFIED FACILITIES CRITERIA (UFC)

PROTECTIVE COATINGS AND PAINTS

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UFC 3-190-06
1 March 2021

UNIFIED FACILITIES CRITERIA (UFC)

PROTECTIVE COATINGS AND PAINTS

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **\1** ... **/1/**)

Change No.	**Date**	**Location**

This UFC supersedes UFC 3-190-06, dated 16 January 2004.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01 for implementation of new issuances on projects.

AUTHORIZED BY:

CHRISTINE T. ALTENDORF, PhD, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Systems Command

NANCY J. BALKUS, P.E., SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW
Deputy Assistant Secretary of Defense (Construction) and Acting Deputy Assistant Secretary of Defense (Housing) Office of the Assistant Secretary of Defense (Sustainment)

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-190-06, *Protective Coatings and Paints*

Superseding: UFC 3-190-06, dated 16 January 2004

Description: This UFC provides requirements and technical guidance for the effective use of paint-type coatings to protect metal, concrete, gypsum board, and wooden structures at military activities from deterioration. This UFC applies to all Navy, Air Force, and Army service elements and contractors.

Reasons for Document:

- This version updates the current UFC documents from a MIL-HDBK to the current requirements for a UFC and updates technologies to the latest industry standards for surface preparation and coatings.

Impact:

- The requirements in this version should not impact initial cost for coatings and paints; however, the requirements should have a positive impact on life cycle costs through extended life of the coatings.

Unification Issues

In addition to OSHA standards for these topics, the Navy adheres to an additional set of OPNAVINST policies for safety and health issues.

TABLE OF CONTENTS

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

UFC 3-190-06 provides requirements and technical guidance for the effective use of paint-type coatings to protect common materials such as metal, concrete, pavements, gypsum board and wooden structures at military activities from deterioration. The words "paint" and "coating" are used interchangeably in this UFC. In the industry, the word "paint" is sometimes used to describe an architectural coating material while “coating” describes a protective “industrial” coating material.

1-2 APPLICABILITY.

This UFC applies to all Navy, Air Force, and Army service elements and contractors. All other DoD and Government agencies may also use this UFC unless explicitly directed otherwise. This UFC does not cover painting of ships, aircraft, or motor vehicles.

1-3 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance, and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-3.1 Environmental Severity Classifications and Humid Locations.

Provide paints and coatings that are durable and minimize the need for preventative and corrective maintenance over the expected service life of the component or system. Different materials will be used based on local environmental conditions. UFC 1-200-01, section titled “Corrosion Prone Locations” identifies corrosive environments and humid locations requiring special attention. Corrosive environments, which require additional corrosion protection, are those project locations which have an Environmental Severity Classification (ESC) of C3, C4 or C5. To determine ESC for specific project locations, refer to UFC 1-200-01 Appendix titled “Environmental Severity Classifications (ESC) for DoD Locations”. Humid locations are those in ASHRAE climate zones 0A, 1A, 2A, 3A, 3C, 4C, and 5C (as identified in ASHRAE 90.1).

1-4 GLOSSARY.

Appendix B includes acronyms and definitions of terms used in this document.

1-5 REFERENCES.

Appendix C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

This Page Intentionally Left Blank

CHAPTER 2 SURFACE PREPARATION

2-1 INTRODUCTION.

Prior to coating application, prepare the surface as required by the project UFGS and as recommended by the coating manufacturer. In case of conflict between the two, use the more stringent requirement. Surface preparation includes:

- Treat and repair surface irregularities including cracks, holes, sharp edges, weld spatter, and other defects that may lead to premature coating failure.
- Remove visible and non-visible surface contaminants (such as mill scale, oil, grease, salts and dirt) and deteriorated substrate surface layers (such as rust, chalk, and sunlight-degraded wood) that hinder coating adhesion.
- Produce a surface profile (texture) that promotes tight adhesion of the primer to the substrate.

2-1.1 Selection Factors.

Determine the type and degree of surface preparation based on these factors:

- Type of substrate
- Surface condition
- Type of exposure (service conditions)
- Desired life of the coating or structure
- Coating to be applied
- Environmental constraints
- Aesthetic requirements
- Desired finish
- Life-cycle cost considerations

2-1.2 Specification Procedure.

Use an industry surface preparation standard applicable to and compatible with the material, existing surface condition, and the selected coating. If an industry standard is not available, provide a performance-based requirement to achieve an acceptable level of surface preparation for the applied coating. Surface preparation methods and associated standards are summarized in Table 2-1.

Table 2-1 Commonly Used Methods of Surface Preparation for Coatings

(IMPORTANT NOTE: Methods may require modification or special control when existing paint or coating contains lead, cadmium, chromium, or other hazardous materials. For Navy projects, refer to UFC 3-810-01N Navy and Marine Corps Environmental Engineering for Facility Construction.)

Cleaning Method	Equipment/Standard	Comments
Organic solvent	Solvents and applicators such as mineral spirits, sprayers, and rags SSPC-SP 1	Removes oil and grease not readily removed by other methods. Take precautions to avoid fires and environmental contamination. Local VOC regulations may restrict use.
Water cleaning with or without detergent or emulsion type cleaners / power washing	Pumps, chemicals, sprayers, brushes SSPC-SP 1	At pressures not exceeding 2,000 psi (14MPa), removes soil, chalk, mildew, grease, and oil, depending upon composition. Good for smoke, stain, chalk, and dirt removal.
Acid	Chemicals, sprayers, and brushes SSPC-SP 1	Removes residual efflorescence and laitance from concrete after dry brushing. Thoroughly rinse to remove acid cleaners.
Chemical paint strippers	Chemicals, sprayers, scrapers, washing equipment No standard	Remove coatings from most substrates, but can be slow, messy, and expensive. May degrade surface of wood substrates. Refer to SSPC-TU 6, Chemical Stripping of Organic Coatings from Steel Structures.
Steam	Heating system pump, lines, and nozzles SSPC-SP 1	Removes heavy oil, grease, and chalk. Usually used prior to other methods.
Low-pressure water cleaning	Low pressure water pumps, lines, and nozzles SSPC-SP 1	At pressures of 2,000 psi to 5,000 psi (14 MPa to 34 MPa), may remove loose paint from steel, concrete, and wood. Can damage wood or masonry unless care is taken. Flash rusting of steel may occur.

High-pressure water cleaning	High pressure water pumps, lines, and nozzles SSPC-SP 1	At pressures of 5,000 psi to 10,000 psi (34 MPa to 70 MPa), removes loose paint from steel, concrete and wood. Can damage wood or masonry unless care is taken. Flash rusting of steel may occur.
Hand tool	Wire brushes, chipping hammers, and scrapers SSPC-SP 2	Removes only loosely adhering contaminants. Used mostly for spot repair. Slow and inconsistent.
Power tool	Wire brushes, grinders, sanders, needle guns, and rotary peeners SSPC-SP 3 SSPC-SP 15 SSPC-SP-11	Faster and more thorough than hand tools because tightly adhering contaminants can be removed. Some tools give a near-white condition on steel but not an angular profile. Slower than abrasive blasting. Some tools are fitted with vacuum collection devices.
Heat	Electric heat guns No standard	Can be used to soften coatings on wood, masonry, or steel. Softened coatings are scraped away. DO NOT use torches.
Shot blasting	Metal shot propelled onto concrete floor by centrifugal force SSPC-SP 13 / NACE No. 6	Can be used to prepare concrete floors for coating. Used to remove laitance and other unsound cementitious material and to provide appropriate surface profile.
Waterjetting	High and Ultra High pressure water pumps, lines, and nozzles SSPC-SP WJ-1 / NACE WJ-1 SSPC-SP WJ-2 / NACE WJ-2 SSPC-SP WJ-3 / NACE WJ-3 SSPC-SP WJ-4 / NACE WJ-4	At pressures above 10,000 psi (70 MPa), removes all oil, grease, and paint. Generally used to remove paint and prepare steel and concrete surfaces. Specify allowable degree of steel flash rusting.

Abrasive blasting	Sand, metal shot, and metal or synthetic grit propelled onto metal by pressurized air, with or without water or centrifugal force SSPC-SP 5 / NACE No. 1 SSPC-SP 6 / NACE No. 3 SSPC-SP 7 / NACE No. 4 SSPC-SP 10 / NACE No. 2 SSPC-SP 16 SSPC-SP 17 SSPC-SP 5 (WAB) / NACE WAB-1 SSPC-SP 6 (WAB) / NACE WAB-3 SSPC-SP 7 (WAB) / NACE WAB-4 SSPC-SP 10 (WAB) / NACE WAB-2 SSPC-SP CAB-1 SSPC-SP CAB-2 SSPC-SP CAB-3	Typically used on metal and, with care, on masonry and soft metals such as aluminum, copper, and galvanizing. Recyclable abrasives can be used. Special precautions are needed when removing lead containing paint. Water may be added to control dust but may require use of inhibitors. Vacuum blasting reduces dust but is slower. Centrifugal blasting is a closed cycle system in which abrasive is thrown by a spinning vane wheel but is typically limited to shop application. Softer, lower density abrasives such as corn cobs, walnut shells, sodium bicarbonate, and plastics may be used but they do not produce a profile. They are primarily used for cleaning purposes such as decal removal from painted surfaces, paint removal from soft metals, or smoke cleanup after a fire.

2-2 TREATMENT AND REPAIR OF SURFACE IRREGULARITIES.

Repair surfaces before recoating. Replace or repair rotten wood, broken siding, and other deteriorated substrates prior to maintenance painting. Repair water-associated problems, such as deteriorated roofs and nonfunctioning drainage systems, and spaces with inadequate ventilation prior to coating. Repair cracks, holes, and other defects prior to painting.

Areas in need of repair can sometimes be identified by associated, localized paint failures. For example, localized peeling paint confined to a wall external to a bathroom may be due to inadequate venting of the bathroom.

2-2.1 Joints, Cracks, Holes, or Other Surface Defects.

Fill joints, cracks, holes, and other surface defects to create a sound substrate with an acceptable texture. Use materials which are compatible with the specified coatings.

Use caulks and sealants to fill joints and cracks in wood, metal and, in some cases, in concrete and masonry. Use putty to fill holes in wood. Use specially formulated Portland cement materials in cracks and over spalled areas in concrete. Some of these contain organic polymers to improve adhesion and flexibility. Use patching plaster to repair large areas of interior plaster, spackle to repair cracks and small holes in wallboard, and joint cement to fill joints between wallboards and repair mortar. Before application of these repair materials, ensure surfaces are clean, dry, free of loose material, and primed according to the written instructions of the material manufacturer.

2-2.2 Cementitious Surfaces.

For concrete repair, use epoxy resin systems that meet ASTM C 881. Select the appropriate material based on application and working temperature.

2-2.3 Steel.

Require removal of accumulated dirt, trash, rust scale, pack rust ,and debris prior to or in conjunction with cleaning and surface preparation operations. Use NACE SP0178 to specify degree of surface imperfection repair for critical applications. This may include removal of slag, flux deposits, weld spatter, and burrs. Use SSPC-Guide 11 to specify edge treatment for critical applications. This may include rounding sharp edges such as those created by flame cutting and shearing by grinding. The rolled edges of angles, channels, and wide flange beams do not normally require further rounding unless specifically required.

2-3 SURFACE PREPARATION.

Select the proper surface preparation method based on the substrate to be coated, condition of the substrate, and the coating to be applied. Appendix A-1 identifies best practices associated with methods of surface preparation. Grease and oil are usually removed by solvent cleaning or steam cleaning, and mildew is killed and removed with a hypochlorite (bleach) solution, as described in Appendix A.

2-3.1 Wood.

Ensure wood surfaces are dry and clean before painting. New treated lumber may require an extended time to dry. Do not expose bare wood to direct sunlight for more than two weeks before priming. Sunlight causes photodegradation of surface wood-cell walls. This results in a cohesively weak layer on the wood surface which may fail when painted. If exposed, remove this layer by sanding prior to painting. Failure of paint caused by a degraded-wood surface is suspected when wood fibers are detected on the backside of peeling paint chips.

2-3.1.1 Existing Intact Paint.

When the existing paint is intact, clean the surface with water, detergent, and bleach as needed to remove surface contaminants, such as soil, chalk, and mildew. Remove loose paint by hand scraping when the existing paint is peeling and does not contain lead. Feather paint edges by sanding. Power sanding may damage the wood if improperly done. Water and abrasive blasting are not recommended for wood, because these techniques can damage the wood. When lead paint is present, use special precautions such as wet scraping.

2-3.1.2 Removal of Existing Paint.

Remove paint from wood when failure is by cross-grain cracking (that is, cracking perpendicular to the wood grain). This failure occurs when the total paint thickness is too thick or the paint is too inflexible. Painting over this condition almost always results in early failure of the maintenance paint layer. Paint removal from wood is difficult and may not always be feasible. Chemical strippers can be used, but the alkaline types may damage (chemically degrade) the surface of the wood and cause a future peeling-paint failure. Failure caused by a stripper-degraded wood surface is more likely for exterior exposures than for interior exposures. This is because the greater expansion and contraction of wood in exterior exposures requires that the surface wood have a greater mechanical strength.

2-3.2 Concrete/Masonry.

Prepare concrete and masonry surfaces to an appropriate class of surface preparation as described in SSPC-SP CAB-1, SSPC-SP CAB-2, SSPC-SP CAB-3, or SSPC-SP 13/NACE No. 6. Bare concrete and masonry surfaces, as well as painted surfaces, are usually best cleaned with water and detergent. Use low-pressure washing (less than 2,000 psi [14MPa]) or steam cleaning (ASTM D4258) to remove loose surface contaminants from surfaces. Use low-pressure water cleaning (2,000 psi to 5,000 psi [14 MPa to 34 MPa]) (ASTM D4259) to remove loose old coatings, other more tightly held contaminants, or chalk. If existing paints contain lead, special worker safety and environmental controls will be needed.

Abrasive blasting (ASTM D4259 and ASTM D4261) or acid etching of bare surfaces (ASTM D4260) may also be used to obtain a surface profile as well as to clean surfaces for coating. Avoid damaging surfaces with high-pressure water or abrasives. Remove grease and oil with detergents or steam before abrasive blasting or acid etching. First, remove any efflorescence present by dry wire brushing or acid washing. Special worker safety and environmental controls may be needed.

2-3.2.1 Testing for Moisture Content.

Concrete surfaces must be free of standing water prior to paint application. Concrete that appears dry can absorb and transfer ground moisture. Moisture vapor emissions can cause failures in non-permeable coatings and flooring systems. For these coatings, perform a moisture vapor emission test at a representative location prior to installing the coating or flooring system.

The plastic sheet method (ASTM D4263) can be used to detect the presence of moisture in concrete. The method involves taping a piece of plastic sheet to the surface and looking for condensed moisture under the sheet after 24 hours. The inside of the sheet should be dry if the moisture content is acceptable. The anhydrous calcium chloride test (ASTM F1869) can be used to determine the Moisture Vapor Emission Rate (MVER) at a point in time and at a specific location.

2-3.3 Steel.

Prepare steel for coating by solvent cleaning as described in SSPC-SP 1. Cleaning methods described in SSPC-SP 1 include organic solvents, vapor degreasing, immersion in appropriate solvent, use of emulsion or alkaline cleaners, and steam cleaning with or without detergents. SSPC-SP 1 is specifically included as the first step in the SSPC surface preparation procedures.

Remove mill scale, rust, and existing coatings by abrasive blasting (SSPC-SP 7, SSPC-SP 6, SSPC-SP 10, SSPC-SP 5) when installing a new coating system on a steel substrate. These methods can both clean the surface and produce a surface profile. The specific abrasive method selected depends upon the conditions of the steel, the desired coating life, the environment, and the coating to be applied. If lead paint is present, take special precautions to protect workers and the environment. Allow high-pressure and ultra-high pressure water jetting, with or without injected abrasives. Prepare the surface using hand tool cleaning (SSPC-SP 2) or power tool cleaning (SSPC-SP 3 or SSPC-SP 11) for localized repair or touch-up of existing coatings.

2-3.3.1 Specific Surface Preparation Requirements for Coatings for Steel.

Different types of coatings require different levels of cleaning. Use the more stringent (highest degree of cleanliness) of manufacturer's written instructions (tech data sheets) or contract specification requirements. Table 2-2 provides typical requirements for use where other guidance is unavailable. In each cell, the surface preparation methods are listed in order of decreasing cleanliness (the highest degree of cleanliness is at the top of the list). For immersion service or ESC C3, C4 and C5 environments, use the higher degree of cleanliness where surface preparation alternatives are provided.

In Table 2-2, “New Coating System,” includes coatings applied to new surfaces and existing uncoated surfaces, and existing coated surfaces made bare by cleaning operations. “Maintenance or Touch-up” refers to work performed on existing coated surfaces or small areas of touch up which is incidental to a new coating system.

Table 2-2 Typical Steel Surface Preparation Requirements for Coatings

Coating	Minimum Surface Preparation	
	New Coating System	Maintenance or Touch-up
Drying Oil	SSPC-SP 3 SSPC-SP 2	SSPC-SP 3 SSPC-SP 2
Alkyd	SSPC-SP 6/NACE No. 3 SSPC-SP 6 (WAB)/NACE WAB-3 SSPC-SP WJ-3 / NACE WJ-3 SSPC-SP 11 SSPC-SP 15	SSPC-SP 3 SSPC-SP 2 SSPC-SP WJ-4 / NACE WJ-4
Asphaltic	SSPC-SP 6/NACE No. 3 SSPC-SP 6 (WAB)/NACE WAB-3 SSPC-SP WJ-3 / NACE WJ-3 SSPC-SP 11 SSPC-SP 15	SSPC-SP 11 SSPC-SP 15 SSPC-SP 3 SSPC-SP WJ-4 / NACE WJ-4
Latex	SSPC-SP 6/NACE No. 3 SSPC-SP 6 (WAB)/NACE WAB-3 SSPC-SP WJ-3 / NACE WJ-3 SSPC-SP 11 SSPC-SP 15	SSPC-SP 11 SSPC-SP 15 SSPC-SP 3 SSPC-SP WJ-4 / NACE WJ-4
Epoxy	SSPC-SP 10/NACE No. 2 SSPC-SP 10 (WAB)/NACE WAB-2 SSPC-SP WJ-2 / NACE WJ-2 SSPC-SP 6/NACE No. 3 SSPC-SP 6 (WAB)/NACE WAB-3 SSPC-SP WJ-3 / NACE WJ-3	SSPC-SP 11 SSPC-SP 15 SSPC-SP 3 SSPC-SP WJ-4 / NACE WJ-4
Polyurethane	SSPC-SP 10/NACE No. 2 SSPC-SP 10 (WAB)/NACE WAB-2 SSPC-SP WJ-2 / NACE WJ-2	SSPC-SP 11 SSPC-SP 15 SSPC-SP WJ-4 / NACE WJ-4
Organic Zinc	SSPC-SP 10/NACE No. 2 SSPC-SP 10 (WAB)/NACE WAB-2 SSPC-SP WJ-2 / NACE WJ-2 SSPC-SP 6/NACE No. 3 SSPC-SP 6 (WAB)/NACE WAB-3 SSPC-SP WJ-3 / NACE WJ-3	SSPC-SP 11 SSPC-SP 15 SSPC-SP WJ-4 / NACE WJ-4
Inorganic Zinc	SSPC-SP 5/NACE No. 1 SSPC-SP 5 (WAB)/NACE WAB-1 SSPC-SP 10/NACE No. 2 SSPC-SP 10 (WAB)/NACE WAB-2	SSPC-SP 11
Metalizing	SSPC-SP 5/NACE No. 1 SSPC-SP 5 (WAB)/NACE WAB-1	SSPC-SP 11

2-3.4 Galvanized Steel or Inorganic Zinc Rich Coated Surfaces.

Clean these surfaces in accordance with SSPC-SP 16.

2-3.5 Aluminum and Other Soft Metals.

Clean aluminum and other soft metals by solvent cleaning (SSPC-SP 1). Use detergents, if necessary, for removal of dirt or loose corrosion products. Abrasive blasting with plastic beads or other soft abrasives may be necessary to remove old coatings. Use SSPC-SP 16 for brush-off blast cleaning of coated and uncoated aluminum and other soft metals. Use SSPC-SP 17 for thorough abrasive blasting of aluminum and other soft metals.

2-3.6 Mildew Removal.

Remove mildew from surfaces prior to painting. Additional requirements can be found in EPA 402-K-01-001.

2-3.7 Job Specific Demonstration.

If a project includes a complex coating system or procedure, require a job-specific mock-up or test patch representative of the completed coating system. The demonstration must represent the quality of work required, use the specified products for the project, and be approved prior to initiating production-scale effort.

2-3.8 Existing Coated Surfaces.

When the surface to be painted is an old weathered coating film (that is, surface preparation will not include removal of the old coating), use ASTM visual standards to evaluate chalk, mildew, and dirt removal. A minimum chalk rating (ASTM D 4214) of 8 is required for chalk removal, a minimum mildew removal rating (ASTM D 3274) of 8 (preferably 10) is required for mildew removal, and an ASTM D 3274 rating of 10 is required for dirt removal. Consider requiring preparation of a job-specific demonstration (as described in 2-3.7) for large jobs. This demonstration will cover removal of loose material, chalk, and mildew, as well as feathering of edges, and other requirements of the contract specification.

2-4 PROCEDURES FOR PAINT REMOVAL.

It is often necessary to remove old coatings that are peeling, checking, cracking, or the like. General recommendations for removal of paint from a variety of substrates are provided in Table 2-3. More detailed Best Practices are provided in Appendix A.

Table 2-3 Procedures for Coating Removal

(IMPORTANT NOTE – Use environmental and worker safety controls when existing paint or coating contains lead, cadmium, chromium, or other hazardous materials. For Navy projects, refer to UFC 3-810-01N Navy and Marine Corps Environmental Engineering for Facility Construction.)

Substrate	Methods
Wood	Chemical paint strippers, low- or high-pressure water cleaning, heat guns or hot plates along with scraping, or power sanding (perform with caution to avoid damaging wood).
Masonry	Acid cleaners, low- and high-pressure water cleaning, waterjetting, shot blasting, brush-off abrasive blast cleaning and power tool cleaning. Exercise caution to avoid undesirable damage to the masonry.
Steel	Abrasive blast cleaning (see Table 2-1), low- and high-pressure water cleaning, water jetting, power tool cleaning, or chemical paint strippers.
Miscellaneous metals	Chemical paint strippers, brush-off abrasive blast cleaning, low- and high-pressure water cleaning, water jetting, and power tool cleaning. Exercise caution to avoid substrate damage.

2-5 PERSONNEL AND CONTRACTOR CERTIFICATION.

Require minimum personnel and company certification requirements for DoD projects. Select more stringent requirements for high performance or complex coating systems, coatings subjected to exceptional service conditions, or installations with an exceptional consequence of failure. In these instances, require personnel meeting the requirements of SSPC-ACS 1/NACE No. 13, and performing contractors with an appropriate Corporate Certification, such as SSPC Painting Contractor Certification Programs (PCCP) or NACE International Institute Contractor Accreditation Program (NIICAP).

CHAPTER 3 SELECTION OF COATINGS

3-1 GENERAL.

Provide paints and coatings that are durable and minimize the need for preventative and corrective maintenance over the expected service life of the component or system. Identify the appropriate coating to be used based on UFC, UFGS, and Master Painters Institute (MPI) requirements. Where conflicts exist, the UFC and UFGS requirements take precedence over MPI. Select appropriate durability and coating system based on the ESC and service environment. Appendix A-2 identifies best practices for selection of coating systems for common substrates. Include surface preparation as a part of the coating system because of its importance in system performance.

3-1.1 Environmental Requirements.

Comply with all applicable Federal, State and local laws and regulations that may pertain to surface preparation and coatings projects. Use MPI products meeting environmental limits for lead, chromate, asbestos, crystalline free silica, and other hazardous materials. Select products with VOC levels that meet Federal, State and local requirements ,as well as UFC 1-200-02. When there is a conflict between Federal, State and local requirements, the more stringent applies; however, at a minimum all coatings must meet the requirements of UFC 1-200-02.

3-1.2 New Surfaces.

Use coating systems that are compatible with the surfaces to which they are applied. Coating incompatibility eventually leads to premature coating failures. Select a coating system based on life-cycle costs. Life-cycle costs include surface preparation, materials, application, necessary maintenance throughout the life of the coating system, disposal costs (waste streams), and environmental impacts. Include costs associated with containment during the removal of old paints and the subsequent disposal of debris that is often considered to be hazardous waste.

3-1.3 Existing Surfaces.

This section applies to existing coated surfaces, existing uncoated surfaces and existing coated surfaces made bare by cleaning operations. Use coating systems that are compatible with the surfaces (substrate and existing coating) to which they are applied. Coating incompatibility eventually leads to premature coating failures. A coating condition survey (CCS) must be accomplished for maintenance coating designs, or to determine if maintenance overcoating is appropriate. At a minimum, the CCS must identify existing coating conditions, analysis of remaining coating life, suitability of overcoating, technical requirements for overcoating, and any other information of interest to the coating system maintenance. Appendix A-3 contains additional information on coating condition surveys.

Select a maintenance approach based on life-cycle costs. Complete replacement of a coating system is typically more expensive than maintenance painting but may provide a substantially longer service life. Life-cycle costs include surface preparation, materials, application, necessary maintenance throughout the life of the coating system, disposal costs (waste streams), and environmental impacts. Include costs associated with containment during the removal of old paints and the subsequent disposal of debris that is often considered to be hazardous waste.

3-2 ARCHITECTURAL FINISHES.

Select durable materials for painting of new and existing, interior and exterior substrates, including masonry, concrete, metal, wood, and other miscellaneous materials from those listed in UFGS 09 90 00.

A Decision Tree that can be used as a guide in selecting Architectural Finishes is available on the MPI website (http://www.specifypaint.com/demo/demo_wbdg.html). Appendix A provides general guidance on coating system selection. Consult with an Army, Navy, or Air Force coatings specialist for applications where the coating will be subjected to exceptional service conditions or there is an exceptional consequence of failure. Note that not all coatings and systems available in MPI are included in the guide specifications. In the event of conflicts between MPI resources and DoD guide specifications, use the paint materials included in the DoD guide specifications.

3-2.1 Coating Selection for Corrosive and Humid Locations

Where available, select more durable coatings for projects located in corrosive environments and humid locations. Some of the coating systems listed in the guide specifications are explicitly for aggressive environments. Corrosive locations are defined in UFC 1-200-01, section titled "Corrosion Prone Locations". For exterior painting of metallic surfaces, corrosive locations include project locations with Environmental Severity Classifications (ESC) of C3 thru C5, or humid locations. For exterior painting of nonmetallic surfaces, corrosive locations are project locations with ESC of C4 and C5, or humid locations. Humid locations are those in ASHRAE climate zones 0A, 1A, 2A, 3A, 3C, 4C and 5C (as identified in ASHRAE 90.1). Interior high humidity areas such as bathrooms, locker rooms, laundry rooms, pools, and trainers are also considered as corrosive locations and require more durable coatings.

When using the MPI resources, such as the MPI Decision Tree, MPI designates systems for “Normal” or Aggressive” service and identifies the coating performance level which the specifier may find helpful when selecting from coating system options. When using the MPI resources, select “Normal” for locations defined as noncorrosive and select “Aggressive” for corrosive locations.

3-2.2 Wooden Floors.

Use the UFGS for paints and coatings for surface preparation (scraping and sanding) and coating of general use wooden floors. Use the appropriate UFGS for gymnasium flooring and other special purpose athletic hardwood floors.

3-3 COATING SYSTEMS FOR SPECIFIC USES.

Use coating systems specifically designed for metal storage tanks, pipelines, towers, waterfront structures, siding, fences, hot surfaces, concrete storage tanks, swimming pools, catchment basins, pavements, concrete floors, and surfaces particularly susceptible to mold and mildew.

3-3.1 Steel Storage Tanks

3-3.1.1 Fuel Storage Tanks.

Use coatings on steel fuel tanks to keep the fuel clean and help prevent leaks resulting from corrosion. Specify internal lining of welded steel petroleum tanks and exterior coating of steel structures as required by UFC 3-460-01. Specify interior cleaning prior to condition assessment of in-service tanks in accordance with applicable UFGS. Specify cathodic protection of fuel storage tanks as required by UFC 3-570-01.

3-3.1.2 Steel Water Tanks.

Specify internal and external coating of welded steel water tanks as required by UFC 3-230-01. Specify cathodic protection of water storage tanks as required by UFC 3-570-01 to supplement the protection afforded by the coatings.

3-3.1.3 Other Steel Tanks.

Use a suitable corrosion-resistant lining (such as fiberglass-reinforced polyester) to protect the interiors of steel tanks containing wastewater, chemicals, or other corrosive liquids from corrosion. Since there are no Federal specifications for such products, consult with protective coating specialists and specialty coating suppliers. Specify exterior coating of steel structures using applicable UFGS. Cathodic protection should be considered for these tanks, but the tanks must be evaluated by a certified Cathodic Protection expert.

3-3.2 Steel Distribution Lines.

Use protective coatings on steel distribution lines containing water, fuel, or other liquids to prevent loss of product from corrosion and contamination of soils and groundwater.

3-3.2.1 Steel Fuel Lines

Protect buried and immersed steel fuel lines using coatings and cathodic protection as required by UFC 3-460-01. Use UFGS 33 52 80 for interior and exterior coating of aboveground and buried, carbon steel, liquid fuel pipelines. Specify cathodic protection as required by UFC 3-570-01 to supplement the protection afforded by the coatings.

3-3.2.2 Steel Water Distribution Lines.

Protect aboveground and buried, carbon steel, steel water distribution lines as required by UFC 3-230-01.

3-3.3 Communication Towers and Other Tall Structures.

Use the UFGS for maintenance, repair, and coating of tall antenna towers. Use marking requirements in Federal Aviation Administration (FAA) Advisory Circular 70/7460-1L.

3-3.4 Waterfront Structures.

Use the UFGS for coating of steel waterfront structures for new construction and maintenance of steel waterfront structures such as “H” piles and sheet piles.

3-3.5 Hydraulic Structures and Appurtenant Works.

Use the UFGS for hydraulic structures for coating items such as locks, gates,and associated pipelines and equipment. Specify cathodic protection when appropriate.

3-3.6 Factory Finished Metal Siding.

Factory-finishing of steel, galvanized steel, or aluminum siding is accomplished by specialized procedures (such as coil coating) using commercial products. Follow the manufacturer recommended coating repair methods.

3-3.7 Hot Steel Surfaces.

Conventional coatings cannot protect mufflers, stacks, and other hot steel. Use specialty coatings selected by the equipment manufacturer for new construction and maintenance.

3-3.8 Concrete Fuel Tanks.

Consult a DoD coatings specialist for maintaining coatings on existing concrete fuel tanks.

3-3.9 Concrete Swimming Pools.

Consult swimming pool operations and maintenance manuals for maintenance painting of interior and exterior swimming pools.

3-3.10 Chemically Resistant Finishes for Concrete Floors.

Use the UFGS for fuel resistive coatings to install chemically resistant coating systems (resistant to fuels and hydraulic fluids). Consult the activity industrial hygienist for coatings on floors where chemicals or hazardous waste is stored.

3-3.11 Fouling-Resistant Coatings.

Antifouling coatings may be used on immersed portions of marker buoys and water cooling pipelines. For marker buoys, follow NAVSEA practices for ship hull antifoulant in NAVSEA Standard Item 009-32, Table One. For water cooling exchange pipelines, follow current industrial practices.

3-3.12 Mildew Resistant Coatings.

Mildewcides in paints are used to control mildew growth in the can and on the paint after application. Abate mildew growth on painted or unpainted surfaces of buildings, repair damaged areas, and clean substrates prior to applying a new or maintenance coating.

3-3.13 Pavement Markings.

Use the UFGS for pavement markings to install markings and applicable products on airfield and road pavements.

This Page Intentionally Left Blank

CHAPTER 4 APPLICATION

4-1 GENERAL.

Review coating suppliers Technical Data Sheets (TDS) or Product Data Sheets (PDS) and Safety Data Sheets (SDS) for each product to be used. Unless otherwise specified, comply with the storage requirements, application instructions, environmental parameters, mixing, curing time, thinning, and film thickness shown on the TDS/PDS.

If thinning is necessary, require a thinner product recommended by the coating manufacturer. Do not exceed the thinner volume recommended by the coating manufacturer or allowed by VOC regulations. Job site tinting is not allowed. The coating manufacturer or certified agent must tint all coatings.

4-1.1 Safety and Environmental Restrictions.

Comply with all applicable Federal, State, and local laws and regulations that may pertain to surface preparation and coatings projects. For Navy projects, refer to UFC 3-810-01N. Air Force components must comply with Air Force Manual (AFMAN) 91-203; in addition, always check with the local Bioenvironmental Department for local requirements. For Army projects, utilize EM 385-1-1 in addition to installation environmental requirements.

4-2 WEATHER CONDITIONS AFFECTING APPLICATION OF PAINTS.

Review the coating manufacturer's technical data sheets to determine if the environmental limits as well as other constraints on application of the paint are readily achieved. Include any extraordinary requirements in the project specifications.

4-3 METHODS OF APPLICATION.

Review the coating manufacturer's technical data sheets to determine if the methods of application are readily achieved. Include any extraordinary requirements in the project specifications.

4-4 PERSONNEL AND CONTRACTOR CERTIFICATION.

UFGS have minimum Contractor certification levels and may have more stringent requirements based on project specifics. Select more stringent requirements for high performance coating systems, complex coating systems, coatings subjected to exceptional service conditions, or installations with an exceptional consequence of failure. In these instances, require personnel meeting the requirements of SSPC-ACS 1/NACE No. 13, and performing contractors with an appropriate Corporate Certification: SSPC Painting Contractor Certification Programs (PCCP) or NACE International Institute Contractor Accreditation Program (NIICAP).

This Page Intentionally Left Blank

CHAPTER 5 INSPECTION OF PAINTING OPERATIONS

5-1 GENERAL.

Inspect painting operations to ensure conformance with the specification requirements. Depending upon the job and the contract requirements, quality-control inspectors may be contractor-supplied (that is, contractor quality control - CQC) or Government personnel. Include clear quality-control technical requirements, reporting requirements, and adjudication processes.

5-2 CONTRACTOR QUALITY CONTROL INSPECTION.

UFGS documents contain minimum quality-control requirements for DOD projects, which may be monitored by the contractor. Require a qualified third-party inspector for high performance or complex coating systems, coatings subjected to exceptional service conditions, or installations with an exceptional consequence of failure.

5-2.1 Duties of an Inspector.

The duties of an inspector include understanding the contract specification requirements, documenting performance of the contract in accordance with the specification, reporting rework requirements, and documenting rework. Keep records during all phases of the job. Records form an important part of the permanent record on each building and provide key information in the case of warranty claims and contract disputes.

5-3 WARRANTY INSPECTION.

Include a warranty inspection requirement for coatings that will be subjected to exceptional service conditions or with an exceptional consequence of failure. The warranty inspection includes a visual inspection of the film, and may involve chalk, film thickness, and adhesion measurements. Any defects found during the warranty inspection must be corrected by the Contractor.

This Page Intentionally Left Blank

APPENDIX A BEST PRACTICES

The Best Practices Appendix is considered guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned, but may not be the only solution to meet the requirement.

A-1 METHODS OF SURFACE PREPARATION.

Information on surface preparation methods and procedures is presented to help select appropriate general procedures and to inspect surface preparation jobs. It is not intended to be a complete source of information for those doing the work.

A-1.1 Abrasive Blasting.

Abrasive blast cleaning is most often associated with cleaning painted and unpainted steel. It may also be used with care to prepare concrete and masonry surfaces and to clean and roughen existing coatings for painting. Abrasive blasting is an impact cleaning method. High-velocity abrasive particles—driven by air, water, or centrifugal force—impact the surface to remove rust, mill scale, and old paint from the surfaces. Abrasive cleaning does not remove oil or grease. If the surface to be abrasive blasted is painted with lead paint, employ additional controls to minimize hazards to workers and the surrounding environment.

There are five degrees of cleanliness of blast cleaning designated by the SSPC/NACE standards for steel substrates. These designations are white metal, near-white metal, commercial, brush-off, and industrial. Note: Industrial is NOT an acceptable method for DoD components. Acceptable methods are summarized in Chapter 2. The degree of cleanliness obtained in abrasive blasting depends on the type of abrasive, the force with which the abrasive particles hits the surface, and the dwell time.

A-1.1.1 Air (Conventional).

In conventional abrasive blasting, dry abrasive is propelled against the surface to be cleaned so that rust, contaminants, and old paint are removed by the impact of the abrasive particles. Clean the surface of blasting residue before painting. This is usually done by vacuuming the surface. In the past, blowing clean air across the surface was used and termed “blow down”. However, this approach has the side effect of pushing the abrasive media into the substrate. This is especially noticeable in high profile requirements, where a tape test is used to verify the substrate is free of embedded grit and dust. Uncontrolled abrasive blasting is restricted in most locations because of environmental regulations. Consult the local industrial hygiene or environmental office for regulations governing local actions. Procedures for containment of blasting debris are being used for paint removal from industrial and other structures. SSPC has developed a guide (SSPC-Guide 6) for selecting containment procedures depending upon the degree of containment desired. Recycling the abrasive can reduce the amount of debris generated. Recycling systems separate the paint waste from the abrasive.

A-1.1.2 Wet Abrasive Blasting.

Wet-abrasive blasting is used to control the amount of airborne dust. It may be considered when dry abrasive blasting cannot be used due to environmental or worker safety restrictions. There are two general types of wet abrasive blasting. In one, water is injected near the nozzle exit into the stream of abrasive. In the other, water is added to the abrasive at the control unit upstream of the nozzle and the mixture of air, water, and sand is propelled through the hose to the nozzle. For both types of wet blasting, the blasting and rinsing water may contain a corrosion inhibitor if approved by the coating manufacturer. After wet blasting, rinse the surface free of spent abrasive. The surface must be completely dry before coating. When lead paint is present, the water and other debris must be contained and disposed of properly. This waste may be classified as a hazardous waste under Federal and local regulations and must be handled accordingly.

A-1.2 Ultra High Pressure Waterjetting

Waterjetting is an alternative method of removing coating systems or other materials from surfaces prior to the application of a protective coating or lining system. Waterjetting can be effective in removing water-soluble surface contaminants that may not be removed by dry abrasive blasting alone, specifically, those contaminants found at the bottom of pits of severely corroded metallic substrates. Waterjetting also helps to remove surface grease and oil, rust, shotcreting spatter, and existing coatings and linings. Waterjetting is also used in areas where abrasive blasting is not a feasible method of surface preparation.

Waterjetting does not provide the primary anchor pattern on steel known to the coatings industry as “profile.” The coatings industry uses waterjetting primarily for recoating or relining projects in which there is an adequate preexisting profile. Waterjetting has application in a broad spectrum of industries. It is used when high-performance coatings require extensive surface preparation or surface decontamination.

A-1.3 Acid Cleaning.

Acid cleaning is used for cleaning efflorescence and laitance from concrete. Remove heavy efflorescence and laitance from concrete surfaces by dry brushing or cleaning prior to acid cleaning. This is to prevent dissolution of the efflorescence and subsequent movement of the salts into the concrete. Prior to application of an acid solution, remove heavy oil, grease, and soil deposits. Oily dirty deposits can be removed by solvent or detergent washing.

A-1.4 Chemical Removal of Paint.

SSPC-TU 6 (Chemical Stripping of Organic Coatings from Steel Structures) outlines the selection and use of chemical strippers to remove paint. Paint strippers can be used when complete paint removal is necessary; other removal methods cannot be used due to environmental restraints, operational restraints or potential damage to the substrate or surrounding equipment. Removers are selected according to the type and condition of the old coating as well as the nature of the substrate. They are available as flammable or nonflammable types and in liquid or semi-paste types. If paint being removed contains lead, additional environmental and worker safety precautions will be needed. Removers are usually toxic and may be fire hazards. Management of the waste associated with the procedure will also be necessary. Consult the local environmental and safety offices for further information.

A-1.5 Solvent Cleaning.

SSPC-SP 1, Solvent Cleaning, defines solvent cleaning in surface preparation. This standard is included as a first step to other surface preparation standards. This standard defines the end-condition of a metal surface from which visible deposits of oil, grease, and other visible contaminants have been removed in preparation for subsequent application of protective coatings or for the use of additional methods to prepare the surface for the application of coatings. The standard also includes requirements for materials and procedures necessary to achieve and verify the end condition. A “solvent” is defined as any liquid or vapor that will dissolve or emulsify visible deposits of soluble contaminants on the surface. Examples of solvents include water, emulsion, or alkaline cleaners, and hydrocarbons.

A-1.6 Hand Tool Cleaning.

SSPC-SP 2, Hand Tool Cleaning, defines hand cleaning. It is primarily used to remove loose mill scale, loose rust, loose paint, and other loose detrimental material. This approach is more applicable to spot repairs in areas where deterioration is not a serious factor or in areas inaccessible to power tools. Remove grease or oil (SSPC-SP 1) prior to hand tool cleaning. Since hand cleaning removes only the loosest contaminants, select primers that are capable of thoroughly wetting the surface. Paint applied to hand-cleaned, steel surfaces has been shown to reduce longevity when compared to application on better-prepared substrates.

A-1.7 Power Tool Cleaning.

SSPC-SP 3, Power Tool Cleaning, defines power tool cleaning. It is primarily used to remove loose mill scale, loose rust, loose paint, and other loose detrimental material. This approach is more applicable to spot repairs in areas where deterioration is not a serious factor. This approach can be used to remove more tightly adhering contaminants and existing paint than hand tool cleaning. SSPC-SP 11 defines a cleanliness level comparable to SSPC-SP 10/NACE No. 2. Some power tools can be used to achieve an anchor profile comparable to abrasive blasting but not as deep. As with other surface preparation methods, remove grease, oil and other contaminants prior to power tool cleaning.

A-1.8 Non-Standard / Non-Traditional Surface Preparation Methods.

Surface preparation methods may be used on substrates not intended by a standard or design of the method. A SSPC Protective Coatings Specialist must be involved in the selection and use for industrial type substrates. For commercial / architectural applications consult MPI Level Two A for new construction or MPI Level Two B for repainting / maintenance.

A-1.9 Mildew Removal.

When a surface is to be cleaned for repainting, scrub with a solution of 2/3 cup (0.16 L) of trisodium phosphate (TSP), 1 liquid ounce of household detergent, 1 quart (0.95L) of 5-1/4 percent sodium hypochlorite (available as household bleach), and 3 quarts (2.8L) of warm water. Use rubber gloves with this caustic solution and rinse it from the surface with water after scrubbing. It will degrade alkyd and other oil-based coatings, but this will be no problem if the surface is to be repainted. An alternate procedure is to remove all the visible mildew by water cleaning at about 700 psi (5 MPa) at the nozzle and kill the rest by rinsing with a solution of 1 quart (0.95L) of 5-1/4 percent sodium hypochlorite and 3 quarts (2.8L) of warm water. If a painted surface is to be merely cleaned without repainting, apply the scrubbing solution without the TSP to avoid damage to the paint. Apply it first to a small test area to see if the hypochlorite bleaches the paint. If the TSP solution causes any damage, clean with detergent and water only.

Mildew on field structures can be distinguished from dirt with bleach. Common household hypochlorite bleach will cause mildew, but not dirt, to whiten.

A-1.10 Methods for Repairing Surface Defects.

A-1.10.1 Caulking and Sealant Compounds.

Caulking and sealant compounds are resin-based ,viscous materials. These compounds tend to dry on the surface but stay soft and tacky underneath. Sealants have application properties similar to caulking materials but tend to be more flexible and have greater extendibility than caulks. Sealants are often considered more durable than caulks and may be more expensive. Commonly available generic types of caulks and sealants include oil-based, butyl rubber, acrylic latex, silicone, polysulfide, and polyurethane. The oil-based and butyl-rubber type are continually oxidized by exposure to sunlight and become brittle on aging. Thus, their service life is limited. Acrylic-latex and silicone caulks tend to be more stable and have longer service lives. NOTE: Unless formulated for painting, silicone caulks will not hold paint. Applications are usually made with a caulking gun. However, some of these materials may also be available as putties or in preformed extruded beads that can be pressed in place.

A-1.10.2 Putty and Glazing Compounds.

Putty and glazing compounds are supplied in bulk and applied with a putty knife. Do not use putties for joints and crevices that require flexible fillers. Glazing compounds set firmly, but not hard, and thus retain some flexibility. Use acrylic-latex paints, such as MPI’s “Exterior Latex” series (MPI 10 – flat, MPI 11 – semigloss or MPI 119 – gloss) over flexible caulking, sealing, and glazing compounds.

A-2 COATING SYSTEMS FOR COMMON SUBSTRATES.

This section provides general recommendations for wood, concrete and masonry, steel, galvanized steel, and aluminum surfaces. A decision tree that can be used as a guide in selecting architectural finishes is available on the Whole Building Design Guide (WBDG) website (http://www.specifypaint.com/demo/demo_wbdg.html).

A-2.1 Recommendations for Wood.

Oil-based coatings (alkyds), waterborne coatings (acrylic emulsions and latex), and stains perform well on wood. A two-coat system consisting of either a paint or stain is typically sufficient. However, as overcoats are applied to resurface or repair weathered paint, the system’s film thickness may become too thick, resulting in the disbonding of the total paint system. Generally, no more than three or four overcoats of new paint will be applied to an existing system. Once this build-up occurs, remove some or all of the existing system prior to application of a new coating system.

Surface preparation of new wood generally consists of a light sanding with special care taken to not damage the wood. Sanding is also appropriate for preparing weathered surfaces for refinishing and for spot repairing areas of localized damage.

A-2.1.1 Oil-Based Paints.

Wood has been successfully painted with oil-based products that penetrate the surface well. These coatings are very easy to apply.

A-2.1.2 Water-Emulsion Paints.

Latex coatings are very effective in providing attractive, protective finishes. They are also less affected by moisture than are oil-based finishes and are generally more flexible and thus less susceptible to cracking as the wood swells and contracts with moisture changes.

A problem sometimes arises when repairing or top coating existing smooth alkyd coatings with latex paints. To obtain good intercoat adhesion, it may be necessary to lightly abrade the existing paint, wipe down, and apply a suitable primer (sometimes called a “transition” or “universal” primer) before applying the first coat of latex paint.

A-2.1.3 Semi-Transparent Stains.

Because oil-based and waterborne paints form continuous films, they may form blisters or disbond because of moisture in the wood attempting to escape. Semi-transparent stains do not form continuous films on wood and so do not have this problem. Thus, they are a good alternative on new wood. However, additional coats applied over the years or heavy-bodied stains will form continuous films.

A-2.1.4 Clear Floor Finishes.

Varieties of clear floor finishes are available for hardwood floors. UFGS documents contain detailed requirements for hardwood floors used in gymnasiums and other applications.

A-2.2 Recommendations for Concrete and Masonry Surfaces.

Concrete and masonry surfaces, as well as those of stucco, plaster, wallboard, and brick, can be coated with a variety of systems depending upon the desired purpose and appearance.

Surface preparation is usually accomplished by power washing with an aqueous detergent solution to remove dirt and other loose materials. Remove any oil or grease by solvent or steam cleaning; any mildew, by scrubbing with bleach; and any efflorescence or laitance, by brushing followed by acid treatment.

A-2.2.1 Waterborne Coatings.

A two-coat waterborne (latex) system provides an attractive breathing film that is normally less affected by moisture in the concrete than non-breathing systems. The latex material is a self-primer in this service, unless otherwise stated. Do not apply alkyd and other oil-based coatings directly to concrete or masonry surfaces, because the alkalinity in the concrete will hydrolyze (breakdown) the binder and cause the coating to peel. However, they can be applied over concrete or masonry surfaces primed with waterborne coatings to produce a tougher, more washable finish.

A-2.2.2 Elastomeric Coatings.

Elastomeric, waterborne acrylic coating systems perform well to seal and protect concrete/masonry surfaces and are normally very low in VOCs. They can successfully bridge fine or larger caulked cracks.

A-2.2.3 Textured Coatings.

Textured coating systems can bridge fine cracks and waterproof from wind-driven rain. They are normally applied over a primer recommended by the supplier to ensure good adhesion. They are available in a variety of textures and may be waterborne, oil or rubber-based products with a VOC limit of 250 grams per liter.

A-2.2.4 Epoxy Coatings.

A two-coat epoxy system will seal and protect concrete/masonry surfaces well. An aliphatic urethane finish coat should be used rather than the second epoxy coat on exterior surfaces to improve the weatherability.

A-2.2.5 Linseed Oil

Linseed oil is effective for sealing, waterproofing and anti-spall protection of concrete where freezing temperatures may cause damage. It is used on roads, bridge decks, sidewalks, curbs, parking ramps, floors, walkways, and other such concrete construction.

A-2.3 Recommendations for Steel.

High-performance coating systems are recommended to prolong the service life of steel structures before it becomes necessary to remove and replace it. Costs for coating maintenance on existing structures can be very high, especially where there are restrictions on abrasive blasting.

Abrasive blasting is always preferred to alternative methods of preparing steel surfaces for painting. It cleans the steel and provides a textured surface to promote good primer adhesion. A commercial blast (SSPC-SP 6/NACE No. 3) is normally adequate for alkyd and epoxy primers for a moderate environment such as interior exposures. A near-white blast (SSPC-SP 10/NACE No. 2) is required for epoxies, including zinc-rich epoxies, exposed to a severe environment such as exterior, marine atmospheric or water or fuel immersion. Some manufacturers may specify a white metal blast (SSPC-SP 5/NACE No. 1) for particular coatings for special applications. It is important that a contract specification does not conflict with the coating manufacturer's written directions. Inorganic zinc-rich primers require a white metal surface with a sharp angular surface profile. Few power tools provide this type of surface. If abrasive blasting cannot be done, then power tool cleaning to bare metal (SSPC-SP 11) can be specified with the additional requirement for an angular profile having a depth meeting the requirements of the coating manufacturer. Hand tool cleaning (SSPC-SP 2) or power tool cleaning (SSPC-SP 3) should not be specified for inorganic zinc primers.

A-2.3.1 Alkyd Systems.

In the past, most military steel structures with atmospheric exposures were coated with an alkyd or other oil-based system. On new painting, they are being replaced in significant part by epoxy systems that provide longer protection. Alkyd systems, however, might still be used for repairing old deteriorated alkyd systems. Alkyd coatings must never be applied directly to concrete or zinc-rich surfaces such as zinc-rich coatings, galvanizing, or zinc containing alloys (to name a few).

A-2.3.2 Epoxy Coating Systems.

A three-coat epoxy system provides good interior service in harsh and moderate environments. An aliphatic urethane finish system is used in place of the third epoxy coat in exterior service to provide greater resistance to deterioration by ultraviolet light. Newer topcoats include Fluorinated Aliphatic Polyurethanes, which provide much better resistance to UV and promise to at least double the life of previous systems. Several different epoxy mastic systems, some aluminum-filled, have been used successfully on steel structures.

A-2.3.3 Zinc-Rich Coatings.

Organic and inorganic zinc-rich coatings can provide good protection from corrosion and abrasion. Inorganic zinc-rich coatings perform well without topcoats in a variety of environments except acidic or alkaline. Inorganic zinc-rich coatings may be topcoated with an acrylic latex finish coat to provide a variety of color finishes or a color pigmented coating of the inorganic zinc-rich coating without the zinc. Epoxy (for interior) or epoxy and aliphatic urethane (for exterior) topcoats may also be used for both types. Localized repair of inorganic zinc systems is usually accomplished with a zinc-rich organic coating to permit good bonding to any exposed steel, inorganic coating, or organic topcoats.

A-2.4 Recommendations for Galvanized Steel.

Galvanized steel corrodes very slowly in moderate environments but may be painted with organic coating systems to provide color or additional corrosion protection, particularly in severe environments. It should never be coated directly with an alkyd paint because the alkalinity on the surface of the galvanizing will hydrolyze the oil in the binder, degrading the binder, and cause paint peeling.

New galvanized steel should be solvent- or steam-cleaned (SSPC-SP 1, Solvent Cleaning) to remove all grease and oil before coating. Older, untopcoated galvanizing should be power-washed to remove any dirt or loose zinc corrosion products. Remove loose coatings by power-washing or scraping and sanding to produce a clean, sound surface. Remove rust by waterjet cleaning to SSPC-SP WJ-2/NACE WJ-2 or SSPC-SP WJ-1/NACE WJ-1 per coating manufacturer requirements or by careful abrasive blasting in accordance with SSPC-SP 16 to limit the removal of galvanizing.

A-2.4.1 Epoxy Systems.

Two coats of epoxy will provide long-term protection to galvanizing in interior service, as will one coat of epoxy and one coat of aliphatic urethane in exterior service. NOTE: Avoid abrasive blasting or waterjet cleaning of light gauge metals / substrates such as sheet metal. The high velocity behind these methods can warp the substrate.

A-2.4.2 Waterborne System.

Two coats of latex paint will provide a pleasing appearance and good protection to galvanized steel in moderate environments.

A-2.5 Recommendations for Aluminum.

Aluminum surfaces corrode very slowly in moderate environments. They may be coated to provide color or additional protection, particularly in severe environments. Epoxy and epoxy/urethane systems perform well in interior or exterior service, respectively. Alkyd systems usually require surface pretreatments containing toxic materials.

Because aluminum surfaces are relatively soft, they should not be cleaned by blasting with conventional abrasives or grinding to avoid damage. Remove grease or oil by solvent or steam cleaning (SSPC-SP 1). Remove dirt and other loose contaminants by power washing. Existing coatings are best removed by careful abrasive blasting in accordance with SSPC-SP 16. Alkaline strippers must never be used; they will attack the aluminum.

A-2.5.1 Epoxy Systems.

Two coats of epoxy will provide long-term protection to aluminum in interior service, as will one coat of epoxy and one coat of aliphatic urethane in exterior service. NOTE: Avoid abrasive blasting or waterjet cleaning of light gauge metals / substrates such as sheet metal. The high velocity behind these methods can warp the substrate.

A-2.5.2 Waterborne System.

Two coats of latex paint will provide a pleasing appearance and good protection to aluminum in moderate environments.

A-3 COATING CONDITION SURVEYS (CCS).

A-3.1 Purpose.

The term "maintenance coating" may include overcoating of existing coated surfaces or coating of existing coated surfaces made bare by cleaning operations. The risks of overcoating can usually be avoided by designing project to remove all existing coatings to bare metal, then providing appropriate surface preparation and coating application. However, the extra costs of the coating removal, especially if containing hazardous material, along with the cost of surface preparation to SSPC-SP 10 Abrasive Blast to Near-White Metal, may be exorbitant compared to the costs of maintenance overcoating where the existing coating system is in fair-to-good condition. For maintenance coating design, or to determine if overcoating is appropriate, a coating condition survey should be accomplished.

Note that the aesthetic features of a coating do not define the coating condition; they only describe how the coating looks. Many coating systems have been replaced when only the topcoat needs "refurbishment." Likewise, many structures such as water tanks and fuel tanks have had complete coating replacement when only the roof coating needed replacement. A CCS can identify the weak components as well as the satisfactory components and propose solutions to make maximum use of existing resources.

A-3.2 Scope of Survey.

The scope of the CCS should be tailored to the specific project, and it should be recognized that while multiple coating failures or deficiencies may look similar, the risks of generalizing to save evaluation costs are potentially very high. The cost of large-scale overcoating failure and subsequent replacement of the coating system is far more than the cost of a CCS for all but the smallest projects.

The CCS should be accomplished by personnel from a business that routinely performs coating evaluations, and the individual investigator should be certified by SSPC as a

Protective Coatings Specialist. The CCS should be sufficiently detailed to provide all technical information about the coatings, and structures to be coated, required to properly design the project. At a minimum, the CCS should provide a detailed report of:

- Existing coating conditions, including condition of coating film, and the existence of potentially hazardous substances that may impact coating management (such as lead, cadmium, chromium);
- Analysis of remaining coating life, suitability of overcoating, and technical requirements for overcoating;
- Technical recommendations for the most cost-effective maintenance of existing coating systems, including any hazardous materials present in paint film; and
- Any other information of interest to the coating system maintenance that should be identifiable by an individual trained and experienced in the field of coating analysis, coating failure analysis, and coating design.

A-3.3 Lead and Other Hazardous Materials.

The requirements for removal and disposal of coatings which contain lead are provided in UFGS 02 83 00 and UFGS 09 97 02. Additional guidance is provided in SSPC-Guide 6 and SSPC-Guide 7.

A-3.4 Other CCS Uses.

Activities should consider an annual CCS to survey all structures to be authorized for design in the coming year. When accomplished for multiple projects, the per-structure cost will decrease. By accomplishing this survey prior to design, the basis for design is fully identified.

The CCS can also be a very useful tool when used to screen structures for maintenance painting requirements. A CCS can be scoped to provide a general inspection of many structures to screen for near-term overcoating or recoating requirements. If necessary, a subsequent investigation can provide appropriate details for project planning and design.

A-3.5 CCS Guidance Document.

SSPC Technology Update SSPC-TU 3 Maintenance Overcoating should be used as a guide for scoping the CCS, for accomplishing the CCS, and for designing the coating work.

A-4 LIFE CYCLE COST CONSIDERATIONS FOR COATINGS.

A-4.1.1 Opportunity When Coating New Structures.

The designer of the first coating system for a new fuel tank, pipeline or other constructed facility has the unique opportunity to specify a system that can provide the best life-cycle performance service. Often the coating system—surface preparation, priming and in some cases application of the complete coating system—can be carried out in a shop environment where the environmental and application parameters can be controlled. Whether shop- or field-applied, by controlling the various coating task application conditions, the surface can be very well prepared and the film properties obtained after curing are optimum. Since the cost difference of the "best" materials may not be much greater than the cost of "poor" materials, the use of these materials must be evaluated on a life-cycle performance basis when selecting the coating system if lower cost coating systems are being considered. Maintenance painting is always more difficult and costlier than shop painting ,and frequent maintenance painting on constructed facilities may interfere unacceptably with the mission of the structure. Thus, high-performance systems provide the optimum life-cycle performance and the appropriate high-performance system must always be specified on new construction or maintenance applications.

APPENDIX B GLOSSARY

B-1 ACRONYMS

AFCEC	Air Force Civil Engineer Center
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	ASTM International
BIA	Bilateral Infrastructure Agreement
CCR	Criteria Change Request
CCS	Coating Condition Survey
CQC	Contractor Quality Control
DoD	Department of Defense
EPA	United States Environmental Protection Agency
ESC	Environmental Severity Classification
FAA	Federal Aviation Administration
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
L	Liter
MPa	Megapascal
MPI	Master Painters Institute
NACE	NACE International – The Corrosion Society
NAVFAC	Naval Facilities Engineering Systems Command
NAVSEA	Naval Sea Systems Command
NICAAP	NACE International Institute Contractor Accreditation Program
OSHA	United States Occupational Safety and Health Administration
PCCP	SSPC Painting Contractor Certification Programs
PDS	Product Data Sheet

psi	Pounds per square inch
SDS	Safety Data Sheet
SOFA	Status of Forces Agreements
SSPC	SSPC – The Society for Protective Coatings
TDS	Technical Data Sheet
TSP	Tri Sodium Phosphate
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specification
U.S.	United States
UV	Ultraviolet
VOC	Volatile Organic Compounds

B-2 DEFINITION OF TERMS

Coating: (1) A liquid, liquefiable, or mastic composition that is converted to a solid protective, decorative, or functional adherent film after application as a thin layer [ASTM D 16]; (2) Generic term for paint, lacquer, and enamel (from SSPC Glossary)

Corrosion: The deterioration of a material or its properties due to a reaction of that material with its chemical environment. (from 10 USC §2228(f))

Corrosion prone locations: Locations with one or more of the following characteristics (1) Exterior exposed metallic elements at a location with an ESC of C3, C4, or C5, (2) Exterior exposed nonmetallic elements at a location with an ESC of C4 or C5, (3) Locations where microenvironmental factors (for example, prevailing winds, ventilation, waterfront environments, industrial emissions, deicing salt application, possible chemical splash/spillage, adverse weather events such as flooding or wind-driven rain, and penetrations of the building envelope) may create a locally corrosive environment regardless of ESC, (4) Humid locations identified in ANSI/ASHRAE/IES 90.1 as climate zones 0A, 1A, 2A, 3A, 3C, 4C, and 5C, and (5) High humidity interior areas (for example, bathrooms, locker rooms, laundry rooms, pools, and trainers).

Environmental Severity. Describes the corrosivity of the local environment of a given location or region.

Environmental Severity Classification (ESC): A classification of geographical macro environments developed by DoD based on the International Standards Organization Corrosivity Classification Method. Additional details are available at https://www.wbdg.org/ffc/dod/cpc-source/environmental-severity-classification.

Paint: (1) Any pigmented liquid, liquefiable, or mastic composition designed for application to a substrate in a thin layer that is converted to an opaque solid film after application. Used for protection, decoration, identification, or to serve some other functional purposes; (2) Application of a coating material. (from SSPC Glossary)

APPENDIX C REFERENCES

ASHRAE

https://www.ashrae.org/

ANSI/ASHRAE/IES Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings

ASTM INTERNATIONAL

https://www.astm.org/

ASTM C881/C881M-20, *Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete*

ASTM D3274-09(2017), *Standard Test Method for Evaluating Degree of Surface Disfigurement of Paint Films by Fungal or Algal Growth, or Soil and Dirt Accumulation*

ASTM D4214-07(2015), *Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films*

ASTM D4258-05(2017), *Standard Practice for Surface Cleaning Concrete for Coating*

ASTM D4259-18, *Standard Practice for Preparation of Concrete by Abrasion Prior to Coating Application*

ASTM D4260-05(2017), *Standard Practice for Liquid and Gelled Acid Etching of Concrete*

ASTM D4261-05(2018), *Standard Practice for Surface Cleaning Concrete Masonry Units for Coating*

ASTM D4263-83(2018), *Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method*

ASTM F1869-16a, *Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride*

ENVIRONMENTAL PROTECTION AGENCY

https://www.epa.gov/

EPA 402-K-01-001, *Mold Remediation in Schools and Commercial Buildings*

FEDERAL AVIATION ADMINISTRATION

https://www.faa.gov/

FAA Advisory Circular 70/7460-1L, *Obstruction Marking and Lighting*

NACE INTERNATIONAL

https://www.nace.org

NACE SP0178, *Design, Fabrication, and Surface Finish Practices for Tanks and Vessels to Be Lined for Immersion Service*

Joint SSPC/NACE standards are listed under the SSPC heading

NAVSEA

https://www.navsea.navy.mil/

NAVSEA Standard Item 009-32, *Cleaning and Painting Requirements; accomplish*

U.S. AIR FORCE

Air Force Manual (AFMAN) 91-203, *Air Force Occupational Safety, Fire, and Health Standards*

U.S. ARMY

EM 385-1-1, *Safety and Health Requirements*

SSPC – THE SOCIETY FOR PROTECTIVE COATINGS

www.sspc.org

SSPC-ACS 1/NACE No. 13, *Industrial Coating and Lining Application Specialist Qualification and Certification*

SSPC-Guide 6, *Guide for Containing Surface Preparation Debris Generated during Paint Removal Operations*

SSPC-Guide 7, *Guide to the Disposal of Lead-Contaminated Surface Preparation Debris*

SSPC-Guide 11, *Protecting Edges, Crevices, and Irregular Steel Surfaces by Stripe Coating*

SSPC-SP 1, *Solvent Cleaning*

SSPC-SP 2, *Hand Tool Cleaning*

SSPC-SP 3, *Power Tool Cleaning*

SSPC-SP 5/NACE No. 1, *White Metal Blast Cleaning*

SSPC-SP 6/NACE No. 3, *Commercial Blast Cleaning*

SSPC-SP 7/NACE No. 4, *Brush-Off Blast Cleaning*

SSPC-SP 10/NACE No. 2, *Near White Metal Blast Cleaning*

SSPC-SP 11, *Power Tool Cleaning to Bare Metal*

SSPC-SP 13/NACE No. 6, *Surface Preparation of Concrete*

SSPC-SP 15, *Commercial Grade Power Tool Cleaning*

SSPC-SP 16, *Brush-Off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels, and Non-Ferrous Metals*

SSPC-SP 17, *Thorough Abrasive Blast Cleaning of Non-Ferrous Metals*

SSPC-SP WJ-1/NACE WJ-1, *Waterjet Cleaning of Metals -- Clean to Bare Substrate*

SSPC-SP WJ-2/NACE WJ-2, *Waterjet Cleaning of Metals -- Very Thorough Cleaning*

SSPC-SP WJ-3/NACE WJ-3, *Waterjet Cleaning of Metals -- Thorough Cleaning*

SSPC-SP WJ-4/NACE WJ-4, *Waterjet Cleaning of Metals -- Light Cleaning*

SSPC-SP 5 (WAB)/NACE WAB-1, *White Metal Wet Abrasive Blast Cleaning*

SSPC-SP 6 (WAB)/NACE WAB-3, *Commercial Wet Abrasive Blast Cleaning*

SSPC-SP 7 (WAB)/NACE WAB-4, *Brush-Off Wet Abrasive Blast Cleaning*

SSPC-SP 10 (WAB)/NACE WAB-2, *Near White Metal Wet Abrasive Blast Cleaning*

SSPC-SP CAB-1, *Thorough Blast Cleaning of Concrete*

SSPC-SP CAB-2, *Intermediate Blast Cleaning of Concrete*

SSPC-SP CAB-3, *Brush Blast Cleaning of Concrete*

SSPC-TU 3, *Overcoating: Existing Coatings Systems Applied to Steel Substrates*

SSPC-TU 6, *Chemical Stripping of Organic Coatings from Steel Structures*

UNIFIED FACILITIES CRITERIA

http://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 1-200-01, *DoD Building Code (General Building Requirements)*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 3-230-01, *Water Storage and Distribution*

UFC 3-460-01, *Design: Petroleum Fuel Facilities*

UFD 5-570-01, *Cathodic Protection*

UNIFIED FACILITIES GUIDE SPECIFICATIONS

https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs

UFGS 02 83 00, *Lead Remediation*

UFGS 09 90 00, *Paints and Coatings*

UFGS 09 96 00, *High-Performance Coatings*

UFGS 09 67 23.15, *Fuel Resistive Resinous Flooring, 3-Coat System*

UFGS 09 67 23.16, *Fuel Resistive Resinous Flooring, 5-Coat System*

UFGS 09 96 59, *High-Build Glaze Coatings*

UFGS 09 97 02, *Painting: Hydraulic Structures*

UFGS 09 97 13.00 40, *Steel Coatings*

UFGS 09 97 13.15, *Low VOC Polysulfide Interior Coating of Welded Steel Petroleum Fuel Tanks*

UFGS 09 97 13.16, *Interior Coating of Welded Steel Water Tanks*

UFGS 09 97 13.17, *Three Coat Epoxy Interior Coating of Welded Steel Petroleum Fuel Tanks*

UFGS 09 97 13.25, *Maintenance, Repair, and Coating of Tall Antenna Towers*

UFGS 09 97 13.26, *Coating of Steel Waterfront Structures, Zero VOC, (SZC) Splash Zone Coating*

UFGS 09 97 13.27, *Exterior Coating of Steel Structures*

UFGS 33 52 80, *Liquid Fuels Pipeline Coating Systems*

UFGS 32 17 23, *Pavement Markings*

UFC 3-201-01
20 December 2022

UNIFIED FACILITIES CRITERIA (UFC)

CIVIL ENGINEERING

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

CIVIL ENGINEERING

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes UFC 3-201-01, dated 01 April 2018.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

PETE G. PEREZ, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Systems Command

DAVID H. DENTINO, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW, SES
Deputy Assistant Secretary of Defense
(Construction)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 REISSUES AND CANCELS.

This UFC supersedes UFC 3-201-01 with Change 5 dated 1 April 2021.

1-2 PURPOSE AND SCOPE.

This UFC provides civil engineering requirements for all new and renovated Government facilities for the Department of Defense (DoD). Where other criteria, statutory or regulatory requirements, are referenced, the more stringent requirement must be met.

1-3 APPLICABILITY.

This UFC applies to all service elements and contractors involved in the planning, design and construction of permanent DoD facilities worldwide. It is applicable to all methods of project delivery and levels of construction.

1-3.1 Foreign Countries.

All design and construction outside of the United States and United States territories is governed by international agreements, such as the Status of Forces Agreements (SOFA), Host Nation-Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA), and country-specific Final Environmental Governing Standards (FGS) or DoDI 4715.05. DoDI 4715.05 is commonly referred to as the Overseas Environmental Baseline Guidance Document (OEBGD). The OEBGD applies when there are no international agreements in place. Therefore, in foreign countries this UFC will be used for DoD projects to the extent that it is allowed by and does not conflict with the applicable international agreements.

1-4 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, *DoD Building Code*. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-4.1 Low Impact Development.

Use UFC 3-210-10 for Low Impact Development (LID) criteria. UFC 3-210-10 was developed to comply with the DoD Memorandum implementing Section 438 of the Energy Independence and Security Act (EISA).

1-5 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-6 BEST PRACTICES.

APPENDIX A provides guidance for accomplishing certain civil design and engineering services. The Designer of Record (DoR) is expected to review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from any UFC or the Unified Facilities Guide Specifications (UFGS), the UFC and the UFGS must be given a higher order of precedence.

1-7 GLOSSARY.

APPENDIX B contains acronyms, abbreviations, and terms.

1-8 REFERENCES.

APPENDIX C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

1-9 COMMENTARY.

Limited commentary has been added to the chapters. Section designations for such commentary are preceded by a “[C]” and the commentary narrative is highlighted with light gray.

CHAPTER 2 SITE DESIGN

2-1 PLANNING.

Site selection and planning require knowledge of environmental requirements, land use restrictions, building setbacks, flood hazard areas, utility connections, utility offsets, vehicle circulation, buffers from natural and manmade features and other similar requirements. Use this UFC prior to starting design to determine specific project requirements including but not limited to demolition, site development, water distribution, and wastewater collection.

2-1.1 Wetlands.

Executive Order (EO) 11990 directs all Federal agencies to avoid wetlands development wherever there is a practicable alternative.

2-1.2 Flood Hazard Planning.

EO 11988 directs all Federal agencies to comply with the minimum requirements of the National Flood Insurance Program. DTM 22-003 directs DoD to avoid development within a flood hazard area to the maximum extent practicable. When mission needs require siting a building within or partially within a flood hazard area, evaluate alternative site locations to avoid or minimize adverse impacts to the floodplain. When no practicable alternative exists, use section 2-1.2.3 to develop a flood risk reduction plan and use section 2-8 to determine the appropriate flood risk reduction criteria.

2-1.2.1 Assessment of Flood Vulnerability.

Provide an assessment of flood vulnerability that integrates: current flood hazard mapping; increases in projected sea level rise; when available, the climate-informed science approach; and future forecasted land use changes over the service life of the facility.

2-1.2.1.1 Non-Tidally Influenced Locations.

Use paragraph 2-8.1.1 Flood Hazard Areas.

2-1.2.1.2 Tidally Influenced Locations.

Use paragraph 2-8.2.1 DoD Regional Sea Level Database.

2-1.2.2 Design Flood Event.

The design flood event is the 100 year or greater flood event used to establish the design flood. The design flood event may include events that exceed the 100-year event, such as areas that may be impacted by projected sea level rise over the service life of the facility, the 500-year flood event, or when available, the Climate-Informed Science Approach.

2-1.2.3 Flood Risk Reduction Plan.

A project-specific Basis for Flood Risk Reduction is required for all facilities sited within a flood hazard area. When developing the Basis for Flood Risk Reduction, fully consider all flood risk reduction measures included in ASCE 24-14 such as breakaway walls, non-engineered and engineered openings, dry proofing and wet proofing. The Basis for Flood Risk Reduction may include temporary flood protection systems.

2-1.2.3.1 Department of Defense Form 1391 Disclosure Requirements.

When mission needs require siting a building within or partially within a flood hazard area, indicate the following information on DoD Form 1391:

1. Identify the type of flood hazard area: 1 percent annual chance event (ACE), 0.2 percent ACE, Climate-Informed Science Approach; or projected sea level rise over the service life of the facility; and
2. For the Climate-Informed Science Approach, the climate informed science flood elevation as the base flood elevation (BFE) and the design flood elevation (DFE);
3. For the Freeboard Approach, the design flood event, BFE and the DFE; or
4. For the DRSL Approach, sea level rise scenario and timeframe used to establish the DFE.

2-1.2.3.2 Flood Risk Reduction Documentation.

In accordance with PL 115-232, Section 2805(a)(3), as amended by PL 116-92, evaluate all applicable flood risk reduction measures and document in the Basis for Flood Risk Reduction. Store the Basis for Flood Risk Reduction in project file during the 1391 development process and retain the Basis for Flood Risk Reduction in the project historical file. In tidally influenced locations, the Basis for Flood Risk Reduction must incorporate DoD component direction, when available. DoD component direction may include scenarios and timeframes that are less than or greater than the default values shown in the DRSL Approach column in Table 2-1. The Basis for Flood Risk Reduction must include:

- A description of the site location and rationale for the project's site selection, including if the site is non-tidally or tidally influenced;
- Information concerning alternative sites that were considered and an explanation of why those sites did not satisfy mission requirements;
- A description of the flood hazard area, such as a high velocity V zone, coastal A zone, X zone, area inundated by projected sea level rise, or the Climate-Informed Science Approach, and an assessment of the flood vulnerability;

- A description of the design flood event, such as the 1 percent ACE, 0.2 percent ACE, Climate-Informed Science Approach, or the projected sea level rise scenario and timeframe;
- If using the Climate–Informed Science Approach, the climate-informed science flood elevation, an assessment of the flood vulnerability (risk of flooding), the BFE and the DFE;
- If the project is in a non-tidally influenced location, an assessment of the flood vulnerability (risk of flooding), the BFE and the DFE;
- If the project is in a tidally influenced location, a description of the approach used, Freeboard Approach or DRSL Approach; whichever is more stringent. For the Freeboard Approach, include an assessment of the flood vulnerability (risk of flooding), BFE and the DFE. For the DRSL Approach, include an assessment of the flood vulnerability (risk of flooding), and the sea level rise scenario and timeframe used to establish the DFE; and
- A description of planned flood risk reduction measures.

2-2 NATIONAL ENVIRONMENTAL POLICY ACT.

National Environmental Policy Act (NEPA) actions should be completed prior to starting design. Obtain NEPA documentation prepared for the project from the Installation environmental staff. Comply with the identified measures and include them as contract requirements.

2-3 PRELIMINARY SITE ANALYSIS.

Use UFC 2-100-01 to develop a preliminary approach appropriate to the site and adjacent facilities, integrate sustainable strategies, and utilizing a holistic design approach. Conduct a preliminary site visit and obtain photographs of the site. Research and obtain Installation’s master plan, utility maps, and as-built record drawings for information related to topography, utility, and storm drainage availability, including design approaches used in the project vicinity. Evaluate the potential for abandoned or unmapped utilities. Research and review available subsurface investigation data and reports in order to evaluate subsurface conditions. Identify flood hazard areas in accordance with the International Building Code (IBC) Section 1612 and sections 2-1.2 and 2-8 of this UFC. Research and obtain explosive safety requirements. Consult with the Government Project Manager to establish contact with the Installation’s Environmental personnel to determine if the site has environmental concerns, such as radon, pesticides, or known contamination. If required, provide radon mitigation system design in accordance with UFC 3-101-01. Evaluate the need for additional analysis based on project requirements and site conditions.

Conduct detailed consultations with the Government in order to clearly define requirements and preferences.

2-4 EXISTING CONDITIONS.

2-4.1 Geotechnical Site Investigation.

Obtain soil exploration, testing, and evaluation from a professional geotechnical engineer. Determine the extent of exploration and testing based on recommendations with the geotechnical engineer, structural engineer (for foundations), civil engineer (for site elements such as LID, pavements, wells, and septic systems), local stormwater permitting agency (for detention ponds), and Government reviewers. Soils investigation (sampling, testing, and evaluation) must be in accordance with UFC 3-220-01, UFC 3-250-01, and UFC 3-260-02.

Indicate the results of the subsurface investigation, including boring locations, boring logs, groundwater observations, a summary of laboratory test results, and any details required to convey requirements for site preparation on the contract documents.

2-4.1.1 Soil Corrosivity.

Require geotechnical site investigation for soil corrosivity, when existing operating records, visual observations, inspections, or testing indicate corrosive soil conditions. Provide an evaluation of existing soils at the proposed depths and locations of piping in accordance with AWWA M27, chapter titled *Evaluating the Potential for Corrosion*.

2-4.2 Surveying.

Unless provided by Government personnel, a licensed or certified professional must seal all surveys in accordance with the applicable requirements of the local regulatory agency or overseas equivalent having jurisdiction over the Installation. Where overseas equivalent requirements do not include an accuracy standard, provide surveys at a minimum third order in accordance with National Oceanic and Atmospheric Administration (NOAA), Federal Geodetic Control Committee, *Standards and Specifications for Geodetic Control Networks*.

Prior to entering property not owned by the Government, consult with the Government Project Manager to establish contact with the Installation’s real estate personnel. Notify and obtain authorization for a right of entry over, across, or through all lands public or private landowners necessary to perform required field survey work. Coordinate with the Installation’s Security section for approval to enter controlled or restricted areas including but not limited to airfields, ranges, and munition storage. Consult with Government Project Manager to establish contact with the Installation’s Environmental personnel before entering the area with regards to any restrictions such as cutting or clearing vegetation, natural resources, or species.

2-4.2.1 Topographic Surveys.

Provide a topographic survey of the project site in accordance with each service’s requirements as well as the requirements of the state or Host nation equivalent in which the site is located. If state or Host nation equivalent requirements are not available, use *Model Standards for Topographic Surveys*.

2-4.3 Environmental Considerations.

Coordinate with the Installation EV Staff during preliminary site investigation, review existing records and evaluate site for environmental concerns or known contamination such as soil or groundwater contamination. If known contamination or environmental concerns are identified, notify the Government Project Manager and evaluate impacts to project cost to ensure adequate funding for current project.

2-4.4 Existing Sewers.

Use WEF MOP FD-6 for guidance when evaluating and rehabilitating existing sewers.

2-5 APPROVALS AND PERMITS.

The DoR must identify, assist, and provide, as applicable, all permits, approvals, and fees required for the design and construction of the new project from Federal, state, and local regulatory authorities or overseas equivalent. The Civil Engineering DoR must be a Professional Civil Engineer experienced and licensed. Licensure in the location of the project may be required to obtain permits and approvals. In the United States and its territories and possessions the Government will review permits for acceptability. In locations outside of the United States and its territories and possessions with Host nation agreements, follow permit approval procedure as directed in project scope and by the Government Project Manager. In locations outside of the United States and its territories and possessions without Host nation agreements, the Government will review and approve site improvement plans for compliance.

Consult with the Government Project Manager to determine the appropriate signatories for permit applications.

2-6 CLEARING AND DEMOLITION.

Identify the following in the construction documents: limits of disturbance; limits of demolition; limits of clearing and grubbing; isolated trees and shrubs to remain or to be removed. Describe size, density, and type of trees to be cleared and grubbed, items to be salvaged or relocated, staging area, temporary storage area and location. Coordinate with the Installation concerning clearing options to remove merchantable timber from the project site.

During site demolition and preparation, remove existing and abandoned utilities under or within 10 feet (3.0 m) of the foundation of any new facility or building foundation. Reroute existing utilities to remain in accordance with paragraph titled “UTILITIES” in Chapter 2.

2-7 SITE DEVELOPMENT.

Location and orientation of facilities must be based on an analysis of activities to be accommodated and on specific requirements for each project, to include all functional, technical, and economic factors. Use UFC 3-101-01 for building function, size, and orientation criteria.

Incorporate the following into site design, as applicable:

a. Land use restrictions and setbacks (existing and future).

b. Circulation (vehicle and pedestrian).

c. Orientation and Location to integrate green space. Provide adequate grading and drainage while preserving natural topographic features to minimize cut and fill, impact on existing drainage patterns and tree removal.

d. Operational and natural constraints.

1. Maintain mandated buffers:

(a) Airfield and helipad clearances.

(b) Explosives safety clearances.

(c) Noise abatement.

(d) Antiterrorism and physical security clearances.

(e) Storage and handling hazardous material clearances.

(f) Separation of incompatible land use or functions.

(g) Building setbacks (if established).

(h) Fire separation zones per building and fire codes.

2. Eliminate or minimize construction activities requiring permits for areas such as archaeological sites, wetlands, utilities, and stormwater management.

3. Minimize site or utility maintenance and operating costs.

4. Accommodate site constructability and security requirements.

5. Minimize distance to existing utility connections.

2-7.1 Accessibility.

Use UFC 1-200-01 to determine accessibility requirements.

2-7.2 Petroleum, Oil and Lubrication (POL).

Use UFC 3-460-01 for POL criteria.

2-8 FLOOD RESISTANT DESIGN.

Facilities sited within or partially within a flood hazard area must be designed in accordance with UFC 1-200-01 and this UFC. For flood resistant design, UFC 1-200-01 implements the IBC and the IBC implements ASCE 24-14. This UFC modifies the IBC and ASCE 24-14. The term facilities applies to buildings and structures and the terms buildings and structures are used interchangeably for flood resistant design criteria. To minimize impacts to the existing floodplain, EO 11988 directs all Federal agencies to elevate buildings rather than filling in land, wherever practicable. Use UFC 4-152-01 for waterfront construction.

When mission needs require siting a building within or partially within a flood hazard area, obtain the project specific Basis for Flood Risk Reduction, when available. When the Basis for Flood Risk Reduction is not available, the DoR is responsible for preparing the Basis for Flood Risk Reduction, consistent with section 2-1.2. Use the Basis for Flood Risk Reduction and Table 2-1 when computing the minimum DFE. Table 2-1 modifies ASCE 24-14, Table 1-1 Flood Design Class of Buildings and Structures and provides DFEs. Ensure proper correlation between vertical datums and submit flood design calculations, including the governing criteria used, to the Government Civil Engineer.

Table 2-1 Design Flood Elevation (DFE)

ASCE 24-14 Flood Design Class	Freeboard Approach [1]	DRSL Approach [2,3,4]	Climate-Informed Science Approach
1 (minimal risk; non-essential facilities)	BFE	Lowest 2065	BFE
2 (moderate risk; non-essential facilities)	BFE + 2 ft (600 mm)	Low 2065	BFE +1 ft (300 mm)
3 Subcategory 3a (high risk; non-essential facilities)	BFE + 2 ft (600 mm)	Medium 2065	BFE +1 ft (300 mm)
3 Subcategory 3b[5] (high risk; essential facilities)	BFE + 3 ft (900 mm)	High 2065	BFE + 2 ft (600 mm)
4[6] (high risk; essential facilities)	BFE + 3 ft (900 mm)	Highest 2065	BFE + 2 ft (600 mm)

1. The freeboard approach complies with PL 115-232, Section 2805(a)(4)(A) and (B).
2. The default sea level rise scenario complies with USD (A&S) DTM 22-003, “Flood Hazard Area Management for DoD Installations,” dated June 7, 2022.
3. Use the site-specific value from the DoD Regional Sea Level (DRSL) database corresponding to the designated scenario (lowest/low/medium/high/highest) for the 1 percent ACE for year 2065. The DRSL database is publicly available at https://drsl.serdp-estcp.org/Site. The FOUO DRSL database is available at https://sealevelscenarios.serdp-estcp.org.
4. These are default values in the absence of a Basis for Flood Risk Reduction. When provided, use the component’s sea level rise scenario and timeframe in lieu of the value provided in this column.
5. Essential facilities that would not need to remain operational during the design flood event but would need to be fully operational immediately following a storm event.
6. Essential facilities that would need to remain operational during the design flood event.

2-8.1 Non-Tidally Influenced Locations.

2-8.1.1 Flood Hazard Areas.

The boundaries of the flood hazard area for the design flood event must be designated by:

a. When available, the Climate-Informed Science Approach,

b. The applicable Flood Insurance Study (FIS) with the accompanying Flood Insurance Rate Map (FIRM) or Flood Boundary and Floodway Map (FBFM) issued by Federal Emergency Management Agency (FEMA), when available,

c. Past flooding events, storm of significant impact,

d. A flood hazard map adopted by the Installation; or

e. A flood study performed to determine flood hazard areas in accordance with FEMA accepted hydrologic and hydraulic engineering practices used to define flood hazard areas.

When a new project site occupies two or more flood hazard areas, site the buildings or most vulnerable buildings to avoid the flood hazard area that presents the highest risk to the extent practicable.

2-8.1.1.1 Base Flood Elevation.

Determine the BFE for the design flood event in accordance with the following order of precedence:

1. When available, the Climate-Informed Science Approach;
2. As indicated on the applicable FIS and accompanying FIRM;
3. When regulation promulgated by a state or other government source is greater than the BFE identified in the Basis for Flood Risk Reduction, use the BFE established by the state or other government source;
4. A flood study performed to determine the BFE in accordance with FEMA; or
5. A flood elevation established by the Installation using documented historical flood data from previous extreme flood events.

When a building is sited within or partially within one or more flood hazard areas or BFE contours, use the flood hazard area or BFE that presents the highest risk to the buildings. In some cases, it may be acceptable to design portions of buildings that are structurally independent.

2-8.1.1.2 Design Flood Elevation.

Determine the DFE in accordance with the following order of precedence:

1. Use Table 2-1 to determine the DFE using the Freeboard Approach or, when available, the Climate-Informed Science Approach.
2. When regulation promulgated by a state or other government source is greater than the DFE computed in the first order of precedence, use the DFE established by the state or other government source.

2-8.2 Tidally Influenced Locations.

2-8.2.1 DoD Regional Sea Level Database.

The DRSL Database provides five global and site-specific sea level change scenarios for three discrete time periods, 2035, 2065, and 2100. These scenarios are bound by the lowest scenario which is based on the 95% confidence interval for sea level trends developed by NOAA and the highest scenario which is based on the highest projection from the United Nations Framework Convention on Climate Change produced by the Intergovernmental Panel on Climate Change. The three intermediate scenarios are based on equally proportional 0.5 m increment subdivisions of the upper bound for the 2100 time period which deviates from the United Nations Framework Convention on climate change scenarios. For the 2100 time period, the five global scenarios from the DRSL Database are lowest 0.7 ft (0.2 m), low 1.6 ft (0.5 m), medium 3.3 ft (1 m), high 4.9 ft (1.5 m), and highest 6.6 ft (2.0 m).

In accordance with PL 116-92, Section 2804 and DTM 22-003 on Flood Hazard Area Management for DoD Installations, use the DRSL Database to determine site-specific mean sea level rise when the tidal record is a minimum of 50 years or two National Tidal Datum Epochs. Use the following order of precedence to select the appropriate sea level rise scenario and timeframe:

1. Basis of Flood Risk Design retained in the project file.
2. The DRSL Approach column in Table 2-1.

For the lowest scenario, the NOAA relative sea level trend from the 95% confidence interval may be interpolated or extrapolated to estimate future sea level rise increases for time periods not provided in the DRSL Database. The low, medium, high and highest scenarios may be graphically interpolated to estimate sea level rise between the time periods provided in the DRSL Database. Do not extrapolate the low, medium, high and highest scenarios in the DRSL Database.

2-8.2.2 Flood Hazard Areas.

Determine the flood hazard area in accordance with the most stringent of the following requirements:

1. Paragraph 2-8.1.1, or

2. The 1 percent ACE EWL elevation from the DRSL Database.

2-8.2.3 Base Flood Elevation.

When using the DRSL approach, set the BFE equal to the EWL for the 1 percent ACE from the DRSL Database.

[C] 2-8.2.3 Base Flood Elevation

The EWL is the historical extreme water level value from the DRSL Database, not including wave height, having a 1 percent chance of being equal or exceeded in any given year. When using the DRSL Approach, the 1 percent ACE EWL from the DRSL Database is used as the 1 percent ACE flood event to consistently apply flood design criteria between the Freeboard Approach and the DRSL Approach.

2-8.2.4 Design Flood Elevation.

Use the following procedure to account for projected current and future mean sea level rise over the service life of the facility. Procedure for determining the DFE in tidally influenced locations:

1. Use paragraph 2-8.1.1.2 to determine $DFE_{freeboard}$.
2. Use paragraph 2-8.2.1 to determine the sea level rise scenario and timeframe.
3. Use Equation 2-1 to determine DFE_{SL}.
4. DFE equals $DFE_{freeboard}$ or DFE_{SL}, whichever is more stringent.

Equation 2-1. Design Flood Elevation

$$\boldsymbol{DFE_{SL} = EWL + SLR}$$

Where:
DFE_{SL} = Sea level rise impacted design flood elevation
EWL = 1 percent ACE EWL from the DRSL Database
SLR = Increases to site-specific mean sea level from the DRSL Database

[C] 2-8.2.4 Design Flood Elevation

Equation 2-1 is equivalent to using the combined tab in the DRSL Database.

2-8.3 Flood Resistant Design Options.

ASCE 24-14 does not require elevating all building types as a minimum standard. ASCE 24-14 allows additional flood resistant design standards to be used when constructing flood resistant buildings and minimizing damage from the design flood event. Flood resistant design standards include flood risk reduction measures such as:

- Design of openings (see ASCE 24-14, paragraph 2.7.2),
- Openings in breakaway walls (see ASCE 24-14, paragraph 2.7.1.1),
- Non-engineered openings (see ASCE 24-14, paragraph 2.7.2.1),
- Engineered openings (see ASCE 24-14, paragraph 2.7.2.2),
- Dry floodproofing (see ASCE 24-14, paragraph 6.2), or
- Wet floodproofing (see ASCE 24-14, paragraph 6.3).

Fully investigate flood resistant design standards, including temporary flood protection systems, and evaluate the impact of their use based on level of risk, non-essential or essential status, level of protection provided, user impacts and cost.

2-8.4 Flood Protection Systems.

When the design flood event cannot be mitigated using the flood risk reduction measures identified in ASCE 24-14, use a flood protection system to protect the building or buildings. A flood protection system may also be used when an engineering and cost analysis indicates that a flood protection system is advantageous to the intent of the project or master development plan. Flood protection systems may consist of dams, levees, floodwalls, and other types of flood protective works.

2-8.4.1 Establishing Flood Protection System Design Criteria.

Flood protection systems meeting the minimum design requirements in 44 CFR 65.10 may be accredited by FEMA for protection against the 1 percent ACE. FEMA accreditation of flood protection systems is encouraged but not required. Use 44 CFR Section 65.10 for the design of flood protection systems providing protection to the 1% ACE. Design flood protection systems to protect the building or buildings to the minimum DFE. When the design flood event exceeds the 1 percent ACE, the DoR must modify the minimum height of wall and associated criteria provided in 44 CFR Section 65.10 to account for the minimum DFE and submit the revised criteria to the Government Civil Engineer for review and approval prior to beginning design. In accordance with 44 CFR Section 65.10, the flood protection system is required to be certified by the DoR. Refer to FEMA GD34 for guidance on FEMA accreditation.

[C] 2-8.4.1 Establishing Flood Protection System Design Criteria

A registered professional engineer is responsible for certifying flood protection systems.

Flood protection system accreditation may be received from FEMA once a registered professional engineer has completed the certification process and all of the required documentation has been submitted to FEMA for review.

2-8.5 Mission Critical Roads.

Design mission critical roads and roads used for evacuation to be above the BFE plus freeboard or in accordance with the Installation's emergency management plan. Determine freeboard based on the reliability of available flood hazard area maps and supporting data, flood elevation and floodway data, increases in projected sea level rise, climate-informed science approach, or in accordance with FEMA accepted hydrologic and hydraulic engineering practices used to define flood hazard areas.

[C] 2-8.5 Mission Critical Roads

Mission critical roads provide at least one route of travel to mission critical buildings.

Freeboard is used to provide a factor of safety. A minimum freeboard of 1 foot (300 mm) is recommended.

2-9 GRADING.

UFC 1-200-01 implements grading requirements from the IBC and provides supplements to IBC criteria. Use UFC 1-200-01, paragraph titled "Soils and Foundations", to determine the appropriate requirements for site grading. Grading must direct water towards new or existing drainage features and away from impervious site features such as buildings, structures, runways, and roads. Grading must not result in low spots that hold water or that direct water towards new or existing site features. Conform to existing topography to the greatest extent possible.

Crowned sections are the standard cross sections for roads, runways, taxiways, and safety areas. Crowned sections are generally symmetrical and slope away from the center line of the pavement.

2-9.1 Transverse and Longitudinal Slopes.

Acceptable ranges of transverse and longitudinal slopes are indicated in Table 2-2. Grading criteria is also indicated in AASHTO GDHS.

Table 2-2 Grading

Item	Item Description	Requirement	Best Practices
1	Longitudinal grades of roads	Min. 0.3%	Min. 0.5%
2	Transverse grades of roads	Min. 2.0%	
3	Concrete pavement in parking areas	Min. 1.0%	Min. 1.5% Max. 5.0%
4	Curb & Gutter or Valley Gutter	Min. 0.3%	Min. 0.5%
5	Bituminous pavement in parking areas	Min. 1.5%	Min. 2.0% Max. 5.0%
6	Permeable Pavements in parking areas*	Min. 1.0%	Max. 5.0%
7	Walks, Transverse	Max. 2.0%	
8	Walks, Longitudinal		Max. 5.0%
9	Concrete Landings	Max. 2.0%	
10	Paved Concrete Ditches, longitudinal	Min. 0.3%	
11	Unpaved Ditches, longitudinal*	Min. 0.5%	
12	Pervious Surfaces (Grass, Turf, or Landscape)*	Min 2.0%	

* Regulatory agency's stormwater management criteria may govern for items used as stormwater management features.

2-9.2 Finished Floor Elevations.

Establish minimum finished floor elevations in accordance with this UFC, UFC 1-200-01 paragraph titled "Structural Design", or UFC 3-101-01, whichever is more stringent.

[C] 2-9.2 Finished Floor Elevations

The referenced criteria is included for projects that many or may not be in a flood hazard area. For example, if a project is not in a flood hazard area, UFC 3-101-01 may provide the more stringent criteria.

2-9.3 Airfields.

Use the airfield grading criteria in UFC 3-260-01.

2-10 VEHICLE CIRCULATION.

The DoR must address unique aspects of military facilities when designing roads and parking. For example, roads on military installations are typically designed for lower speeds while also addressing the movement of specialized military vehicles. Roads, parking areas and structures must conform to current antiterrorism and accessibility requirements.

2-10.1 Special Circulation Areas.

Circulation areas for vehicles other than normal passenger cars have special requirements to maintain traffic safety. These areas require additional space to accommodate unusual traffic patterns and greater turning radii for maneuverability. Special circulation areas include areas such as drop off areas, delivery and service zones, garbage collection areas (dumpsters), drive-in facilities, emergency vehicle access, and entry control facilities. The design must also address the turning and reverse movements for the largest vehicle including but not limited to deliveries, emergencies, and garbage collection that will use the facility and discourage through traffic.

2-10.1.1 Dumpster Pads.

Consider site circulation, building location, and distance to service doors. Coordinate the location of dumpster pads with Government personnel. Provide access to dumpster pads that is fully coordinated with the operation of the facility and facilities waste collection plan. When wheeled trash cans or carts are used as part of the facilities waste collection plan, provide sidewalks and ramps for access to and from the facility. Size dumpster pads in accordance with the Installation waste collection service. Provide site circulation and reverse turning area that allows dumpster trucks to maintain a forward movement to and from the dumpster pads. For frontloading dumpster trucks, provide a straight approach for dumpster trucks to access and align with the dumpster, reverse away, and exit forward. For rear-loading dumpster or roll off trucks, provide a reverse turning area that allows for a straight approach for dumpster trucks to access and align with the dumpster after reversing, and exit forward. For side-loading dumpster trucks, provide a straight approach for dumpster trucks to access and align with the dumpster, reverse away if needed, and exit forward. The concrete dumpster pad must be large enough to accommodate the:

- Front wheels of frontloading dumpster trucks;
- Rear wheels of rear-loading and roll-off dumpster trucks; or
- Front and rear wheels of side-loading dumpster trucks.

2-10.1.1.1 Airfields.

Locate dumpsters in locations approved by Airfield Operations (AIROPS) to avoid a Bird/Animal Aircraft Strike Hazard (BASH) issue.

2-10.2 Traffic Studies.

Provide traffic studies and analysis in accordance with Surface Deployment and Distribution Command Transportation Engineering Agency (SDDCTEA) Pamphlet 55-17 and SDDCTEA Pamphlet 55-8.

2-10.3 Design Vehicles.

Design vehicle types include:

a. Passenger car, truck, light-delivery truck, bus, and truck combinations are as defined by AASHTO (moving vans, refuse trucks and school buses, snow-clearing trucks).

b. Emergency vehicles.

c. Specialized military vehicles such as tracked vehicles.

Obtain design information for emergency vehicles and specialized military vehicles from the Government Project Manager.

2-10.4 Design Traffic.

Use ITE LP-674B to evaluate average daily traffic (ADT) and peak hourly traffic, as applicable. Adjust for vehicles other than passenger cars. In addition to the vehicles indicated in ITE LP-674B (trucks, RV's, buses), add specialized military vehicles as a vehicle type and determine the nearest equivalent AASHTO vehicle type.

2-10.5 Roads.

Design roads in accordance with SDDCTEA Pamphlet 55-17, AASHTO GDHS, AASHTO RSDG-4, and AASHTO VLVLR as applicable.

Single-lane roads may be provided for fire lanes and approach drives to buildings within built-up areas. Access roads to unmanned facilities may also be single-lane roads. Where shoulders are not sufficiently stable to permit all-weather use and the distance between intersections is greater than ½-mile (805 m), turnouts must be provided at 1/4-mile (402 m) intervals along single lane roads for use by occasional passing or meeting vehicles.

2-10.5.1 Fire Lane and Emergency Vehicle Access.

Fire lanes and emergency vehicle access must comply with UFC 3-600-01.

2-10.6 Parking Areas.

Design parking areas in accordance with SDDCTEA Pamphlet 55-17, Chapter titled "Parking". Parking areas include on-street parking, off-street parking lots, and parking structures. Refer to scope of work to determine the gross area or number of parking spaces. If the number of parking spaces is not identified in the project scope of work, use Table A-2 for guidance. Provide parking spaces primarily by off-street parking areas or structures.

For Flood Design Class IV facilities, design parking supporting essential personnel that would need to remain at the facility during the design flood event to be above the BFE plus freeboard. Determine freeboard based on the reliability of available flood hazard area maps and supporting data, flood elevation and floodway data, increases in projected sea level rise, climate-informed science approach, or in accordance with FEMA accepted hydrologic and hydraulic engineering practices used to define flood hazard areas.

[C] 2-10.6 Parking Areas

Freeboard is used to provide a factor of safety. A minimum freeboard of 1 foot (300 mm) is recommended.

2-10.6.1 On-Street Parking.

The use of on-street parking is discouraged. On-street parking will not be allowed within 20 feet (6.1 m) of an intersection. The minimum length for the first and last stall is 20 feet (6.1 m). The minimum length for each interior stall is 22 feet (6.7 m).

Exception to SDDCTEA Pamphlet 55-17: The minimum width for all passenger vehicle stalls is 8 feet (2.4 m).

2-10.6.2 Off-Street Parking.

Typically, 90 degree parking is preferred for off-street parking for ease of traffic flow. If 90 degree parking is not used, the designer must be able to justify by showing that the minimum functional and technical requirements are met while providing an economic benefit to the Government. Provide minimum 9 feet (2.7 m) wide and 18.5 feet (5.6 m) long parking spaces for 90 degree parking. The design must discourage through traffic.

Exception to SDDCTEA Pamphlet 55-17: In areas of limited space, provide a minimum buffer strip of 8 feet (2.4 m) when sufficient space is available.

2-10.6.3 Compact Cars.

Compact spaces may be used when there will be a consistent number of compact size vehicles accessing the facility on a regular basis. Do not use compact spaces when sufficient space is available for standard size passenger vehicles.

2-10.6.4 Motorcycles.

When motorcycle spaces are subtracted from the required regular spaces a parking study must be performed to determine the consistent number of motorcycles regularly parking at the facility throughout the year. When performing the traffic study, take into account adverse weather (winter in northern climates). Do not subtract motorcycle spaces from required regular spaces unless supported by a traffic study.

Motorcycle parking surfaces are typically designed as rigid pavements to prevent kickstands from penetrating bituminous pavement in warm weather. The minimum size for motorcycle spaces is 9 feet (2.7 m) long and 4.5 feet (1.3 m) wide.

2-10.6.5 Parking Areas Outside of the United States.

Use UFC 1-200-01 and refer to the “Forward” at the beginning of this UFC to determine accessibility requirements for areas outside of the United States. When standard passenger car dimensions, as indicated in SDDCTEA Pamphlet 55-17, are not used, a traffic engineering study (parking study, parking design vehicle study) must be performed to determine the predominant vehicle size and parking layout. Perform traffic engineering studies in accordance with SDDCTEA Pamphlet 55-8. The minimum parking size for all cars is 8 feet (2.4 m) x 16 feet (4.8 m).

During the parking study, take into account the following at a minimum:

- Requirements for each project.
- An analysis of activities to be accommodated.
- Government vehicle use.
- Standard vehicles from the United States.
- Current and future parking demand.
- Variety of parking areas needed.
- Truck traffic, including deliveries- and garbage collection.
- Emergency vehicles.
- Minimum entrance widths.
- Number of entrances.
- AT setbacks.
- Parking (on-street, off-street, parking orientation, aisle widths, minimum stall size and orientation, accessible spaces).

2-10.7 Bicycle Facilities.

Use AASHTO GDHS and SDDCTEA Pamphlet 55-17 for the design of bicycle facilities. Use Best Practices document, AASHTO GBF for additional design guidance.

2-11 SITE APPURTENANCES.

Provide site appurtenances in accordance with state or local standards where project is located.

2-11.1 Pedestrian Circulation.

Allow for pedestrian circulation between various new and existing facilities by providing a network of new sidewalks that connect new pedestrian circulation systems with existing pedestrian circulation systems. Use UFC 1-200-01 to determine accessibility requirements. Use AASHTO GDHS and SDDCTEA Pamphlet 55-17 for the design of pedestrian circulation systems. Use Best Practices document, AASHTO GPF for additional design guidance.

Sidewalks may consist of portland cement concrete, bituminous concrete (asphalt), solid pavers, permeable pavers, or pervious concrete. The minimum thickness of PCC concrete sidewalks is 4 inches (100 mm). Provide bituminous sidewalks with a minimum 4 inches (100 mm) thick base and a 1 inch (25 mm) thick bituminous surfacing. The minimum width for all sidewalks is 4 feet (1.2 m). In high volume or urban areas, the minimum width for sidewalks is 6 feet (1.8 m). Where the sidewalk is adjacent to the curb, increase the minimum width to account for obstacles such as signs and fire hydrants. Consult with the Government Project Manager for special sidewalk requirements for facilities with high pedestrian volumes such as barracks, medical facilities, where extra wide walks may be required.

2-11.2 Curb or Curb and Gutter.

Use concrete curb and gutter when overland flow cannot be achieved; to extend curb or curb and gutter from an adjacent facility; or to confine traffic. Asphalt-type curbs are only allowed in remote areas where approved by the Installation.

2-11.2.1 Airfields.

Curbs and gutters are not permitted to interrupt surface runoff along a runway, taxiway, heliport, or apron. The runoff must be allowed unimpeded travel transversely off the runway and then directed to the inlets.

2-11.3 Wheelstops.

Provide 6 feet (1.8 m) long wheelstops anchored to the pavement at parking spaces adjacent to sidewalks, buildings, stormwater management facilities, areas of extreme slope, and other areas without curb where a vehicle would likely cause property damage. Locate the front face of the wheelstop 30 inches (750 mm) from the edge of the pavement or sidewalk.

Where snow removal equipment is used, wheelstops may not be allowed by the Installation; coordinate with Government Project Manager.

2-11.4 Bollards.

2-11.4.1 Bollards around Structures.

Provide bollards around any structures subject to damage from vehicular traffic by incidental contact; such bollards must be at minimum 4 feet (1.2 m) high. For steel bollards, provide minimum 4 inch (100 mm) diameter filled with concrete and painted. Bollards on aircraft aprons protecting fire hydrants must not exceed 30 inches (750 mm) aboveground and 24 inches (600 mm) above load bearing paving.

2-11.4.2 Bollards for Security.

For vehicular barrier and crash rated applications, use UFC 4-022-02.

2-11.5 Signage and Markings.

Provide signs and associated pavement markings to facilitate proper utilization of the project site. Provide new traffic control devices such as signs and markings in accordance with SDDCTEA Pamphlet 55-17. Also use Manual on Uniform Traffic Control Devices, SHSM, and *Department of Defense Supplement to the National Manual on Uniform Traffic Control Devices*.

Provide non-reflectorized pavement markings for paved parking areas, reflectorized pavement markings for paved roads, and fire access markings in accordance with marking criteria and procedures recognized by the Department of Transportation (DOT) in the state in which the project is located or local governing authority's requirements.

2-11.6 Dumpster Enclosures.

Where dumpster pads are required on a project, provide a dumpster pad enclosure conforming to the Installation Appearance Plan.

2-12 UTILITIES.

New underground utilities such as water, sanitary sewer, electrical, telecommunications, and natural gas) must be at least 10 feet (3.0 m) from foundations for buildings and structures. For building connections, minimize the length of piping under the building by running the service piping around the outside of the building. Provide horizontal and vertical separation between new and existing utilities for rehabilitation, maintenance, repair or replacement. Minimize underground utilities located beneath pavements, except where crossings are required. Locate utilities to minimize connection costs and traffic interference with future maintenance.

Obstructions including signs and poles for overhead utilities must be located outside the limits of usable shoulder on roads designed without barrier curbs. Where practicable, roads designed with barrier curbs must have the desirable lateral clearances to obstructions as indicated in AASHTO GDHS except that fire hydrant clearances must be in accordance with UFC 3-600-01.

2-12.1 Water Distribution Systems.

Use UFC 3-230-01 for water distribution system criteria. Use UFC 3-230-03 to establish water demand.

2-12.2 Wastewater Collection Systems.

Use UFC 3-240-01 for wastewater collection and treatment criteria.

2-12.3 Lighting.

Use UFC 3-530-01 for lighting criteria.

2-13 STORM DRAINAGE SYSTEMS.

Refer to Chapter 3 of this UFC.

2-14 ENTRY CONTROL FACILITIES.

Use UFC 4-022-01 and SDDCTEA Pamphlet 55-15 for entry control facility criteria.

2-15 BRIDGES, OVERPASSES AND UNDERPASSES.

Where applicable, comply with AASHTO GDHS, AASHTO RSDG-4 and AASHTO LRFDBDS. Use Best Practices document USDA 0625 1808P as applicable.

For railroad bridges, also comply with UFC 4-860-01, the design manual of the relevant railroad company and use Best Practices document, the American Railway Engineering and Maintenance-of-Way Association (AREMA) publication *Manual for Railway Engineering*.

CHAPTER 3 STORM DRAINAGE SYSTEMS

3-1 DESIGN CRITERIA.

Design surface drainage, underground drainage systems, stormwater management facilities, and erosion and sediment control in accordance with the criteria noted in this UFC, UFC 3-210-10, HDS-5, state drainage manual, or the local regulatory agency with jurisdiction over the Installation; whichever is more stringent. Ensure that the stormwater runoff does not adversely affect the project site (building function, parking, roads) for the service life of the facility, the surrounding facilities for the service life of the surrounding facilities, and future forecasted land use changes. Submit calculations to the Government Civil Engineer and document the governing criteria used. For additional design guidance, consult Best Practices, as indicated in APPENDIX A and manufacturer’s data.

The design of the storm drainage system and stormwater management features must address the following:

- The storm drainage system and stormwater management plan must comply with Federal, state, and local regulatory requirements including regional or site-specific stormwater management agreements.
- Minimize grading to complement the features and functions of the natural drainage system and the existing contours.
- The siting and sizing of stormwater management facilities must take into account the high and seasonal groundwater table elevations.
- Utilize overland flow and natural site features where storm drainage will not impact site function or adversely affect surrounding sites. Drainage systems must prevent erosion of existing soils, ponding, and convey flow to a suitable outfall location.
- Culverts, ditches, and other drainage structures must be designed to minimize adverse environmental effects such as erosion, impacts to wetlands, and blocking fish passage.
- If a suitable point of discharge does not exist, one must be constructed.

3-1.1 Approved Methodologies.

Peak design flow must be calculated using the Rational Method for drainage areas smaller than 200 acres, Technical Release 55 (TR-55) curve number method or as approved by the Government Civil Engineer. Intensity-duration-frequency (IDF) curves are available in most state or local regulatory agency drainage manuals or from NOAA. If the IDF curves are not available, particularly in areas outside of the United States, the DOR needs to develop them on a project-by-project basis. Submit IDF curves with the calculations for approval from the Government Civil Engineer.

The TR-55 curve number methodology is approved and recommend for LID calculations required by UFC 3-210-10.

3-1.2 Design Storm Frequency.

For the design of surface and underground stormwater drainage systems, use a minimum 10-year storm frequency, the facility type minimum, or the minimum required by the state or local governing authority; whichever is more stringent.

3-1.2.1 Airfields.

Runways, taxiways, heliports, and aprons use the minimum required by the local governing authority for airfields and heliports or a minimum 5 year storm frequency. Retrofit projects on existing runways, taxiways, heliports, and aprons should be designed using a 5 year storm. Where an engineering and cost analysis indicates that it is advantageous to the project, a minimum 2 year storm frequency may be used for retrofit projects.

3-1.2.2 Principal Roads.

For principal roads, collector or local roads with speeds greater than 50 mph (80 kph) use the minimum storm frequency and intensity required in the state drainage manual or a minimum intensity of 4 in/hr (100 mm/hr); whichever is more stringent.

3-1.3 Maximum Spread.

The maximum spread for roads is ½ driving lane. For collector and local roads, use a minimum 5-year storm frequency. Roads with speeds greater than 50 mph must be designed in accordance with the state or local regulatory agency with jurisdiction over the Installation; whichever is more stringent.

3-1.3.1 Airfields.

The maximum spread for airfields must not include runways, taxiways and heliport pavements or paved shoulders using a 5 year storm frequency.

The maximum spread for airfields must not encroach on the center 50 percent, along the centerline, of runways, taxiways, or helipad surfaces using a 10 year storm frequency.

3-1.3.1.1 Aprons.

The maximum spread for aprons is a depth of 4 inches (100 mm) using a 5 year storm frequency.

The maximum ponding depth is 4 inches (100 mm) around apron inlets.

3-1.4 Inlet Design.

Size and locate drainage inlets to limit the spread of water. Use bicycle safe inlet grates where bicycle travel is possible.

For paved parking, storage, and similar areas, inlets must be provided in sag locations.

3-1.4.1 Airfields.

Avoid drainage patterns consisting of closely spaced interior inlets in pavements with intervening ridges for airfields. Such grading may cause taxiing problems, including bumping or scraping of wing tanks. For paved apron areas, inlets must be provided in sag locations.

If there is a long, gradually sloping swale between a runway and its parallel taxiway (in which the longitudinal grade is all in one direction), additional inlets should be placed at regular intervals down this swale. The area around these additional inlets may have ridges to protect the area around the inlet, prevent bypassing, and facilitate the entry of the water into the structure. The grades and grade changes for ridges must be provided in accordance with UFC 3-260-01.

3-1.5 Erosion and Sediment Control.

Design erosion and sediment controls that minimize the discharge of pollutants from earth disturbing activities in conformance with the applicable requirements of the regulatory agency with jurisdiction over the Installation regarding erosion and sediment control. Where requirements do not exist, provide an erosion and sediment control plan in accordance with the requirements of Environmental Protection Agency's (EPA) Construction General Permit.

3-1.6 Pollution Prevention.

Segregate stormwater from industrial processes that may introduce conventional pollutants, such as oil, grease or lubricants, or any toxic or non-conventional pollutant. When stormwater segregation is not possible, provide collection and treatment in accordance with UFC 3-240-01.

3-1.6.1 Petroleum Fuel Facilities.

Use UFC 3-460-01 for the design of stormwater collection systems associated with petroleum fuel facilities.

3-2 MATERIAL SELECTION FOR AIRFIELDS.

The use of plastic pipe is not approved for use under any type of airfield pavement except for subsurface water collection and disposal.

3-3 ROOF DRAINAGE.

Use UFC 3-420-01 to size underground roof drainage or use a minimum interior diameter of 6 inches (150 mm), whichever is greater. When using underground piping to collect roof drainage, provide an air break between the downspouts and underground piping. Connect a maximum of three downspouts to each underground roof drainage header and connect each underground roof drainage header to a storm drainage structure. Use a maximum length of 150 feet (45.7 m) from the most distant downspout to the storm drainage structure. Provide cleanouts for changes in direction and each downspout connection. Provide cleanouts for underground roof drainage piping to prevent cleanouts from being located more than 100 feet (30.4 m) apart.

Where roof drainage is discharged to grade, provide splash blocks or paved channels to direct the flow away from the structure. Eliminate safety hazards such as ice, ponding, and flooding in pedestrian and vehicular traffic areas.

3-4 SURFACE DRAINAGE.

Surface drainage must convey flow to a point of discharge capable of handling the stormwater flow from the design storm event.

3-4.1 Open Channels.

For channels with flows greater than 100 cfs (2.83 cms), provide 1 foot (300 mm) of freeboard or design for the 100 year storm event. Major channels with flows greater than 100 cfs (2.83 cms) are usually trapezoidal in cross section. Minor channels are usually V shaped in cross section.

3-4.1.1 Channel Characteristics.

Use the following channel characteristics for channels:

- Maximum side slopes of 2:1, horizontal to vertical, unless using steeper side slopes are supported by a geotechnical report.
- Use Manning’s Roughness Coefficient, “n”, of 0.030 for unmaintained earth channels. For other surface materials see state or local regulatory agency’s requirement.

3-4.1.2 Airfields.

Open channels or natural water courses are permitted only at the periphery of an airfield or heliport facility and must be well removed from the landing strips and traffic areas.

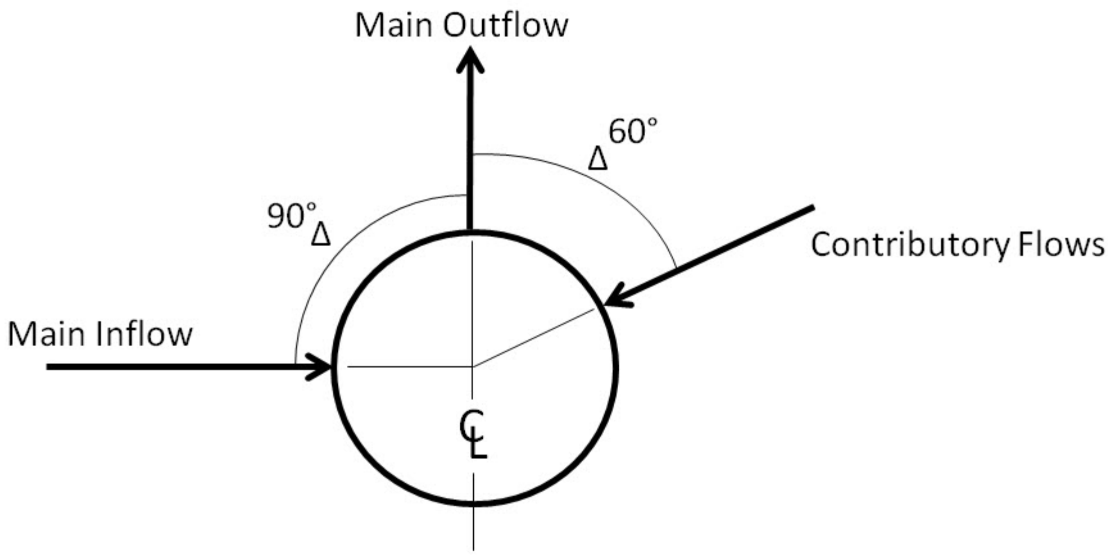
3-5 UNDERGROUND GRAVITY STORM DRAINAGE SYSTEM.

For underground storm drainage design comply with the documents referenced in the paragraph titled, “Design Criteria” in Chapter 3, or the following criteria, whichever is more stringent.

a. Provide straight alignments for piping between storm drainage structures. Use of curvilinear alignment is not allowed for pipes with a diameter of 48 inches (1200 mm) or less. For pipes with a diameter greater than 48 inches (1200 mm) use of curvilinear alignment may be allowed with explicit authorization by the Government.

b. Deflection at structures must not be less than 90 degrees for main line flows and not less than 60 degrees for contributory flows, as measured from the centerline of the mainline discharge. See Figure 3-1.

Figure 3-1 Deflection at Structures



c. Storm drainage piping must not pass under buildings and must be a parallel distance of at least 10 feet (3.0 m) from building foundations.

d. Avoid conflicts with other utilities.

e. Conflict structures will not be allowed without Government approval.

f. Comply with state or applicable regulatory agency's requirements for separation distances between utilities and other public health and safety issues.

g. Provide a structure at collection and inlet points, at changes in horizontal or vertical alignment, at pipe junctions and with minimum spacing of a pipe run according to Table 3-1. Provide a discharge structure wherever flow changes from piped to open channel flow.

Table 3-1 Storm Structure Spacing Criteria

Pipe Diameter		**Maximum Spacing**	
inches	mm	feet	meters
12 – 24	300 – 600	300	91.4
27 – 36	675 – 900	400	121.9
42 – 54	1050 – 1350	500	152.4
60 and up	1500 and up	1000	304.8

h. In the design of culverts and storm drains, account for headwater and tailwater and their effects on hydraulic grade line and capacity.

i. The following upstream controls limit headwater elevation:

   1. Not higher than an elevation that is 18 inches (450 mm) below the outer edge of the shoulder at its lowest point in the grade.

   2. Upstream property damage.

   3. Elevations established to delineate National Flood Insurance Program or other floodplain zoning.

   4. HW/D is at least 1.0 and not to exceed 1.5 or the local requirement. Where HW is the headwater depth from the culvert inlet invert and D is the height of the barrel.

   5. Low point in the road grade which is not necessarily at the culvert location.

   6. Elevation of terrain and ditches that will permit flow to divert around the culvert.

j. The tailwater elevation in the storm drain outfall must be either the average of the critical depth and the height of the storm drain conduit, (dc + D)/2, or the mean high tide if tidal conditions are present, whichever is greater. Storm drains must be designed for open channel flow. The hydraulic grade line for the storm sewer system must not exceed the pipe crown elevation unless the outfall is submerged. If the controlling tailwater elevation is above the crown elevation of the outfall, the hydraulic grade line for the storm sewer system must not exceed one foot (300 mm) above the crown, or one foot (300 mm) below the structure rim or gutter flow line at inlets, whichever is the lower elevation at each structure.

k. At structures, set the invert elevation of the inlet pipe equal to or greater than the invert elevation of the outlet pipe to minimize the hydraulic turbulence at the junction in accordance with Table 3-2.

m. The downstream pipe configuration, slope, and size must have capacity for the upstream hydraulic peak flow. The pipe size must not decrease downstream in the direction of flow.

n. Locate drainage structures out of paved areas wherever possible. Adjust structure locations to avoid primary wheel tracks when structures must be located in roads.

o. During design evaluate the potential for infiltration of fine soils into drainage pipe joints and coordinate with the Installation to see if it is a known maintenance issue. Specify watertight joints to mitigate the possibility.

Table 3-2 Minimum Invert Elevations

Item Description	Requirement	Best Practice
Main Flow Line[1] (change in grade or depth of pipe do not adversely affect design)	Match inverts[2]	Match crowns[3]
Main Flow Line or Contributory line (lateral) of same size diameter	Match inverts[2]	0.1 feet (30 mm)
Contributory line (lateral) of smaller diameter	0.1 feet (30 mm)	Match crowns[3]

1. Applicable for pipes that are the same size or smaller diameter.
2. In areas where the grade is relatively flat or significantly steep, matching invert elevations will reduce the depth of pipe and may increase headloss.
3. Matching crown line elevations may slightly reduce headloss; however, setting the invert elevation of the outflow pipe at least 0.1 feet (30 mm) lower than the lowest inflow pipe invert elevation is preferred.

3-5.2 Minimum Pipe Size.

Use a minimum inside diameter of 12 inches (300 mm) for storm drainage piping (not including roof drainage piping) for runs 50 feet (15.2 m) or less and where the existing downstream pipe is a 12-inch (300 mm) inside diameter with sufficient capacity; otherwise, use a minimum inside diameter of 15 inches (375 mm).

3-5.3 Minimum and Maximum Cover.

Use the paragraphs below, as applicable, or perform calculations to determine minimum and maximum cover, pipe material, pipe strength, and bedding requirements to accommodate the imposed dead and live loads during and after construction for all pipes. Minimum and maximum cover tables, for selected pipe material, may be used for single barrel applications with equivalent shapes and loadings. Refer to Chapter 9 of AC 150/5320-5 for additional design guidance on minimum and maximum cover. Account for loads from expected maintenance equipment in non-paved areas.

3-5.3.1 Minimum Cover.

Where the live load does not exceed H-20 Highway loading, the minimum cover for single barrel circular concrete pipe, reinforced concrete pipe, corrugated aluminum pipe, corrugated steel pipe, structural plate aluminum alloy pipe and structural plate steel pipe must be the most stringent of the following requirements:

- Equal to or greater than 24 inches (600 mm);
- Equal to or greater than one-half of the pipe diameter; or

- Equal to or greater than the frost penetration depth minus the inside diameter of the pipe. Best Practice: Equal to or greater than the frost penetration depth minus one-half of the pipe diameter.

[C] 3-5.3.1 Minimum Cover

Frost penetration depth minus the inside diameter is used to keep the invert of the pipe below the frost penetration depth.

Frost penetration depth minus the one-half of the inside diameter is used to keep the springline of the pipe below the frost penetration depth. The springline is the horizontal centerline of the pipe section.

Use UFC 3-301-01 to determine the minimum frost penetration depth. For pipe under a minimum 6 inch (150 mm) rigid pavement section, minimum cover may be reduced to 12 inches (300 mm) from the top of pipe to the bottom of the rigid pavement section if:

- Single barrel application;
- Live load does not exceed H-20;
- ASTM C76 or ASTM C76M, Class V, circular reinforced concrete pipe is used; and
- Design assumptions and calculations are approved by the Government Civil Engineer.

3-5.3.1.1 Airfields.

Use Tables 9-9 included in Chapter 9 of AC 150/5320-5 as applicable or determine minimum cover based on project specific loads and conditions.

3-5.3.2 Maximum Cover.

Use Tables 9-1 through 9-7 in Chapter 9 of AC 150/5320-5 as applicable or determine maximum cover based on project specific loads and conditions.

3-5.4 Design Velocity.

Provide a minimum full flow velocity as indicated in Table 3-3. Determine full flow velocity using the Manning equation, without surcharge.

Table 3-3 Design Velocity

Item Description	Requirement	Best Practice
Full Flow Velocity	Min. 2.5 ft/sec (0.76 m/sec)	Min. 3 ft/sec (0.91 m/sec)

For storm drain system constructability, a minimum slope of 0.2 percent is recommended. The minimum full flow velocity requirement must be met regardless of the pipe slope.

3-5.5 Manning's Roughness Coefficient.

Use Manning's roughness coefficient, "n" of 0.013 for smooth concrete pipe. For other drainage materials see state or local regulatory agency's requirement.

3-5.6 Material Selection.

Provide storm drain system materials in conformance with the UFGS to meet specific site conditions and soil characteristics. Consider thermal expansion of pipe material based on pipe location and temperatures of stormwater.

3-5.7 Culverts and Outfalls.

Culverts and outfalls must have headwalls, endwalls, wingwalls, flared end sections, or mitered end sections at free outlets. In areas of seasonal freezing, the structure must also be designed to preclude detrimental heave or lateral displacement caused by frost action. The most satisfactory method of preventing such damage is to restrict frost penetration beneath and behind the wall to non-frost-susceptible materials. Positive drainage behind the wall is also essential. Outlets and endwalls must be protected against undermining, bottom scour, damaging lateral erosion, and degradation of the downstream channel.

3-5.7.1 Security and Storm Drainage System Components.

Provide security barriers at all locations where security fences must cross drainage ditches or swales to ensure that intruders are prevented from passing under the fence. Use protective measures for pipes crossing under security fences with diameters larger than 10 inches (250 mm).

3-5.8 Storm Structures.

Storm structures for roads and site drainage must be in accordance with the UFGS, state DOT standards and specifications where the project is located or the requirements of the applicable local regulatory agency that governs stormwater management, whichever is more stringent. Structures must provide access for maintenance. Internal dimensions must not be less than 2 feet (0.6 m) in any one direction. Ensure that catch basins, curb inlets, and manholes are of adequate size to accommodate inlet and outlet pipes.

Provide structures of cast-in-place or precast concrete. Masonry structures are allowed for shallow installations less than 5 feet (1.5 m) in depth. Design structure frames, covers and grates to withstand traffic loadings and meet any additional requirements set forth in the using agency criteria for the particular application. Select grate type based on such factors as hydraulic efficiency, debris handling characteristics, pedestrian and bicycle safety, and loading conditions. Grates in traffic areas must be able to withstand traffic loads.

3-5.8.1 Airfields.

Use frames, covers, and grates capable of withstanding airfield traffic loadings and meeting any additional requirements set forth in the using agency's criteria. Isolate airfield structures from the pavement section. Provide structures of cast-in-place or precast concrete; do not use masonry structures in airfield construction. Watertight joints are recommended under airfield pavements.

Use ductile iron or steel frames, grates and covers. Frames, grates, and covers must be designed to withstand maximum aircraft wheel loads, considering the gear configuration, of the largest aircraft using or expected to use the facility. Provide hold-down devices to prevent grate displacement by aircraft traffic. Commercially manufactured frames and grates that have been designed specifically for aircraft loads may be used. When manufactured grates are used, the manufacturer must certify the design load capacity of each type of structure.

3-5.8.1.1 Diagonal Routes.

For structures that will be required to support both in-line and directional traffic lanes such as diagonal taxiways or apron taxi routes, do not consider load transfer at expansion joints in the design process; however, if specific knowledge about the long-term load transfer characteristics of a particular feature supports the use of load transfer in the design of a particular drainage structure, then an exception can be allowed and load transfer considered.

3-6 STORMWATER MANAGEMENT FACILITIES.

Design stormwater management facilities in accordance with the criteria referenced in the paragraph titled, "Design Criteria" in Chapter 3. The selected approach must conform to stormwater management regulations and applicable stormwater management agreements.

Include an overflow or bypass device for inflow volumes in excess of the treatment volume, or, if applicable, the peak attenuation volume. Ensure stormwater overflow does not adversely affect the stormwater management facility or pertinent site features such as building function, parking, and roads for the service life of the facility, surrounding sites over the service life of the surrounding facilities, and future forecasted land use changes.

3-6.1 Safety and Storm Drainage System Components.

Provide protective measures for stormwater management facilities such as detention and retention ponds in residential housing areas and other areas frequented by children in accordance with the applicable requirements of the locality, State or Host Nation equivalent. Protective measures include but are not limited to appropriate site selection for the storm water management facility or providing a fenced enclosure surrounding the facility. When provided, fence must be at a minimum of 4 feet (1.2 m) high with locking access gates.

3-6.2 Airfields.

Avoid stormwater management facilities with surface storage that attract wildlife to the facility; avoid a BASH issue.

3-7 STORMWATER PUMP STATIONS.

Use of stormwater pump stations is not allowed except with explicit authorization by the Government. Design stormwater pump stations in accordance with UFC 3-240-01. Use Best Practices documents Pumping Station Design and WEF MOP FD-4 for guidance.

3-7.1 Existing Pump Stations: Upgrades and Additional Flow.

Existing pump stations may be upgraded where a complete hydraulic analysis shows that the upgraded pump station can operate at the new capacity and in conformance with the jurisdictional requirements. Include effects on the existing force main to its point of discharge in the hydraulic analysis, and if networked, the effects on all other pump stations connected to the system. This analysis is required whenever additional flow is added to a pump station, even if physical changes to the station are not proposed.

This Page Intentionally Left Blank

CHAPTER 4 PAVEMENTS

4-1 SURFACED AND UNSURFACED ROADS AND SITE PAVEMENTS.

Provide geometric design of vehicular roads in accordance with Chapter 2 of this UFC. Unless specified otherwise in project specific requirements, design pavement based upon anticipated vehicles and loadings for a 25 year life; however, sections shall not be less than the minimums indicated below. Use pavement design criteria and procedures recognized by the DOT in the state in which the project is located or UFC 3-250-01. When state design criteria and procedures are used, the entire pavement section must conform in every detail to the applicable state criteria and materials must conform to the DOT material specifications.

Use UFC 3-250-01 for design of roads and parking areas trafficked by special military vehicles and in areas outside of the United States. Special military vehicles include, but are not limited to: cranes, aircraft tow tractors, forklifts, container handling vehicles, tracked vehicles, heavy military cargo trucks greater than 10,000 pounds (4535 kg) including but not limited to Heavy Expanded Mobility Tactical Truck, Heavy Equipment Transport Systems, Palletized Load Systems (M1074, or M1075), Mine-Resistant Ambush Protected, and Stryker vehicles.)

4-1.1 Frost Conditions.

The design must address seasonal frost conditions per State DOT. For overseas locations or locations where the State DOT does not address seasonal frost conditions use UFC 3-250-01.

4-1.2 Recycled Materials.

Limit recycled materials to limits in applicable UFGS sections. Recycled concrete and recycled asphalt affected by Alkali-Silica Reaction (ASR) must not be used as subbase or base course materials.

4-1.3 Flexible Pavements.

The minimum thickness of the flexible pavement section for roads and parking areas is 6 inches (150 mm). The typical flexible pavement section consists of an asphalt surface course, aggregate base course, and an optional subbase course.

4-1.3.1 Surface Course.

The minimum thickness of the surface course is 2 inches (50 mm).

4-1.3.2 Base and Subbase Courses.

The minimum thickness of the aggregate base course is 4 inches (100 mm). Provide a thicker aggregate base or subbase(s) if required to protect weak subgrade soils or to reduce frost penetration into the subgrade.

4-1.4 Rigid Pavements.

The minimum flexural strength for portland cement concrete pavements at 28 days is 650 psi (4.48 MPa). No reduction in thickness will be allowed for increased flexural strength. The minimum compressive strength for portland cement concrete sidewalks, curbs, and gutters is 3500 psi (25 MPa). Provide air entrainment in all exterior concrete pavements in areas subject to freezing temperatures. Use plain (non-reinforced) concrete for rigid pavements for roads and parking areas at military installations; use reinforced concrete for odd-shaped slabs or mismatched joints. An odd-shaped slab has a length to width ratio greater than 1.25:1. Clearly indicate on the drawings the specific individual slabs requiring reinforcement.

During design evaluate the potential for ASR and specify requirements for aggregates and cementitious materials to mitigate the possibility of ASR occurring in the concrete job mix formula for the project.

4-1.4.1 Concrete Pavement.

4-1.4.1.1 Plain Concrete.

The minimum thickness of plain concrete for roads and parking areas is 6 inches (150 mm).

4-1.4.2 Joints.

Provide joints in a manner to form a regular rectangular pattern and to prevent random or uncontrolled cracking. Do not allow the use of insertable forms for contraction joints. The use of keyed joints is discouraged, but may be used subject to evaluation of subgrade strength, loadings, pavement thickness, and details in UFC 3-250-01 and UFC 3-250-04. Dowels and tie-bars shall not be placed closer than 0.6 times the dowel or tie-bar length from the planned joint line.

4-1.5 Permeable Pavements.

Permeable pavements (such as permeable interlocking concrete pavers or pervious portland cement concrete) may be used on site pavements, such as parking lots, provided there is documented evidence of successful past performance for similar applications. Provide signage to indicate salting and sanding is not allowed for pervious portland cement concrete. Permeable pavements may not be used in areas where there is the potential to contaminate existing soils, such as fuel areas, industrial storage, marinas, vehicle maintenance or service areas. Porous asphalt pavement is not allowed. Compacted gravel is not considered permeable pavement.

Use Best Practices documents, Permeable Interlocking Concrete Pavements Manual - Design, Specification, Construction, Maintenance, from the Interlocking Concrete Pavement Institute and ACI 522R for additional design guidance.

4-1.6 Aggregate Pavements.

Minimum thickness for aggregate surfaced roads and parking areas is 8 inches (200 mm).

4-2 AIRFIELD PAVEMENTS AND MARKINGS.

Use UFC 3-260-01, UFC 3-260-02 and UFC 3-260-04 for the design of airfield pavements and airfield markings. Key joints for rigid pavements are not allowed for airfields.

This Page Intentionally Left Blank

APPENDIX A BEST PRACTICES

This appendix identifies background information and practices for accomplishing certain civil design and engineering services. The Designer of Record (DoR) is expected to review and interpret this guidance and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from the UFGS or UFC, the UFGS and the UFC must prevail. If a Best Practices document has guidelines or requirements that are not discussed in the UFGS or UFC, the DoR must submit a list of the guidelines or requirements being used for the project with sufficient documentation to the Government Civil Engineer for review and approval prior to completing design.

A-1 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide (WBDG) (www.wbdg.org) provides additional information and discussion on practice and facility design, including a holistic approach to integrated design of facilities.

The WBDG provides access to criteria, standards, and codes for DoD Military Departments. The criteria includes UFC, UFGS, Performance Technical Specifications, design manuals, and specifications. For approved Government employees, it also provides access to non-government standards.

A-2 BEST PRACTICES CIVIL ENGINEERING RELATED GUIDANCE.

A-2.1 Building Location and Orientation.

Consider the following in regard to spacing between buildings:

- Functional relationships
- Operational efficiency
- Future expansion
- Open space – passive and active

A building's relationships to its support facilities and to other primary facilities influence its location. Proximity to access roads, existing utility lines, and other compatible functions (especially if they share facilities or have interdependent activities) also influence location. When a building is a shared facility, it should be centrally located and within a reasonable distance from all participating users. Buildings which depend upon a shared facility should orient either the front building face or a doorway area towards the shared facility.

A-2.2 Flood Hazard Areas.

A-2.2.1 National Defense Authorization Act for Fiscal Year 2019.

PL 115-232, Section 2805(a)(4) of The National Defense Authorization Act for Fiscal year 2019 requires a flood risk reduction plan or minimum building elevations for non-essential and essential buildings. The flood design classes found in Table A-1 can be used as guidance when evaluating a buildings essential or non-essential status.

Table A-1 Essential and Non-Essential Guidance

ASCE 24-14 Flood Design Class	NDAA Building Classification
1 (minimal risk; non-essential facilities)	No Impact to mission
2 (moderate risk; non-essential facilities)	Non-Essential
3 Subcategory 3a (high risk; non-essential facilities) Building types (1) through (9)	Non-Essential
3 Subcategory 3b (high risk; essential facilities) Building types (10) and (11)	Essential
4 (high risk; essential facilities)	Essential

A-2.2.2 National Defense Authorization Act for Fiscal Year 2020.

PL 116-92, Section 2804, required DoD to develop sea level rise projection criteria and provide criteria to project designers and master planners on how to use sea level rise projections.

PL 115-232, Section 2805 as amended by PL 116-92 requires DoD to include how projects will be impacted by projected mean sea level rise over the lifetime of the project.

A-2.2.3 National Defense Authorization Act for Fiscal Year 2022.

PL 115-232, Section 2805 as amended by PL 117-81 requires DoD to disclose if a project will be sited within or partially within a 500-year floodplain if outside a 100-year floodplain or be impacted by sea level rise projections and adopting hydrologic, hydraulic, and hydrodynamic data, methods, and analysis that integrate changes in flooding over the anticipated service life of the facility.

A-2.2.4 Executive Order 11988.

EO 11988 establishes key terms, sets the 1 percent ACE, also referred to as the 100-year flood, as the minimum flood requirement and identifies floodplain management concepts.

A-2.2.5 DoD Memorandum on Floodplain Management for DoD Installations.

DTM 22-003 canceled DoD Memorandum on Floodplain Management for DoD Installations dated 11 February 2014.

A-2.2.6 DoD Memorandum on Improving Defense Installation Resilience to Rising Sea Levels.

DTM 22-003 incorporates and supersedes DoD Memorandum on Improving Defense Installation Resilience to Rising Sea Levels dated 24 February June 2020.

A-2.2.7 DTM 22-003, Directive-type Memorandum “Flood Hazard Area Management for DoD Installations”

DTM 22-003 establishes policy, assigns responsibilities, and prescribes procedures to incorporate:

- The Climate-Informed Science Approach, when available;
- Flood hazard management practices stipulated by Section 2805 of Public Law 115-232 and Section 2806 of Public Law 116-92; and
- Implements flood hazard requirements in EO 11988, EO 13690, and EO 14030.

A-2.3 Flood Protection Systems.

In addition to 44 CFR 65.10, considered other design criteria for design of levees and floodwalls. Evaluate soil types, including but not limited to seepage, scour and erosion, structure type, embankment stability, foundation stability, settlement, and interior drainage. Levee and floodwall systems may include active and passive components such as gates, barriers and movable walls that would need to be closed prior to a flood. When addressing operation plans include appropriate warning systems and test in place. Best Practice documents may include EM 1110-2-1913, EM 1110-2-2104, EM 1110-2-2502, EM 1110-1-1904, EM 1110-2-2504, ETL 1110-2-583, EM 1110-2-1619, ER 1105-2-101, ER 1110-2-1150, and ETL 1110-2-299.

A-2.3.1 Buildings and Structures.

Based on an individual site analysis, it may be more advantageous to protect a facility or a group of facilities with a flood protection system. Flood protection systems meeting the minimum design requirements in 44 CFR 65.10 may be accredited by FEMA for protection against the 1 percent ACE. ASCE 24-14 requires flood protection systems to be shown on the community's flood hazard map prior to being considered as providing adequate protection.

A-2.4 Roads.

Roads and similar infrastructure do not need to be designed to the same standard as buildings and structures. An engineering analysis should be conducted to determine the DFE.

A-2.5 Vehicle Circulation.

Consider bicycle lanes and pedestrian corridors to reduce vehicle traffic.

A-2.5.1 Access and Service Drives.

Consider the following in locating access drives:

- Spacing.
- Corner Clearances.
- Sight Distances.
- Left Turns.
- Entrances.
- Grading and Drainage.
- Traffic Controls.

When a safe sight distance cannot be met, consider the following alternatives:

- Removal of sight obstructions.

- Relocation of the access drive to a more favorable location along the access road or an alternate access road.
- Prohibition of critical movements at the access drive.

A-2.6 Parking Areas.

Where slopes are steep consider providing more than one level of parking.

Table A-2 Parking Space Guidelines for Non-Organizational Vehicles

Facility	Number of Parking Spaces
Administration, Headquarters, and Office Buildings	60 percent of assigned personnel
Bakeries	75 percent of employees
Bank and Credit Union, when not included in a Community Shopping Center	2 percent of customers served
Cafeteria, Civilian, when not included in a Community Shopping Center	15 percent of seating capacity
Central Food Preparation Facilities	38 percent of employees
Chapels	30 percent of seating capacity
Child Development Centers (Staff Parking)	80 percent of staff
Child Development Centers (Patron Parking)	10 percent of children served
Commissary Stores, Food Sales, when not included in a Community Shopping Center	Contact DeCA for parking requirements
Community Shopping Center, including such elements as Main Exchange, Miscellaneous Shops, Restaurant, Commissary Stores, Food Sales, Bank, Theater, Post Office	4 percent of customers served
Dental Clinic Parking	3 spaces per treatment room
Dormitories, BEQ, Enlisted Unaccompanied Personnel Housing	70% of design capacity
Enlisted Personnel Dining Facilities (Staff Parking)	38 percent of employees
Enlisted Personnel Dining Facilities (Patron Parking)	8 percent of enlisted personnel served

Facility	Number of Parking Spaces
Exchanges, Main, when not included in a Community Shopping Center	25 percent of customers served
Family Housing	2.5 spaces per living unit
Field House, combined with Football and Baseball Facilities	1 percent of military strength served
Fire Stations	100% of largest shift
Guard Houses, Brigs, Military Police Stations	30 percent of guard and staff strength
Fitness Center	1 percent of military strength served
Laundry Plants and Dry Cleaning Plants	38 percent of employees
Central Libraries	1 space for each 500 ft^2 (46.5 m2) gross area of floor area
Branch Libraries	8 spaces
Maintenance Shops	40 percent of employees
Medical Facilities	Use UFC 4-510-01
Officers' Quarters, BOQ, Officer Unaccompanied Personnel Housing	100% of living suites
Schools, Dependent with Auditorium	2 spaces per classroom, plus 15 percent of auditorium seats
Schools, Dependent without Auditorium	2 spaces per classroom
Security Offices: Population served 100 to 2,000	5 spaces
Security Offices: Population served 2,001 to 4,000	10 spaces
Security Offices Population served 4,001 to 6,000	15 spaces

Facility	Number of Parking Spaces
Security Offices Population served 6,001 to 10,000	20 spaces
Security Offices Population served 10,001 and over	To be based on a special study
Service Clubs (Open Mess and Club Facility)	2 percent of military strength served
Swimming Pools	20 percent pool capacity
Temporary Lodging Facilities	90 percent of bedrooms
Theaters, when not included in a Community Shopping Center	25 percent of seating capacity
Training Buildings (Staff Parking)	70 percent of staff
Training Buildings (Student Parking)	60 percent of students
Warehouses	40 percent of employees

A-2.6.2 On-Street Parking.

Consider the width of the travel lane and the types of vehicles. A parking lane width of 10 feet (3.0 m) to 12 feet (3.6 m) is recommended for delivery vehicles.

A-2.6.3 Off-Street Parking.

Consider the following in the parking lot design:

a. Maintain two-way movement.
b. Avoid dead end parking lots.
c. Provide cross aisles every 20 to 30 spaces.
d. Provide curbs or painted lines at the ends of stalls for vehicle control.
e. Provide adequate walkway width to allow comfortable pedestrian movement in areas of bumper overhang.
f. Consider requirements for snow removal.

A-2.6.3.1 Islands and Medians.

Locate islands at the ends of parking stalls and at the intersections of parking aisles. The islands establish turning radii for vehicular movement and protect end stalls. Consider the height of driver's eye level when providing shrubs and small trees.

A-2.6.4 Compact Parking.

The use of compact space is limited for the following reasons:

- The potential for building function to change.
- They do not comply with accessible parking requirements.
- Compact spaces limit the amount of available parking for standard vehicles.

A-2.6.5 Motorcycle Parking.

- Locate parking close to building entrances.
- Locate parking in parking lot corners.
- Provide signage and pavement markings.

A-2.6.6 Buffers.

Provide a 20 feet (6.1 m) wide buffer strip to separate parking areas from adjacent roads.

A-2.6.7 Drop Off Areas.

Design considerations for drop-off areas include adequate width and length to accommodate the safe movement of vehicles in and out of the flow of traffic.

A-2.6.8 Delivery and Service Zones.

Delivery and service trucks need to access service doors in buildings. Delivery may require dock facilities, which need to accommodate the necessary maneuvering into and out of the dock. Design considerations for delivery zones include:

a. Separate service access drives from parking circulation because these functions are incompatible. Service access that is required through a parking area goes straight to and straight out of the service area.
b. On a dead-end service drive, provide the necessary turning movements.
c. Provide for visual screening with walls, fences, or plant material.

A-2.6.8.1 Garbage Collection Areas.

The design of garbage collection removal areas (dumpster pads) is controlled by the frequency of waste removal. Coordinate with the Installation to determine the frequency of waste removal and determine appropriate dumpster pad size. Consider screening solid waste removal areas with fences, walls, or plant material in accordance with the Installation Appearance Plan.

A-2.6.9 Facilities with Drive Thru Lanes.

Facilities with one or more drive thru lanes, such as banks, pharmacies, and fast–food restaurants, require careful and clear establishment of traffic patterns and a continuous traffic flow. The standard configuration for a single – or double-service position facility does not lend itself to a two–lane approach and departure design. It usually relies on some form of loop system. Average stacking distance is recommended as 180 feet (54.8 m). Stacking space is determined by subtracting the number served (serving time averages 2-3 minutes per customer) from the expected arrivals per 15-minute period (4-14 minutes is the average) and multiplying the difference times 20 feet (6.1 m). Recommended parking for facilities with drive thru lane(s) is 17.5 spaces per 1,000 sq. feet (93.0 square meters) of building area. Design considerations for facilities with drive thru lane(s) include:

- Maintain traffic lanes into and out of the drive thru windows while working with other on-site vehicular traffic flow including parking.
- Minimize interference with pedestrian traffic flow.
- Provide the recommended average stacking distance in the drive-thru lanes.
- Provide the recommended average stacking distance on-site to prevent traffic safety conflicts with access roads.
- Use curb and planting islands for vehicle control.
- Provide adequate pavement markings.

A-2.7 Rational Formula.

Use the Rational Formula to determine peak flow from small watersheds. The Rational Formula is based on the following assumptions:

- Peak flow occurs when the entire watershed is contributing runoff.
- The rainfall intensity is uniform over a period of time equal to or greater than the time of concentration.
- The frequency of the peak flow equals the frequency of the peak rainfall intensity. For example, the 10-year peak rainfall will produce the peak 10-year volume.

These assumptions are not fully valid in every case. However, if the Rational Formula is used on small watersheds, parking lots, or small developed areas, the errors will not be large.

The most common form of the Rational Formula is:

$$Q = c\,I\,A$$

Where:
Q = peak flow in cfs.
C = a dimensionless coefficient that is a function of the watershed characteristics.
I = rainfall intensity in inches per hour.
A = watershed area in acres.

A-2.8 Airfield Pavements.

For additional guidance on design and construction of airfield pavements see IPRF-01-G-002-1 and ACPA Document No. JP007P.

This Page Intentionally Left Blank

APPENDIX B GLOSSARY

B-1 ACRONYMS.

AASHTO	American Association of State Highway and Transportation Officials
ACE	Annual Chance Event
ADT	Average Daily Traffic
AFCEC	Air Force Civil Engineer Center
AIROPS	Airfield Operations Bird/Animal Aircraft Strike Hazard
AREMA	American Railway Engineering and Maintenance-of-Way Association
ASR	Alkali-Silica Reaction
AT&L	Acquisition, Technology, and Logistics
AWWA	AMERICAN WATER WORKS ASSOCIATION
BASH	Bird/Animal Aircraft Strike Hazard
BFE	Base Flood Elevation
BIA	Bilateral Infrastructure Agreement
DFE	Design Flood Elevation
DoD	Department of Defense
DoR	Designer of Record
DOT	Department of Transportation
DRSL	DoD Regional Sea Level
EISA	Energy Independence and Security Act
EO	Executive Order
EPA	Environmental Protection Agency
EWL	Extreme Water Level
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study

HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
IBC	International Building Code
IDF	Intensity-Duration-Frequency
LID	Low Impact Development
NAVFAC	Naval Facilities Engineering Command
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
OEBGD	Overseas Environmental Baseline Guidance Document
SDDCTEA	Surface Deployment and Distribution Command Transportation Engineering Agency
SOFA	Status of Forces Agreements
TR-55	Technical Release 55
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
U.S.	United States
WBDG	Whole Building Design Guide

B-2 DEFINITION OF TERMS.

Climate-Informed Science Approach: The elevation and flood hazard area that result from using the best-available, actionable hydrologic and hydraulic data and methods that integrate current and future changes in flooding and tidally-influenced inundation based on climate science. This approach will also include an emphasis on whether the action is a critical action as one of the factors to be considered when conducting the analysis.

Non-Tidally Influenced Locations: Locations that are not subject to oceanic astronomical tidal influence.

Tidally Influenced Locations: Coastal and inland locations with oceanic astronomical tidal influence.

Use the following order of precedence for additional definitions:

1. The applicable legal definition.
2. The definitions provided in the applicable building code.
3. The definitions provided in the applicable standard.

This Page Intentionally Left Blank

APPENDIX C REFERENCES

C-1 FEDERAL GOVERNMENT.

CODE OF FEDERAL REGULATIONS

44 CFR Section 65.10, *Mapping of Areas Protected by Levee Systems*

EXECUTIVE ORDERS

EO 11988, *Floodplain Management* (May 24 1977), 42 FR 26951, 3 CFR, 1977

EO 11990, *Protection of Wetlands* (May 24 1977), 42 FR 26961, 3 CFR, 1977

EO 13690, *Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input* (January 30, 2015), 3 CFR, 2016

EO 14030, *Climate Related Financial Risk*, (May 20, 2021)

PUBLIC LAW

PL 115-232, Public Law 115-232, The National Defense Authorization Act for Fiscal Year 2019, Section 2805: Updates And Modifications To Department Of Defense Form 1391, Unified Facilities Criteria, And Military Installation Master Plans as amended by PL 116-92

PL 116-92, Public Law 116-92, The National Defense Authorization Act for Fiscal Year 2020, Section 2804 Amendment Of Unified Facilities Criteria To Promote Military Installation Resilience, Energy Resilience, Energy And Climate Resiliency, And Cyber Resilience

PL 117-81, Public Law 117-81, The National Defense Authorization Act for Fiscal Year 2022, Section 2805 Flood Risk Management For Military Construction

DEPARTMENT OF TRANSPORTATION

AC 150/5320-5, *Airport Drainage Design*[1]
https://www.faa.gov/regulations_policies/advisory_circulars/

HDS-5, *Hydraulic Design of Highway Culverts*
https://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm

Manual on Uniform Traffic Control Devices
https://mutcd.fhwa.dot.gov/ser-pubs.htm

SHSM, *Standard Highway Signs and Markings*

[1] Requirement for Airfield Drainage criteria and Best Practice for storm drainage systems other than airfields

FEDERAL EMERCENCY MANAGEMENT AGENCY (FEMA)

FEMA GD34, *Guidance for Flood Risk Analysis and Mapping*
https://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, FEDERAL GEODETIC CONTROL COMMITTEE

Standards and Specifications for Geodetic Control Networks
https://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodetic-control-networks.pdf

DEPARTMENT OF DEFENSE

DoDI 4715.05, *Overseas Environmental Baseline Guidance Document*

Regional Sea Level Database

Public: https://drsl.serdp-estcp.org/Site

FOUO: https://sealevelscenarios.serdp-estcp.org

DTM 22-003, Directive-type Memorandum (DTM) 22-003, "Flood Hazard Area Management for DoD Installations"

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

Consult active UFCs for all aspects of design, including but not limited to:

UFC 1-200-01, *DoD Building Code*

UFC 2-100-01, *Installation Master Planning*

UFC 3-101-01, *Architecture*

UFC 3-210-10, *Low Impact Development*

UFC 3-220-01, *Geotechnical Engineering*

UFC 3-230-01, *Water Storage and Distribution*

UFC 3-230-03, *Water Treatment*

UFC 3-240-01, *Wastewater Collection and Treatment*

UFC 3-250-01, *Pavement Design for Roads and Parking Areas*

UFC 3-250-04, *Standard Practice for Concrete Pavements*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 3-260-02, *Pavement Design for Airfields*

UFC 3-301-01, *Structural Engineering*

UFC 3-420-01, *Plumbing Systems*

UFC 3-460-01, *Design: Petroleum Fuel Facilities*

UFC 3-530-01, *Interior and Exterior Lighting Systems and Controls*

UFC 3-600-01, *Fire Protection Engineering for Facilities*

UFC 4-022-01, *Security Engineering: Entry Control Facilities/Access Control Points*

UFC 4-022-02, *Selection and Application of Vehicle Barriers*

UFC 4-152-01, *Design: Piers And Wharves*

UFC 4-860-01, *Railroad Design and Rehabilitation*

U.S. ARMY CORPS OF ENGINEERS (HQUSACE)

EM 1110-2-1913, *Design and Construction of Levees*

EM 1110-2-2104, *Strength Design for Reinforced-Concrete Hydraulic Structures*

EM 1110-2-2502, *Floodwalls and Other Hydraulic Retaining Walls*

EM 1110-1-1904, *Settlement Analysis*

EM 1110-2-2504, *Sheet Pile Walls*

ETL 1110-2-583, *Engineering and Design: Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures*

EM 1110-2-1619, *Risk-Based Analysis for Flood Damage Reduction Studies*

ER 1105-2-101, *Risk Assessment for Flood Risk Management Studies*

ER 1110-2-1150, *Engineering and Design for Civil Works Projects*

ETL 1110-2-299, *Overtopping of Flood Control Levees and Floodwalls*

U.S. ARMY SURFACE DEPLOYMENT AND DISTRIBUTION COMMAND - TRANSPORTATION ENGINEERING AGENCY

https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/Pages/pamphlets.aspx

SDDCTEA Pamphlet 55-8, *Traffic Engineering Study Reference*

SDDCTEA Pamphlet 55-15, *Traffic and Safety Engineering for Better Entry Control Facilities*

SDDCTEA Pamphlet 55-17, Better Military Traffic Engineering

U.S. DEPARTMENT OF AGRICULTURE - FOREST SERVICE

USDA 0625 1808-SDTDC, *Low-Water Crossings: Geomorphic, Biological, and Engineering Design Considerations* https://www.fs.usda.gov/t-d/pubs/pdf/LowWaterCrossings/LoWholeDoc.pdf

U.S. DEPARTMENT OF AGRICULTURE - NATURAL RESOURCES CONSERVATION SERVICE

TR-55, Technical Release 55, *Urban Hydrology for Small Watersheds*

C-2 NON-GOVERNMENT.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

https://www.transportation.org/

AASHTO GBF, *Guide for the Development of Bicycle Facilities*

AASHTO GDHS, *A Policy on Geometric Design of Highways and Streets*

AASHTO GPF, *Guide for the Planning, Design and Operation of Pedestrian Facilities*

AASHTO LRFDBDS, *LRFD Bridge Design Specifications*

AASHTO RSDG-4, *Roadside Design Guide*

AASHTO VLVLR, *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)*

AMERICAN CONCRETE INSTITUTE

https://www.concrete.org/

ACI 522R, *Report on Pervious Concrete*

AMERICAN RAILWAY ENGINEERING AND MAINTENANCE-OF-WAY ASSOCIATION (AREMA)

http://www.arema.org

Manual for Railway Engineering (Volumes 1 and 2)

AMERICAN SOCIETY FOR TESTING AND MATERIALS

https://www.astm.org/

ASTM C76, *Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe*

ASTM C76M, *Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe (Metric)*

AMERICAN SOCIETY OF CIVIL ENGINEERS

https://www.asce.org/

ASCE 24-14, *Flood Resistant Design and Construction*

AMERICAN WATER WORKS ASSOCIATION (AWWA)

https://www.awwa.org/

AWWA M27, *External Corrosion for Infrastructure Sustainability*

INNOVATIVE PAVEMENT RESEARCH FOUNDATION, AIRPORT CONCRETE PAVEMENT TECHNOLOGY PROGRAM

http://www.iprf.org

ACPA Document No. JP007P, *Best Practices for Airport Portland Cement Concrete Pavement Construction*

INTERLOCKING CONCRETE PAVEMENT INSTITUTE (ICPI)

https://www.icpi.org

Permeable Interlocking Concrete Pavements Manual - Design, Specification, Construction, Maintenance

INSTITUTE OF TRANSPORTATION ENGINEERS

https://www.ite.org/

ITE LP-674B, *Highway Capacity Manual*

INTERNATIONAL CODE COUNCIL

https://www.iccsafe.org/

IBC, *International Building Code*

NATIONAL SOCIETY OF PROFESSIONAL SURVEYORS

https://www.nsps.us.com/

Model Standards for Topographic Surveys

WATER ENVIRONMENT FEDERATION

https://www.wef.org/

WEF MOP FD-4, *Design of Wastewater and Stormwater Pumping Stations*, 1993

WEF MOP FD-6, *Existing Sewer Evaluation and Rehabilitation, Third Edition*

C-3 INDUSTRY PUBLICATIONS.

Pumping Station Design, 3rd Edition, edited by Garr M. Jones with Robert L. Sanks, George Tchobanoglous, and Bayard Bosserman, Butterworth-Heinemann, 2008.

UFC 3-201-02
29 April 2020
Change 1, 09 February 2021

UNIFIED FACILITIES CRITERIA (UFC)

LANDSCAPE ARCHITECTURE

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

LANDSCAPE ARCHITECTURE

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND

(Preparing Activity) AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	09 FEB 2021	1. Deleted references to American Society of Heating, Refrigeration, Air-conditioning Engineers (ASHRAE 189.1) in Chapter 2, paragraphs 2-3.2, 2-6.12, Appendix B, and Appendix C. 2. Revised Chapter 2, paragraphs 2-3.2 and 2-6.12 for tree requirements in parking areas to comply with International Green Construction Code (IgCC). 3. Added International Green Construction Code (IgCC) to Chapter 2, paragraphs 2-6.1, 2-6.12, 2-6.13, 2-7, Appendix B, and Appendix C.

This UFC supersedes UFC 3-201-02 Change 1, dated November 2009.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

CHRISTINE T. ALTENDORF, PhD, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Systems Command

NANCY J. BALKUS, P.E., SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL MCANDREW, SES
Deputy Assistant Secretary of Defense
(Facilities Management)
Office of the Assistant Secretary of Defense
(Sustainment)

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-201-02, *Landscape Architecture*, unifies the landscape architectural criteria for DoD.

Superseding: UFC 3-201-02, 23 February 2009, including change 1 November 2009

Description: This document assimilates and applies current policies, technology, and environmental planning critical to the long-term success of DoD facilities and projects. The integration of government and industry codes, practices, materials, and reference works ensure the contemporary relevance of the UFC Landscape Architecture document.

Reasons for Document:

- Improve the quality-of-life at DoD facilities through informed, user-centric input to planning, design, construction, and maintenance projects.
- Encourage innovation and alternatives to planning, design, construction, and maintenance projects across the DoD.
- Integrate the DoD commitment to sustainable practices and Low Impact Development (LID).

Impact:

The following direct impacts will result from revision of this UFC:

- Design and construction initial cost benefit
- Energy and water efficiency
- Life-cycle cost reduction
- Facility functionality, safety, and security

Unification Issues:

For **Army** projects, comply with the Assistant Secretary of the Army Installations, Energy and Environment (ASA IE&E) Water Use Memorandums:

- ASA IE&E Memorandum, January 13, 2017, “Energy and Water Goal Attainment Responsibility Policy,” which sets policy and assigns responsibilities to achieve federal water use goals.
- ASA IE&E Memorandum, January 17, 2017, “Sustainable Design and Development Policy,” Update 5, 3-b Outdoor Water Use.

For **Navy and Marine Corps** projects, comply with UFC 4-750-02N, which includes design requirements for a variety of outdoor sports and recreational facilities.

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC establishes minimum landscape architectural requirements and best practices to promote consistent landscape architectural quality for DoD facilities worldwide. Where other criteria, statutory or regulatory requirements are referenced, comply with the more stringent requirement.

1-2 APPLICABILITY.

This UFC applies to all DoD agencies and contractors involved in landscape architectural design and implementation of projects with site improvements for permanent DoD facilities worldwide. Use the information in this document for the site analysis, development of plans, specifications, calculations, and deliverables.

1-3 PROFESSIONAL REQUIREMENTS.

Design of all site improvement features must be accomplished by a licensed professional. All DoD military construction (MILCON) projects with site improvement costs over $250,000, must include a landscape plan with supporting details and specifications prepared by a registered professional (Architect, Engineer, or Landscape Architect) as required by the Federal Acquisition Regulations (FAR) (Subpart 2.1). Additional professional requirements and/or certifications may be required based upon specific project needs as defined in the project Request for Proposal (RFP).

1-4 GENERAL BUILDING REQUIREMENTS.

UFC 1-200-01, *DOD Building Code* provides applicability of model building codes and government-unique criteria for design disciplines and building systems, as well as accessibility, antiterrorism, safety, security, high performance and sustainability requirements.

1-5 CYBERSECURITY.

All control systems (including systems separate from an energy management control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by Individual Service Implementation Policy.

1-6 BEST PRACTICES.

Appendix A identifies background information, lessons learned, and proven best practices for landscape architectural design services. The information is considered guidance and not criteria, and is not intended to address all possible design solutions.

1-7 GLOSSARY.

Appendix B contains a list of acronyms, abbreviations, and definitions.

1-8 REFERENCES.

Appendix C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 LANDSCAPE ARCHITECTURAL SITE CRITERIA

2-1 INTRODUCTION.

The following requirements address specific landscape architectural design practices, site elements, and materials. These requirements have been compiled from DoD policy and industry standards.

2-2 LANDSCAPE ARCHITECTURAL SITE DESIGN.

The focus of DoD landscape architecture is to support the users' mission. Landscape architecture combines ecology, hydrology, engineering, planning, and functional design to create successful DoD facilities that achieve the following goals:

- Protect the health, safety, and welfare of all users.
- Elevate Installation functionality and appearance to enhance the quality of life.
- Establish a sense of place and unique identity.
- Preserve cultural and historic landscapes.
- Provide spaces considering 'human factors'.
- Achieve environmentally sustainable development and operations.
- Protect natural communities of plants and wildlife.
- Meet DoD requirements for outdoor water use and management.
- Utilize operation and maintenance plans to ensure successful long-term viability of landscapes.

Effective integration of the landscape architectural discipline into DoD projects requires early involvement, including participation in DD1391 development and project programming, pre-design, and schematic design development.

2-3 WATER USE MANAGEMENT.

2-3.1 General.

Prepare a water management plan that identifies the minimal amount of water required to sustain the project landscape. Develop a plan for how the water can be most efficiently delivered. Include application of reuse water (also called reclaimed or recycled water), when available in conformance with applicable installation and local water reuse policies and guidelines.

2-3.2 Potable Water Reduction.

It is the Department of Defense's policy that DoD Components reduce or eliminate the use of potable/domestic water for purposes of landscape maintenance, consistent with existing legal and contractual obligations. Use water-efficient irrigation strategies that comply with UFC 1-200-02 for required DoD reduction in combined indoor and outdoor potable water use. **1**\ Refer to the International Green Construction Code (IgCC), Chapter 6 "Water Use Efficiency"./1/

For water use management criteria, comply with the “Water Use for Landscape Architecture on Department of Defense Installations/Sites” (March 10, 2017) memorandum from the Office of Assistant Secretary of Defense for Energy, Installations, and Environment (OASD EI&E). Ornamental water features and irrigation systems must comply with this policy.

For Army projects: comply with the Assistant Secretary of the Army Installations, Energy and Environment (ASA IE&E) Water Use Memorandums:

- ASA IE&E Memorandum, January 13, 2017, “Energy and Water Goal Attainment Responsibility Policy,” which sets policy and assigns responsibilities to achieve federal water use goals.
- ASA IE&E Memorandum, January 17, 2017, “Sustainable Design and Development Policy,” Update 5, 3-b Outdoor Water Use.

For Navy projects: comply with the “Guidance for Xeriscaping on CNIC Installations (11010, 04 April 2017) memorandums from the Commander, Navy Installations Command.

2-4 CONSERVATION AND RESOURCE PROTECTION.

2-4.1 Natural Resources.

Coordinate with the Installation Environmental (EV) staff to obtain the project NEPA documentation, as applicable, for project specific requirements. Comply with seasonal limitations for site impacts specific to the threatened and endangered species present on site, including all clearing, site disturbance, and tree mitigation requirements.

2-4.2 Cultural Resources.

Discuss the project with the Installation Cultural Resources Manager (CRM) prior to design initiation, to ensure compliance with federal laws and DoD policies for cultural resources, including Section 106 of National Historic Preservation Act (NHPA) and DoD Instructions 4715.16, 4710.02, and 4710.03, or equivalent Host Nation agreements, as applicable. Coordinate with the CRM to identify relevant documentation from the site assessment concerning cultural resources located on or adjacent to the project site. Obtain any additional information necessary to complete the Section 106 consultation process, including the Integrated Cultural Resource Management Plan. Coordinate with the Installation CRM to identify existing cultural resources or tribal consultation agreement documents, such as a Programmatic Agreement, Tribal Consultation Protocol, Comprehensive Agreement, or Memorandum of Agreement. Consult with the CRM to gather appropriate cultural resources information for the project site for purposes of Section 106 compliance, including CRs listed in or eligible for inclusion in the National Register of Historic Places. Engage the CRM to consult with federally recognized tribes and Native Hawaiian Organizations (NHO) with historical or cultural affiliations with Installation lands as required by DoDI 4710.02 and DoDI 4710.03. Include activities that may impact cultural resources of traditional religious and/or cultural importance to the tribe or NHO, including sacred sites, or other resources to which tribes may retain treaty rights.

Coordinate with the CRM, tribes, NHO, Tribal Historic Preservation Officers, and State Historic Preservation Officers to avoid and minimize effects to the cultural resources. If an adverse effect cannot be avoided, partner with the CRM and external stakeholders to develop a memorandum of agreement to mitigate adverse effects. Collaborate with Installation CRM on methods to reduce water use and remove invasive species from historic landscapes. Consider potential impacts of plantings and furnishings to historic properties.

2-4.3 Viewsheds.

Preserve significant viewsheds as a part of initial project planning and design. Identify significant or historic viewsheds in the project RFP. Historic viewsheds and their features are those that are listed in, or eligible for, inclusion in the National Register of Historic Places. Implement screening elements as appropriate to minimize and mitigate impacts to significant and historic viewsheds. Work with the Installation CRM to consider impacts to historic viewsheds and their historical features, as a part of the Section 106 and tribal consultation responsibilities listed in 2-4.2 Cultural Resources.

2-4.4 Tree Preservation Plan.

Prepare a Tree Preservation Plan to identify existing vegetation to be preserved. Coordinate the Tree Preservation Plan with the Civil Engineer and include it as part of the Erosion and Sediment Control Plan. Calculate the tree critical root zone (CRZ) using a 1.5-foot (0.45 m) protection radius for each 1 inch (3 cm) of tree diameter measured at breast height (DBH).

Figure 2-1 Critical Root Zone Diagram

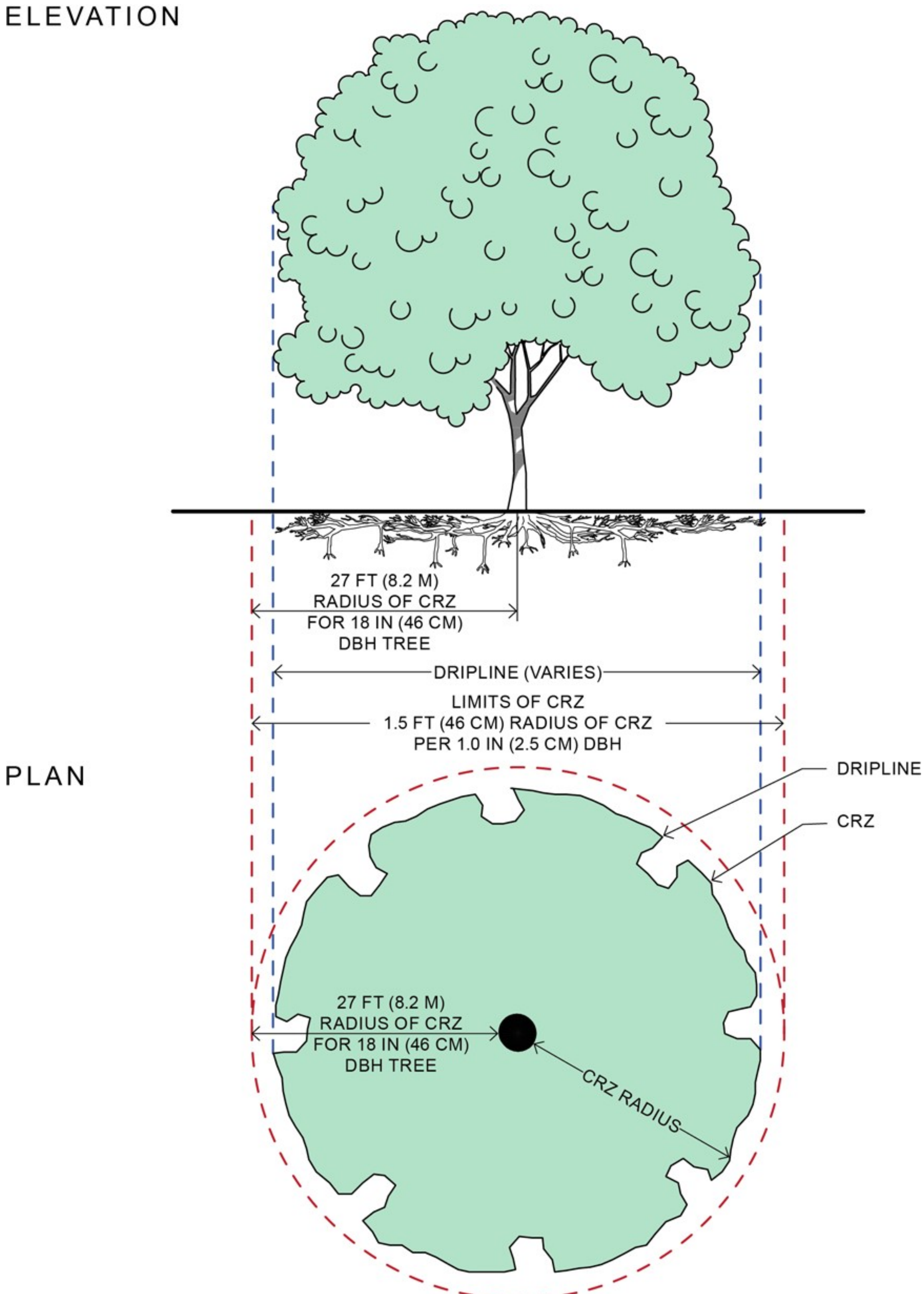
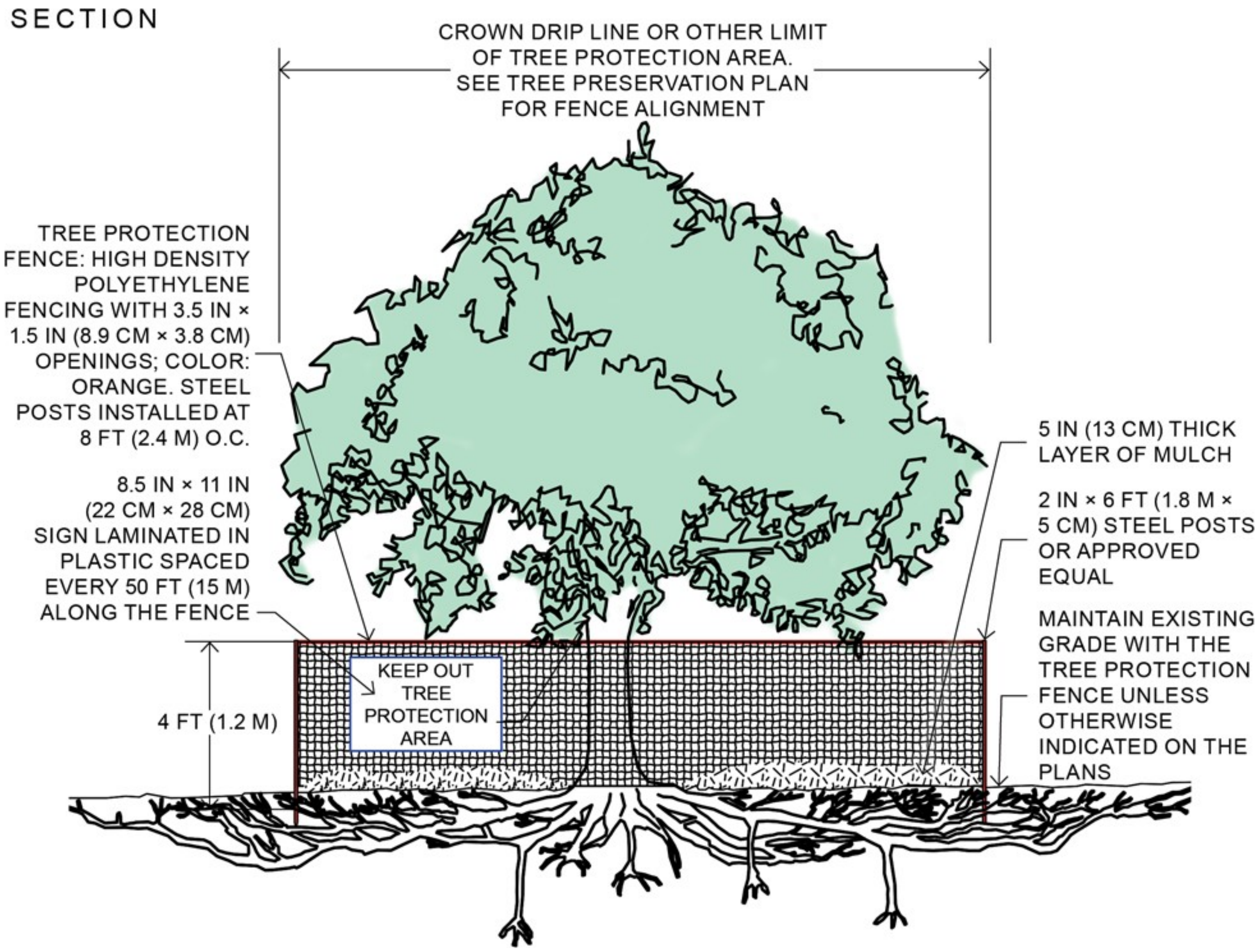


Figure 2-2 Sample Tree Protection Detail[1]



2-5 CIRCULATION AND ACCESSIBILITY.

2-5.1 General.

Employ a well-integrated circulation system with a network hierarchy that strengthens connectivity, reduces conflicts, and enhances the visual quality of the installation. Connect significant elements, destinations, and features. Promote design of streetscapes that balance vehicular traffic, pedestrian access, and safety of all users. Define goals with the end-user during conceptual design. Establish a comprehensive circulation network, hierarchy of uses, and times of day to optimize use.

Utilize UFC 3-201-01 for circulation requirements, including standards for street widths, sight lines, parking layouts, drop-off zones, and special areas.

[1] Adapted from Urban Tree Foundation, "Planting Details and Specifications," 2014, http://www.urbantree.org/details_specs.shtml.

2-5.2 Pedestrian Circulation.

Coordinate pedestrian circulation with the Transportation Component Plan for Installation Development Plans (IDP) and Area Development Plans (ADP).

Figure 2-3 Pedestrian Circulation[2]

2-5.3 Bicycle Facilities.

Utilize the American Association of State and Highway Transportation Officials (AASHTO) Guide for the Development of Bicycle Facilities for bicycle circulation design and multi-use trails.

2-6 PLANTING DESIGN.

2-6.1 Sustainable and Resilient Planting Design.

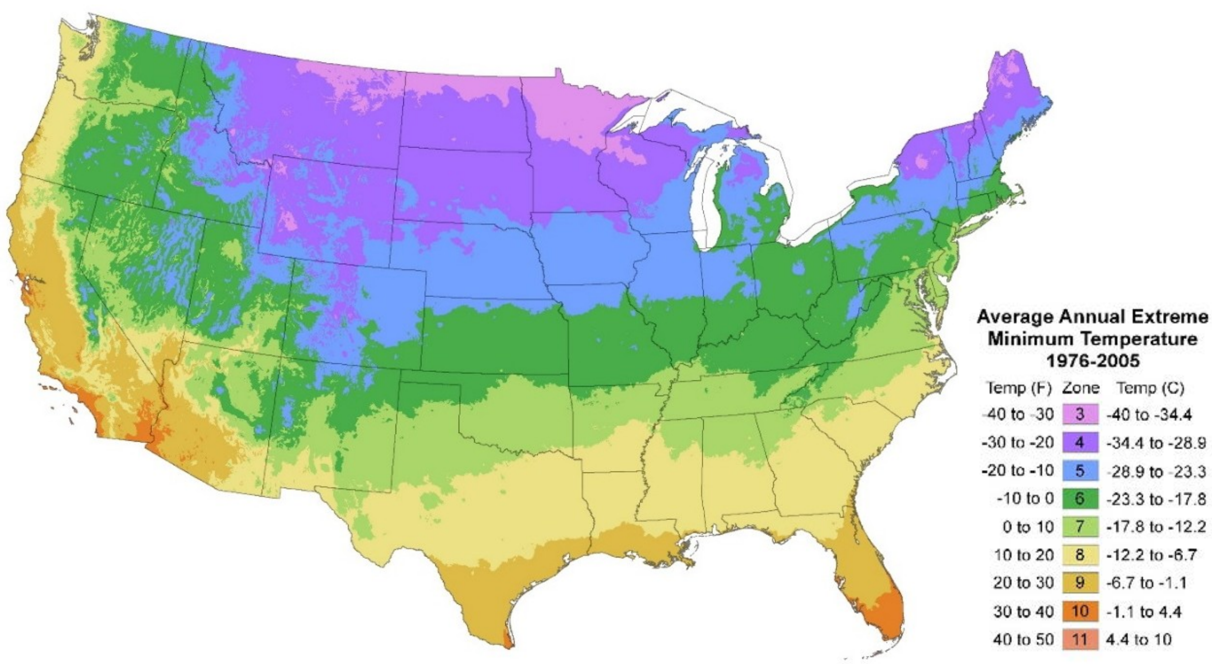
Design for water conservation and minimize maintenance requirements on all new and retrofitted landscape projects. Assess existing irrigated plant and turf areas for opportunities to reduce or eliminate existing irrigation systems. Use vegetation that does not require irrigation beyond the plant establishment period. Specify and install trees to provide shade for paving, vehicles, and pedestrians. Use only non-invasive vegetation; see Chapter 2-6.6 for requirements. \1\ Refer to the International Green Construction Code (IgCC), Chapter 6 “Water Use Efficiency”. /**1**/

[2] Image: CallisonRTKL, https://www.callisonrtkl.com/

Design plantings for climate resiliency and natural hazards:

- Select plant species and cultivars that can tolerate shifts in U.S. Department of Agriculture (USDA) plant hardiness zones. Recent shifts are reflected in the 2012 update to the USDA Plant Hardiness Zone Map (Figure 2-4). Future changes are projected. See Figure 2-5 for a composite model of future changes projected through 2040.
- Specify plant species and cultivars, based on regional conditions that will be resilient to extreme weather events.
- Specify plant materials to withstand flooding and saltwater intrusion from storm surge where those events are anticipated risks.
- Specify plant materials with high tolerance for wind strength along coastal areas.

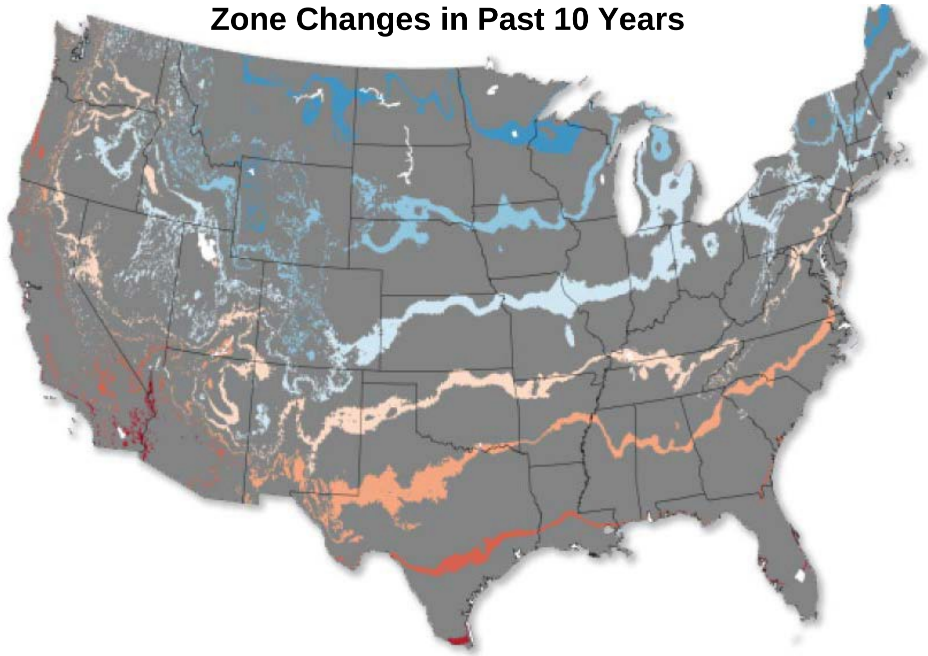
Figure 2-4 USDA Plant Hardiness Zone Map (2012)[3]



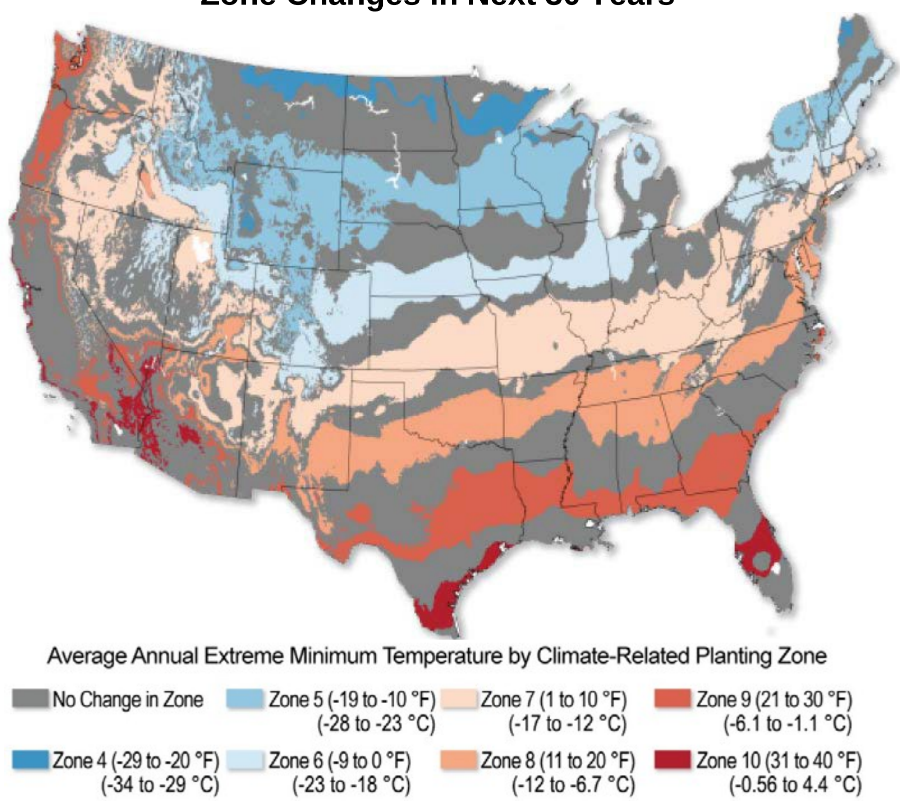
[3] USDA, "Map Downloads," 20 June 2018, http://planthardiness.ars.usda.gov/PHZMWeb/Downloads.aspx

Figure 2-5 Shifts in Plant Hardiness Zones as of 2010[4]

Zone Changes in Past 10 Years



Zone Changes in Next 30 Years



[4] National Oceanic and Atmospheric Administration, "Shifts in Plant Hardiness Zones," *Climate Change Impacts in the United States: The Third National Climate Assessment*, U.S. Global Change Research Program, 6 May 2013, https://nca2014.globalchange.gov/report/appendices/climate-science-supplement/graphics/shifts-plant-hardiness-zones.

2-6.2 Security and Anti-Terrorism.

Coordinate planting design with security and antiterrorism requirements for unobstructed spaces and clear zones per UFC 4-010-01. Explore creative Landscape Architectural solutions to meet force protection and site security requirements through strategic site planning and circulation design.

Eliminate any opportunity for concealment of objects in the unobstructed space that are larger than a 6-inch (15.24 cm) diameter sphere. Specify and install a minimum tree size of 3-inch (8 cm) caliper or 36-inch (91 cm) box at installation for all trees located within unobstructed spaces. At installation, limb all branches within the unobstructed space to meet antiterrorism requirements. Retain a minimum 2/3 height of branches and 1/3 height of clear trunk. Verify the use of multi-trunked trees within the unobstructed space with Antiterrorism/Force Protection Subject Matter Expert.

Eliminate any opportunity for concealment of objects in clear zones. Specify only low shrubs and ground covers within the clear zone. Trees are not permitted.

2-6.3 Foreign Object Debris and Bird/Wildlife Aircraft Strike Hazard.

Foreign Object Debris (FOD) compliance is critical for selection and placement of plant materials, aggregates, and mulches. Select materials to mitigate site-specific foreign object debris concerns.

The Wildlife Hazard Assessment identifies areas of an airfield that are attractive to wildlife and provides recommendations to remove or modify the features. Adhere to species selection requirements for all plantings within identified Bird Aircraft Strike Hazard (BASH) areas. Consider Installation-specific issues. Do not specify plants that create habitat or food sources for avian species that would attract them to the BASH zone.

2-6.4 Plant Selection.

Design planting plans that define space, reinforce circulation systems, frame views, screen site elements, and provide scale, form, line, mass, texture and color. Apply the following requirements when selecting plant materials:

- Comply with all Installation requirements, including the Installation design guidance documents (IDGD), Integrated Natural Resources Management Plan (INRMP), and project specific Scope of Work (SoW).
- Follow requirements of Mariachero's *American Standard for Nursery Stock*-American National Standards Institute (ANSI) Z60.1.
- Use healthy, disease and pest-free plant materials.
- Select plants with low-maintenance characteristics, disease resistance, and drought tolerance, where appropriate.
- Satisfy sight distance requirements as defined by the AHJ for all streetscape plant materials.

- Provide a plant schedule with each required submittal. Include plant key, quantity, botanical name, common name, minimum installed size (height/spread), container, spacing, and remarks as appropriate. Organize the plants by type (deciduous trees, evergreen trees, and so forth). See Figure 2-6 for plant schedule format.

Figure 2-6 Plant Material Schedule – Typical Format

PLANT MATERIAL SCHEDULE								
SYMBOL	BOTANICAL NAME	COMMON NAME	MINIMUM CONTAINER SIZE OR CALIPER	MINIMUM HEIGHT	MINIMUM SPREAD	QUANTITY	REMARKS	DETAIL
TREES								
XX ‘X’ OR XXX ‘X’	ALL UPPER-CASE LATIN	ALL UPPER CASE COMMON	X’ – X2’	X’ – X2’	X’ – X2’			XX/LPXXX
SHRUBS								
XX ‘X’ OR XXX XXX ‘X’								
XX ‘X’ OR XXX XXX ‘X’								
GROUND COVERS								
XX ‘X’ OR XXX XXX ‘X’								
SEED								
XX ‘X’ OR XXX XXX ‘X’								

2-6.5 Native and Regionally Adapted Plants.

Use hardy native and regionally adapted plant materials. Select plant species based on current science-based information and Installation-specific institutional knowledge and practice. Install plants that are appropriate for site conditions, climate, and design intent. Additional standards for projects located in arid and semi-arid conditions may be required.

2-6.6 Invasive Species.

Do not use plants deemed invasive by the USDA, noxious weed control boards, state and local agencies, or other AHJ. The USDA National Invasive Species Information Center (NISIC) website is a central repository for relevant information. Use extreme care when using non-native species or creating conditions that will attract such species.

Detect, monitor, and eradicate populations of invasive species using Integrated Pest Management (IPM) techniques on Installations whenever feasible. Comply with DoDI 4150.07 and guidance in the Installation’s INRMP.

2-6.7 Tree Replacement.

Meet INRMP requirements for the replacement of existing trees. Follow requirements for all trees removed on a project site. Determine the size of the replacement tree from the SoW and IDGD.

2-6.8 Trees.

DoD is committed to establishing a significant tree canopy on base Installations. Each project will be unique in the ability to include significant tree canopy requirements. Tree canopy requirements for projects located in arid and semi-arid conditions may be adjusted. The recommended planting requirement provides trees at a minimum rate of one tree per 1,000 square feet (92.9 m^2) of landscape area and identifies off site areas for designated alternative planting. Identify reductions and/or additions to the number of required trees in the Supplementary Instructions to Offerors. Confirm the planting rate with the Government Landscape Architect.

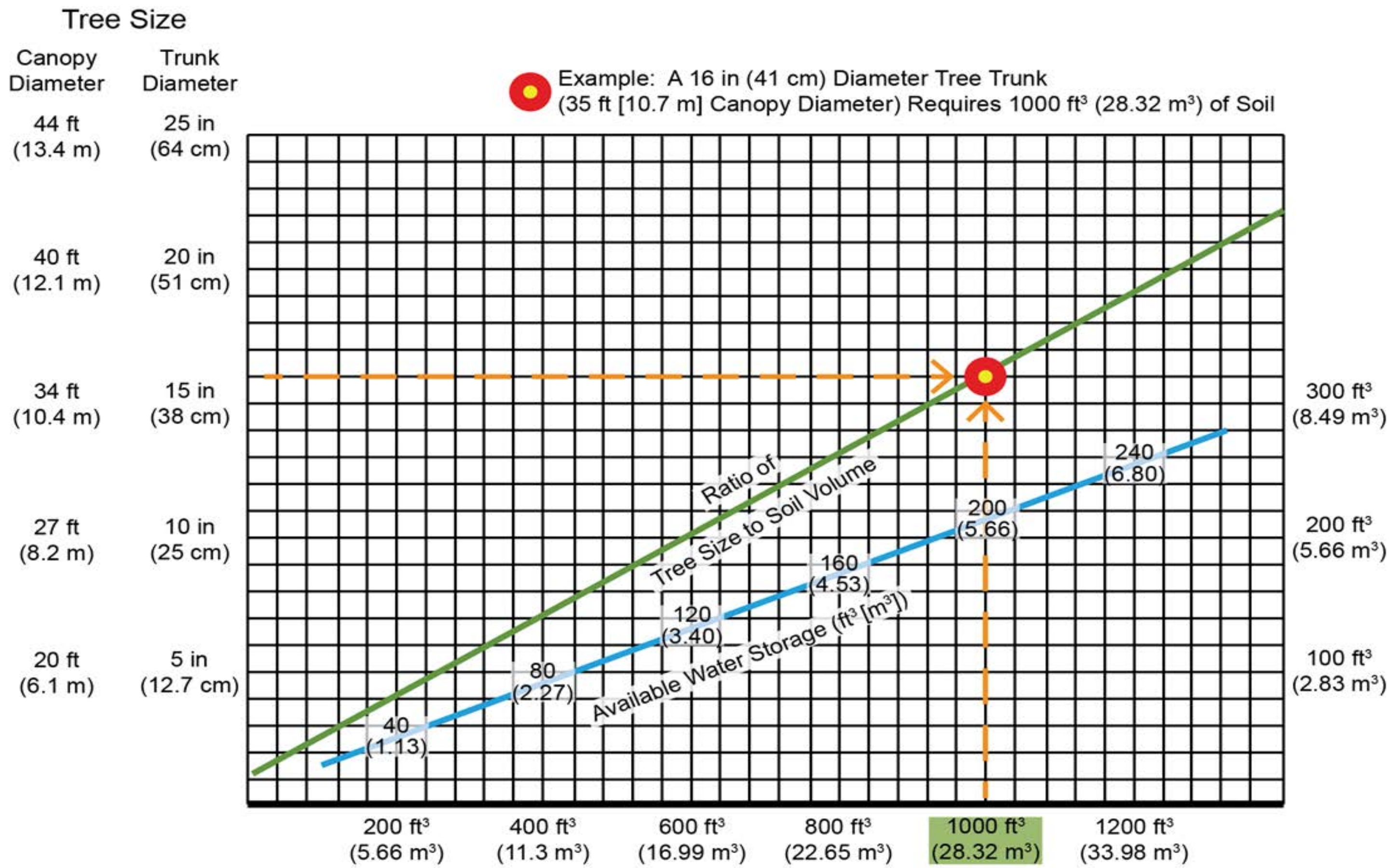
Evaluate placement and species selection to avoid overplanting the site. Ensure that the size and form of trees conforms to ANSI Z60.1 and the Installation INRMP. Refer to Chapter 2-6.2 for size requirements within standoff distances. Size new trees by type as follows:

- Shade Trees:
    - Type 1 and 2: Trees must meet or exceed 3 inches (7.6 cm) caliper and 14 feet (4.2 m) in height at installation.
    - Type 3 and 4: Trees must meet or exceed 2 inches (5 cm) caliber at installation.
- Evergreens:
    - Type 3, 4, 5 and 6: Trees must meet or exceed 6 feet (1.8 m) in height at installation.
- Multi-stem Trees: Trees must meet or exceed 6 feet (1.8 m) in height at installation.
- Palm Trees: Trees must meet or exceed 12 feet (3.6 m) in height at installation.

2-6.8.1 Tree Planting.

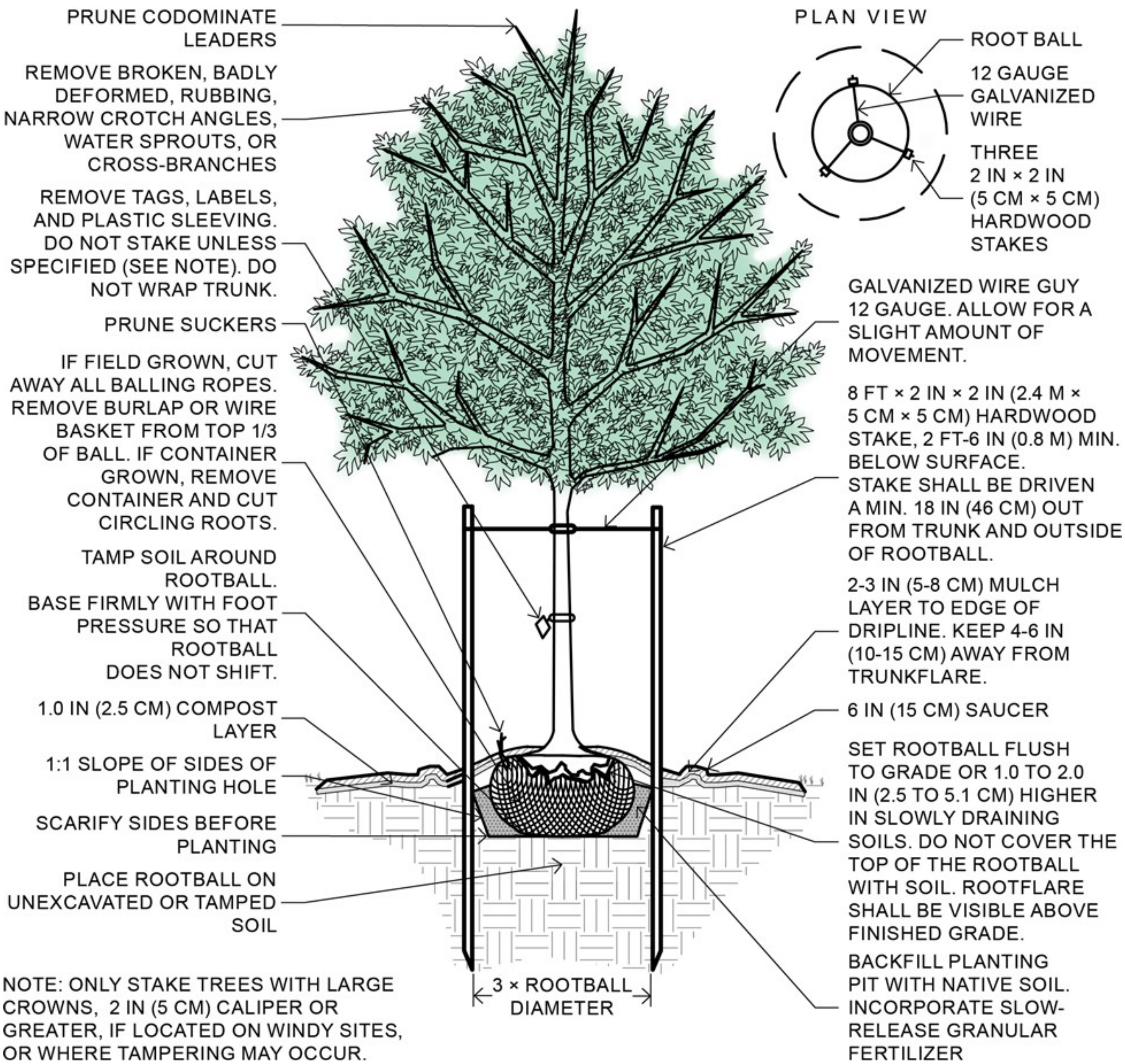
To ensure adequate soil volume and quality for trees located within plazas, sidewalks, or other paved areas, specify adequate non-paved planting area and/or other measures, such as suspended pavements. To facilitate root development and proper drainage, restore overly compacted sub-grade soils to an acceptable compaction level prior to planting. The required soil volume is based on ultimate tree canopy or trunk diameter; see Figure 2-7 for recommended soil volumes. See Figure 2-8 for an example of a standard tree planting detail.

Figure 2-7 Soil Volume Needed to Grow Large Urban Trees[1]



[1] Adapted from "Timely Tree Tips—Minimum Soil Volume," 10 June 2016, https://dnrtreelink.wordpress.com/2016/06/10/timely-tree-tips-minimum-soil-volume/. Originally from James Urban, *Up by Roots: Health Soil and Trees in the Built Environment*, 2008, International Society of Arboriculture Books, Champaign, IL.

Figure 2-8 Example Tree Planting Detail (Deciduous Tree)



2-6.9 Shrubs.

Specify shrubs to meet or exceed the size of a #3 container at installation, except for those within clear zone. Ensure the size, form, and species selected conform to ANSI Z60.1 and the Installation INRMP. The Government Landscape Architect has final approval authority on selected plant material. Species deemed unsuitable for planting will not be allowed.

2-6.10 Ground Covers, Perennials, Ornamental Grasses, Vines, and Annuals.

Specify ground covers, herbaceous perennials, ornamental grasses, and vines to meet or exceed size of a #1 container at installation, except for those within standoff distances. Refer to Chapter 2-6.2 for size requirements within standoff distances. Provide plants in a healthy, disease and pest free condition. Ensure the size, form, and species selected conform to ANSI Z60.1 and the Installation INRMP. The Government Landscape Architect has final approval authority on selected plant material. Species deemed unsuitable for planting will not be allowed.

2-6.11 Utilities.

Coordinate with other disciplines to design a centrally located utility corridor to minimize conflicts between plants and utilities. Balance site and landscape requirements with location of underground utilities.

Place trees so that the mature canopy will meet or exceed an offset of 10 feet (3.3 m), in any direction, from permanent structures such as buildings, light poles, signs, hydrants, backflow devices, overhead utilities. For transmission lines, towers, and poles, ensure a mature canopy clearance of a minimum of 25 feet (7.6 m).

Place trees a minimum of 10 feet (3.3) from underground utilities to minimize conflicts, or provide a root barrier system to mitigate tree conflicts with underground utilities.

2-6.12 Parking Areas.

1\ At parking areas, provide plantings and/or other methods to comply with International Green Construction Code (IgCC) Chapter 5 “Site Sustainability” to mitigate heat island effect at site hardscape. Coordinate with Government Project Landscape Architect regarding proposed solution(s) based on project location or site conditions. /**1**/

2-6.13 Lawns and Grasses.

Use certified seed, sod, and sprigs of good quality and established identity verified by an official certification agency. Provide certification prior to installation. Select seed, sprigs, and sod that include mixes that require no potable irrigation post-establishment and are low-maintenance. Selection of regional seed mixes is preferred. Refer to Installation INRMP and other applicable guidance. **1**\ Refer to the International Green Construction Code (IgCC), Chapter 6 “Water Use Efficiency”. /**1**/ The Government Landscape Architect may set exceptions and/or different standards for projects located in arid and semi-arid climates.

2-6.14 Pollinator Habitat.

Comply with the Office of the State Department Memorandum for “Department of Defense (DoD) Policy to Use Pollinator-Friendly Management Prescriptions” and the

DoDI 4715.03 Integrated Natural Resources Management Plan (INRMP) Implementation Manual. Implement sustainable goals in coordination with the Installation. Develop corridors for pollinators and connectivity of corridors Installation-wide.

Design planting plans to establish, enhance and restore year-round pollinator habitats. Select plant materials and maintenance strategies to ensure a variety of habitat and native nectar and pollen sources. Select plant materials and design strategies that support pollinators. Install native trees, shrubs, and flowering species that produce nectar and pollen.

Figure 2-9 Pollinator-Friendly Planting

2-6.15 Stormwater Management Areas.

Comply with UFC 3-210-01. Within stormwater management areas, specify and install quantities and species of plants in accordance with state and local regulations or other AHJ.

Ensure appropriate plant selection for each stormwater feature type and expected inundation levels and durations. Observe all antiterrorism requirements within the unobstructed space or clear zone during plant selection and placement.

2-6.16 Vegetative Roofs.

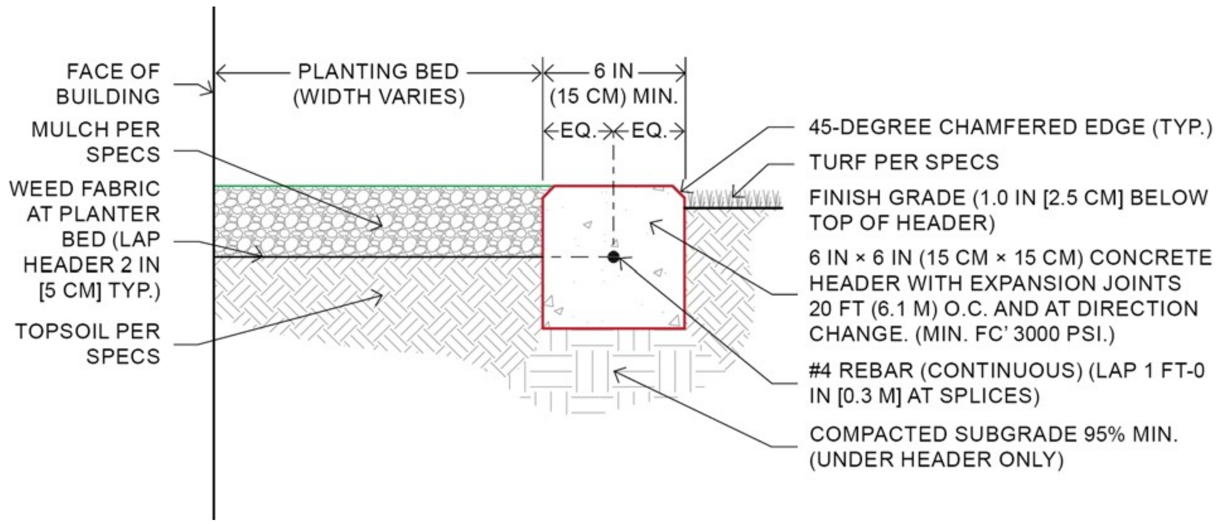
Include the Landscape Architect with all vegetative roof designs, including plant and media selection.

Use plant materials that are appropriate for selected media depth and type. Use herbicides, insecticides, and fungicides currently registered by the United States Environmental Protection Agency (EPA) or approved for such use by the appropriate agency of the host country. Select non-repellant termiticides for maximum effectiveness and duration after application. Select a termiticide that is suitable for the soil and climatic conditions at the project site and apply at the highest labeled rate. Apply herbicides, insecticides, and fungicides by a commercially certified pesticide applicator in the jurisdiction where the work is to be performed as required by Department of Defense Instruction (DODI) 4150.07. Use temporary irrigation during establishment, unless permanent irrigation is planned. Only non-potable water may be used for permanent irrigation. Coordinate with Installation-specific contract services to identify regular O&M needs.

2-6.17 Landscape Edging.

Separate turf areas from planting beds or mulched areas with landscape edging. Specify concrete or metal edging materials. Utilize aluminum, weathering steel (CorTen), or galvanized steel if specifying metal edging materials. Provide stake type and spacing for metal edging per manufacturer's recommendations. Plastic edging is prohibited.

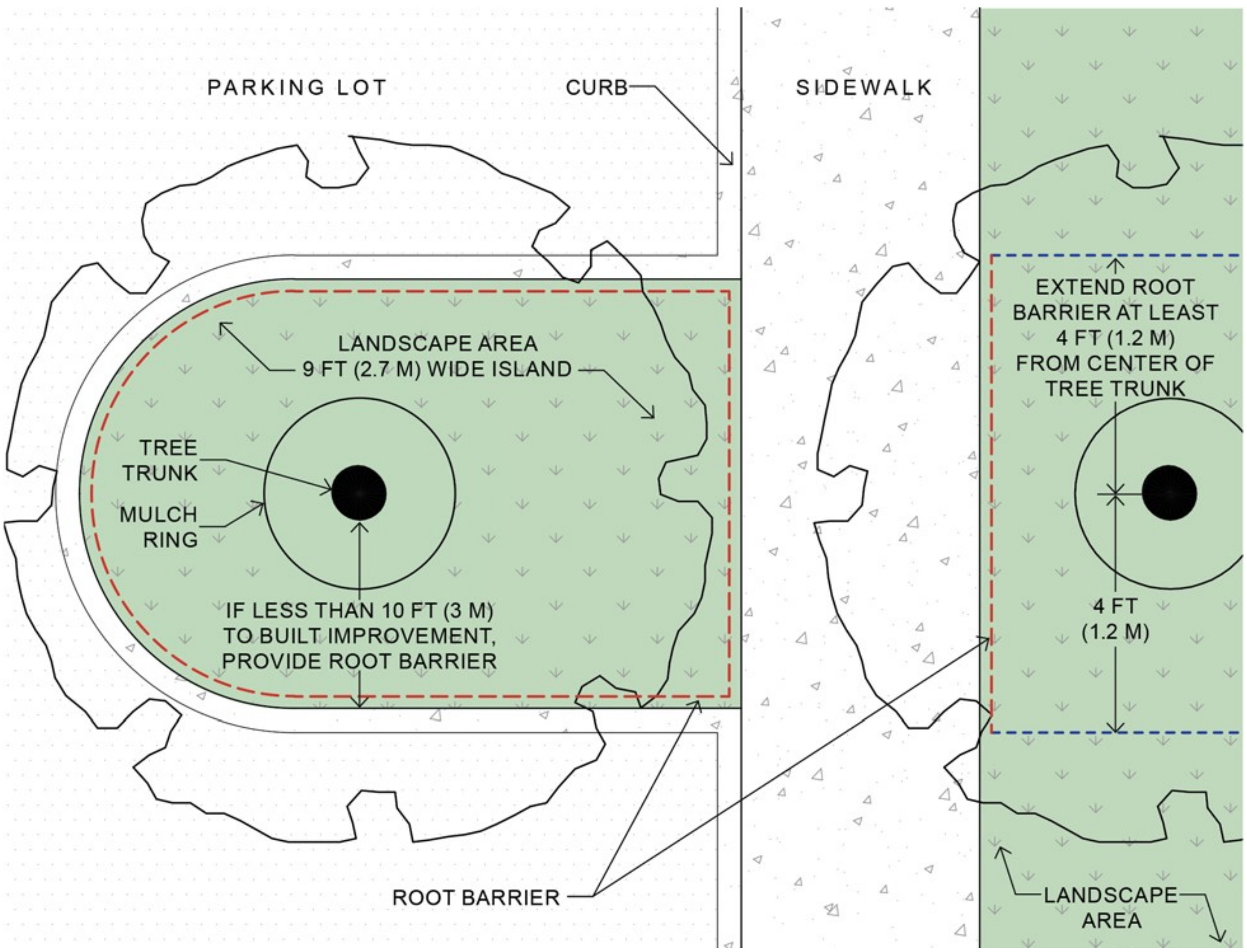
Figure 2-10 Concrete Header Mow Edge



2-6.18 Root Barrier.

Install linear tree root barriers along the edge of the built improvement where trees are planted within 10 feet (3 m) of hardscape, paving, structures, or utilities that could be compromised by root systems. Install root barrier parallel to the structure or utility to allow for the maximum amount of contiguous root zone. Extend the root barrier parallel to the site improvement at least 4 feet (1.2 m) from the center of the tree trunk in either direction as shown in Figure 2-11.

Figure 2-11 Example Root Barrier



2-7 IRRIGATION.

Design irrigation to promote optimum health, growth, color, and appearance of plant materials. Abide by the regulations of all local, state, federal, and international water agencies and authorities.

The irrigation designer manages the design and coordination of new irrigation systems with supporting plans, details, specifications, irrigation equipment (including smart controllers), schedule, and calculations. Use the following documents for DoD irrigation criteria:

- UFC 3-420-01 Plumbing Systems
- **\1** International Green Construction Code (IgCC), Chapter 6 “Water Use Efficiency” **/1/**

2-8 WALLS AND FENCES.

Comply with UFC 3-201-01, UFC 3-301-01, and UFC 4-022-03. Design walls and fences to correspond with the material palette for the Installation or facility, and correspond with the overall design concept of the site and building.

2-9 SITE LIGHTING.

For exterior lighting criteria, refer to UFC 3-530-01. Select fixtures and criteria to conform to IDGD unless otherwise stated within the project Program of Requirements (PoR) or RFP. Coordinate with the Electrical Engineer for overall lighting design, integrated pole placement, and selection of fixtures. Coordinate tree and light fixture placement to avoid conflicts that will obstruct lighting and prevent tree placement where required. Include the Landscape Architect in the design of appropriately scaled site lighting that reflects a sequence of arrival for the user, inclusive of vehicular circulation and parking, as well as pedestrian circulation, including plazas and entries.

2-10 EXTERIOR WAYFINDING AND SIGNAGE.

For exterior wayfinding and signage, comply with UFC 3-120-01.

2-11 SITE FURNISHINGS.

Provide site furnishings per the IDGD.

Comply with UFC 4-022-02 for site furnishings, including bollards and planters, intended to provide crash resistance and other security measures. Comply with UFC 4-010-01 to ensure site furnishings and elements will not conceal a threat.

2-11.1 Shelters.

Outdoor shelters include bus shelters, pavilions, gazebos, canopies, shade structures, pergolas, arbors, and other open-air facilities. Structures may consist of pre-fabricated shelters, shade structure products, or site-built shelters. Coordinate with the structural engineer on the design of footings, foundations, and other structural elements. Coordinate with the electrical engineer on the design of lighting and other electrical components.

Design shelters to match or coordinate with the material palette for the Installation or facility and correspond with the overall design concept. Scale shelters appropriately in relation to adjacent buildings. Provide plantings and other landscape features to integrate shelters into the site and enhance their visual appeal.

2-11.2 Flagpoles.

Locate flagpoles on paved surfaces that allow for routine and ceremonial access. Identify and design to avoid conflicts with trees, overhead utilities, adjacent banners, and other vertical elements. Space flagpoles so that flags do not touch when fully extended. At a minimum, specify flagpoles to meet National Association of Architectural Metal Manufacturers (NAAMM) FP1001-07 and all regional wind velocity standards for sustained wind and wind gusts.

2-11.3 Dumpster Enclosures (Trash and Recycling).

Design dumpster enclosure components and service requirements to comply with the IDGD, and to be compatible with the facility's architecture and materials. Use masonry materials for construction of enclosure unless alternate screening materials such as fencing or vegetated barriers are allowed. Construct enclosures to screen all contents from public view. Provide doors unless otherwise stated in the IDGD. Provide an evergreen screen, which at maturity is a minimum of 6 feet (1.8 m) high, to buffer walled enclosures, where applicable.

2-12 COMMON AREAS, RECREATIONAL FACILITIES, AND PLAYGROUNDS.

2-12.1 General.

Common areas may include campus entrances, main gates, building entrances, drop-off zones, plazas, courtyards, parade grounds, parks, playgrounds, recreational areas, monuments, and memorials. Ensure the area is adequately sized to accommodate the program requirements. See specific IDGD for programming and design requirements.

2-12.2 Recreational Facilities.

See the 4-700 Series UFC for requirements pertaining to specific recreational facilities. For outdoor gathering areas at military recreation centers, comply with UFC 4-740-16. Comply with requirements for recreational facilities in the U.S. Access Board's *Architectural Barriers Act (ABA) Standards*, "Chapter 10: Recreational Facilities" and ASTM F1951, "Standard Specification for Determination of Accessibility of Surface Systems Under and Around Playground Equipment".

Comply with UFC 4-750-02N for **Navy and Marine Corps** outdoor sports and recreational facilities.

2-12.3 Playgrounds.

Conform to the requirements in all relevant Housing and Community Facilities UFC (Series 4-700) and Facilities Criteria (FC) (Series 4-700) for playground designs. Comply with requirements for play areas in the U.S. Access Board's *Guide on Play Areas.* Ensure that playground equipment is age-appropriate. Equipment is typically designed for areas designated as tot lots (ages 2 to 5) and play lots (ages 5 to 12). Install signage to indicate age-appropriateness. For equipment layout, account for both the full zone of use (fall zone) for each piece of play equipment, which requires protective surfacing, and any non-encroachment zone for the equipment as specified for the equipment by the manufacturer. Comply with ASTM F1487, "Standard Consumer Safety Performance Specification for Playground Equipment for Public Use".

Comply with UFC 4-740-14 and FC 4-740-14N requirements for child development centers.

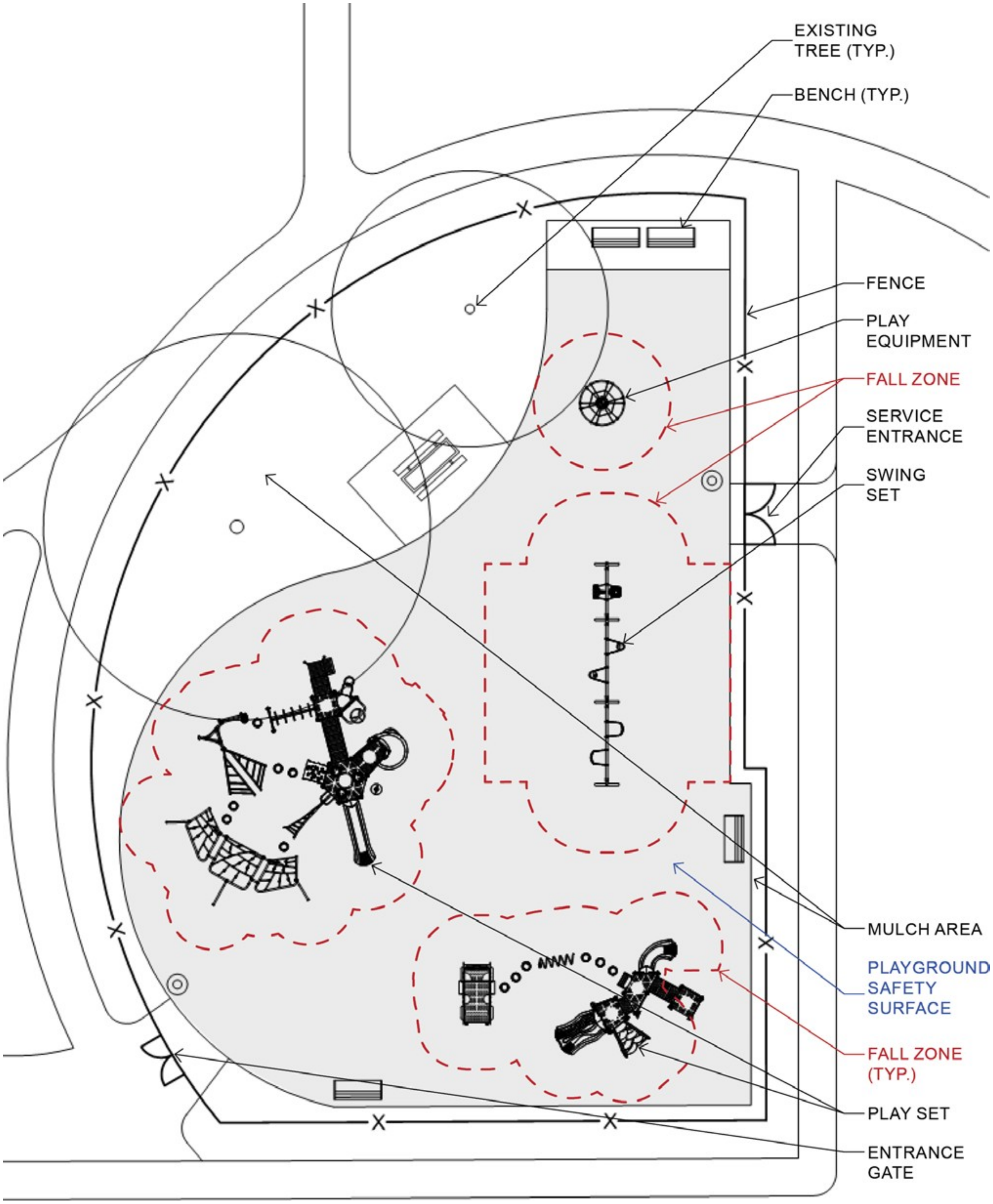
2-12.3.1 Playground Protective Surfacing.

Use a playground safety surface under play equipment, such that the surface covers the extent-of-use zones and extends at least 6 feet (1.8 m) out from all equipment. Materials at risk for compaction, flammability, and wind dispersion, or that are ingestible, are prohibited. The use of chromated copper arsenate (CCA) treated lumber is prohibited. Manage CCA-treated lumber at existing sites to prevent arsenic migration. Comply with ASTM F1292, "Standard Specification for Impact Attenuation of Surface Systems Under and Around Playground Equipment".

2-12.3.2 Planting Design at Playgrounds.

Identify and remove existing poisonous plants and plants that have thorns or other hazardous physical characteristics. Do not specify or install poisonous or hazardous plants near playgrounds. Refer to a comprehensive, commercially available field guide for complete lists of poisonous plants. Consult local cooperative extension services, regional poison control centers, or other relevant agencies for specific guidelines.

Figure 2-12 Playground Equipment Layout Plan with Fall Zones



2-12.4 Pool and Aquatic Complexes.

Comply with UFC 4-750-07 for pool and aquatic complexes.

Recreation pools and splash pads are often free form in shape, responding to the site layout and design aesthetic. Direct water away from the pool coping to the drainage system around the pool deck perimeter. Provide fence enclosures that meet minimum height, gap, and material requirements for public pools. Landscape architectural construction documents may include: pool layout, hardscape, grading, lighting, planting, and materials selection.

2-12.5 Smoking Areas.

Comply with provisions for environmental tobacco smoke control in UFC 1-200-02. See Chapter A-24.4 for best practices.

CHAPTER 3 LANDSCAPE ARCHITECTURAL PROJECT DOCUMENTATION

3-1 GENERAL.

Prepare landscape architectural design submittals and requirements in accordance with the following criteria. Landscape architectural project documentation is key to the successful execution of work. This body of work includes deliverables from project inception through project completion.

Submit required documentation as defined in the project contract and based upon component-specific guidance.

3-2 PRE-DESIGN SUBMITTALS.

3-2.1 Concept Design Workshop/Charrette.

The DoR must participate in the Concept Design Workshop/Charrette and contribute to the development of the conceptual site plan and charrette report as they relate to landscape architecture.

3-2.2 Site Inventory and Analysis.

The goal of Site Inventory and Analysis is to gather site-specific information, identify applicable requirements and regulations, and establish opportunities and constraints. Conduct a Site Inventory and Analysis narrative during Concept Design Workshops and charrettes. Include deliverables in the charrette report and into the BoD documentation. Collect the following components in the site inventory:

- Existing Conditions:
  - Environmental Checklist and NEPA Documentation
  - Visual Resources: including but not limited to photographs, existing maps, and video recordings
  - Site context
  - Climate and microclimate(s)
  - Solar aspect and wind conditions
  - Topography
  - Hydrology
    - Delineated wetlands
    - Floodplain boundaries and storm surge projections
    - Existing waterbodies
    - Man-made BMPs and stormwater structures and outfalls
    - Groundwater wells (production wells and monitoring wells)
  - Geology and soils
    - Horticultural soils analysis, including but not limited to pH, soil organic matter, and macro- and micronutrients
  - Ecosystems
  - Wildlife corridors

  - Threatened and endangered species
  - Vegetation
    - Tree inventory
    - Existing vegetation inventory
    - Identified preservation and protection areas
    - USDA Plant Hardiness Zone, or overseas equivalent
    - Ecoregion, using EPA or U.S. Forest Service (USFS) designations, or overseas equivalent
    - Invasive plants
    - Hazardous trees
    - Existing vegetation corridors and connectivity
  - Existing utilities
  - Sanitary sewer lines and pumping stations
  - Industrial activities and structures (e.g., hazardous waste, hazardous material storage facilities, fuel storage facilities, landfills, etc.)
  - Access and circulation patterns, including existing and proposed walks, trails, and pathways
  - Views (internal and external)
  - Odors
  - Noise
- Cultural Resources
  - Historic structures, objects, landscape elements, and viewsheds
  - Traditional cultural properties, Native American sacred sites, and archaeological resources that have the potential to be disturbed during construction and ground disturbance
  - Heritage or significant trees
  - Cultural landscapes that are listed in or eligible for listing in the National Register Historic Places (NRHP)
- Cultural landscapes as identified by the appropriate federal agency in consultation with state and Native American stakeholders, as appropriate
- Criteria compliance
- IDGD and local, state, federal, and international regulations
- Buffers and setbacks
- Security and antiterrorism

Perform site analysis to weigh the program of requirements against the constraints and opportunities present on the project site. Consider all existing planning documents such as the IDP and ADP.

Figure 3-1 Examples of Site Analysis Plans

Grading and Drainage

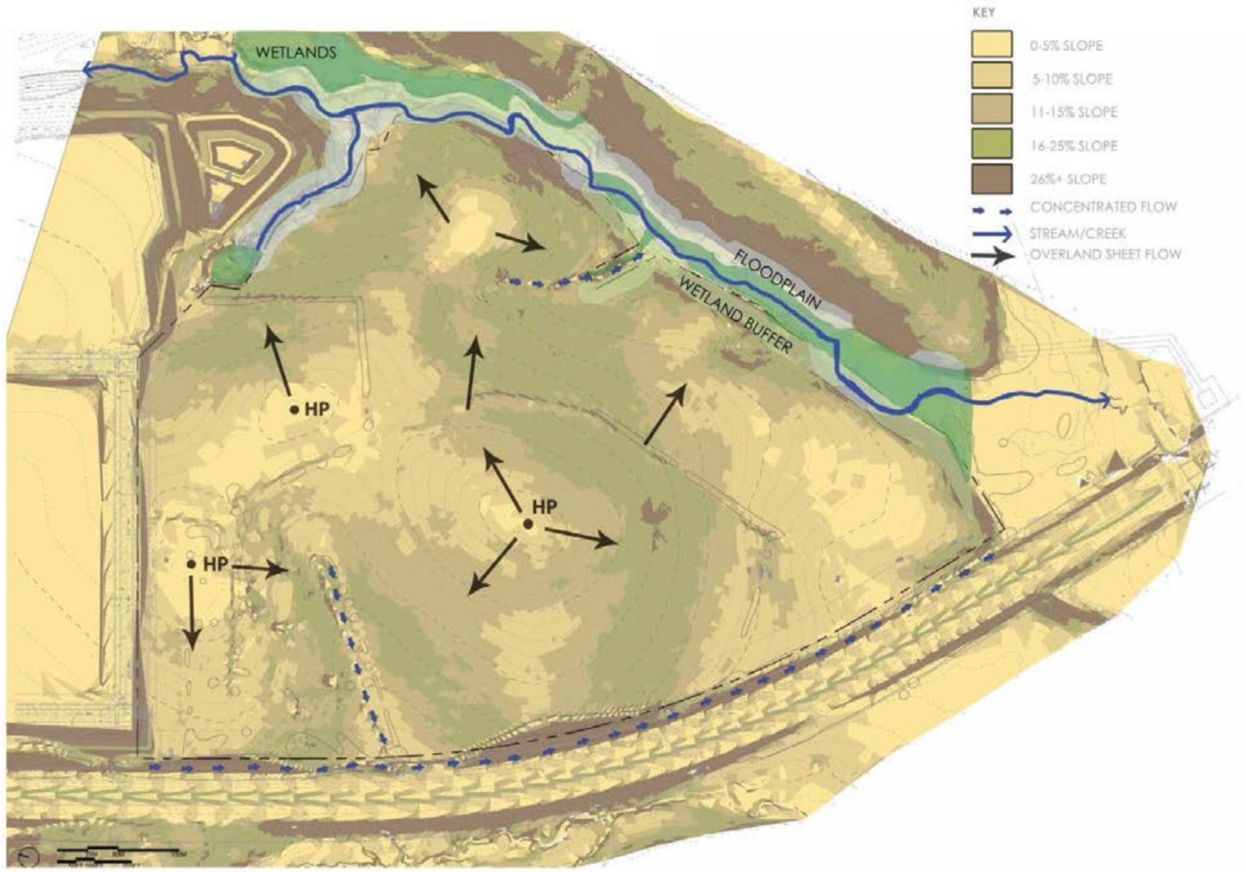
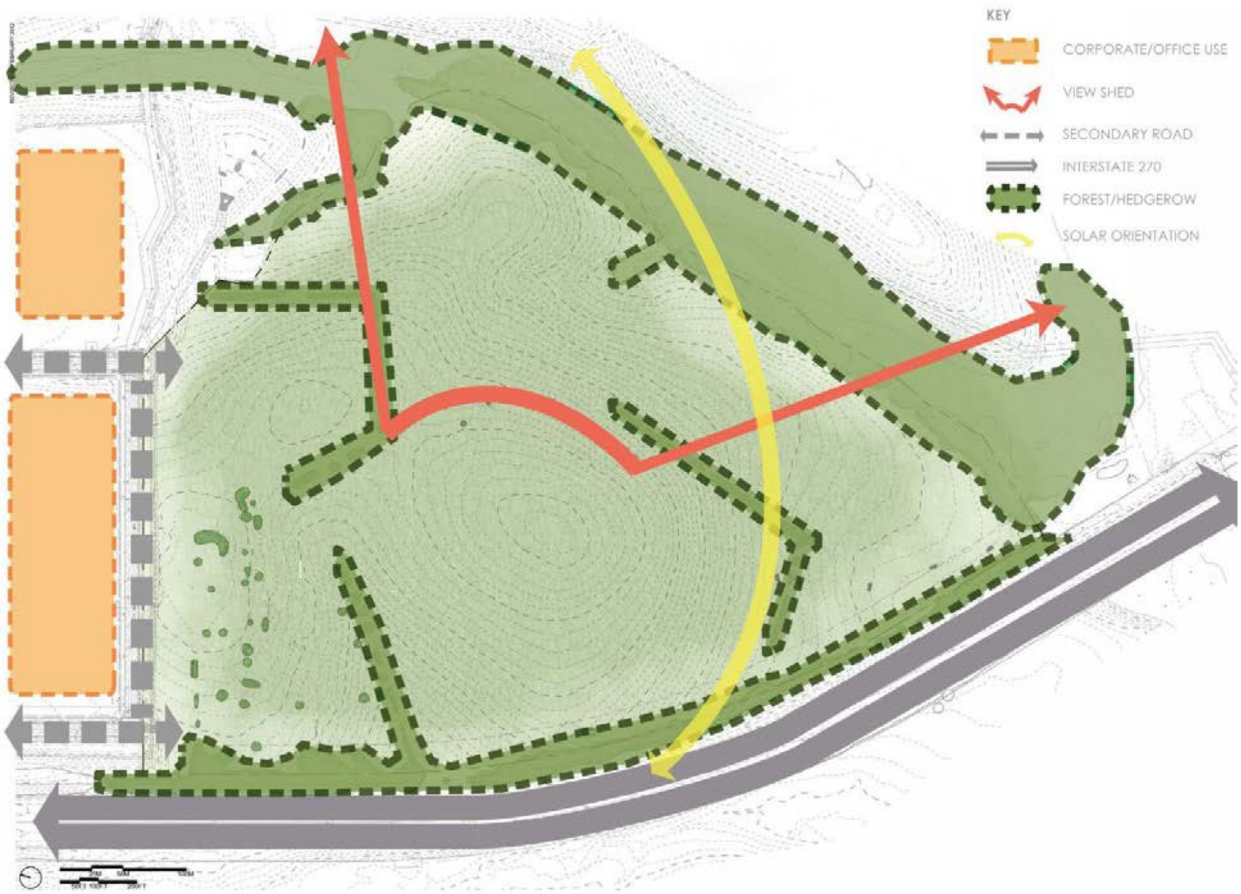


Figure 3-1 (Cont'd) Examples of Site Analysis Plans

Land Use, Viewsheds, and Solar Aspect



3-2.3 Basis of Design.

The Basis of Design is a narrative presentation of facts, sufficiently complete, to demonstrate that the project concept is fully understood, and that subsequent design details, and their ultimate presentation in the final drawings and specifications, will be based on sound decisions. Update and submit the BoD at each submittal. Address all requirements presented with the PoR in the BoD narrative, including:

- Project SoW
- Site compliance with Installation Planning Standards (IPS)
- Synopsis
    - Site inventory
    - Site analysis
    - Design approach
    - Resiliency and sustainability
    - Antiterrorism standards
    - Proposed circulation and accessibility plan
    - Stormwater design and planting

- Planting design
- Site Furnishings
- Hardscape
- Site lighting
- Irrigation: temporary or non-potable permanent
- Reference documents
- Third Party Certification (TPC) – requirements where applicable
- Maintenance plan
- IPM plan

3-3 DESIGN SERVICES.

3-3.1 General.

Address the following key components in the design documents from landscape establishment through landscape warranty periods:

- Field consultation during construction including site observations, shop drawings, and submittal review.

3-4 POST-DESIGN SERVICES.

3-4.1 General.

Address the following key components during construction from landscape establishment through landscape warranty periods:

- Field consultation during construction including site observations, shop drawings, and submittal review.
- Landscape establishment, maintenance, and management through the warranty period.

3-4.2 Construction.

Review the construction package, site conditions, criteria, schedule, procedures, and coordination with related work. Address specific landscape architecture and site-related items at the pre-construction meeting:

- Tree Mitigation
- Environmental Issues
- Endangered Species
- Other critical project specific issues

3-4.3 As-Built and Record Drawings.

Require record drawings for planting, hardscape, site lighting, and irrigation at project completion as part of the entire construction document package. As-builts and record drawings are not required for planting unless there are overall field changes in plant material types or location.

3-4.4 Landscape Establishment and Landscape Warranty Periods.

Specify the landscape establishment period and landscape warranty period for a minimum of 365 days after the date of final acceptance to run concurrently. Provide temporary potable or non-potable water or permanent non-potable water irrigation systems to improve plant establishment and viability.

At the end of the warranty period, plant materials must have a minimum 95% survival rate. Require replacement of all unacceptable material. If the overall survival rate is less than 95%, the contractor is responsible for another full warranty period of 365 days for the replacement plants.

3-4.5 Site observations and Project Acceptance.

Perform site observations as required. Determine final turf acceptance based on a satisfactory stand of turf. Acceptable turf area is defined as 95% coverage of the specified turf species at the end of the landscape establishment period with no bare turf areas larger than 6 inches by 6 inches (15 cm by 15 cm). Bare meadow or prairie mix(es) areas greater than 12 inches by 12 inches (30 cm by 30 cm) are not acceptable.

Replace dead plant material during the next approved planting season. Replace plants in their entirety with more than 20% dead material. Require another 365 day warranty period from the date of installation for replacement plant material. Test the irrigation system at final acceptance and at the end of the establishment period. Extend plant establishment and warranty periods for work that does not meet contract requirements. Conduct a final site observation at least 10 days prior to the expiration of the warranty period.

3-4.6 Operations & Maintenance (O&M).

After the establishment and warranty period, the DoD is responsible for coordination and completion of maintenance tasks by the Installation-specific grounds or resource management authority.

Perform tree care by an International Society of Arboriculture Certified Arborist in compliance with Tree Care Industry Association standards. Perform pesticide applications using a commercial-grade licensed or certified professional.

APPENDIX A BEST PRACTICES

A-1 GENERAL.

The Best Practices Appendix is considered guidance and not criteria. Its main purpose is to communicate proven facility solutions, systems, and lessons learned, but may not be the only solution to meet the requirement or design issue.

This Appendix identifies background information and practices for accomplishing certain landscape architectural site design services.

A-2 RESILIENCE.

Resilience and adaptation are essential considerations for Installation planning and design. Assess all potential site risks and design projects to minimize the long-term vulnerability of the site and optimize the opportunity for recovery. Consult databased methodologies that project models for future conditions.

For Army projects: Apply the Army's "Prepare-Absorb-Recover-Adapt" (PARA) framework to resilience planning at the project level. Consult the Screening Level Vulnerability Assessment (SLVA) available for each Installation. The Screening Level Vulnerability Assessment provides qualitative data to identify the need for more in-depth studies and data collection.

A-2.1 Hazard Response.

Hazards pose direct threats to Installations and DoD operations. For each project, inventory potential hazards. Develop and implement design strategies that serve as appropriate response measures to these hazards. This includes the conservation, restoration, and creation of natural infrastructure assets, such as wetlands that mitigate flooding and storm surge. In selecting response measures, prioritize the Installation's critical built infrastructure, including energy, fuel, water supply, and utility services.

A-2.2 Climate Resilience.

Consider the following potential climate change effects:

- Shifts in USDA plant hardiness zone designation
- Stresses on specific species
- Changes in disease and pest vector distribution
- Changes in regional precipitation patterns

Coastal erosion, flooding, storm surge, and sea level rise pose risks to DoD Installations. Address solutions to these through strategic land use planning, modifications and design interventions. Consider natural and nature-based adaptation approaches, including preserving and restoring natural coastal ecosystem defenses, vegetated dunes, living shorelines, and living breakwaters. Alteration and plant installation in and around natural landscape features may require environmental permitting.

A-3 SUSTAINABILITY.

Aspects of sustainability are covered in UFC 1-200-02, UFC 3-201-01, and UFC 3-210-10. For sustainable site development, see best practices in UFC 1-200-02.

A-3.1 Energy Conservation Planning.

Minimize building energy use for heating, ventilation, and air conditioning using vegetation to shade facades and shield the building from winds. Minimize outdoor energy consumption for lighting and other site amenities.

A-3.2 Materials.

Address material selection from the basis of embodied energy and life cycle costs. Practice waste reduction and diversion and consult the integrated solid waste management (ISWM) plan at the Installation level. Employ the use of:

- Salvaged, reclaimed, or refurbished materials. Verify that salvage, such as brick, is appropriate for outdoor use.
- Locally and regionally sourced materials.
- Materials with recycled content.
- Non-toxic materials, including the use of low-emitting and non-emitting materials.
- Raw materials that have been extracted responsibly or products that contain such raw materials.
- Sustainably grown and harvested trees and other plant material.

A-3.3 Site Commissioning and Landscape Performance.

Site commissioning is used to verify the performance of a built work by evaluating sustainability metrics and cost-effectiveness and ensuring greater longevity for the project. Site and building commissioning processes can be combined to form a total commissioning process. The nature of living systems within the landscape requires that the site commissioning processes include on-going post-occupancy evaluation. Incorporate site commissioning into landscape maintenance and management plans.

A-4 REMEDIATION AND RECLAMATION.

Engage an interdisciplinary team for projects that require bioremediation, including phytoremediation, to address the complexities of rehabilitating a brownfield site. Identify the benefits of bioremediation as applied to the identified project site. Select the appropriate methodology for mitigation based on specific site contaminants.

Adhere to EPA guidance and other AHJ guidance pertaining to soil and groundwater remediation.

A-5 SECURITY AND ANTI-TERRORISM.

Utilize design principles defined in Crime Prevention Through Environmental Design (CPTED) to minimize safety and security risks. Design and construct projects to meet security and anti-terrorism criteria as required in the project BoD and RFP including stand-off distances, planting restrictions, and visibility.

A-6 CIRCULATION AND ACCESSIBILITY.

A-6.1 Streetscape System.

Collaborate with the design team to create streetscapes that enable safe access for all users, including pedestrians, bicyclists, motorists, and transit riders of all ages and abilities. Integrated streetscapes will improve user health by facilitating and encouraging walking and biking. Refer to Smart Growth America's National Complete Streets Coalition program for complete streets design goals and standards.

Collaborate with the design team to:

- Encourage circulation patterns that reduce the need for automobile use.
- Develop a hierarchy of streets, walkways, and trails based on adjacent land use, demand, and peak travel times.
- Plan corridors utilizing the IDGD for standard design requirements.
- Minimize impacts on natural and cultural resources, including stormwater runoff, heat island effect, and visual impact.
- Delineate and clarify circulation systems to facilitate wayfinding, using elements such as signage, special pavements, lighting, furnishings, trees, and other plantings.

A-6.2 Sustainable Streetscape Design.

Sustainable streetscapes function as a part of the greater ecosystem employing technologies that manage stormwater runoff and reduce carbon footprint. Sustainable streets create benefits relating to movement, ecology, and community that together support a broad sustainability agenda embracing the environment and economy. Implementing sustainable streets will create more livable communities.

Landscape verges are an effective treatment between sidewalks and streets that create a buffer from moving vehicles. Verge width is a key factor in pedestrian-friendly design. The greater the separation between vehicular and pedestrian circulation, the safer and more pleasant the pedestrian experience. Installation standoff requirements often create opportunities to establish verge widths that exceed ten feet. Verges adapt for stormwater infiltration and shade tree planting. A minimum verge width of 4 feet (1.2 m) is recommended for small street tree installations and 6 feet (1.8 m) is recommended for large street tree installations. Rain gardens offer a greener solution to detaining and treating street runoff and easily integrate into streetscape design. Filtered runoff is then fed back into the drainage system or allowed to infiltrate and recharge the water table. Structured stormwater planters effectively infiltrate and filter large amounts of runoff using special media, adaptive plantings, and underdrains.

A-6.3 Drop-offs.

Consider dedicated passenger drop-off zones for high-use facilities. Design of covered drop-offs should reflect safety and security best practices. Separate passenger drop-off circulation from service vehicular circulation. Drop-off circulation should be one-way traffic with a counter-clockwise movement. Place seating adjacent to drop-off.

A-6.4 Transit.

The integration of complete street design and public transportation is critical in improving the efficiency of circulation on DoD Installations and projects by reducing the dependence on automobiles. Incorporate these principles within project designs where feasible:

- Parking. Adapt and design streets that accommodate transit vehicles.
- Establish direct pedestrian access routes to transit stops.
- Include transit shelters for new stops and stations that protect from rain, sun, and wind.

A-6.5

Utilize proven design components to mitigate stormwater, reduce ambient temperature, and ensure safety for all users. Include the following design features where feasible:

- Introduce stormwater treatment trains, pervious parking, dark-sky compliant lighting, and shade within parking lots.
- Consider collection and reuse of parking lot runoff for landscape watering.
- Design pedestrian circulation through parking lots to minimize conflicts.
- Strategically place shade trees to mitigate heat island effect.
- Designate snow storage areas that will not adversely affect plant health.
- Utilize appropriate specialty paving materials that meet accessible design standards.
- Coordinate placement of cameras and trees to create and maintain unobstructed sight lines for security cameras.
- Include step outs and convenience strips along pedestrian corridors to increase pedestrian safety and protect plant materials.

A-6.6 Trails and Troop Movement.

Utilize the *ABA Standards*, “Chapter 10: Recreational Facilities.” for trail design, accessibility standards, technical requirements, surface, slope, tread width, and other standards.

Troop movement walkways are specific to military Installations. Include special design considerations for troops that regularly move from one location to another. Design routes with a minimum unobstructed width of 10 feet (3.0 m) to accommodate four individuals abreast, or as directed by the IDGD.

A-7 PLANTING DESIGN.

Each Installation should promote a simple, drought tolerant, and low-maintenance planting style. To ensure consistency in planting design, utilize detailed plant lists specifically developed for each Installation. Plant lists should be dominated by durable, long-lived species.

To ensure plant diversity, do not plant monocultures of the same species or cultivar. Select plants to meet a site-wide goal of no more than:

- 10% of the same plant species
- 20% of the same genus
- 30% of the same family

Table A-1 Example of Plant Diversity Calculation

Botanical name	Common Name	Quantity	Percent of Total
Species			
Amelanchier x grandiflora 'Autumn Brilliance'	Apple serviceberry	6	5.61
Betula nigra 'Heritage'	River birch	10	9.34
Carpinus betulus 'Fastigiata'	Pyramidal European hornbeam	10	9.34
Cercis canadensis	Eastern redbud	6	5.61
Chionanthus virginicus	White fringe tree	7	6.54
Ilex x attenuata 'Fosteri'	Foster's holly	10	9.34
Ilex opaca	American holly	8	7.48
Juniperus virginiana	Eastern red cedar	9	8.41
Magnolia virginiana	Sweet bay	3	2.80
Myrica cerifera	Southern wax myrtle	10	9.34
Nyssa sylvatica 'Wildfire'	Black gum	3	2.80
Pinus taeda	Loblolly pine	8	7.48
Pinus virginiana	Virginia pine	6	5.61
Quercus bicolor	Swamp white oak	4	3.74
Quercus phellos	Willow oak	5	4.67
Quercus virginiana 'Burkii'	Live oak	2	1.87
	TOTAL	107	100
Genus			
Amelanchier		6	5.61
Betula		10	9.34
Carpinus		10	9.34
Cercis		6	5.61
Chionanthus		7	6.54
Ilex		18	16.82
Juniperus		9	8.41
Magnolia		3	2.80
Myrica		10	9.34
Nyssa		3	2.80
Pinus		14	13.08
Quercus		11	10.28
	TOTAL	107	100
Family			
Aquifoliaceae		18	16.82
Betulaceae		20	18.69
Cornaceae		3	2.80
Cupressaceae		9	8.41
Fabaceae		6	5.61
Fagaceae		11	10.28
Magnoliaceae		3	2.80
Myricaceae		10	9.34
Oleaceae		7	6.54
Pinaceae		14	13.08
Rosaceae		6	5.61
	TOTAL	107	100

A-7.1 Sustainable and Resilient Planting Design.

Employ ecological design principles to restore natural communities, improve the health of ecosystems, and to support wildlife. Design plantings for climate resiliency and natural hazards by:

- Transforming hardened shorelines into living shorelines while mitigating coastal erosion and flooding, creating wildlife habitat, and improving water quality.
- Identifying opportunities for managing natural plant communities using strategies that restore ecological processes, such as controlled burning or prescribed fires that mimics the effects and benefits of wildfires.
- Layering plantings that emulate natural communities, reduce the need for watering, and are self-supporting once established.

A-7.2 Native and Regionally Adapted Plants.

Design the landscape to achieve an Installation-wide target of 80% native plant species.

Design with plant communities that mimic natural ecosystems. These designed plant communities should include native species that form associations in their natural habitat. Also, incorporate non-native, adapted species that perform similar ecological functions and niches to native counterparts.

A-7.3 Landscape Areas.

If there is inadequate space on the project site to meet the landscape area or tree planting requirements, identify auxiliary location for installation of trees. Coordinate with the landscape architect, the Installation forestry manager, arborist, natural resources group, or other designated point of contact. Refer to IDGD and project specific SoW for additional guidance. The Government Landscape Architect may set alternate standards for projects located in arid or semi-arid conditions.

Install large street trees 40 feet on center. Maximize continuous root zone to the greatest extent possible. Design parking lot landscaping to meet the following recommended requirements:

- Select trees that have a normal life span of greater than 40 years.
- Limb branches a minimum of 5 feet (1.5 m) above grade to avoid vehicular and pedestrian conflict. Maintain a balance of 2/3 foliage and 1/3 trunk.
- Strive for a minimum 10% of interior greenspace for privately owned vehicle (POV) parking lots.
- Strive for a minimum 10% of interior greenspace for non-POV parking lots where possible. If user requirements for non-POV lots do not warrant interior tree planting, consider planting trees elsewhere on-site or Installation.
- Provide 30 square feet (25 m^2) of landscape area per parking space.

- Design a 9-foot (2.7 m) minimum width interior landscape area, exclusive of curbing, for all small trees.
- Design a 15-foot (4.6 m) minimum width interior landscape area, exclusive of curbing, for all large trees.
- Design a 10-foot (3.0 m) minimum width interior landscape area, exclusive of curbing, for linear landscape islands running perpendicular to the parking stalls.
- A 15-foot (4.6) wide landscape area is preferred in areas utilizing LID strategies.
- End islands should aim to have two trees where space allows.
- Install required trees within 5 feet (1.5 m) to 10 feet (3.0 m) outside the parking lot perimeter if room within islands is not available.
- Coordinate with DoD or the designated point of contact, for parking lot requirements in climates that are non-conducive to tree planting within parking lots.

A-7.4 Wildlife Borders.

Wildlife edge plantings are composed of native vegetation that include a mixture of woody and herbaceous plant materials, including grasses, that attract and sustain wildlife. The inclusion of wildlife borders establishes habitat and food sources. Wildlife borders, with a width of at least 30 feet (9.1 m), should be located at the edges of woodlands, fields, and drainage areas. The establishment of interconnected wildlife corridors is encouraged. Wildlife corridors should reinforce the Green Infrastructure plans of the Installation-specific IDP and ADP, the INRMP, and other IDGD.

Comply with BASH guidance if located within the zone for active runways. Once established, maintain borders by removing invasive species and large trees and shrubs as they begin to shade out low-growing plants.

Figure A-1 Wildlife Border

A-7.5 Integrated Pest Management.

IPM provides an effective and environmentally sensitive approach to pest control through a focus on prevention and the use of pesticides only as needed. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. Multiple approaches are combined to establish an IPM plan that is site specific and incorporates situational needs. A four-tired implementation approach should be applied:

1. Identify pests and monitor weekly progress
2. Set action thresholds to focus the size, scope, and intensity of the plan
3. Prevent infestation by removing conditions that attract pests
4. Control by employing mitigation options if action thresholds are exceeded

Comply with Installation-specific guidance when preparing IPM plans.

A-7.6 Fire-resistant Landscaping.

Employ strategies to reduce the risks posed by fire, including wildland fire, to structures, facilities, and infrastructure:

- Remove fuel sources and use fire-resistant materials, such as plants and mulch with low resin content, around structures.
- Create permanent firebreaks that are least 10 feet (3.0 m) wide, using hardscape or appropriate vegetation.
- Select plants that are low growing, fire-resistant, have high-moisture content and low sap or resin content. Perform regular maintenance such as pruning and removing deadwood.

Refer to guidance from the National Fire Protection Association (NFPA), including the “NFPA 1144 Standard for Reducing Structure Ignition Hazards from Wildland Fire” and recommendations for “Firewise Landscaping” in the NFPA’s *Safer from the Start: A Guide to Firewise-Friendly Developments*.

A-7.7 Xeriscaping.

Practice conservation through the implementation of the seven horticultural principles of xeriscaping. Xeriscaping will provide attractive solutions that save water and reduce maintenance requirements. Provide plantings that cover at least 60% of a planting area (planting bed) with shrubs and ground cover so that masses form within five years. The remaining area may be mulched. Follow Installation-specific guidelines for mulch requirements. Limit large areas of rock to minimize the creation of heat sinks.

Minimize lawn areas. Avoid unnecessary or unusable, small areas of lawn that cannot be irrigated effectively and efficiently. Reduce maintenance by maintaining lawn at a height that will shade out weeds. Use native or regionally adapted plant materials.

A-7.7.1 Xeriscaping Maintenance.

Perform yearly soil tests and apply soil amendments as recommended. Xeriscaping techniques may reduce, but do not eliminate the need for, weed control, pruning, mowing, fertilizing, and annual mulch replenishment.

A-7.8 Lawns and Grasses.

Limiting turf grass areas will reduce water required for establishment. Minimize turf areas in arid climates, except where required for active or passive recreation.

Avoid a monoculture lawn. Use seed, sod, or sprig mixes that combine multiple varieties of native and adaptive species, require less water, and grow to a maximum height of 6 inches (15 cm). A maintenance guide and schedule should be written for the specific species to be installed.

Meadows and Native Prairies.

Meadows and native prairies are designed to replicate natural ecosystems. The installation of meadows and native prairie restorations will reduce maintenance, fertilizer, and water use, and will create a more varied landscape. Educate maintenance staff about the unique attributes and requirements of a meadow or prairie installation. The establishment period is typically three years, at which point the meadow will begin to look full and diverse.

Create a manicured edge adjacent to pedestrian areas to allow for a clean transition to the taller meadow areas. Mow manicured edge to a maximum height of 6 inches (15 cm). Include educational signage for meadow areas in high use traffic areas to educate users and maintenance staff. Refer to section A-21 Exterior Wayfinding and Signage.

A-7.9.1 Meadow and Native Prairie Maintenance.

Meadows and native prairies require different maintenance practices than traditional lawns. Mowing is performed one to two times per year, as opposed to weekly. Specialty mowing equipment capable of raising mowing deck to 6 inches (15 cm) will be required. Native prairies can be managed through controlled burns, where appropriate, to minimize invasive plants and to rejuvenate growth of desirable species.

The active management of invasive plant materials is critical to the success and diversity of the meadow or prairie. A maintenance guide and schedule should be written for the specific species to be installed.

A-8 EXISTING VEGETATION.

Existing vegetation on Installations, especially trees, is an asset and analyzing the type, amount and condition of the vegetation is an important step in understanding the site. Design the project to preserve existing vegetation, including pollinator or host food-source plants. Examine and document sites to determine individual species and plant associations.

A-8.1 Tree Inventory.

If required, tree inventories must be performed by a licensed landscape architect or an International Society of Arboriculture (ISA) Certified Arborist ®.

For wooded areas, survey the edge of the tree line and inventory the density and species of trees. The tree inventory should identify and record any tree over 6 inches (15 cm) DBH. Trees with 24 inches (61 cm) DBH or greater are defined as a significant, heritage, champion, or specimen tree. Note these trees on the survey where present. Gather the following information during the tree inventory:

- Botanical and common names
- Size (height, canopy spread, trunk DBH)
- Approximate age and life expectancy
- Condition
- Replacement value
- Maintenance needs
- Tree location reference points
- Hazard potential

A-9 TIMBERING.

Coordinate all timbering activity with the Installation forestry manager, landscape architect, arborist, natural resources group, or other designated point of contact. Comply with applicable regulations for each jurisdiction.

A-10 REFORESTATION.

Coordinate reforestation with the Installation forestry manager, landscape architect, arborist, natural resources group, or other designated point of contact. Specify a minimum of five species of trees to avoid the installation of a monoculture. Plant species as a diverse mix across the landscape, not in rows or blocks of single species. Install a 10-foot (3.0 m) to 15-foot (4.6 m) wide wildlife border at the edge of all reforestation areas. If there are no established state, local, or Installation reforestation criteria, then plant seedlings at a minimum rate of 625 trees per acre (0.4 hectare). Include the implementation of a wildlife border where space allows. A final walkthrough and inspection are recommended prior to acceptance. A one-year warranty is recommended. Require 90% viability of seedlings at final acceptance.

A-11 FORESTRY MANAGEMENT PLAN.

Identifying, quantifying and understanding an Installation's tree population is crucial to devising a comprehensive, long-term approach to its viability. Trees that receive scheduled maintenance will generally live longer.

Tree management categories include the following:

- Native Forests: If found in undeveloped areas, native forests should be managed as part of a commercial forestry program.

- Native Trees in developed areas: Inventory and add to the forest database, which should receive regularly scheduled maintenance and care.
- Installed Trees: Include all trees planted as seedlings, transplants, or nursery stock in the forestry inventory, which should receive regularly scheduled maintenance and care.

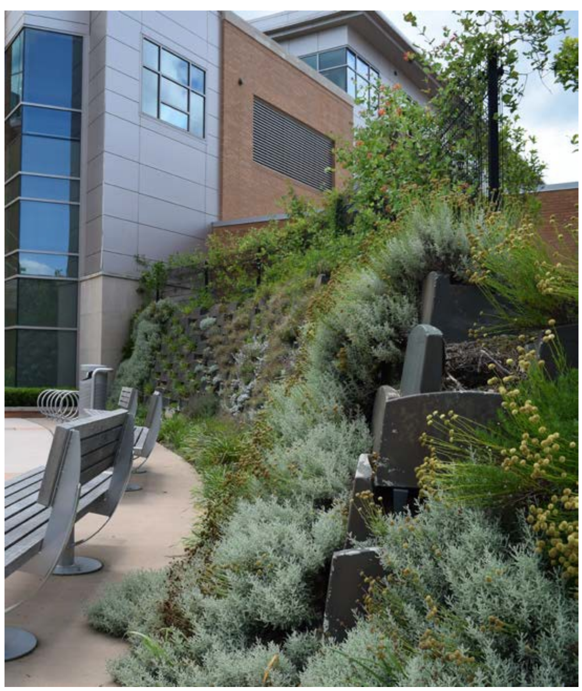
A-12 GREEN WALLS.

Green walls include all types of vegetated vertical surfaces. Systems typically include plants growing into supporting structures. Green walls may be freestanding or attached to a structure. Benefits of implementation include the support of the natural cooling processes and improved air quality. Design to adhere to Installation-specific development and design policies. Consider the following in the design of green walls:

- Location and setting-defined: maintenance level, drainage, space constraints, soil bed or growing media, or application type
- User-defined: desired benefits, function, and access
- Environmental-defined: light, temperature, atmosphere, humidity, and watering needs

Identify and address watering needs of the plant materials during the establishment period and beyond. Consider the use of alternative water sources. The installer should submit an irrigation schedule and watering contract.

Figure A-2 Green Wall with Green Screen



A-13 GREEN ROOFS.

Green roofs are typically vegetative plantings installed over an integrated drainage and growing system on a rooftop. Benefits include enhancing visual quality, stormwater mitigation, energy savings, increasing building insulation, and mitigating heat island effect. Green roofs typically have higher initial costs than traditional roofs; however, the costs are offset through reduced energy and stormwater management costs, as well as increased lifespan of the membrane and roofing system.

A-13.1 Extensive and Intensive Green Roofs.

Extensive green roofs have a shallow growing medium, usually less than 6 inches (15 cm), with a lesser roof load, limited plant selection, and minimal maintenance. Extensive green roofs employ more low-growing plant sections. Due to the shallow nature of the system, extensive roofs can be utilized on sloped surfaces up to 30 degrees.

Intensive roofs have a deep growing medium section that will support a diverse range of plants, including trees. Intensive systems have greater loads, and it is critical that the supporting structure can handle the additional weight. A higher level of visual quality is achieved with a wider plant palette. Typically, intensive roofs are physically and visually accessible and are combined with hardscape pedestal systems for access. Intensive roofs require a greater level of maintenance.

A-13.2 Media Selection.

Green roof growing medium is a mixture of porous mineral aggregates and small amounts of organic material. Permeability, porosity, and weight are key considerations. Select the media mix to resist decomposition and compression. The media mix should be able to withstand freeze-thaw cycles that may degrade the material. Media selections should comply with German Landscape Research, Development and Construction Society (FLL) recommendations for extensive and intensive green roofs in *Green Roof Guidelines: Guidelines for the Planning, Construction and Maintenance of Green Roofs*.

A-13.3 Plant Selection.

Plant materials can be installed in a variety of ways, including trays, plugs, containers, and carpets. Select plants with the following considerations:

- Roof type: extensive vs. intensive
- Growth habit
- Climate and micro-climates: wind, temperature, precipitation, freeze/thaw cycles
- Low-maintenance: native, drought tolerant, hardy plants that require limited irrigation and nutritional needs
- Purpose: stormwater management, energy conservation, heat island reduction, aesthetics, or a combination

A-13.4 Green Roof Establishment and Maintenance.

Consider establishment as well as long-term irrigation needs.

Weed seeds have the potential to be deposited onto the roof by birds, insects, and the wind. Weed the green roof aggressively during establishment to remove weeds and to prolong the life of the plants and growing medium. Create a maintenance guide and seasonal schedule for the specific plant species and system to be installed.

Figure A-3 Extensive Green Roof

A-14 EROSION CONTROL.

Erosion is influenced by soil type, vegetation, and topography. Use slope stabilization techniques on all slopes greater than 3:1. Methods include the use of specialty plantings, hydro seeding, geotextiles, and erosion control mats. Lawn areas should not exceed a 3:1 slope.

A-14.1 Vegetative Stabilization of Soils.

Vegetative stabilization measures employ low-maintenance plant materials to protect soil exposed to the erosive forces of water and wind. Vegetation intercepts and slows runoff, offers direct protection of the soil from wind, and removes water from the soil through evapotranspiration. Below the surface, vegetation binds the soil and increases the infiltration of runoff that recharges the water table.

Select plant materials and ground covers that withstand erosion during periods of intensive rainfall. Use grasses, ground covers, and woody plants with root systems to help stabilize soils and reduce surface erosion on slopes and embankments.

A-15 SOILS.

A-15.1 Specialty Soils.

Coordinate specialty soil mixes, such as bioretention media, green roof media and structural soils, with the DoR.

A-15.2 Topsoil.

Spread topsoil across all areas to be seeded, sodded, or planted. Apply topsoil at a depth appropriate to intended plant materials, existing soils, and moisture needs. Under no circumstances should the depth be less than 4 inches (10 cm).

A-15.3 Organic Matter Application.

Apply compost to existing soils with inadequate and low percentages of organic matter. Organic matter keeps soils friable, which is critical for optimal plant growth. Aerate and spread compost at a rate of 1 inch per acre (25 mm per 0.4 hectare), over the target area, to increase the organic matter percentage by approximately 2%. Lighter applications may be applied in subsequent years. Perform soil testing periodically to gauge application efficacy.

A-16 INTERIOR PLANTING.

The installation of plants within a building environment has quantifiable benefits, including the improvement of indoor air quality, environmental cooling, and noise mitigation. Research has shown that workers with a view of plants, either indoor or outdoor, have increased productivity and morale. Adhere to Installation-specific interior landscape development and design policies where applicable. Consider the following in the design of interior planting:

- Location: maintenance level, drainage, space constraints, and application type, including moveable planters, living walls, planting beds, and trellises
- User: desired benefits, location within individual workspaces, and access
- Environmental-defined: light, temperature, atmosphere, humidity, and watering needs

A-16.1 Interior Planting Maintenance.

Maintenance is the key to successful interior planting design. Interior plantings will need an irrigation system, hose bibs, or watering contract. Drip irrigation is recommended. Do not use non-potable water sources for spray irrigation. Consider the use of alternative water sources. The installer should submit an irrigation schedule and watering contract to address watering needs.

A-17 IRRIGATION.

Irrigation systems are an important part of establishing a landscape. Planting is a large investment and without proper establishment, it will not survive. A one-year establishment period is typical; however, some plantings may need up to 3 years for establishment. Design efficient temporary irrigation systems to conserve water while delivering required resources. Consider the unique characteristics of the soil, climate, topography, quantity and quality of water availability, and specific plant materials when determining a temporary irrigation strategy.

High-efficiency irrigation systems, whether permanent or temporary, deliver up to 95 percent of the water supplied versus conventional irrigation systems that are as little as 60 percent efficient. Use smart irrigation controllers that draw on data from sensors, weather forecasts and plant-care databases to determine watering requirements and time of delivery. Drip irrigation will deliver water to shrub beds more efficiently with little water loss due to evaporation or runoff. Replace or upgrade existing irrigation systems as practical to maximize water utilization. Refer to the Irrigation Association's publication *Landscape Irrigation: Best Management Practices*.

A-17.1 Plant Associations.

Design a comprehensive landscape plan to minimize water requirements. Consider water requirements when choosing plant material to reduce water consumption. The following planting practices will reduce water needs:

- Limit the amount of turf grass.
- Select plant associations to ensure similar requirements.
- Group plants with similar water requirements.
- Specify native plants that are more acclimated to regional conditions.

A-17.2 Alternative Water Sources.

Research opportunities to update existing irrigation systems, especially on golf courses and driving ranges, in order to reduce the use of potable water by taking advantage of alternative water sources. Alternative water sources, including captured rainwater and gray water, and water conservation systems, including drip irrigation, are being used successfully on DoD projects to reduce demand on potable water sources. Alternative methods include:

- Collection and storage of rainwater in cisterns
- Reuse of chiller condensate
- Retention and detention of runoff in stormwater features

Inspect existing irrigation systems for efficiency and soundness.

A-18 HARDSCAPE.

Hardscape design has essential requirements for drainage, accessibility, health, and safety. Safety considerations include safe lighting levels and slip-resistant surfaces. There are opportunities to design hardscape to reduce stormwater runoff, heat island effect, and life-cycle costs.

General recommendations for hardscape include the following:

- Select paving materials for the local climatic conditions to ensure longevity, functionality, and aesthetics.
- Distinguish between vehicular and pedestrian rated pavers.
- Utilize a raised or flush curb as an edge restraint for asphalt and paver areas.
- Review samples and field-constructed mockups with a minimum area of 8 feet by 8 feet (2.4 m by 2.4 m) of specialty pavements.

A-18.1 Concrete.

Design a scoring plan and details to indicate control and expansion joints. When designing colored concrete applications, for durability, always use a foundation of integral color. Topically applied color (color hardener or dust-on color) may then be used for enhancement purposes where not prohibited by IDGD.

A-18.2 Pervious Pavements.

Pervious or permeable pavements may be part of a strategy to restore a more natural hydrologic system on site. Evaluate these pavements for cost-effectiveness, structural capacity, and maintenance requirements. Follow the manufacturer’s recommended installation specifications. General recommended standards include the following:

- Limit the use of pervious surfaces to flat or slightly sloped areas. Terrace slopes greater than 5%.
- Verify that soils have a permeability rate of 1 inch (2.5 cm) per hour or greater.
- Verify a 2 foot (0.6 m) minimum clearance (vertical distance) between the bottom of the pavement system and the seasonal high-water table.
- Ensure that the permeable pavement system is not hydraulically connected to structural foundations.
- Verify that selections for joint filler, void material, and bedding material ensure permeability.
- Use a herringbone pattern or other approved pattern for vehicular surfaces.

Figure A-4 Vehicular-Grade Pervious Pavement Systems[1]

A-18.2.1 Pervious Pavement Maintenance.

A major design consideration for pervious pavements is maintenance requirements. Vacuum pervious pavements yearly. Prevent soil and mulch from clogging the stormwater system.

Pervious pavements are susceptible to damage from conventional snow removal practices. Plows with metal blades can damage surfaces. Salt, chemicals, and sand treatments may reduce porosity. Sanding should not be used on pervious surfaces without permission from AHJ. The use of a rotary broom or snow blower is the preferred method for snow removal. Plows with rubber or plastic-edged blades are acceptable. If a metal blade is used, keep the blade 1 inch (3 cm) above the pavement surface.

A-19 HEAT ISLAND EFFECT.

Landscape architectural site design plays a major role in unifying efforts to reduce heat-island effect. Reduction strategies include use of the following:

- Paving materials with a high Solar Reflectivity (R) value or high Solar Reflectance Index (SRI). SRI is a composite measure of solar reflectivity and thermal emissivity. An SRI value of 29 or higher is recommended for site

[1] Image: Cascade Design Collaborative, http://www.cascadedesigncollab.com/

materials exposed to sunlight. Solar reflectivity characteristics can be obtained from the material manufacturer.

- Open-grid paver systems with a high SRI value
- Vegetated surfaces or rock mulch with a high R or SRI value in lieu of hardscape
- Tree canopy and structures to shade paved surfaces, buildings and lawns
- Vegetated roofs

Prioritize the retention of existing vegetative cover to shade hardscape, especially dark surfaces. In arid and polar climates, tree canopy is less likely to be used. Parking canopy structures are more common. Consider parking canopy options with vegetative roofs or photovoltaic solar panels.

Figure A-5 Covered Parking: Parking Canopy with Photovoltaic Solar Panels[2]

A-20 WALLS, FENCES, AND GATES.

Limit the use of chain link fence to temporary, secondary, and utilitarian applications. Select decorative styles for primary entrances, formal contexts, and highly visible perimeters. Scale these elements appropriately in relation to adjacent buildings. Balance security needs with pedestrian access and circulation through common areas and along typical pedestrian routes.

Consider the use of green screens (vining plants growing on fences or trellises) to provide privacy, protection, or visual screening, while creating a softer, more aesthetically appealing barrier.

[2] Image: Airman 1st Class Cary Smith/U.S. Air Force, "Building resilient infrastructures one panel at a time," 2016 August 12, https://www.usafe.af.mil/News/Article-Display/Article/916922/building-resilient-infrastructures-one-panel-at-a-time/

A-21 EXTERIOR WAYFINDING AND SIGNAGE.

Successful wayfinding and signage systems clearly communicate information, making a campus legible and accessible. Signage systems operate on a hierarchy of scale, graphics standards, and strategic placement, and should form a cohesive scheme. Integrate the following components into a comprehensive wayfinding system:

- Maps
- Visual communication including variation in colors, patterns and marking of hardscape
- Visual guidance created by structural elements in the landscape
- Non-visual communication, such as auditory and tactile wayfinding

Signage programs are unique for each Installation. Consult the individual IDGD for wayfinding and signage standards. Minimize the number of signs for directions, identification, and customer service to achieve an efficient, cost-effective, and attractive system. The design of wayfinding features and signage should correspond with the material palette for the Installation or facility. Integrate interior signage standards and wayfinding elements into the overall project design and coordinate with exterior features.

A-22 SITE LIGHTING.

Consult the individual IDGD for site lighting standards. Use multiscale lighting across the site to emphasize circulation corridors and highlight significant site features. Incorporate vehicular, pedestrian, bollard, and accent lighting into the lighting design.

A-22.1 Lighting Coordination and Placement.

Lighting coordination and placement are critical components of a safe and secure site. Coordinate with the electrical engineer and design team to implement the following recommended standards:

- Place lighting to minimize conflicts with trees, utilities and stormwater structures, closed-circuit television (CCTV), and other site elements.
- Locate vehicular lighting along travel ways and within parking areas. In vehicular lighting areas, meet or exceed the minimum industry standard of 1 foot-candle (10 lux) average.
- Set light fixtures back a minimum of 2 feet (0.6 m) from circulation aisles and parking stall curbs.
- Use pedestrian-scale lighting in gathering spaces and along walkways. Install pedestrian lighting at a maximum height of 12 feet (3.7 m), unless IPS guidance directs higher or lower installations.
- Bollards and accent lighting may be used in place of traditional light poles within pedestrian areas. Ensure fixtures do not emit light skyward and meet minimum foot-candle requirements.
- Light all pedestrian areas to a minimum industry standard of 1 foot-candle (10

- lux) average, unless otherwise stated in IPS guidance.
- Position light fixtures to avoid light trespass along property lines. Maximum light levels at the property line should not exceed 0.1 foot-candle (1 lux).

A-22.2 Dark Sky and Light Trespass.

Meet dark-sky criteria and ensure all light fixtures have horizontal cut off at 90 degrees. The dark-sky movement encourages the use of full cut-off light fixtures that cast no light upward. Control the direction and spread of light by choosing appropriate light fixtures. Refer to the International Dark-Sky Association (IDA) website for resources on product selection. Select all light fixtures to conform to the Illuminating Engineering Society's (IES) standards for "full cut-off" or "fully shielded" fixtures.

Minimize light trespass from site lighting to reduce sky-glow, increase nighttime visibility, minimize negative effects on nocturnal animals, and improve human health and functioning.

A-22.3 Environmental Considerations.

Poorly designed lighting may adversely affect wildlife populations, including endangered species such as nesting sea turtles and migrating birds and bats. Consult with the Installation natural resources manager to identify any potential conflicts with wildlife and appropriate design modifications.

A-22.4 Energy Efficiency.

Select lighting in accordance with the Installation-specific energy efficiency goals and criteria.

Solid state lighting (SSL), including light-emitting diodes (LED), or improved systems that meet more stringent energy goals must be the first consideration for all exterior applications such as building area, roadway, parking lot, pathway, sidewalk, signage, landscape, and security lighting. Formulate site lighting to minimize energy use while maintaining safe light levels.

A-23 SITE FURNISHINGS.

Select site furnishings to match the IDGD and create a cohesive design palette that is applied consistently across a project, including use of the same materials, colors, and finishes. Affix all site furnishings to a permanent surface. Ground mounting or use of a ground-set foundation is preferred.

Site furnishings, together with active users (as in the case of seating), should not impede the flow of vehicular, bicycle, or pedestrian traffic, except where used as traffic barriers or security features.

A-23.1 Flagpoles.

Use the following recommended design standards for ground-mounted flagpoles:

- Appropriate flagpole size for the flag desired per manufacturer recommendations
- Tapered flagpole
- Foundation tube is ground set in a concrete footing. Roof mounting or use of an outrigger pole are acceptable alternatives if ground-mounting is not possible
- An internal cable halyard assembly
- Finial ball ornamentation
- Lightning kit recommended for the pole specified which supplies the required protection
- Stainless steel or aluminum pole with matching components

Table A-2 Flagpole Size Recommendations[3]

Flagpole Height	Recommended Flag Dimensions
20 ft (6.1 m)	3-1/2 ft by 6-2/3 ft (1.1 m by 2.0 m)
30 ft (9.1 m)	5 ft by 9-1/2 ft (1.5 m by 2.9 m)
40 ft (12.2 m)	5 ft by 9-1/2 ft (1.5 m by 2.9 m)
50 ft (15.2 m)	8-2/3 ft by 17 ft (2.6 m by 5.2 m)
60 ft (18.3 m)	8-2/3 ft by 17 ft (2.6 m by 5.2 m)

A-23.2 Bike Storage.

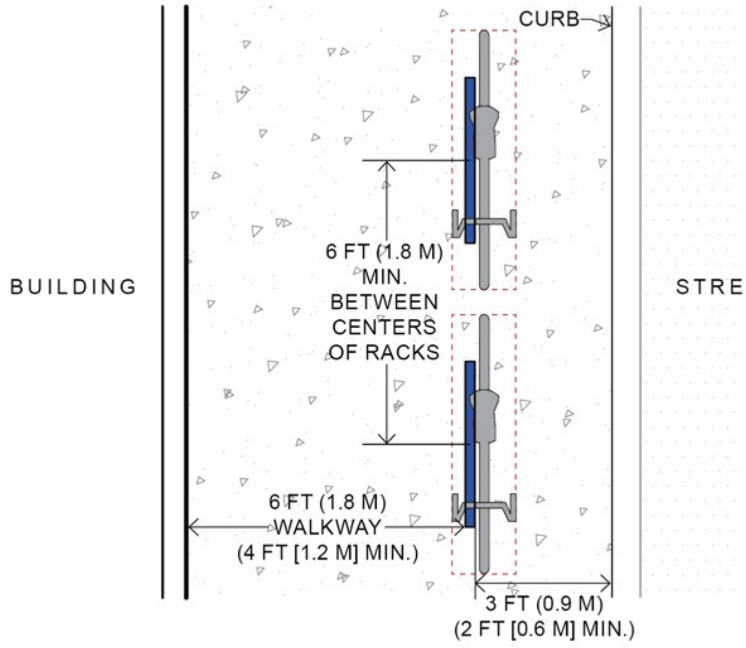
Placement of at least one bicycle storage unit at every facility is recommended, with space to accommodate a minimum of four bicycles with each storage unit. Align bicycle storage with occupancy requirements as stated in the IDGD and other project-specific documents. Install storage units in a secure location near facility entrances. Bike storage can be divided into three types:

- Short-term bike storage consists of outdoor racks; see Figure A-6 for examples of recommended space requirements.
- Long-term storage consisting of a covered facility, including racks under or inside of a shelter.
- Long-term bike lockers.

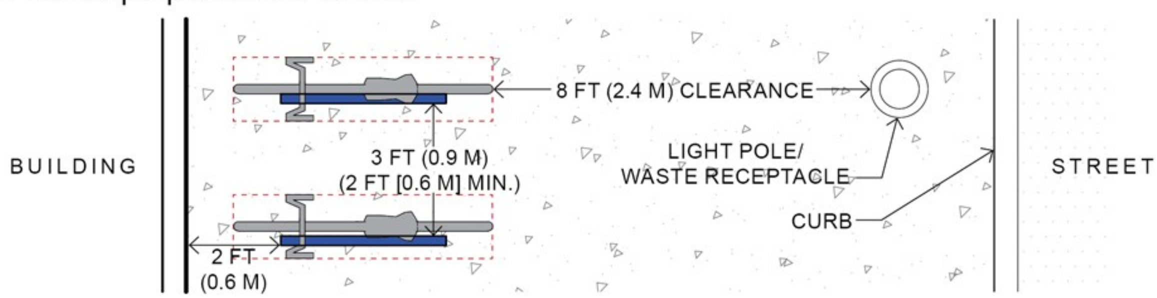
[3] General Services Administration. *Facilities Standards for the Public Buildings Service* (PBS-P100), April 2017, https://www.wbdg.org/FFC/GSA/p100_2017.pdf.

Figure A-6 Short-Term Bike Storage: Layout Options

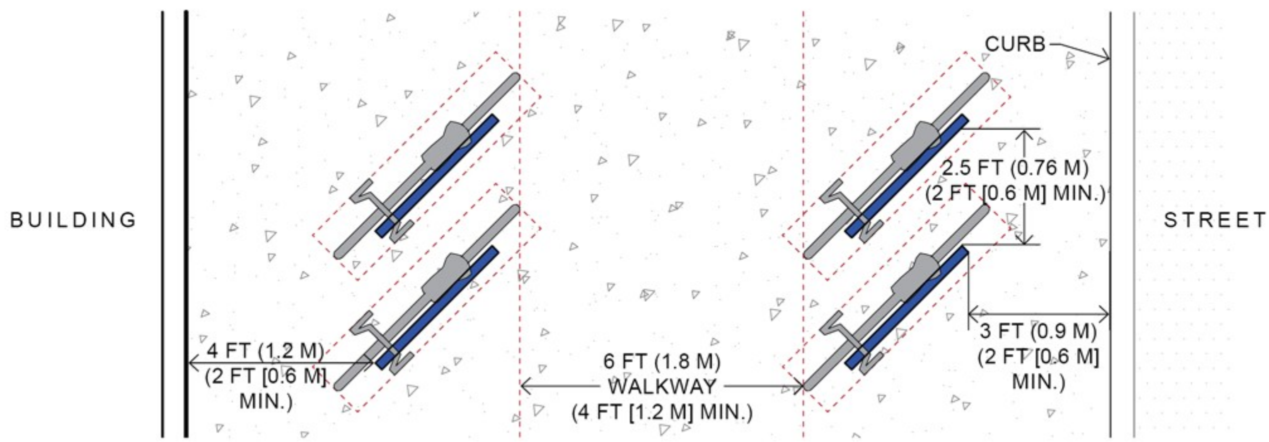
A. Racks parallel to curb



B. Racks perpendicular to curb



C. Racks diagonal to curb – 45 degree angle



A-23.3 Seating.

Select benches that create a unified system of seating. Locate benches and seat walls at primary building entrances, drop-off zones, and gathering spaces such as plazas and courtyards. Design for a minimum of 1 linear foot (0.3 m) of seating per 50 square feet (4.6 m^2) of plaza or courtyard space. Ensure that seating options accommodate all user groups. Locate a minimum of one bench along every 1/4 mile (0.40 km) of trail. Consider accessibility requirements when designing seating areas.

To facilitate good pedestrian traffic flow, place benches and other seating:

- A minimum of 3 feet (0.9 m) from the path of travel, such as a sidewalk or trail.
- At least 3 feet (0.9 m) away from sign posts, waste receptacles, or any stationary obstacle.

A-23.4 Outdoor Dining.

Locate outdoor dining spaces according to the project program requirements and locate on concrete paving that extends at least 3 feet (0.9 m) beyond the edge of seating on all sides. Consider accessibility when designing seating areas.

Include permanent grill stations in picnic areas. Use grills with a minimum 200 square inch (0.12 m^2) size grill area, and preferably a stainless-steel lid. Specify whether the grill is gas or charcoal in the RFP.

A-23.5 Grates.

Use tree grates in pedestrian areas where there is a need for additional walkable surface area. Design tree grates no smaller than 5 feet by 5 feet (1.5 m by 1.5 m), and plan to replace or modify grates to accommodate trunks as they grow in diameter. Specify decorative metal grates in pedestrian areas.

Place grates over trench drains and other stormwater conduits that traverse walkways. Dome grates are recommended in yard areas to reduce clogging.

A-23.6 Planters.

Use planters for decorative purposes at building entrances and in pedestrian plazas. Planters may function as security barriers, if they meet the design specifications in UFC 4-022-02. Planters may be used to screen security barriers. Design or select planters to contain the soil volume needed to support the intended planting and include appropriate drainage requirements. Consider the option for a self-watering container with a reservoir system.

A-23.7 Waste Collection and Trash Enclosures.

Designate separate receptacles for trash and recycling. Locate waste receptacles in common areas. Screen trash enclosures with evergreen vegetation.

A-24 COMMON AREAS, RECREATIONAL FACILITIES, AND PLAYGROUNDS.

Design common areas, recreational facilities, and playgrounds using principles and standards for universal or barrier-free design. This includes facilities for both users and spectators. As appropriate, furnish these spaces with shade, benches, bicycle racks, and waste receptacles. Wherever possible, maintain existing natural features, open areas or greenspace that can be used for passive recreational use.

Design recommendations for specific facilities include the following:

- Use main gate and building entrances to elevate the image and importance of the Installation and facility. Coordinate closely between disciplines to balance aesthetics with access and security needs.
- Size plazas and courtyards to allow for 4 to 12 square feet (0.36 to 1.1 m^2) per person, depending on the anticipated site programming.
- Design monuments to create the environment needed to properly memorialize and commemorate significant events and people.
- Locate bus shelters near common areas. Specify bus shelters that are universally accessible and provide seating.

A-24.1 Parade Grounds.

Design parade grounds to create the large open space needed for formation drills, parade and review functions, honor ceremonies, and other events. Parade grounds traditionally take the form of manicured lawns. Surface with turf and stabilize as needed. Use water-saving grasses or ground cover such as low-water engineered turf blends or other low-water alternatives where possible and in consideration of local climatic conditions. Size parade grounds at 1 acre (0.4 hectare) per 125 persons, and size reviewing stands to accommodate a capacity of 5% of officer strength at the Installation.

A-24.2 Exercise Equipment.

Incorporate exercise equipment and fitness trails into outdoor recreational areas. Install equipment on a surface recommended by the manufacturer. Select and design fitness stations for universal accessibility.

A-24.3 Playgrounds.

For playground design and safety, refer to the U.S. Consumer Product Safety Commission (CPSC) 325, *Public Playground Safety Handbook*, or equivalent overseas standards. Apply accessibility design guidance in the *ADA Accessibility Guidelines for Play Areas*. Use a Certified Playground Safety Inspector (CPSI) for design of all playground plans.

Fence play areas to mitigate nearby accessible hazards, such as roads, waterbodies, and steep slopes. Fencing should be a minimum of 4 feet (1.2 m) tall. The preferred material is a decorative aluminum fence. Install an 8-foot (2.4 m) wide gate to allow a service vehicle to enter the play area. Concrete curbing is recommended as a border for the play surface. Place benches in play areas and establish a clear view across the play area. Play areas should have shaded areas in the form of mature tree canopy, shade sails, a shelter or other type of canopy.

A-24.4 Smoking Areas.

Prohibit smoking in common areas frequented by nonsmokers including sidewalks, courtyards, plazas, gathering spaces, main entrances, seating and pavilions. Display clear signage indicating no smoking zone within 50 feet (15.25 m) of all building entrances, windows, other openings or ventilation intake systems. Comply with DODI 1010.10 “Health Promotion and Disease Prevention”.

Consider placing shelters with seating and protection from the elements in the designated smoking area to encourage use of identified space. Use stand-alone ash receptacles or ash receptacles mounted on trash cans. Label hot ash receptacles with logos or text indicating their use. Do not wall-mount hot ash receptacles.

A-25 POST-DESIGN SERVICES.

A-25.1 Operations and Maintenance Manual.

Educate maintenance personnel on the goals and implementation of the site maintenance plan. Address the following in the O&M manual, as applicable:

- Seasonal plant care and pruning
- IPM
- Mowing
- Removal of stakes and guys
- Removal of invasive plants
- Fertilization and soil amendments
- Stormwater planting
- Interior plants
- Green roofs
- Irrigation system
- Hardscape: including resealing, pervious paver vacuuming, salting limitations, and repairs
- Structures, including wall maintenance
- Lighting

Identify maintenance requirements pre-acceptance, during the warranty period, and post-establishment. Identify the responsibilities for each party outlined in the project specifications.

Figure A-7 Example Seasonal Maintenance Schedule

Activity	Season			
General Maintenance:	**Spring**	**Summer**	**Fall**	**Winter**
Trash pick-up	Weekly	Weekly	Weekly	Biweekly
Remove all broken or fallen twigs and limbs	Weekly	Weekly	Weekly	Biweekly
Sweep pavement	Weekly	Weekly	Weekly	Biweekly
Mulching:				
All planting beds with double-shredded hardwood (maintain at 3-in. depth) *			Biannually	
Perennials:				
Deadhead spent flowers		Monthly	Monthly	
Cut back tender varieties after frost			Monthly	Monthly
Pruning:				
Remove sucker growth from tree trunks**				Annually
Prune shrubs to maintain optimal height**				Annually
Fertilization:				
Fertilize shrub plantings with granular application	Biannually (Full Rate)		Biannually (Half Rate)	
Fertilize meadow/lawn	Biannually (Full Rate)		Biannually (Half Rate)	
Chemicals:				
Apply pre-emergent				Annually
Apply post-emergent	Monthly	Monthly		
Insect controls as needed	Monthly	Monthly	Monthly	Monthly
General Meadow/Grasses:				
Mow with Bush Hog – Warm/Cool Season Mix #1 and #2 ***				Annually
Mowing – Cool Season Mix #3 and #4	Biweekly (or as needed to maintain desired height)	Biweekly (or as needed to maintain desired height)	Biweekly (or as needed to maintain desired height)	
Reforestation:				
Reposition or replace tree shelters that are tilted or severely damaged	Monthly	Monthly	Monthly	Monthly
Replace dead/decayed trees per warranty agreement	Biannually		Biannually	
Other:				
Leaf removal			Monthly	Monthly
Irrigation start-up	Annually			
Irrigation shut-down			Annually	
Hand water dry or stressed plants – First 1-2 years (establishment period)	Monthly	Monthly	Monthly	Monthly
Remove dead plants/Replace per warranty – First 1-2 years	Monthly	Monthly	Monthly	Monthly
Spray and grub weeds and invasive plants	Monthly	Monthly	Monthly	

* Flexibility with mulch replenishment in either the spring or the fall
** Prior to spring flush
*** Could be done more than once a year as needed

APPENDIX B GLOSSARY

B-1 ACRONYMS AND ABBREVIATIONS.

AASHTO	American Association of State and Highway Transportation Officials
ABA	Architectural Barriers Act
ADP	Area Development Plan
AHJ	Authority Having Jurisdiction
ANSI	American National Standards Institute
ASA IE&E	Assistant Secretary of the Army Installations, Energy and Environment **1**\\/**1**/
BASH	Bird/Wildlife Aircraft Strike Hazard
BIA	Bilateral Infrastructure Agreement
BoD	Basis of Design
CRM	Cultural Resources Manager
CRZ	Critical Root Zone
DBH	Diameter at Breast Height
DoDI	DoD Instruction
DoR	Designer of Record
EPA	Environmental Protection Agency
FGS	Final Governing Standards
HNFA	Host Nation Funded Construction Agreements
IDGD	Installation Design Guidance Documents
IDP	Installation Development Plan **1**\\
IgCC	International Green Construction Code /1/
INRMP	Integrated Natural Resource Management Plan
IPM	Integrated Pest Management
IPS	Installation Planning Standards

LID	Low Impact Development
MILCON	Military Construction
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NHPA	National Historic Preservation Act
NHO	Native Hawaiian Organization
OASD EI&E	Office of Assistant Secretary of Defense for Energy, Installations, and Environment
O&M	Operations and Maintenance
PoR	Program of Requirements
POV	Privately Owned Vehicle
R	Solar Reflectivity
RFP	Request for Proposals
SAES	Statement of Architectural and Engineering Services
SOFA	Status of Forces Agreements
SoW	Scope of Work
SRI	Solar Reflectance Index
UFC	Unified Facilities Criteria
USDA	United States Department of Agriculture
WBDG	Whole Building Design Guide

B-2 DEFINITION OF TERMS.

Authority Having Jurisdiction (AHJ): The component office of responsibility, i.e., U.S. Army, HQ USACE/CECW-CE; U.S. Navy, NAVFACENGCOM HQ Code CHE; U.S. Marine Corps, HQMC Code LFF-1; and U.S. Air Force, AFCEC. The enforcement of the codes and standards as they pertain to facility projects can be delegated to the local Components Office's Chief Engineer's Technical Representative at the discretion of the components aforementioned office.

Bioremediation: The treatment of pollutants or waste (as in an oil spill, contaminated groundwater, or an industrial process) by the use of microorganisms (such as bacteria) that break down the undesirable substances.

Bird/Aircraft Strike Hazard (BASH): The conflict between birds, airfields, and flight paths that poses safety issues for the flying environment. Problem species can be drawn away from active airfield areas by managing habitats on or near airfields, including enhancing habitat elsewhere.[1]

Building: "A roofed and floored facility enclosed by exterior walls and consisting of one or more levels that is suitable for single or multiple functions and that protects human beings and their properties from direct harsh effects of weather such as rain, wind, sun, etc."[2]

Certified Seed: "Certification is the process by which a state seed certifying agency gives official recognition to seeds produced of a cultivar or named variety under a limited generation system which ensures genetic purity, identity, and a given minimum level of quality. Progeny of breeder, foundation or registered seed, handled under procedures acceptable to the Department of Agriculture and Forestry to maintain satisfactory genetic purity and identity."[3]

Charrette: "An intensive creative work session in which a design team focuses on a design problem and arrives at a collaborative solution with stakeholders from the project area. A charrette can be a breakthrough event that helps creates a meaningful master plan or facility design. Properly executed, this technique can produce a master plan or facility design that is more useful, better understood, and more quickly produced than

---

[1] DoD Natural Resources Program, "DoD Bird Conservation Focus Area: Bird/Animal Aircraft Strike Hazard Bird Conservation on Military Lands," December 2016, file:///S:/310/99999-UFC%20Landscape%20Architecture/Docs/1-Working%20Files/6-Reference%20Documents/Resources/DOD/focusarea-fs_BASH_Dec2016.pdf

[2] DoDI 4165.14, "Real Property Inventory (RPI) and Forecasting," 17 January 2014, http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/416514p.pdf?ver=2017-11-14-112325-230.

[3] USDA, Natural Resources Conservation Service, "Plant Materials Technical Note No. 10: Understanding Seed Certification and Seed Labels," 10 July 2009, https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/lapmctn9030.pdf.

one formed by any other method."[4]

Complete streets: Complete streets "are designed and operated to enable safe access for all users, including pedestrians, bicyclists, motorists, and transit riders of all ages and abilities."[5]

Cultural landscape: "Cultural landscapes are geographical areas (including both cultural and natural resources and the wildlife or domestic animals therein), associated with a historic event, activity or person or exhibiting other cultural or aesthetic values. There are primarily four types of cultural landscape: designed landscapes, ethnographic landscapes, historic sites, and vernacular landscapes."[6]

Cultural resource (CR): Per DoDI 4715.16:

- Historic properties (any prehistoric or historic district, site, building, structure, or object as defined by part 800 of Reference (k) included in, or eligible for inclusion in, the National Register of Historic Places, whether such eligibility has been formally determined), including artifacts, records, and material remains related to such a property or resource.
- Cultural items as defined in Reference (m).
- American Indian, Eskimo, Aleut, or Native Hawaiian sacred sites as defined in Reference (l).
- Archaeological resources as defined in section 470 aa-mm of Reference (x).
- Archaeological artifact collections and associated records as defined in part 79 of Reference (k).[7]

Embodied energy: The total energy required to manufacture or produce a material, transport it to a project site, and install it.

Hardscape: Inorganic or inanimate landscape elements, primarily referring to pavements and other non-vegetative materials used for paths and gathering areas.

Integrated Cultural Resources Management Plan: "A plan that defines the process for the management of cultural resources on DoD Installations."[8]

---

[4] UFC 1-200-02, *High Performance and Sustainable Building Requirements, with Change 2*, 7 June 2018, https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-1-200-02.

[5] Smart Growth America – National Complete Streets Coalition, https://smartgrowthamerica.org/program/national-complete-streets-coalition/

[6] National Park Service, *The Secretary of the Interior's Standards for the Treatment of Historic Properties and Guidelines for the Treatment of Cultural Landscapes*, 12 July 1995, https://www.nps.gov/tps/standards/four-treatments/landscape-guidelines/terminology.htm.

[7] DoDI 4715.16, "Cultural Resources Management," 18 September 2008, http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/471516p.pdf?ver=2017-11-21-114100-670.

[8] DoDI 4715.16, "Cultural Resources Management," 18 September 2008, http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/471516p.pdf?ver=2017-11-21-114100-670.

Installation Design Guidance Documents (IDGD): Installation-level plans and guidelines including, but not limited to the Installation Master Plan (IMP), Installation Development Plan (IDP), Area Development Plan (ADP), Base Exterior Architectural Plan (BEAP), and Installation Planning Standards (IPS), Air Force's Installation Facilities Standards (IFS), Army's Installation Design Guides (IDG), and Navy's Installation Appearance Plans (IAP).

Landscape area: Pervious area with landscape improvements that is not covered by built improvements and impervious surfaces (including buildings, other structures, or paved surfaces such as including parking areas and walkways).

Large tree: Type 1 and 2 shade trees as classified by the *American Standard for Nursery Stock* (ANSI Z60.1).

Lawn: A managed grass space.

Native plant: A species that is endemic to a geographic or ecological region, or a cultivar of that species.

Landscape establishment period: A period lasting a minimum of 365 days from final acceptance of project, during which plant material is irrigated and observed for viability. The irrigation system, if used is maintained and repaired as needed. This period may be adjusted by the Reviewing Government Landscape Architect. Runs concurrently with *landscape warranty period*.

Landscape warranty period: A period lasting a minimum of 365 days from final acceptance of project, during which plant material must meet 95% survival rate and the irrigation system is in good working order. Runs concurrently with *landscape establishment period*.

Phytoremediation: the treatment of pollutants or waste (as in contaminated soil or groundwater) by the use of green plants that remove, degrade, or stabilize the undesirable substances (such as toxic metals).

Resiliency: The capacity to anticipate, prepare for, respond to, recover from, and adapt to hazards and the risks they pose, including severe weather events and the effects of climate change.

Site commissioning: "Site Commissioning is a systematic process of verifying that systems within the built environment, beyond a building's skin, perform in accordance with design intent and the property owner's operational needs."[9]

Site furnishings: Functional and aesthetic amenities that enhance a site for human comfort.

[9] General Services Administration, *Site Commissioning White Paper*, July 2017, https://www.gsa.gov/cdnstatic/2017-13-07_SiteCommissioning_AccSingle_WhitePaper.pdf.

Site improvements: All site modification that will result in permanent paving features or landforms. Does not refer to enclosed buildings or airfield pavements.

Small Tree: Type 3 small upright trees and Type 4 small spreading trees as classified by the *American Standard for Nursery Stock* (ANSI Z60.1).

Turf: The upper stratum of soil bound by grass and plant roots into a thick mat.

Viewshed: The natural environment that is visible from one or more viewing points

Xeriscaping: Xeriscaping is landscaping and gardening that reduces or eliminates the need for supplemental water from irrigation. This term was coined by Denver Water in 1981 and is associated with seven design principles elaborated on at utility's website: https://www.denverwater.org/residential/rebates-and-conservation-tips/remodel-your-yard/xeriscape-plans/xeriscape-principles.

APPENDIX C REFERENCES

GOVERNMENT

DEPARTMENT OF DEFENSE

General Services Administration/Department of Defense/National Aeronautics and Space Administration
Federal Acquisition Regulation (FAR), Issued Fiscal Year 2019

Office of Assistant Secretary of Defense – Energy, Installations, and Environment (ASD EI&E)
Memorandum–"Water Use for Landscape Architecture on Department of Defense Installations/Sites," 10 March 2017, https://www.acq.osd.mil/eie/Downloads/IE/Water%20Use%20for%20Landscape%20Architecture%203.10.17.pdf

Office of Under Secretary of Defense – Acquisition and Sustainment (USD A&S)

DoDI 1010.10, "Health Promotion and Disease Prevention", April 28, 2014 Incorporating Change 2, January 12, 2018, https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/101010p.pdf

DoDI 4150.07, "DoD Pest Management Training and Certification Program: The DoD Plan for Non-Federal Insecticide, Fungicide, and Rodenticide Act Pesticide Applicators," 23 May 2013, http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodm/415007m_vol2.pdf?ver=2017-12-08-113556-650

DoDI 4165.14, "Real Property Inventory (RPI) and Forecasting," 17 January 2014, http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/416514p.pdf?ver=2017-11-14-112325-230

DoDI 4710.02, "DoD Interactions with Federally-Recognized Tribes," 14 September 2006, http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/471002p.pdf

DoDI 4710.03, "Consultation Policy with Native Hawaiian Organizations," 25 October 2011, http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/471003p.pdf

DoDI 4715.03, "Natural Resources Conservation Program," 18 March 2011, http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/471503p.pdf

DoDI 4715.16, "Cultural Resources Management," 18 September 2008, http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/471516p.pdf?ver=2017-11-21-114100-670

Memorandum—"Department of Defense (DoD) Policy to Use Pollinator-Friendly Management Prescriptions," 5 September 2014, http://www.nmfwa.net/uploads/documents/Pollinator_Friendly_Management_-_signed_memo001.pdf

Unified Facilities Criteria (UFC)
http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

UFC 1-200-01, *DoD Building Code*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 3-120-01, *Design: Sign Standards*

UFC 3-201-01, *Civil Engineering*

UFC 3-210-10, *Low Impact Development*

UFC 3-301-01, *Structural Engineering*

UFC 3-420-01, *Plumbing Systems*

UFC 3-530-01, *Interior and Exterior Lighting Systems and Controls*

UFC 4-010-01, *DoD Minimum Anti-Terrorism Standard for Buildings*

UFC 4-010-06, Cybersecurity of Facility-related Control Systems

UFC 4-022-02, *Selection and Application of Vehicle Barriers*

UFC 4-022-03, *Security Fences and Gates*

UFC 4-740-14, *Design: Child Development Centers*

FC 4-740-14N, *Navy and Marine Corps Child Development Centers*

UFC 4-740-16, *Design: Military Recreation Centers*

UFC 4-750-02N, *Design: Outdoor Sports and Recreational Facilities*

UFC 4-750-07, *Recreational Aquatics Facilities*

U.S. Assistant Secretary for the Army – Installations, Energy, and Environment (ASA IE&E)

Memorandum–"Sustainable Design and Development Policy Update," 17 January 2017, https://www.wbdg.org/FFC/ARMYCOE/POLICY/Army_SDD_Policy_Update_2017.pdf

Memorandum– "Water Goal Attainment Responsibility Policy," 20 December 2012, https://www.usace.army.mil/Portals/2/docs/Sustainability/Hydrology_LID/Water_Goal_Attainment_Responsibility_Policy_for_Installations.pdf

OTHER DEPARTMENTS AND AGENCIES

Advisory Council on Historic Preservation
National Historic Preservation Act (NHPA) "Section 106 Assistance for Users," 31 January 2018, http://www.achp.gov/usersguide.html

Council on Environmental Quality
National Environmental Policy Act, https://ceq.doe.gov/index.html

General Services Administration (GSA)
Facilities Standards for the Public Buildings Service (PBS-P100), April 2017, https://www.wbdg.org/FFC/GSA/p100_2017.pdf

National Oceanic and Atmospheric Administration

"Shifts in Plant Hardiness Zones," *Climate Change Impacts in the United States: The Third National Climate Assessment*, U.S. Global Change Research Program, 6 May 2013, https://nca2014.globalchange.gov/report/appendices/climate-science-supplement/graphics/shifts-plant-hardiness-zones

National Park Service (NPS), U.S. Department of the Interior
National Register of Historic Places, https://www.nps.gov/nr/

The Secretary of the Interior's Standards for the Treatment of Historic Properties and Guidelines for the Treatment of Cultural Landscapes, 12 July 1995, https://www.nps.gov/tps/standards/four-treatments/landscape-guidelines/terminology.htm

U.S. Access Board (USAB)
ABA Standards, https://www.access-board.gov/guidelines-and-standards/buildings-and-sites/about-the-aba-standards/aba-standards

Guide on Play Areas, https://www.access-board.gov/guidelines-and-standards/recreation-facilities/guides/play-areas

U.S. Consumer Product Safety Commission (CPSC)
CPSC 325, Public Playground Safety Handbook, 29 December 2015, https://www.cpsc.gov/s3fs-public/325.pdf

U.S. Department of Agriculture (USDA)
NATIONAL INVASIVE SPECIES INFORMATION CENTER (NISIC), https://www.invasivespeciesinfo.gov/index.shtml

Plant Hardiness Zone Map, http://planthardiness.ars.usda.gov/PHZMWeb/

NON-GOVERNMENT

American Association of State and Highway Transportation Officials (AASHTO)
Guide for the Development of Bicycle Facilities,
https://bookstore.transportation.org/collection_detail.aspx?ID=116

AmericanHort
American Standard for Nursery Stock (ANSI Z60.1),
https://www.americanhort.org/page/standards **\1\/1/**

Denver Water
Xeriscape Principles, https://www.denverwater.org/residential/rebates-and-conservation-tips/remodel-your-yard/xeriscape-plans/xeriscape-principles

German Landscape Research, Development and Construction Society (FLL)
Green Roof Guidelines: Guidelines for the Planning, Construction and Maintenance of Green Roofs, https://shop.fll.de/de/auswahl-startseite/green-roof-guidelines-2018-download.html

International Dark-sky Association
Find Dark Sky Friendly Lighting, http://www.darksky.org/fsa/fsa-products/ **1**\\

International Green Construction Code (IgCC),
https://www.iccsafe.org/products-and-services/i-codes/2018-i-codes/igcc/ /**1**/

Illuminating Engineering Society (IES)
Standards, https://www.ies.org/standards/

Irrigation Association
Landscape Irrigation: Best Management Practices,
https://www.irrigation.org/IA/Advocacy/Standards-Best-Practices/Landscape-Irrigation-BMPs/IA/Advocacy/Landscape-Irrigation-BMPs.aspx?hkey=93b546ad-c87a-41b8-bf70-8c4fd2cff931

National Fire Protection Association (NFPA), NFPA 1144
Standard for Reducing Structure Ignition Hazards from Wildland Fire
https://catalog.nfpa.org/NFPA-1144-Standard-for-Reducing-Structure-Ignition-Hazards-from-Wildland-Fire-P1414.aspx

National Fire Protection Association (NFPA)
Safer from the Start: A Guide to Firewise-Friendly Developments, 2009,
http://www.firewise.net/wp-content/uploads/2012/05/Safer-From-the-Start.pdf

National Recreation and Park Association (NRPA)
Certified Playground Safety Inspector (CPSI) Certification,
https://www.nrpa.org/certification/CPSI/

Smart Growth America
National Complete Streets Coalition,
https://smartgrowthamerica.org/program/national-complete-streets-coalition/

UFC 3-210-10
28 August 2023

UNIFIED FACILITIES CRITERIA (UFC)

LOW IMPACT DEVELOPMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

LOW IMPACT DEVELOPMENT

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **\1** ... **/1/**)

Change No.	Date	Location

This UFC supersedes UFC 3-210-10, dated June 2015.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website https://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

PETE G. PEREZ, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. S. SILVER, P.E.
Acting Chief Engineer and Assistant
Commander, Design and Construction
Naval Facilities Engineering Systems Command

DAVID H. DENTINO, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW, SES
Deputy Assistant Secretary of Defense
(Construction)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 REISSUES AND CANCELS.

This UFC reissues and cancels UFC 3-210-10 Low Impact Development, with Change 3, 1 March 2020.

1-2 PURPOSE AND SCOPE.

This UFC provides technical criteria, technical requirements, and references for the planning and design of applicable Department of Defense (DoD) projects to comply with stormwater requirements under Section 438 of the Energy Independence and Security Act (EISA) enacted in December 2007 (hereafter referred to as EISA Section 438) and the Deputy Under Secretary of Defense DoD policy on the implementation of stormwater requirements under EISA Section 438.

1-3 APPLICABILITY.

This UFC applies to all service elements and contractors involved in the planning, design, and construction of all permanent DoD projects in the United States, United States Territories and Possessions of the United States that meet both of the following conditions:

- The project includes construction or expansion of one or more buildings as part of its primary scope. For example, primary facilities vice supporting facilities.
- The "footprint" is greater than 5,000 gross square feet (464.5 square meters). "Footprint" consists of all new impervious surfaces associated with the building(s), including both building area and pavement area of associated supporting facilities (such as parking and sidewalks). "Footprint" does not include existing building area to be renovated, existing pavement area to be resurfaced, or new pavement area other than supporting facilities associated with the building(s).

For projects in the United States, United States Territories, and Possessions of the United States that do not meet the applicability requirements above, Low Impact Development (LID) techniques apply to the extent practicable.

1-3.1 Overseas Locations.

All design and construction outside of the United States and United States territories is governed by international agreements, such as the Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA), and country-specific Final Environmental Governing Standards or DoDI 4715.05. DoDI 4715.05 is commonly referred to as the Overseas Environmental Baseline Guidance Document (OEBGD). The OEBGD applies when there are no international agreements in place. Therefore, in foreign countries this UFC will be used for DoD projects to the extent that it is allowed by and does not conflict with the applicable international agreements. For projects where the OEBGD is applicable, consider and apply LID techniques to the extent practicable.

1-4 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, *DoD Building Code*. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-5 CYBERSECURITY.

All facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-6 GLOSSARY.

APPENDIX B contains acronyms, abbreviations, and terms.

1-7 REFERENCES.

APPENDIX C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 TECHNICAL REQUIREMENTS

2-1 DESIGN OBJECTIVE.

2-1.1 Establishing Pre-Development Condition.

The overall design objective for each applicable project is to maintain pre-development hydrology and prevent any net increase in stormwater runoff. DoD defines "pre-development hydrology" as the pre-project hydrologic conditions of temperature, rate, volume, and duration of stormwater flow from the project site. The analysis of the pre-development hydrology must include site-specific factors (such as soil type, ground cover, and ground slope) and use modeling or other recognized tools to establish the design objective for the water volume to be managed from the project site. The Designer of Record (hereafter referred to as the designer) must document the existing features that comprise the existing development condition.

Manage the increase in runoff between pre- and post-development conditions on the project site, to the maximum extent technically feasible, through interception, infiltration, storage, or evapotranspiration processes. Other design requirements may need to be considered. Calculations must be performed by the designer indicating the difference between the post-development hydrology and pre-development hydrology for the design storm event. Calculations must demonstrate "No net increase" in stormwater runoff where technically feasible.

2-1.2 Design Storm Event.

The design storm is the 95th percentile rainfall event. It is based on daily measured precipitation depths accumulated over a 24-hour period. The design storm event is derived from rainfall data collected for a minimum of 10 years, but ideally should be based on 30 years of data, where 30 or more years of rainfall records are available. Tables A-8 and A-9 in APPENDIX A contain rainfall analyses for selected locations. Use the values in APPENDIX A or calculate the 95th percentile rainfall depth based on rainfall records. Rainfall records can be obtained from National Oceanic and Atmospheric Administration (NOAA) at https://www.ncdc.noaa.gov/cdo-web/. A general procedure for selecting rainfall stations and downloading historical rainfall records is outlined in APPENDIX A, Section A-4.7.

2-1.3 Maximum Extent Technically Feasible (METF).

Evaluate project site options to achieve the design objective to the maximum extent technically feasible. The "maximum extent technically feasible" criterion requires full employment of accepted and reasonable stormwater retention and reuse technologies subject to in-situ site conditions and applicable regulatory constraints (for example, site size, soil types, vegetation, demand for recycled water, existing structural limitations and state or local prohibitions on water collection).

2-1.4 Technical Infeasibility.

Cost alone should not be used as a constraint to justify technical infeasibility. Document all applicable technical constraints if the design objective is infeasible due to technical constraints. In most cases, the designer should be able to document more than one technical constraint to demonstrate technical infeasibility. If the project meets the design objective, technical constraints do not need to be documented. Examples of technical constraints are as follows:

- Retaining stormwater on-site would adversely impact receiving water flows
- Site has shallow bedrock, contaminated soils, high groundwater table, underground facilities, or utilities
- Soil infiltration capacity is limited
- Site is too small to infiltrate significant volume
- Non-potable water demand, including irrigation, toilets, and wash-water, is too small to warrant water harvesting and reuse systems
- Structural, plumbing, and other modifications to existing building to manage stormwater are infeasible
- State or local regulations restrict water harvesting
- State or local regulations restrict use of green infrastructure or LID.

2-2 DOCUMENTATION.

Provide the following documentation at the pre-final design stage:

- Pre-development conditions, such as soil conditions, groundwater table of the project site, description of typical surrounding natural lands, and a brief history of existing development, including impervious area, lawns, meadows, forested areas, wetlands, and water bodies.
- Calculations for pre-development and post-development runoff volumes and rates using the 95th percentile rainfall event to identify the volume of stormwater requiring management and the extent to which the design objective was met.
- Technical constraints, if applicable.
- Stormwater management practices used to meet the design objective and whether they were located on-site, off-site or both.
- LID cost estimate from DD Form 1391.

Update pre-final data at the final design stage, as applicable, and perform post-construction analysis at the end of construction. Maintain this documentation as part of the project historical file.

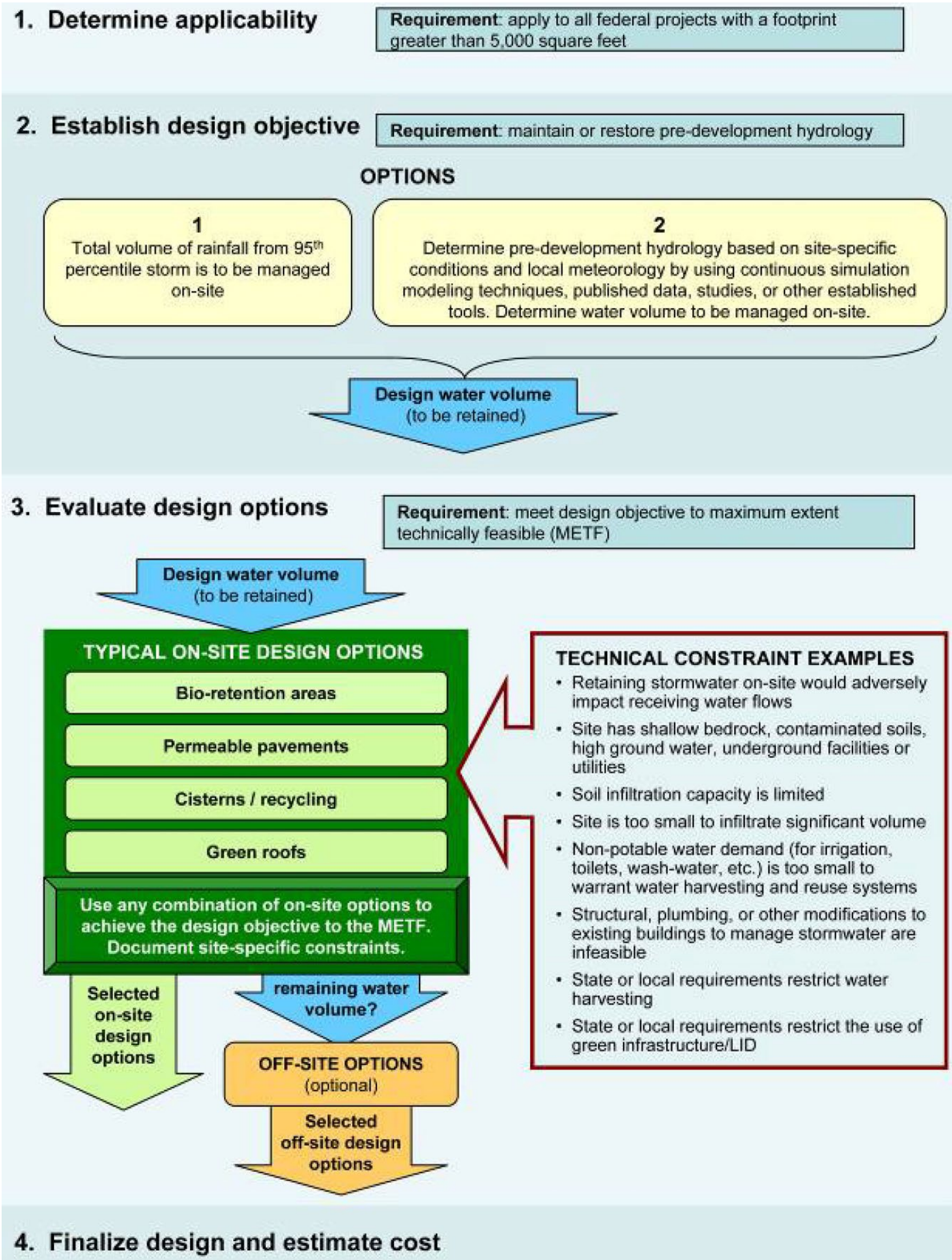
2-3 POST-CONSTRUCTION ANALYSIS.

The designer is required to validate LID features have been constructed according to plans and specifications. Validation may be accomplished by conducting a post-construction site visit to assess the as-built LID features or by having the construction contractor complete a post construction analysis report. If LID features were not constructed according to plans and specifications indicate the technical constraints that precluded meeting the design objective.

2-3.1 Documentation.

- Post-construction validation indicating that the LID features have been constructed according to plans and specifications.

Figure 2-1 Implementation of EISA Section 438



CHAPTER 3 PLANNING AND DESIGN

3-1 HYDROLOGIC ANALYSIS.

Determine pre-development hydrology based on site-specific conditions and local meteorology by using the 95th percentile storm. The designer must identify the pre-development condition of the site and quantify the post-development runoff volume and peak flow discharges that are equivalent to pre-development conditions.

When performing hydrologic analysis, the designer is required to understand the hydrologic methodology, the limitations of the methodology, and the site-specific hydrologic conditions. The results of the hydrologic analysis are only as good as the assumptions and site-specific data used by the designer. Inappropriate assumptions or site data can affect the reliability of the results. The designer must be able to validate the design assumptions, site data and results to demonstrate that the design objective has been met.

3-1.1 Approved Methodologies.

To control the stormwater volume in accordance with DoD policy, the use of TR-55, Chapter 2: "Estimating Runoff", Curve Number Methodology is approved and recommended. Continuous simulation modeling may be used to complete the hydrologic analysis. Other approved methodologies are WinTR-20 and the Storm Water Management Model (SWMM) computer program developed by the Environmental Protection Agency (EPA). Computer programs that use the approved methodology are also approved.

3-1.2 Other Methodologies.

If other hydrologic methodologies are used, they must be documented and submitted to the Government Civil Engineer for approval. Models developed for watershed nonpoint source analysis like EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) should not be used for this type of hydrologic analysis.

3-2 TR-55 METHODOLOGY.

TR-55 methodology is likely the most efficient and practical for designers to comply with EISA Section 438 requirements. Therefore, details of this methodology have been summarized in the following paragraphs.

3-2.1 Storm Event.

During a storm event a portion of the precipitation is caught in the form of interception, depression storage, evaporation, transpiration, and infiltration. The process of infiltration is responsible for the largest portion of rainfall losses in pervious areas. These losses are collectively referred to as *abstractions*. Only that part of the rainfall in excess of abstractions is defined as stormwater runoff and reaches receiving water bodies, such as streams and lakes.

The Soil Conservation Service (SCS 1986), now the Natural Resources Conservation Service (NRCS), presented an empirical method of determining initial abstraction based on the runoff curve number (CN) of the site and is given by:

Equation 3-1. Initial Abstraction (inches)

$$I_a = 0.2 * S$$

Where:
I_a = Initial abstraction (inches)
S = potential maximum retention after runoff begins (inches)

$$S = \frac{1000}{CN} - 10$$

The initial abstraction defined in Equation 3-1 also represents the rainfall at which the direct runoff begins. Any rainfall over and above the initial abstraction results in direct surface runoff.

3-2.2 Runoff Depth for Calculating LID Volume.

Calculate the difference between pre- and post-development runoff depths, from which the volume to be retained on-site can be determined (for TR-55 methodology see Equation 3-2 below).

Equation 3-2. Total Depth of Increase in Runoff (inches)

$$D = \frac{(P - 0.2 * S')^2}{(P + 0.8 * S')} - \frac{(P - 0.2 * S)^2}{(P + 0.8 * S)}$$

Where:
D = runoff depth for calculating LID volume (inches)
P = design storm rainfall depth (inches)
S = potential maximum retention after runoff begins (inches) during the pre - development conditions
S' = potential maximum retention after runoff begins (inches) during the post- development conditions

Note: Equation. 3-2 is valid if P > 0.2*S. Otherwise, the term calculating the runoff depth is:

$$\frac{(P - 0.2 * S)^2}{(P + 0.8 * S)} = 0$$

When calculating pre- and post-development runoff volumes, consider water features present within the project footprint to be impervious.

3-2.3 LID Storage Volume.

Equation 3-3. LID Storage Volume

$$V_{LID} = D * A$$

Where:
V_{LID} = LID Storage Volume (cubic units)
D = total depth of increase in stormwater runoff (inches)
A = drainage area or the area of the parcel being developed (square units)

The minimum required LID Storage Volume is calculated using Equation 3-3 to comply with the design objective, and must be followed for the design storm depth (using Equation 3-2).

Additional details on hydrologic analysis are located in APPENDIX A, Section A-5, LID Design.

3-2.4 Time of Concentration for Pre- and Post-Development Conditions.

To mimic pre-project hydrologic patterns, the site designer needs to provide features that limit the rate at which runoff leaves the site. See A-5.2.2 for guidance on T_c. The post-development T_c should be as close as is technically feasible to the pre-development T_c.

3-3 LID IMPLEMENTATION.

LID implementation is achieved by selecting a set of LID features that can closely maintain or replicate hydrological behavior of the pre-project site for the design storm event. Most LID features are distributed small-scale controls that increase rainfall interception and lengthen the time of concentration (T_c). Some LID features provide greater benefits (that is, groundwater recharge and increased T_c) than others. Give priority to those LID features that are proven in their regional area, provide the most benefits in relation to replicating pre-project hydrology and have the lowest lifecycle costs. LID features typically include natural features with low maintenance costs. Selecting appropriate LID features with the lowest long-term maintenance cost will extend the useful life of the LID features. Highly developed sites, sites with a high ratio of impervious to pervious area (that is, industrial sites) may require more costly, higher maintenance LID features in order to meet the design objective within the constraint of maximum extent technically feasible (see Section 2-1.3). Provide a minimum 10 ft (3.05

m) offset from the LID feature to the face of the nearest building. Comply with the offset and clear zone requirements in UFC 4-010-01 *DoD Minimum Antiterrorism Standards for Buildings* when placing LID features near buildings.

Verify with the Installation the capability to maintain LID features prior to selecting for use on-site. LID features that cannot be maintained by the Installation with current capability and contract capacity may not be used.

3-3.1 LID Features.

Implementing LID features help replicate the pre-development hydrology and can generally be grouped into two categories.

3-3.1.1 Engineered Natural Treatments.

Engineered natural treatments provide depression storage, infiltration, and evapotranspiration. These design options are typically the least costly and easiest to accomplish if site availability, soils and groundwater table are conducive. Site features such as bioretention, vegetated swales, rain gardens, vegetated filter strips, downspout disconnection, reduced impervious area, tree preservation or re-vegetation using native plants, soil amendments, and open space fall under this general category and are advisable due to lower lifecycle costs.

3-3.1.2 Engineered Subsurface Treatments.

Engineered subsurface treatment provides infiltration and prevents concentrated flow. Site features may include permeable pavements and infiltration trenches. Engineered subsurface treatment may be the next most lifecycle cost effective method, as compared to engineered natural treatment, in meeting the design objective. These design options may be limited by wheel loading, traffic, ability to provide maintenance and foreign object debris danger. Avoid locating infiltration trenches and similar features under pavements wherever possible. Refer to UFC 3-201-01 for additional criteria on permeable pavement.

3-3.2 Non-Potable Rainwater Harvesting.

Rainwater harvesting systems store stormwater for non-potable uses, such as irrigation or toilet flushing. Site features may include LID features like cisterns and rain barrels. This design option may be used if adequate demands for reuse water exist. The reuse of harvested water (through rain barrels and cisterns, also called alternative sources of water) for purposes other than irrigation must comply with UFC 3-420-01 *Plumbing Systems*. Certain types of facilities, such as a warehouse, may not have adequate water demand to make reuse lifecycle cost effective. Consider freeze protection for winter months.

3-3.3 Green (Vegetative) Roofs.

Vegetative roofs increase both the T_c and seasonal evapotranspiration while reducing building energy usage and noise levels. They do not assist in infiltrating water into the ground at the source and have high initial and annual maintenance costs. Vegetative roofs are a design option where other LID features do not meet the design objective. Vegetative roofs should be assessed with consideration of other benefits such as lower energy costs and noise reduction.

3-4 OFF-SITE OPTIONS.

If the design objectives cannot be met within the project footprint, off-site options within the same watershed may be used. Off-site options are generally less desirable than on-site options, as many of the benefits of managing the stormwater close to the source may be lost. The designer must confirm site approval for off-site options with the Government Project Manager.

3-5 CLEAN WATER ACT PERMITS.

Comply with applicable state and local requirements for stormwater management in addition to UFC requirements. Obtain state stormwater construction permits required under the Clean Water Act using the state's approved methodology. Coordination of the design is the responsibility of the designer to ensure that the criteria are met from both the regulatory and LID perspectives. Design the stormwater management (SWM) features to control all regulated storm events, as stipulated by state and local regulations to handle the peak rate and volume of discharge for flood control purposes.

EISA Section 438 requirements are independent of stormwater requirements under the Clean Water Act and should not be included in permits for stormwater unless a state (or EPA) has promulgated regulations for certain EISA Section 438 requirements (that is, temperature or heat criteria) that are applicable to all regulated entities under its Clean Water Act authority. Compliance with applicable regulatory stormwater management requirements may satisfy all or part of the EISA Section 438 requirement for the project.

3-6 OTHER DESIGN REQUIREMENTS.

Where state and local standards for design of LID features to satisfy EISA Section 438 requirements do not exist, refer to *Low-Impact Development Design Strategies, An Integrated Design Approach* and *Low-Impact Development Hydrologic Analysis* prepared by Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division (PGDER). Follow applicable industry practice standards and local building codes (for example, earthquake zones).

3-6.1 Sustainable Design.

Incorporate sustainable development concepts to reduce energy consumption, O&M costs, reduce waste, and reduce pollution. Refer to UFC 1-200-02, for additional criteria.

3-6.2 Architectural Compatibility.

Comply with DoD, and Activity requirements and provide LID features compatible with surrounding base architecture.

3-6.3 Base Design and Development Documents.

Incorporate the intent of Installation Master Planning into designs. Follow published design guidelines that contain criteria relative to achieving, maintaining, and emphasizing a positive exterior visual environment applicable to military installations. Consult with the Government Project Manager for direction in case of conflicts. Direction to deviate from these documents should be given in writing.

3-6.4 Antiterrorism.

Comply with UFC 4-010-01 when designing LID features.

3-6.5 Airfield Criteria.

Where the criteria provided in this UFC conflicts with UFC 3-260-01, UFC 3-260-01 criteria governs.

APPENDIX A BEST PRACTICES

This Best Practices appendix provides additional detail and analysis supporting the criteria and builds process action steps in the Planning, Design, and Post-Construction stages of project development. In addition, the appendix gives a basic level of understanding for the rationale behind the UFC criteria hydrology and methods of calculation. The UFC criteria are predicated on standard practices in the field of stormwater management. The design storm event is defined by the 95th percentile storm. By using all storm events that occur within 24 hours for several years, the designer can statistically estimate the rainfall depth that is less than or equal to 95 percent of all storms, see Section 2-1.2.

By design, LID methods do not control runoff in excess of the runoff generated from the 95th percentile storm. Excess runoff from larger storm events, such as the 2-, or 10-year storm, is intended to bypass into conventional stormwater management facilities. LID practices help meet regulatory runoff requirements by reducing the volume of water leaving the site. The runoff calculation method is adopted from the NRCS, formerly the Soil Conservation Service (SCS) TR-55 method. A site designer can easily hand calculate the necessary information for small sites using formulas given in the criteria. For larger sites, computer calculations and simulation modeling are encouraged.

A-1 BACKGROUND.

In December 2007, Congress enacted EISA which established into law new stormwater design requirements for federal agencies to develop and redevelop applicable facilities in a manner that maintains or restores stormwater runoff to the METF with regard to the temperature, rate, volume, and duration of flow. In December of 2009, EPA issued EPA 841-B-09-001. EPA 841-B-09-001 provides technical guidance to assist federal agencies in implementing EISA Section 438 and was intended solely as guidance.

Deputy Under Secretary of Defense (Installations and Environment) memorandum of 19 January 2010 directs DoD components to implement EISA Section 438 using LID techniques in accordance with the methodology illustrated in Figure 2-1 and further described below. This policy directs DoD to implement EISA Section 438 EPA technical guidance in accordance with DoD Policy on Implementing EISA Section 438. Where DoD policy or the criteria provided in this UFC conflicts with EPA Technical Guidance, the DoD policy and UFC govern. Individual Services may have more stringent implementation and applicability requirements relating to LID.

A-1.1 What is LID?

The use of LID was pioneered in the 1990s by Prince George's County, Maryland Department of Environmental Resources (PGDER) under a grant from the EPA. Since 2004, LID techniques for controlling stormwater runoff have been considered for many projects based on site requirements and constraints. LID strategies provide a decentralized hydrologic source control for stormwater. LID implementation is based on selecting LID features that are distributed small-scale controls that can closely maintain or replicate hydrological behavior of the pre-project site for a defined design storm event. These small-scale practices are sometimes referred to as integrated management practices (IMPs).

LID differs from conventional SWM principles in that it does not store and release stormwater. LID uses infiltration, evaporation, plant transpiration, and reuse of rainwater to keep the additional stormwater generated due to the developed condition contained on-site. Increased impervious area changes the natural flow of water and decreases the quantity of water that infiltrates into the ground. Increased runoff increases sediment transport and decreases water quality. LID seeks to restore pre-development infiltration rates at the project site through one or more LID IMPs.

A-1.2 Types of LID Features.

The application of LID to an infrastructure development program is practical and achievable, but it will require a change of thinking on the part of the site designer. The engineered natural and subsurface LID treatments described in Section 3-3.1 fall into five types as follows:

1. Site Utilization: Begin the site process by reducing the impervious footprint if possible. Narrower streets, vertical construction, parking structures, and the removal of curb, gutter, and paved swales are a few of the ways to reduce impervious surfaces. Choose rougher surfaces, disconnect impervious areas, and increase the time of concentration (T_c). Retain as much of the natural tree cover as practical and place the impervious structures in areas of the poorest soil types where possible.
2. Filtration: Include filtration practices in the site design. Vegetative buffers, filter strips, vegetative swales, check dams, sediment traps, and overland flow will provide natural water quality treatment and increase T_c. By providing and maintaining natural buffers adjacent to water bodies, and directing stormwater to vegetated areas, stormwater infiltration is maximized thereby reducing pollutant discharges.
3. Interception and Infiltration: The infiltration techniques of LID are the backbone of the runoff volume reduction. Depression storage, bio-infiltration, pervious pavements, open pavers, rain gardens, infiltration trenches, and tree boxes are gaining wide acceptance as tools in the SWM toolbox. Interception can also play a major role in reducing runoff volumes. Interception techniques include deep mulch beds, tree cover, and soil amendments.
4. Retention of Stormwater Volumes: Retention can play an important part in successful LID implementation. Retention seeks to hold runoff from localized impervious surfaces for subsequent treatment after the rainfall event. Rain barrels, cisterns, and parking lot storage that slowly infiltrates into the ground are examples of retention techniques.
5. Structural Solutions: Structural solutions represent the last line of defense in LID features. Structural solutions will increase the facility construction cost and must be balanced with mission requirements. In urban and

industrial areas, sensitive environments, or known contaminated sites, structural solutions are often the only feasible solution. These techniques are specific solutions engineered for the particular facility and can include green roofs, rainwater reuse systems, parking structures, and irrigation storage systems.

A-2 CONSTRUCTION PERMIT PROCESS.

Conventional SWM is a patterned response to maximize the efficiency of site landscaping and site design to achieve a reduction in pollutant loading of rainfall that ends up as runoff due to human development. The EPA's CWA defined an appropriate level of SWM to help to keep our rivers, lakes, and shorelines clean. The CWA established the base guidelines for SWM, but for the most part turned the execution of those guidelines over to the local, state, or municipal regulatory agencies. The states then promulgated additional or clarifying requirements to a minimum level as the EPA requirements to meet the needs of the local geographic conditions. For example, SWM techniques suitable for Florida are not necessarily appropriate to the arid Southwest. Almost all projects will require local, or state construction permit in order to begin work. As such, the LID requirements must be complementary to state and local requirements for SWM. Without the regulatory acceptance and approval of the SWM plan, a project cannot be constructed.

The site designer is encouraged to contact the Government Civil Engineer, as well as state and local regulatory officials to coordinate LID requirements with applicable stormwater programs. Table A-1 has useful links on stormwater topics which includes a link to NPDES state program statuses as granted by EPA. Additional information may be found on the following link to the WBDG LID Resource Page: https://www.wbdg.org/resources/low-impact-development-technologies

Table A-1 U.S. EPA Websites Related to Stormwater

U.S. Environmental Protection Agency
LID Information
Urban Runoff: Low Impact Development (LID) https://www.epa.gov/nps/urban-runoff-low-impact-development
Managing Wet Weather with Green Infrastructure https://www.epa.gov/green-infrastructure
Regulatory Information
NPDES Stormwater Program https://www.epa.gov/npdes/npdes-stormwater-program
Authorization Status for EPA's Stormwater Construction and Industrial Programs https://www.epa.gov/npdes/authorization-status-epas-construction-and-industrial-stormwater-programs
State Program Status https://www.epa.gov/npdes/npdes-state-program-authority

A-3 INITIAL LID PLANNING COMPONENTS.

Successful implementation of LID begins during the planning process. During the planning phase, the exact configuration of LID features and the ways in which LID will shape the site design is not expected to be determined. This section provides the first steps to build upon in considering LID in the final project.

The initial planning phase begins with identifying possible LID features for a given project. Potential features to meet the project requirements will depend on considerations such as the required storage volume, existing infrastructure, and feasibility based on site conditions. Non-structural techniques should also be considered during the initial planning phase. Steps 1 through 6 below will help identify LID features which may satisfy the design requirements for a given project. In the preliminary planning phase, several alternatives may be identified which can then be narrowed down through cost analyses, or additional planning stages involving more detailed information about the site conditions, existing infrastructure, and project requirements.

A-3.1 Organizing the Planning Process and Timeline.

Step 1. Identify the LID objectives and legal requirements for the project (for example, stormwater permits, state erosion control and flood requirements, EISA

Section 438). Estimate runoff volume, peak runoff rate, duration, frequency, and water quality.

Step 2. Make assumptions on existing stormwater infrastructure in terms of how well it functions with respect to each of these aspects.

Step 3. Evaluate the goals and feasibility for control of runoff volume, duration, and water quality, as well as on-site use of stormwater (for example, irrigation, flushing toilets).

Step 4. Prioritize and rank basic objectives.

Step 5. Identify applicable local regulations or codes.

Step 6. Determine typical LID features required to meet objectives as best as possible (that is, infiltration, filtration, discharge frequency, volume of discharges, and groundwater recharge) taking into consideration available space, underground utilities, soil infiltration characteristics, slope, drainage patterns, groundwater table protected areas, setbacks, easements, topographic features, and other site features that should be protected such as floodplains, steep slopes, and wetlands.

Non-structural site planning techniques that may be considered:

- Minimizing total site impervious area.
- Reducing on-street parking.
- Using permeable pavement (pavers, concrete, or asphalt).
- Directing flows from paved areas to stabilized vegetated areas.
- Increasing overland sheet flow.
- Using open swale systems.
- Minimizing ground disturbance.
- Maintaining existing topography, where feasible.
- Locating new impervious areas where soils have lower hydrologic functions, such as clayey or disturbed soils.

For a more comprehensive list of non-structural site planning techniques refer to *Low-Impact Development Design Strategies, An Integrated Design Approach* from PGDER.

A-3.2 Cost Analysis.

One of the most difficult challenges is to properly allocate resources for projects so that they are successful and fulfill the mission as programmed. LID requirements can add a new level of complexity to the project that must be addressed during planning. While it may be too early in the process to determine the configuration of LID features, a preliminary analysis is needed to determine the level of effort required to implement LID. (LID Design is discussed in APPENDIX A, Section A-5).

The three items that should be addressed for LID are:

1. Implementation cost (may be less than traditional)
2. Operation & Maintenance costs (lifecycle)
3. Time impacts to design and permitting process

Information on the project mission should be gathered including geographical location, site requirements, available sites, programmed space requirements related to increased impervious area, and the ability of the Installation to maintain the LID feature. These set points will also help to determine the proper resource allocations to apply for the implementation of the LID site. LID features may be used in conjunction with conventional SWM will create a treatment train to hold, infiltrate, and filter the stormwater runoff. The LID site will contain less channelization of stormwater, less impervious pavement, more trees, more open ditches, less curb and gutter, and more planting buffers. Many parameters must be weighed during the LID design process. Design must match the particular regional conditions.

A-3.2.1 Cost Considerations.

Many of the following site conditions affect the design of LID features. Regional differences in weather patterns, soil types, groundwater conditions, existing development status, and current stormwater patterns will greatly influence the actual design and layout of the LID site and the choice of the LID features. However, one of the most important parameters will be the ratio of increased impervious surface area to the available land area or change in land cover.

Optimal LID implementation on a suitable site may result in a reduction in project cost. Classic LID design should reduce the amount of disturbed land, reduce impervious surface area, eliminate curb and gutter, reduce the size of pipes and holding ponds and increase the area planted in low maintenance tree cover. Building a large facility on a small site will increase the cost of implementing LID because the small site may require the selection of LID features that are structural in nature and are more expensive to build and maintain. On the other hand, a small building on the large site may use more natural LID features that are less costly and more easily maintained.

A-3.3 EPA LID Guidance.

The following EPA manuals may be used as best practice resources: “Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices” and “Low Impact Development (LID) A Literature Review”. These manuals were based on “Low-Impact Development Design Strategies; An Integrated Design Approach” and are geared toward general site development. Sites on military bases may have additional constraints that will influence which LID features may be used.

A-4 STORMWATER MANAGEMENT.

Man-made land development increases impervious surfaces. Buildings, roads, sidewalks, and parking lots quickly shed rainwater and increase the percentage of rainfall that ends up as runoff. The resulting increase in runoff volume and the peak flows create negative consequences such as stream degradation and flooding risk. The principal objective of LID is to retain this increase in runoff on-site.

LID builds on the conventional SWM philosophies and carries them a step further. LID processes begin at the point where the rain falls. Consideration for incorporating LID concepts, tools, and approaches requires assessment of the following at a minimum:

- Will the concept closely mimic the hydrology of pre-development condition?
- Will the concept mitigate adverse effects from increased stormwater runoff from the project?
- Can the drainage conveyance structures be optimized and reduce the overall cost of the project?
- What might be the hurdles for public acceptance? If required for the project to move forward, can these be reasonably achieved?

A-4.1 Hydrologic Cycle.

Dr. David Maidment in his *Handbook of Hydrology* states:

> "The hydrologic cycle is the most fundamental principle of hydrology. Water evaporates from the oceans and the land surface, is carried over earth in atmospheric circulation as water vapor, precipitates again as rain or snow, is intercepted by trees and vegetation, provides runoff on the land surface, infiltrates into soils, recharges groundwater, discharges into streams, and ultimately, flows out into the oceans from which it will eventually evaporate once again. This immense water engine, fueled by solar energy, driven by gravity, proceeds endlessly in the presence or absence of human activity."

A-4.2 Conventional Stormwater Management vs LID.

Conventional SWM facilities are primarily designed to temporarily store runoff, control flooding and downstream impacts due to increased runoff. These SWM facilities also provide water quality benefits. Whereas decentralized LID features include infiltration, increasing the length and time of flow over pervious areas, and disconnecting impervious areas that drain to stormwater collection systems. This helps to retain the increase in runoff from new development on-site.

Table A-2 contrasts conventional SWM methods that use "end-of-pipe" treatment and LID techniques that may reduce land requirements associated with conventional treatment. LID may reduce the overall costs of a project and reap benefits in protecting the environment and natural habitats.

Table A-2 Summary of Concepts of SWM and LID Techniques

Concepts of SWM	Concepts of LID Techniques
End-of-pipe stormwater treatment.	Stormwater is treated at or very close to the source.
Centralized collection system.	Decentralized system.
Reroute stormwater away from the site quickly and efficiently.	Mimics the pre-development hydrologic condition. The goal of LID is to retain the same amount of rainfall within the development site as that was retained on the site prior to the project.
Many of the stormwater management facilities are designed to control or attenuate peak runoff.	LID techniques reduce the size of stormwater management facilities.
SWM facilities are designed to detain the first-flush (the first ½ inch (13 mm) of runoff) from impervious areas of development.	LID techniques infiltrate stormwater on-site.

Table A-3 summarizes how conventional SWM, and LID technology alter the hydrologic regime for on-site and off-site conditions.

Table A-3 Comparison of Conventional SWM and LID Technologies

Hydrologic Parameter	Conventional SWM	LID
	On-Site	
Impervious Cover	Encouraged to achieve effective drainage	Minimized to increase infiltration
Vegetation or Natural Cover	Reduced to provide or improve centralized drainage system	Maximized to maintain pre-development hydrology
Time of concentration (T_c)	Shortened, reduced as a by-product of drainage efficiency	Maintained or maximized to approximate pre-development conditions
Runoff Volume	Large increases in runoff volume not controlled	Controlled to pre-development conditions
Peak Discharge	Controlled to pre-development conditions for the design storm event (i.e., the 2-year, 10-year, or 25-year storms)	Controlled to pre-development conditions for the 95th percentile storm event
Runoff Frequency	Greatly increased, especially for small, frequent storms	Reduced or minimized
Runoff Duration	Increased for all storms because volume is not controlled	Controlled to pre-development conditions
Rainfall Abstractions (interception, infiltration, depression storage)	Large reduction in all elements	Maintained to pre-development conditions
Groundwater Recharge	Reduction in recharge	Maintained to pre-development conditions
	Off-Site	
Water Quality	Reduction in pollutant loadings but limited control of stormwater volume leaving site	Improved pollutant loading reductions, full volume control for the 95th percentile storm event
Receiving Streams	Severe impacts documented – channel erosion and degradation, sediment deposition, reduced base flow, and habitat suitability decreased, or eliminated	Stream ecology maintained to pre-development conditions for the 95th percentile storm event
Downstream Flooding	Peak discharge control reduces flooding immediately below control structure, but can increase flooding downstream through cumulative impacts and super positioning of hydrographs	Controlled to pre-development conditions for the 95th percentile storm event
Source: Low-Impact Development Design Strategies, prepared by Prince George's County, Maryland.		

A-4.3 Low Impact Design Elements for Stormwater Management.

The LID concept encourages innovation and creativity in management of site planning impacts. As mentioned in Section 3-3, the implementation of LID techniques must be carefully evaluated for opportunities and constraints on a case-by-case basis. Many of the techniques are site-specific. Table A-4 summarizes the specific use of LID techniques, requirement, and applicability. Table A-5 summarizes hydrologic functions of LID practices.

Table A-4 Summary of LID Techniques, Constraints, Requirements and Applicability

Maintenance	Max. Depth	Proximity to Building Foundations	Water Table or Bedrock	Slopes	Soils	Space Required	
Low requirement, property owner can include in normal site landscape maintenance	2- to 4-ft (600 to 1200 mm) depth depending on soil type	Minimum distance of 10 ft (3 m) down gradient from buildings and foundations recommended	2- to 4-ft (600 to 1200 mm) clearance above water table or bedrock recommended	Usually not a limitation, but a design consideration.	Permeable soils with infiltration rates > 0.27 inches/hr (7 mm/hr) are recommended. Soil limitations can be overcome with use of underdrains.	Minimum surface area range: 50 to 200 ft^2 (4.6 to 18.6 m^2). Minimum length to width ratio 2:1	**Bioretention**
Low requirement	6- to 10-ft (1.8 to 3 m) depth depending on soil type	Minimum distance of 10 ft down gradient from buildings and foundations recommended	2- to 4-ft (600 to 1200 mm) clearance above water table or bedrock recommended	Usually not a limitation, but a design consideration. Must locate down gradient of building foundations.	Permeable soils with infiltration rates > 0.27 inches/hr (7 mm/hr) are recommended.	Minimum surface area range: 8 to 20 ft^2 (0.7 to 1.9 m^2). Minimum length to width ratio 2:1	**Dry Well**
Low requirement, routine landscape maintenance	Not applicable	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Generally, not a constraint.	Usually not a limitation, but a design consideration.	Permeable soils perform better, but soil not a limitation.	Minimum length of 15 to 20 ft (4.6 to 6.1 m^2)	**Filter Buffer Strip**
Low requirement, routine landscape maintenance	Not applicable	Minimum distance of 10 ft down gradient from buildings and foundations recommended	Generally, not a constraint.	Swale side slopes: 3:1 or flatter. Longitudinal slope: 1.0% minimum; maximum based on permissible velocities.	Permeable soils provide better hydrologic performance, but soils not a limitation. Selection of type of swale, grassed, infiltration or wet is influenced by soils.	Bottom width: minimum 2 ft (600 mm), maximum 6 ft (1800 mm)	**Swales: Grass, Infiltration, Wet**
Low requirement	Not applicable	Not a factor	Generally, not a constraint.	Usually not a limitation, but a design consideration.	Not a factor	Not a factor	**Rain Barrels**
				Not a factor	Not a factor	Not a factor	**Cistern**
Moderate to high	6- to 10-ft (1.8 to 3 m) depth depending on soil type	Minimum distance of 10 ft down gradient from buildings and foundations recommended	2- to 4-ft (600 to 1200 mm) clearance required	Usually not a limitation, but a design consideration. Must locate down gradient of building foundations.	Permeable soils with infiltration rates > 0.52 inches/hr (13 mm/hr) are recommended.	Minimum surface area range: 8 to 20 ft^2 (0.7 to 1.9 m^2). Minimum length to width ratio 2:1	**Infiltration Trench**

Source: Low-Impact Development Design Strategies, prepared by Prince George's County, Maryland

Table A-5 Summary of Hydrologic Functions of LID Practices

Hydrologic Functions	Bioretention	Dry Well	Filter or Buffer Strip	Swales: Grass, Infiltration, Wet Wells	Rain Barrels	Cistern	Infiltration Trench
Interception	High	None	High	Moderate	None	None	None
Depression Storage	High	None	High	High	None	None	Moderate
Infiltration	High	High	Moderate	Moderate	None	None	High
Ground Water Recharge	High	High	Moderate	Moderate	None	None	High
Runoff Volume	High	High	Moderate	Moderate	Low	Moderate	High
Peak Discharge	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate
Runoff Frequency	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Water Quality	High	High	High	High	Low	Low	High
Base Flow	Moderate	High	High	Moderate	Moderate	None	Low
Stream Quality	High	High	High	Moderate	None	Low	High

Source: Low-Impact Development Design Strategies, prepared by Prince George's County, Maryland.

A-4.4 Water Quality and Pollution Prevention.

LID features may address additional regulatory requirements or other resource protection goals. Similarly, in meeting the regulatory requirements, BMPs can be designed to act as effective, practicable means of minimizing the impacts of development associated with water quality and quantity control.

Because of the very nature of decentralized hydrologic source control, the nonpoint source pollution is greatly reduced, thereby, increasing the water quality of the receiving water bodies.

A-4.5 Design Inputs.

If possible, the following design inputs should be obtained for successful implementation of LID techniques into a site development project:

a. Detailed land cover and land-use information

b. Topographic contours, preferably at an interval that allows the flow paths to be distinguished (Generally 1 ft (.25 m) interval contours minimum, supplemented by spot elevations).

c. Soil borings; minimum of three borings, 15 ft (4.6 m) deep. These borings should reveal the nature and condition of the shallow subsurface soils at this location, as well as defining the groundwater table, usability of on-site material for select fill, and through compositional analysis should determine both vertical and horizontal hydraulic conductivities.

d. Existing site drainage outfall conditions and characteristics including water level elevation and water quality

e. Watershed reports and master plans

f. Flooding issues, past or present

g. Installation Appearance Guide

A-4.6 Precipitation Data.

The intensity-duration-frequency curves for the United States were recently revised and published by the NOAA and are called Atlas -14 curves. These curves are found on NOAA's Atlas 14 Precipitation Frequency Data Server at https://toolkit.climate.gov/dashboard-noaa-atlas-14-precipitation-frequency-data-server. These curves should be used when determining the precipitation depth and intensity for required duration and frequency.

Long-term rainfall records for regional weather stations can be obtained from many sources, including the NOAA's Climate Data Online webpage, at https://www.ncdc.noaa.gov/cdo-web/. Historical rainfall data are routinely published by many other agencies including the National Water and Climate Center, the United States Geological Survey, the Agriculture Research Service, etc., (NRCS NEH-4, 2019). Tables A-8 and A-9 provide a summary of rainfall analyses for 50 selected rainfall stations located in the continental United States, and 12 stations located overseas, respectively. Precipitation stations listed in Table A-8 and Table A-9 were selected based on proximity to those DoD installations anticipating major construction activity. The stations listed in Table A-8 and Table A-9 are from two types of station datasets found on the Climate Data Online webpage.

A-4.7 Types of Rainfall Datasets.

The first dataset type is daily summary data from the Global Historical Climate Network (GHCN). GHCN stations have an 11-character alpha-numeric station identification number. The GHCN observation data on NOAA's website incorporates measurement data from approximately 30 data sources from over 90,000 land-based stations worldwide including observation data from the World Meteorological Organization (WMO). Uploaded GHCN data undergoes a series of quality assurance checks.

The second dataset type is Global Surface Summary of the Day (GSOD) which is derived from the Integrated Surface Hourly (ISH) dataset. The ISH dataset includes data from the United States Air Force (USAF) Climatology Center. Data from approximately 9,000 stations are available online. GSOD stations are identified in Table A-8 and Table A-9 by an eleven-digit number.

More information about the GHCN and GSOD datasets can be found on NOAA's website at https://www.ncdc.noaa.gov/cdo-web/datasets.

A-4.7.1 GHCN Station Download Procedures.

The GHCN Station data download procedures involve several steps and depends on individual's knowledge of station and location. For clarity, these steps are listed below under separate headings.

A-4.7.1.1 GHCN Station Search.

When searching for GHCN stations near a specific Installation and the GHCN station name or ID number is not known, the user should navigate to NOAA's Daily Observational Data map page at https://www.ncei.noaa.gov/maps/daily/. By default, the GHCN Daily layer is checked in the upper left. The GHCN Daily layer displays weather station locations for the contiguous United States as well as Alaska and Hawaii as shown in Figure A-1. For GHCN observation data outside of the United States, selecting the WMO layer on the map page as shown in Figure A-2 displays GHCN station locations across the globe. The user may elect to show all GHCN stations including historical stations, or just the active stations using the settings icon beside the layer name for both the GHCN Daily and the WMO layers. The station selection and precipitation data download procedures described below are applicable to both GHCN Daily and WMO layers.

Figure A-1 NOAA's Daily Observational Map Page – GHCN Daily Layer

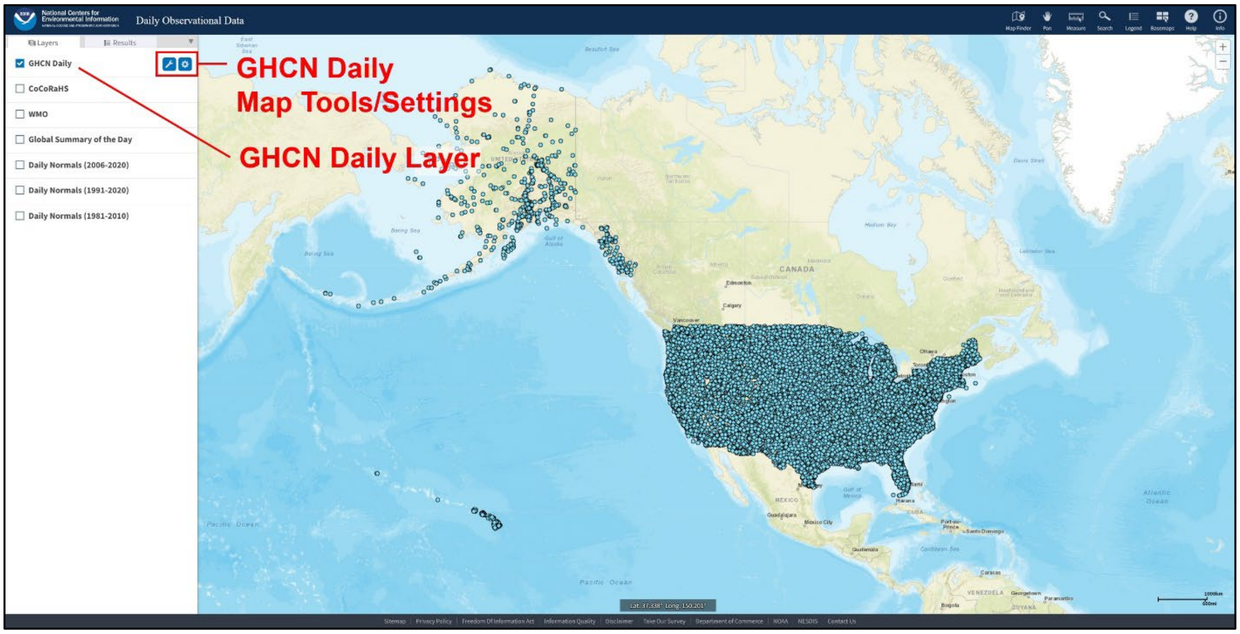
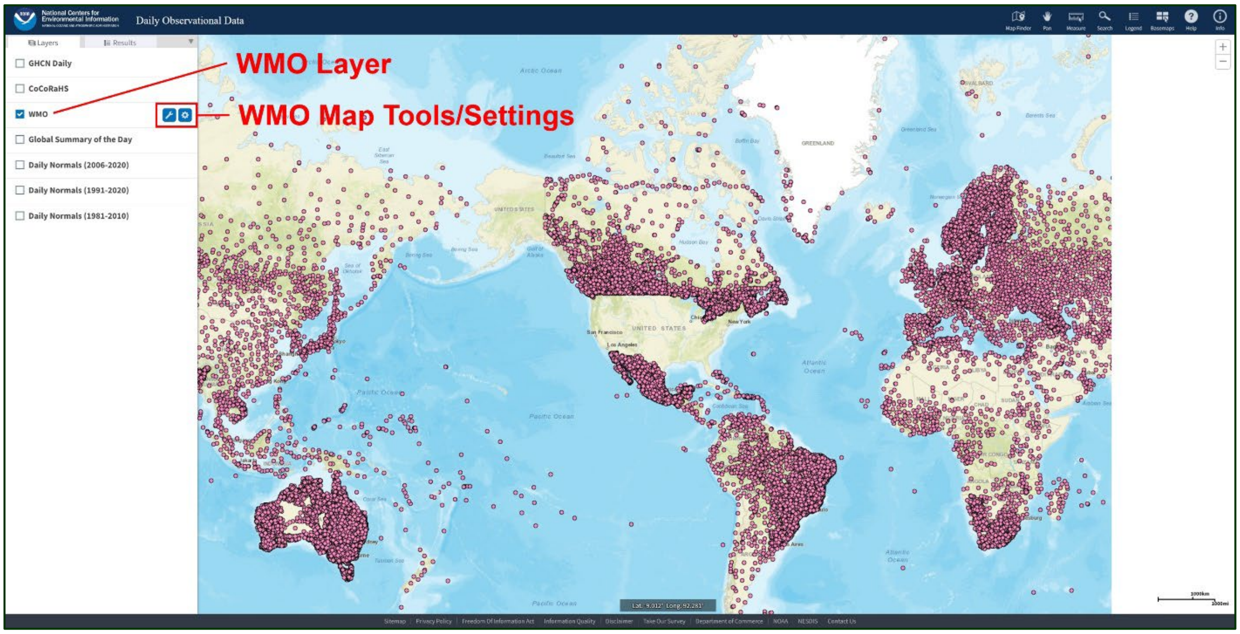


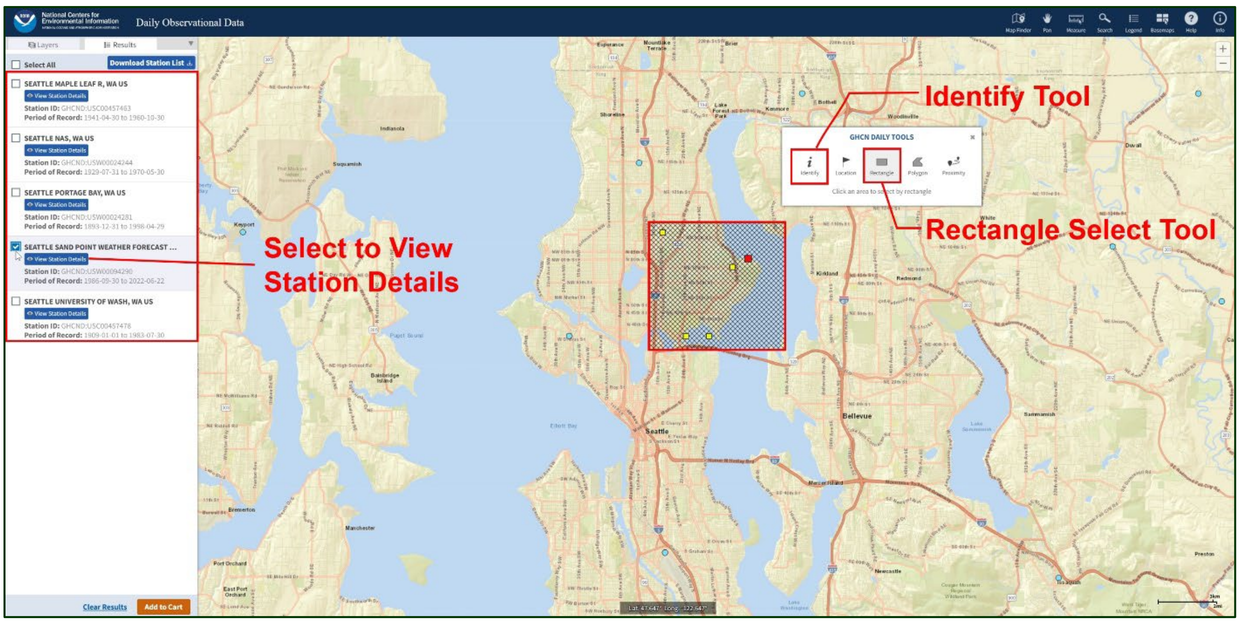
Figure A-2 NOAA's Daily Observational Map Page – WMO Layer



A-4.7.1.2 GHCN Specific Station Search.

From the Daily Observational Data map pages, users may zoom in and pan to a specific location, or search for a location or facility using the tools in the upper right of the page. Clicking on the Map Tools icon beside the layer name in the upper left allows the user to select an individual station using the identify tool, or multiple stations using the rectangle select tool to draw a box around multiple stations as shown in Figure A-3. Station information for the selected station(s) will appear in the results tab to the left and includes the station name, station ID, and period of record.

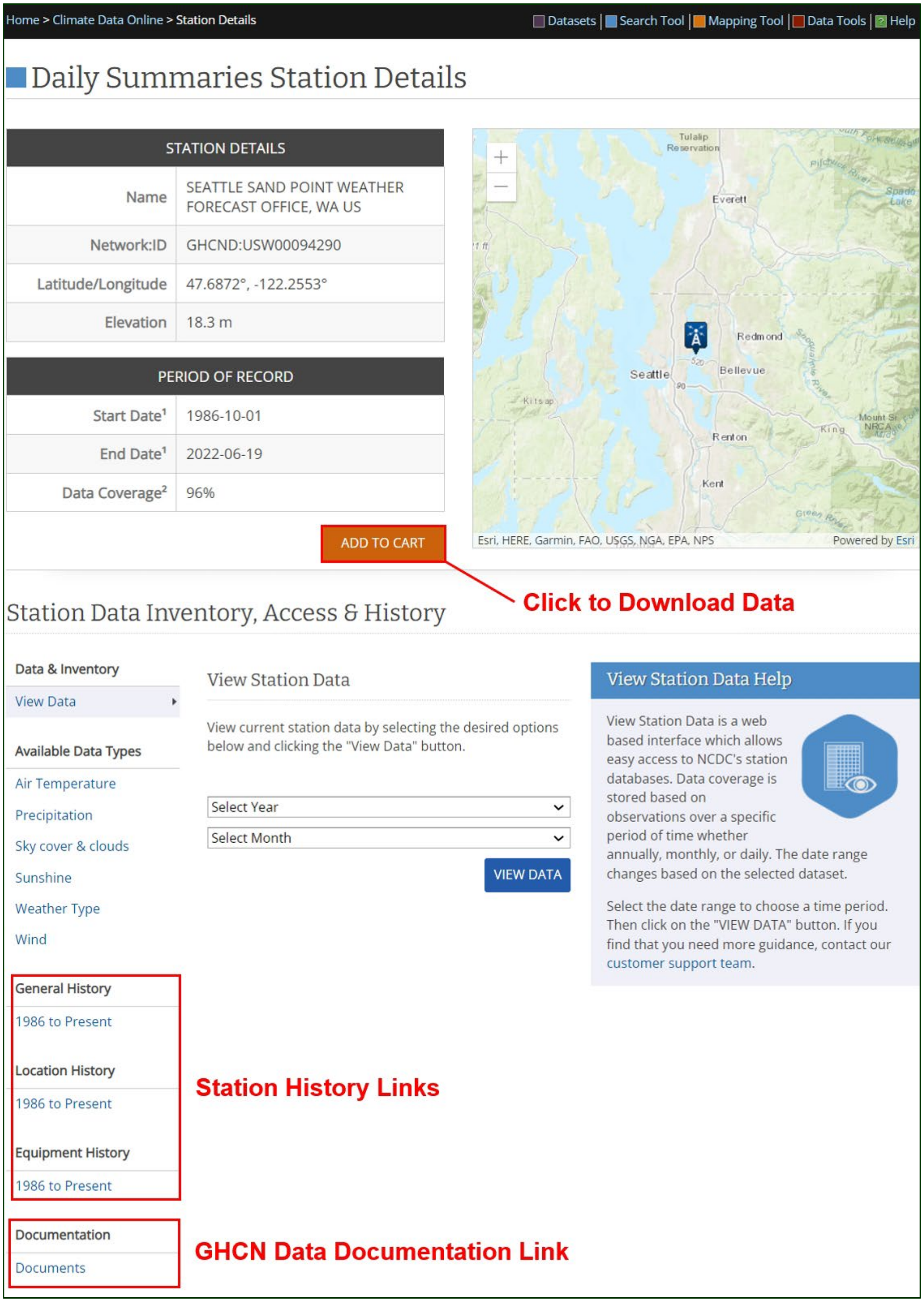
Figure A-3 GHCN Station Selection



A-4.7.1.3 Viewing GHCN Station Details.

Clicking on “View Station Details” below the station name will show additional information about the station as shown in Figure A-4. This includes Latitude/Longitude coordinates, station elevation, and the data coverage for the period of record as a percentage. Users should note that the data coverage percentage is for the most complete set of measurements at the station and may or may not reflect the precipitation data, but instead may refer to other observational data such as temperature or barometric pressure instead. The Station Details page will also have links to the station’s history if available and a link to GHCN Daily summary documentation detailing data formats, observation values, and a list of measurement, quality, and source flags for GHCN data.

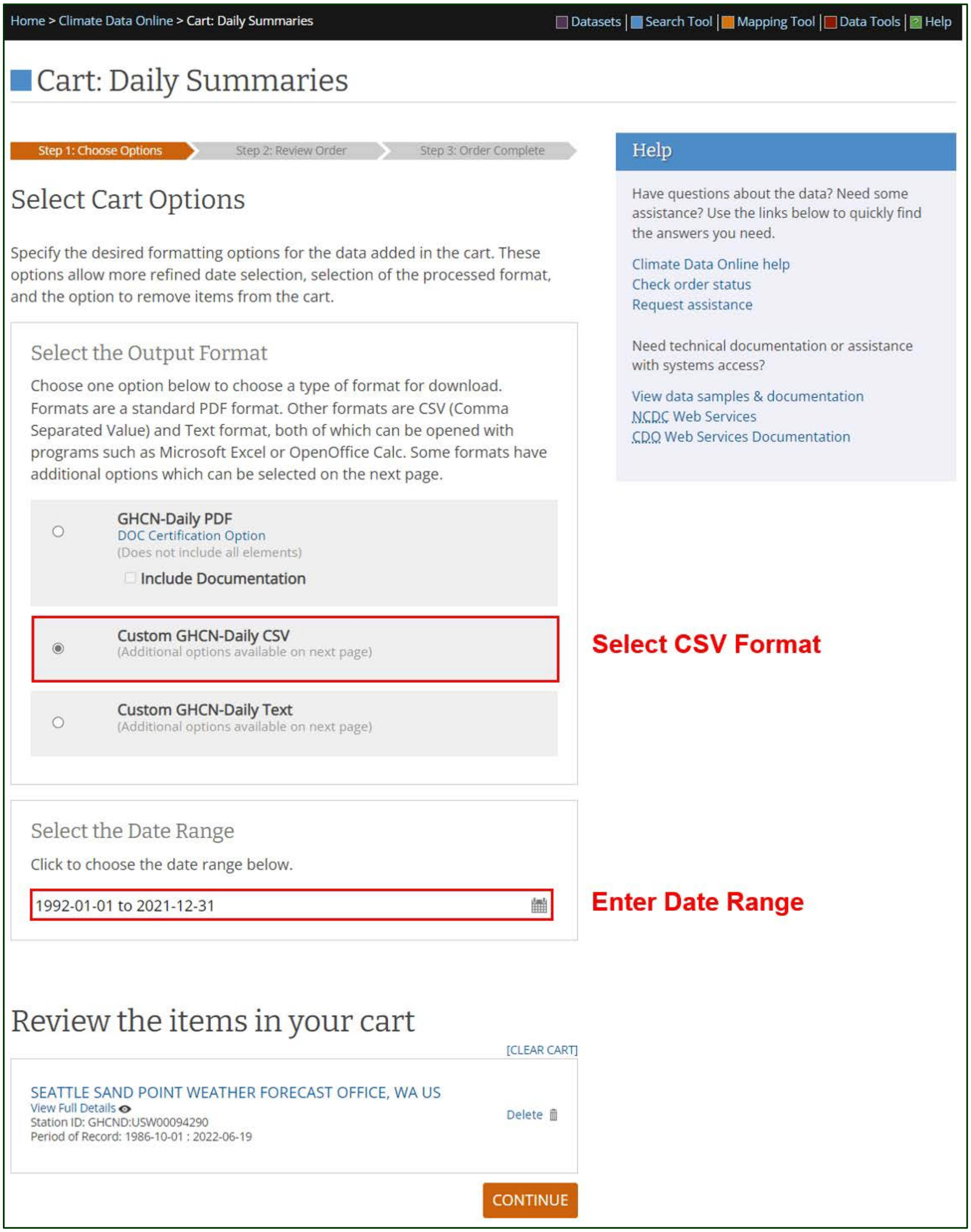
Figure A-4 Station Details



A-4.7.1.4 Adding GHCN Data to Cart.

To download the precipitation data for a selected station, click the “Add to Cart” button found on the Station Details page, or at the bottom of the Daily Observational Data map page. The station will then be added to the user’s cart. After clicking on the cart button at the top right of the page, users must then select the format and the date range of the data to be downloaded from the cart page as shown in Figure A-5. The preferred output format for the precipitation analysis is “Custom GHCN-Daily CSV”.

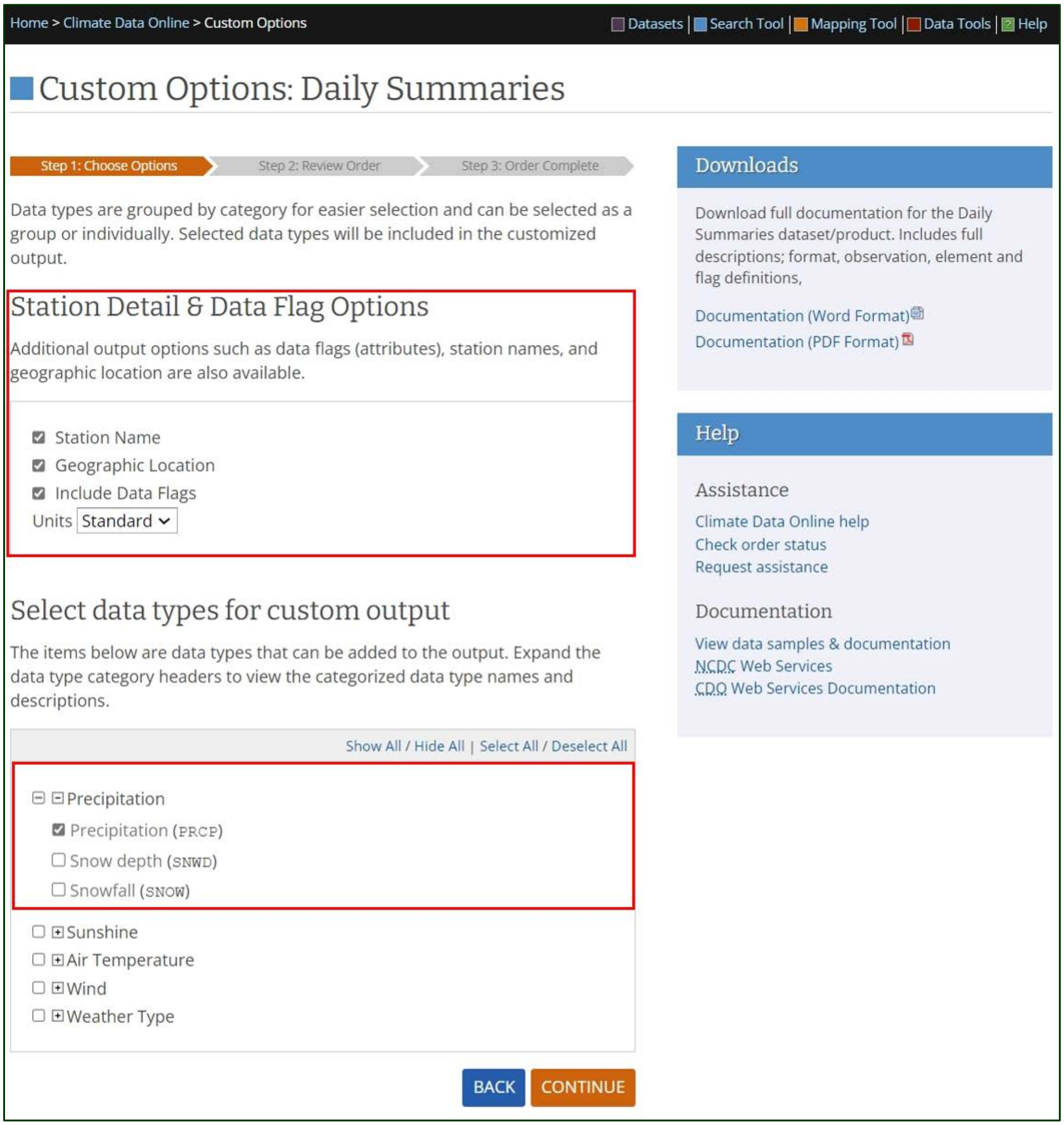
Figure A-5 Cart Options



A-4.7.1.5 GHCN Data Cart Options.

After selecting the format and date range, users should select “Continue” at the bottom of the page to select data options as well as station details to be included with the data. Figure A-6 shows the additional station details that may be included with the data download. If selected, the station name, geographic location and data flags will be included with the precipitation data. Geographic location is the station’s latitude and longitude in decimal degrees. Information about the types of data flags can be found through the documentation link under “Downloads” beside the station detail and flag options.

Figure A-6 Data Download Options



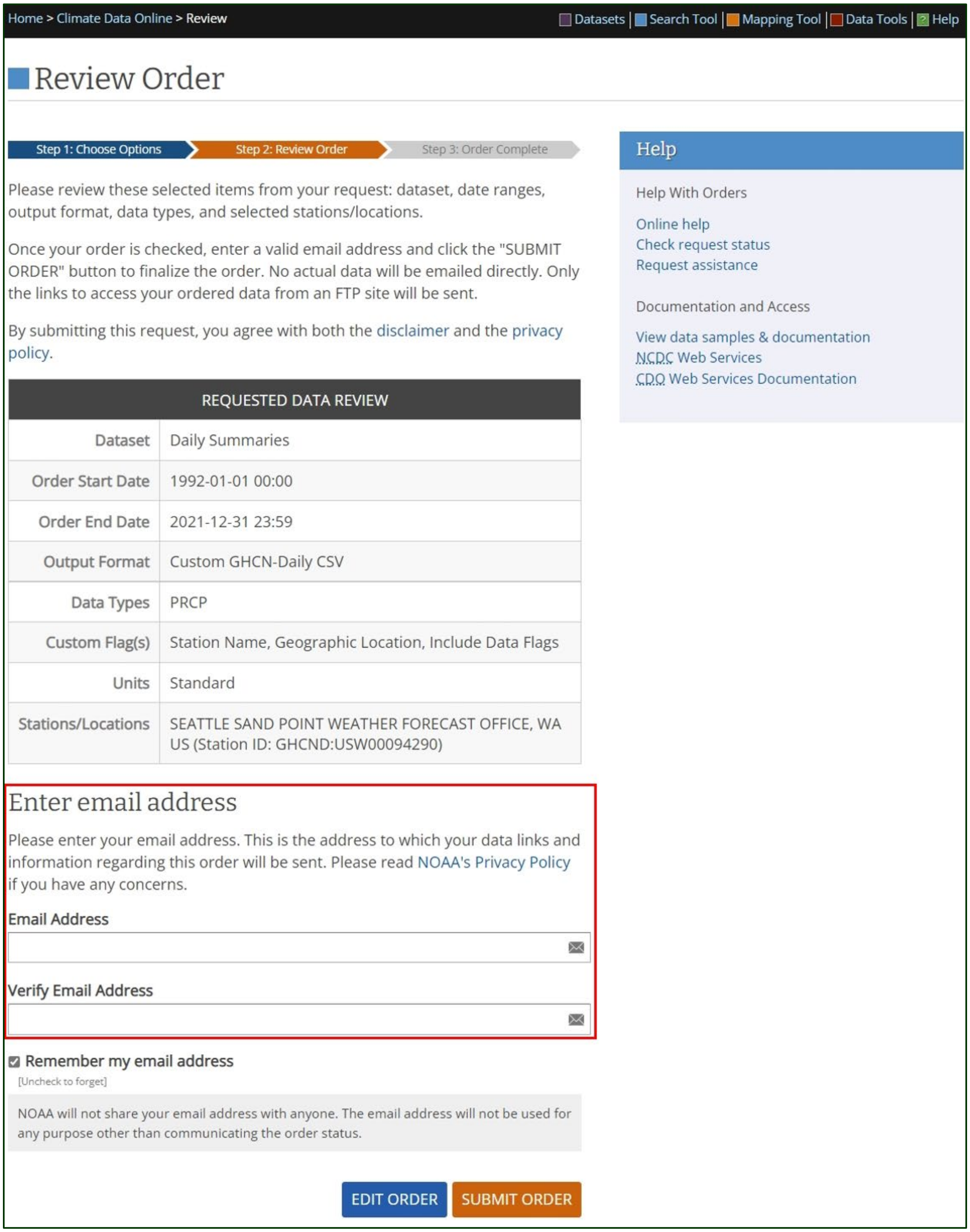
A-4.7.1.6 GHCN Data Units of Measure.

The default units of measure are “Standard” but may be changed to metric units under the Station Detail and Data Flag Options. The standard unit for precipitation data is inches measured to the hundredths of an inch. Users should note that the units of measure are not listed or shown with the downloaded precipitation data. Snow depth and snowfall measurements are not required. Precipitation measurements are for total precipitation during the recording period and include any snowfall during that period.

A-4.7.1.7 Review of GHCN Data and Submit Order.

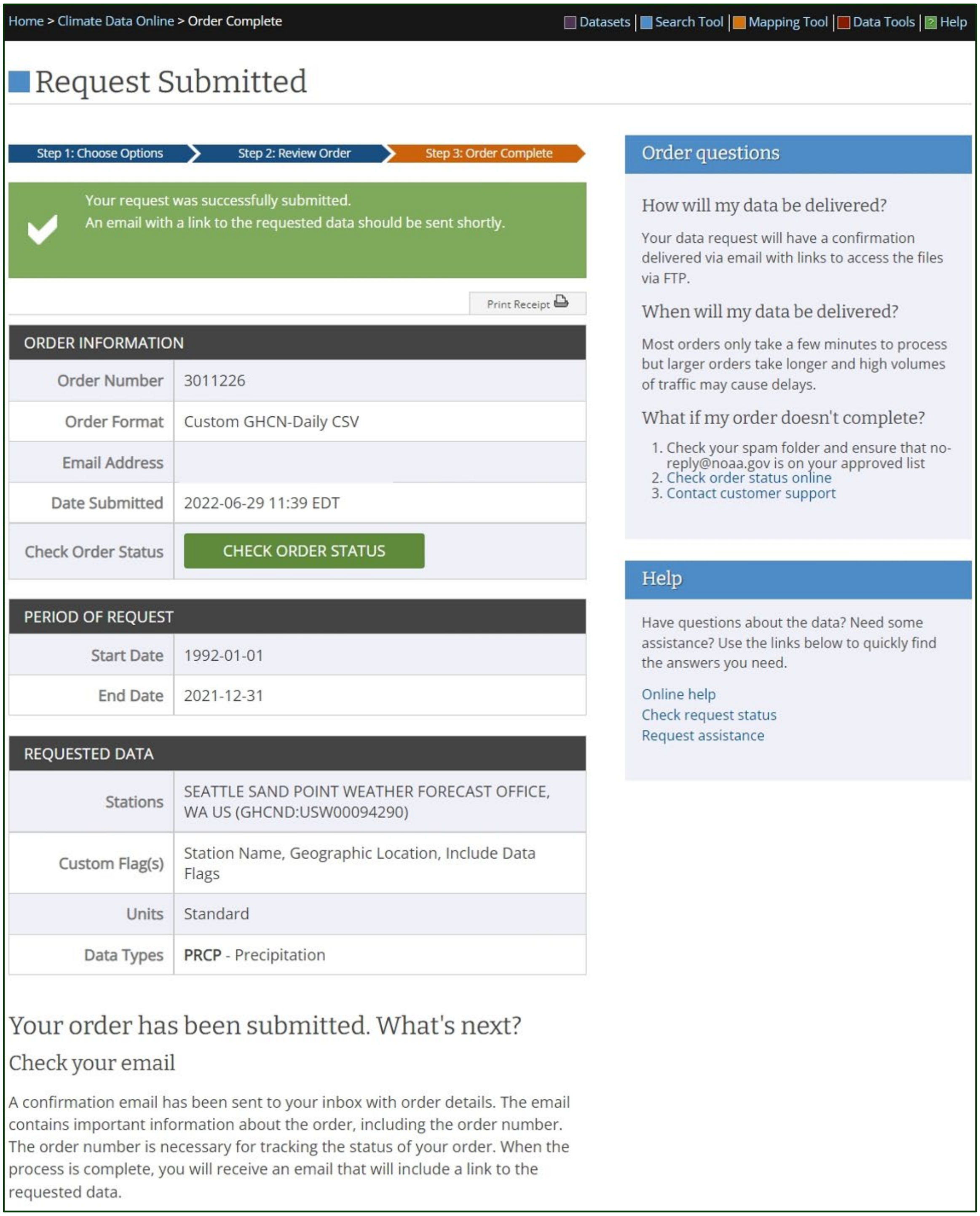
Once the station detail and data options have been set, clicking “continue” at the bottom of the page will take the user to the last page, shown in Figure A-7, before placing the order. Here the user can review the data request. The user must then enter and confirm their email address. The last step is to click “Submit Order.”

Figure A-7 Review of Order



Once the order has been submitted the user will see the order confirmation page, shown in Figure A-8, summarizing the data request. The user will receive an email from the National Centers for Environmental Information (NCEI) at noreply@noaa.gov confirming the data request, followed by an email with a download link for the data. The time between placing an order and receiving the data download link will vary but should not take more than a few minutes.

Figure A-8 Order Confirmation



A-4.7.2 GSOD Station Download Procedures.

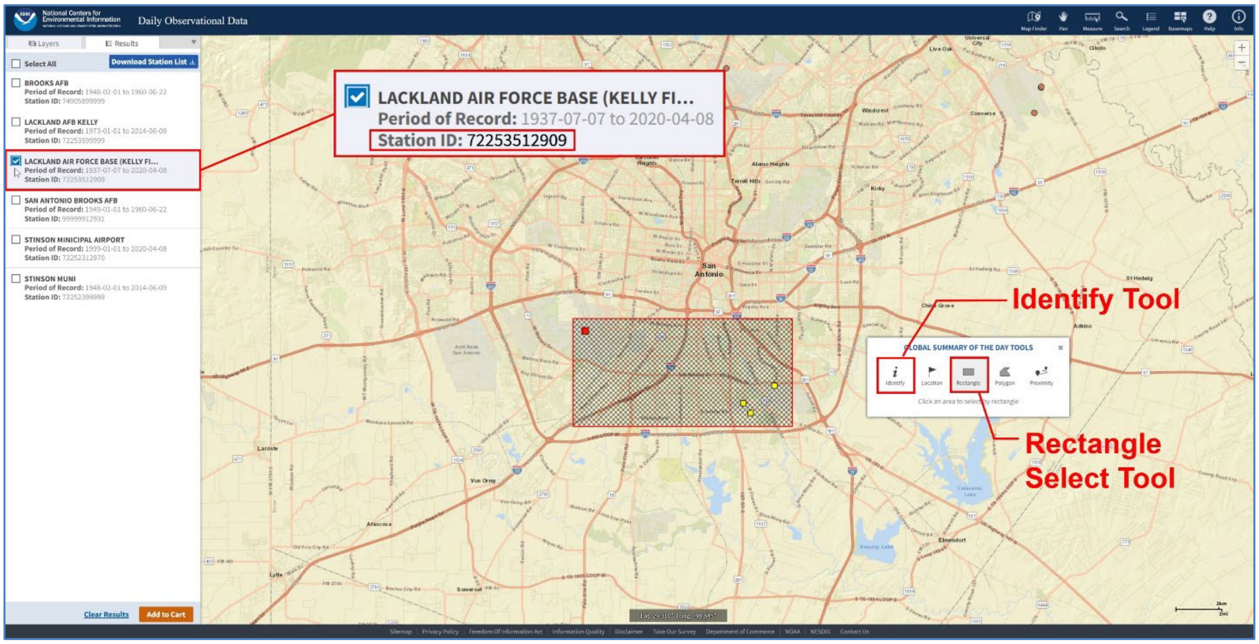
To download GSOD station data go to NOAA's Daily Observational Data map page at https://www.ncei.noaa.gov/maps/daily/ and select the Global Summary of the Day layer as shown in Figure A-9 to display GSOD station locations across the globe. The user may elect to show all GSOD stations including historical stations, or just the active stations using the settings icon beside the layer name.

Figure A-9 NOAA's Daily Observational Map Page – GSOD Layer

A-4.7.2.1 GSOD Specific Station Search.

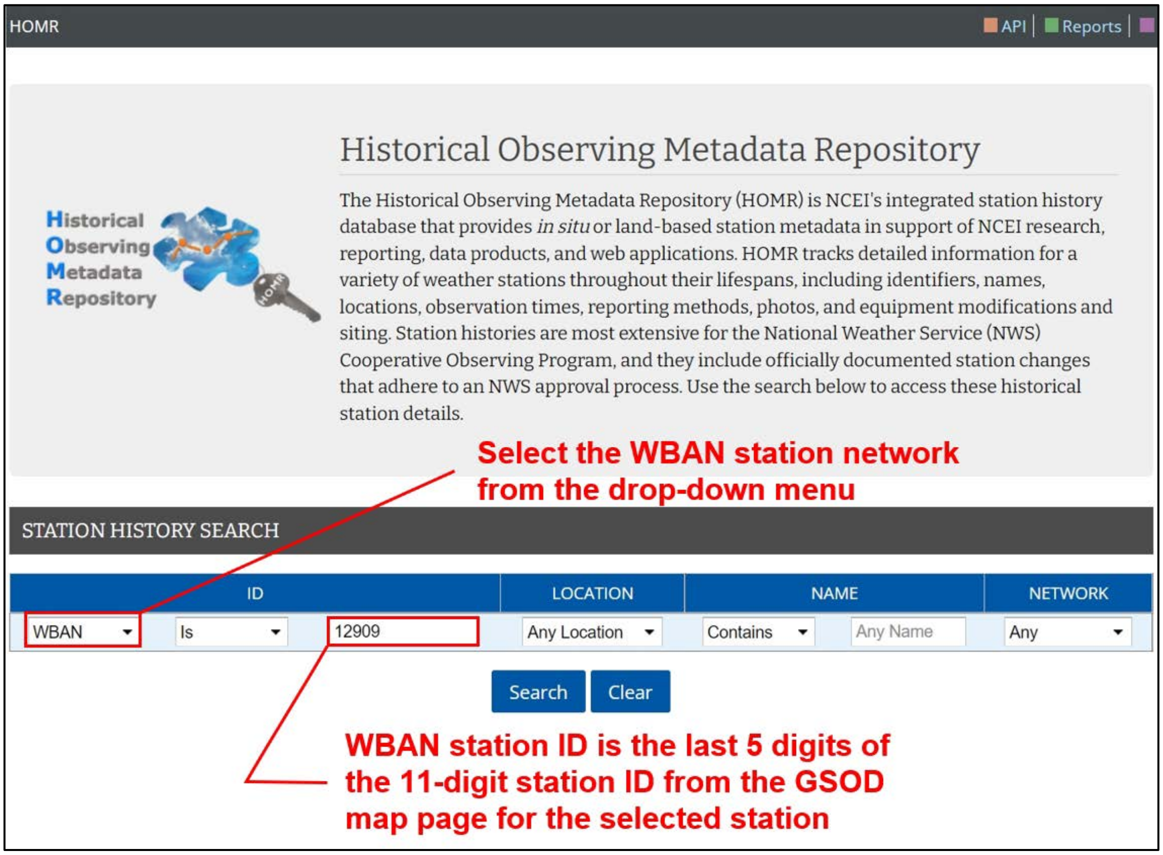
From the Daily Observational Data map page, users may zoom in and pan to a specific location, or search for a location or facility using the tools in the upper right of the page. Clicking on the Map Tools icon beside the layer name in the upper left allows the user to select an individual station using the identify tool, or multiple stations using the rectangle tool to draw a box around multiple stations as shown in Figure A-10. Station information for the selected station(s) will appear in the results tab to the left and includes the station name, station ID, and period of record.

Figure A-10 NOAA's Daily Observational Map Page



Unlike GHCN and WMO stations described in Section A-4.7.1.3, individual station details as shown in Figure A-4 are not linked to selected stations on the GSOD map page. Users must download and examine the data from a selected station to determine its completeness for a given period of record. Station history, if available, can be found on the NOAA website. The most efficient way to search for a GSOD station's history is from the Historic Observing Metadata Repository (HOMR) webpage at: https://www.ncei.noaa.gov/access/homr/;jsessionid=6C5634D8611E5A0E4F7FD2152BC1CE75. From the HOMR webpage, select WBAN from the drop-down menu for the network type as shown in Figure A-11. The WBAN station ID is the last five digits of the 11-digit station ID shown for a selected station on the GSOD map page.

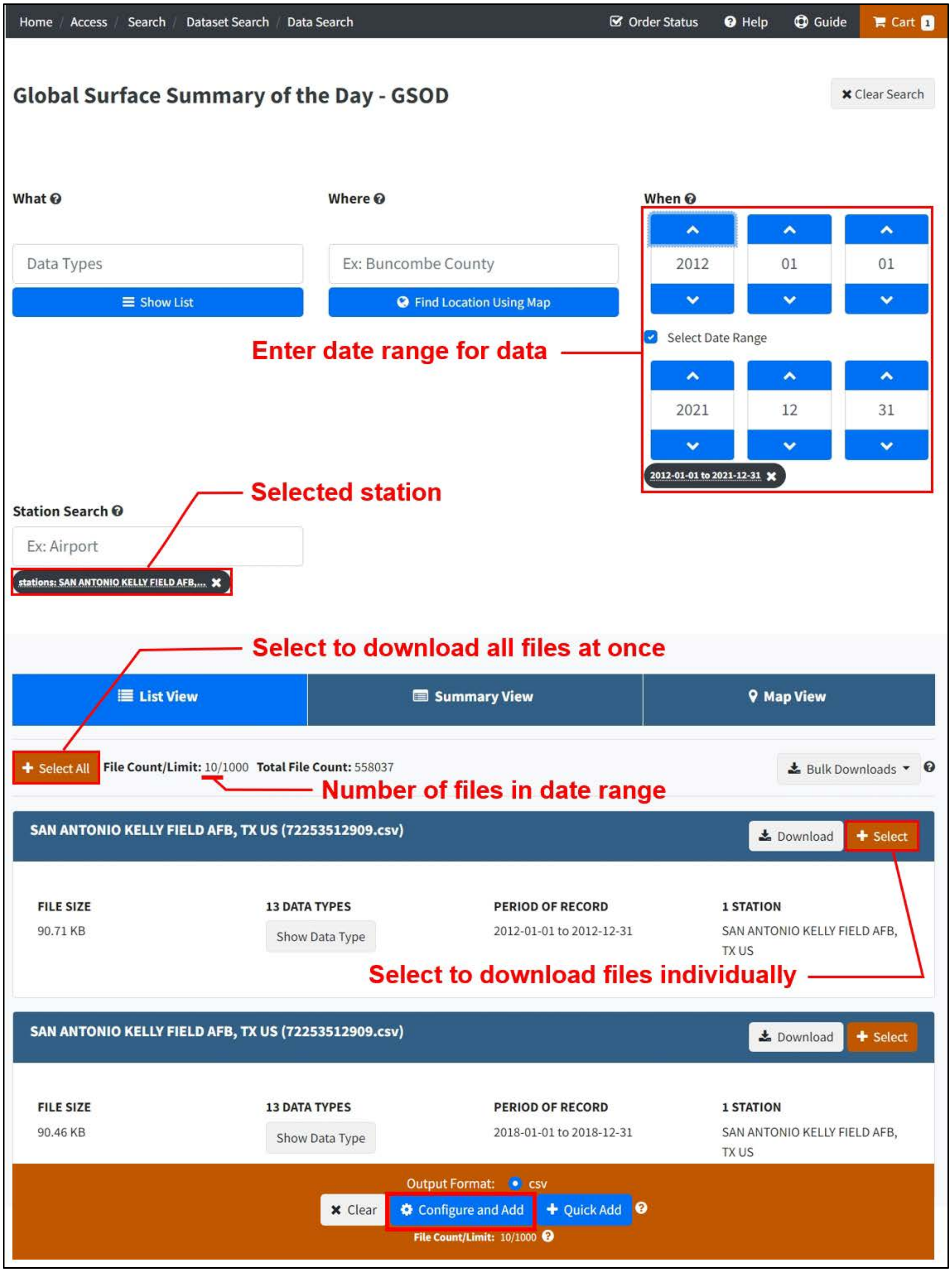
Figure A-11 GSOD Station History Search



A-4.7.2.2 Adding GSOD Data to Cart.

To download GSOD data after identifying a suitable station for analysis, select the station on the GSOD map page as shown in Figure A-10 and click “Add to Cart”. This will open a new webpage for the selected station as shown in Figure A-12 below. The selected station will be shown on the left side of the page below the station search bar.

Figure A-12 GSOD Data Selection



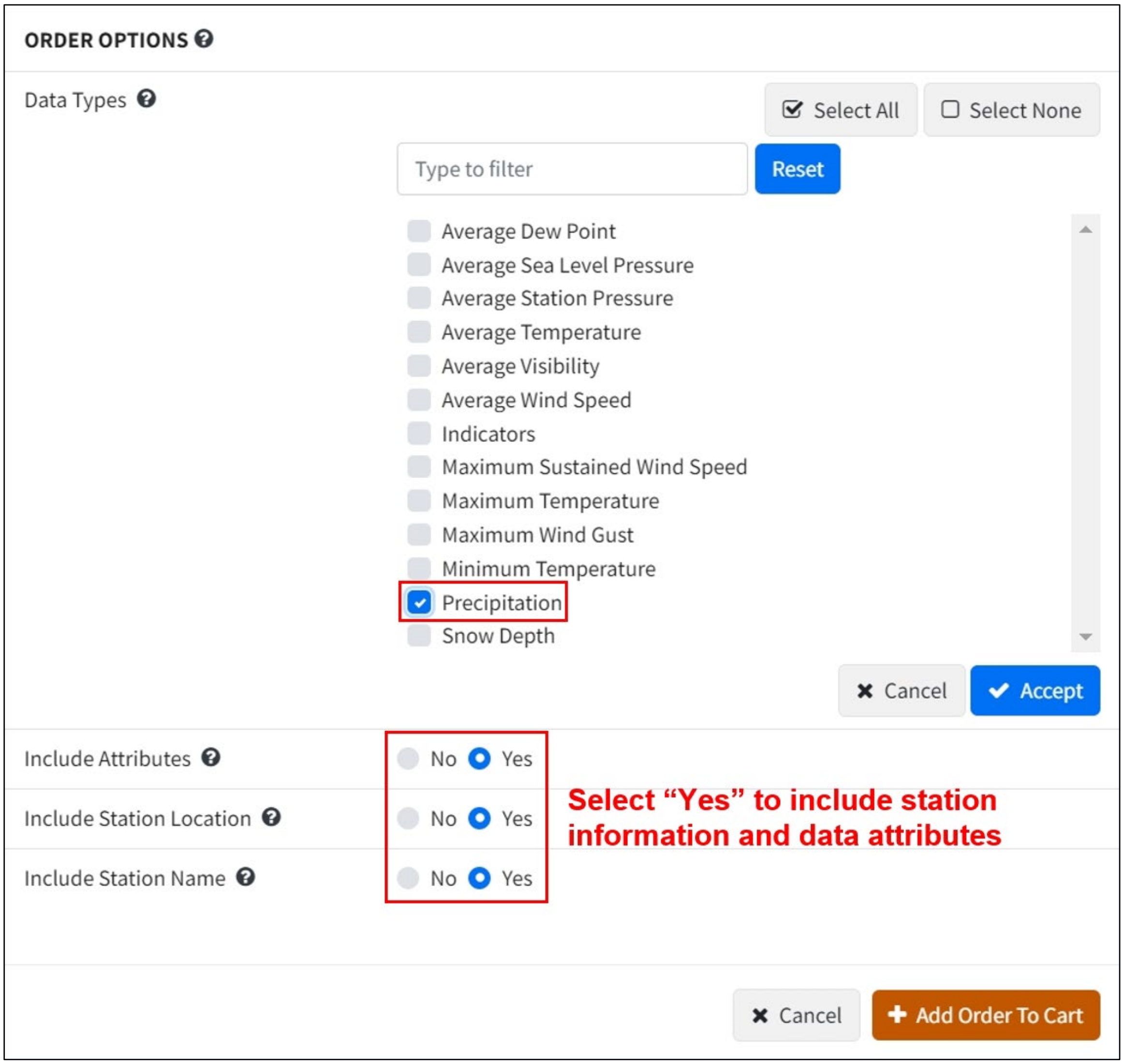
Below the station name, the number of files for the station will be displayed, with each file containing data for one calendar year. The default output file format for GSOD data is a comma separated values (.CSV) file. Before the user specifies a date range, the number of files for the station's entire period of record will be shown. Once a date range has been entered by the user, the number of files in the specified date range will be shown. The number of files should equal the number of years specified in the date range. When the number of files is fewer than years in the date range it indicates that data is missing for one or more years. The individual files for each year in the selected date range will be displayed at the bottom of the page and may continue on other pages depending on the length of the selected date range. Users can scroll down and look at the individual files to see which years are missing.

A-4.7.2.3 Options When Selecting GSOD Data.

Users may select and download the files individually, however the most efficient way to download the data is to click the "Select All" button on the left side of the page below the station name. This will select all the files for the specified date range and combine it into a single file for downloading. After the "Select All" button has been clicked, the user will see three options at the bottom of the page. The "Clear" button will unselect the files chosen for downloading but it does not clear the date range in the upper right of the page specified by the user. The "Quick Add" button automatically selects all data types collected by the station to include in the data download for each year in the date range and sends the request to the user's cart. However, this will include unneeded data such as wind speed, barometric pressure, etc. and will not include station information or data indicators with the data download.

Instead, users should select the "Configure and Add" button which lets them select or unselect the data types to be downloaded. More importantly, the station name and location, as well as data attributes, are not included with the data unless those items are selected. Figure A-13 below shows the order options for the GSOD data. Precipitation data attributes are listed in the GSOD data documentation and can be found at the following link https://www.ncei.noaa.gov/data/global-summary-of-the-day/doc/readme.txt. GSOD precipitation data is measured in inches to the nearest hundredth of an inch as stated in the GSOD data documentation linked above. Users should note that the units are not mentioned or shown on the download pages and are not listed with the downloaded data.

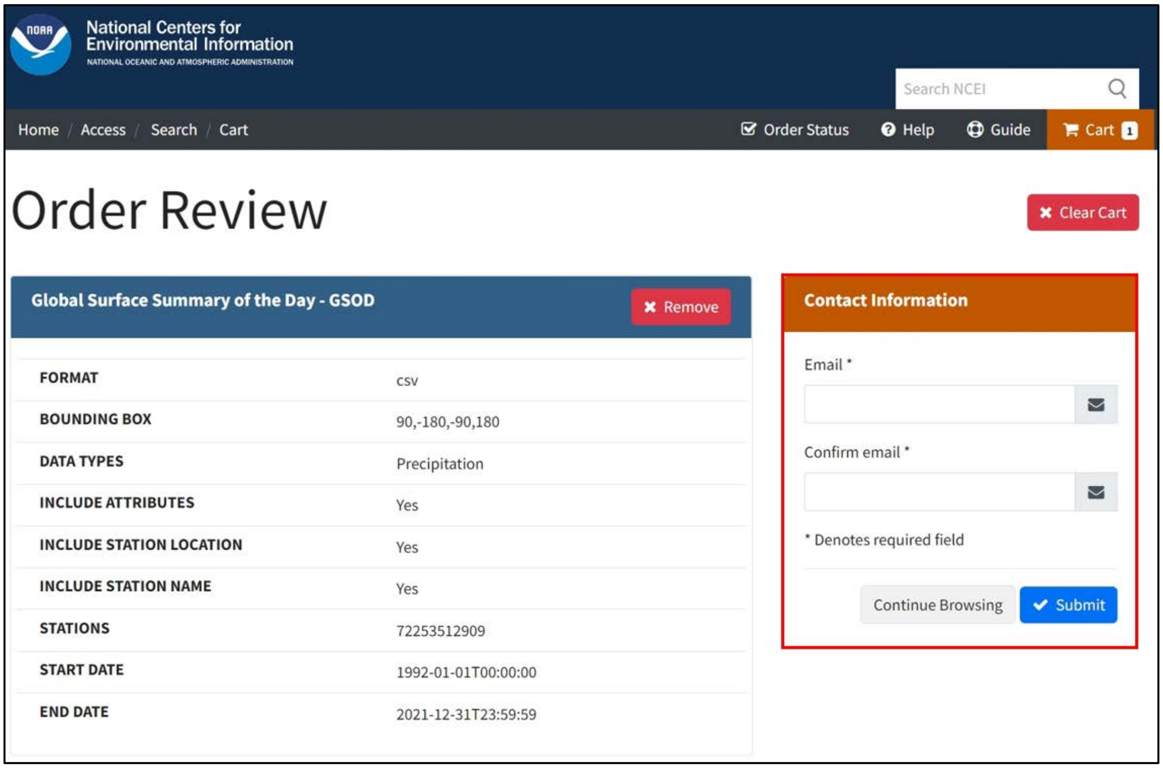
Figure A-13 GSOD Data – Order Options



A-4.7.2.4 Review of GSOD Data and Submit Order.

Once the data options have been selected, select "Add Order to Cart". This will take the user to the order review page shown in Figure A-14. After reviewing the order, the user must input and confirm their password before hitting the submit button to complete the data request.

Figure A-14 Order Review



After submitting the data request the user will receive an email from the NCEI at noreply@noaa.gov confirming the data request, followed by an email with a download link for the data. The time between placing an order and receiving the data link will vary but should not take more than a few minutes.

A-4.8 Procedure to Compute 95th Percentile Rainfall Event.

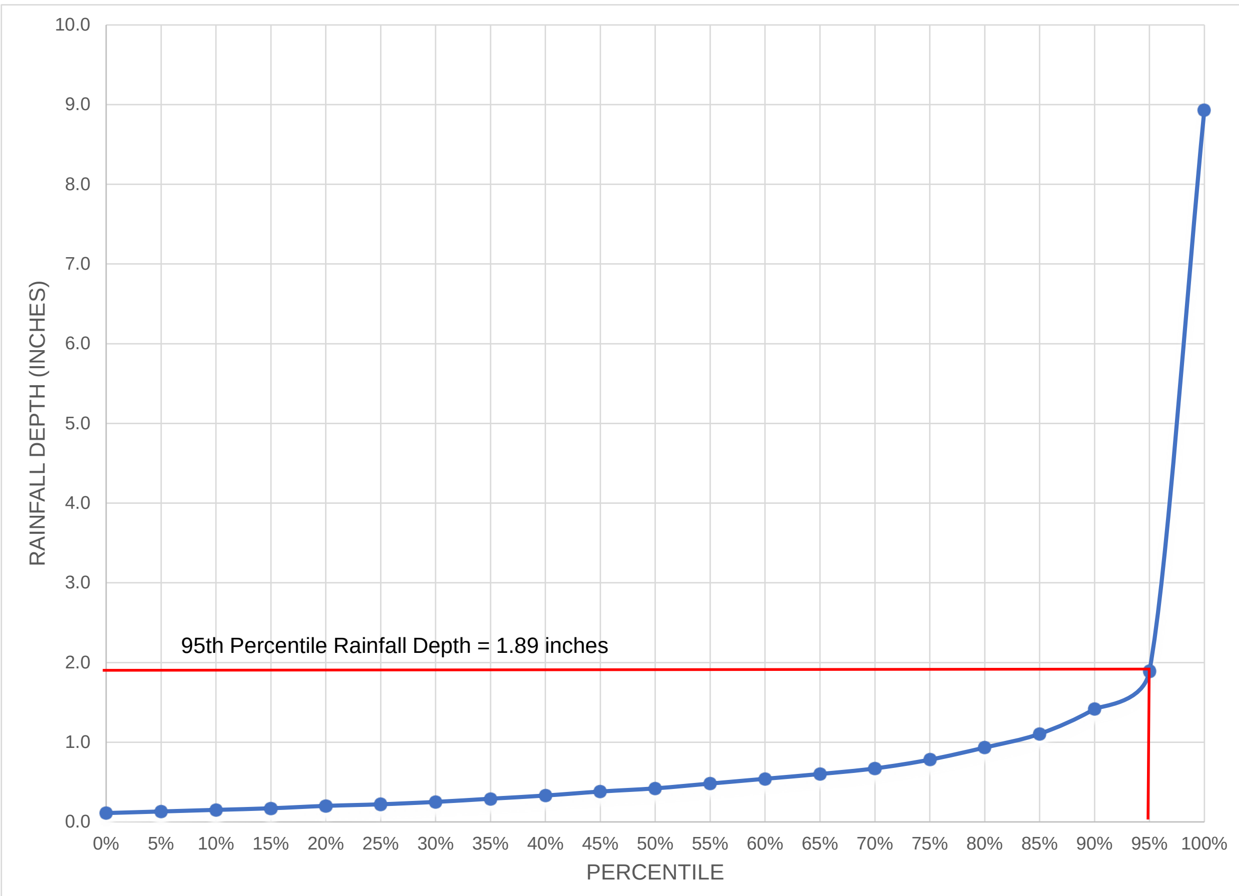
The design storm is the 95th percentile rainfall, described in Section 2-1.2. The step-by-step procedure for calculating the 95th percentile rainfall depth, using a spreadsheet, is summarized below:

1. Obtain a long-term rainfall record, in comma separated value or ".CSV" format, as detailed in Sections A-4.7.1 and A-4.7.2. These are daily or 24-hour rainfall records over the period.
2. Import the data into a spreadsheet. The daily precipitation data downloaded is typically arranged in a single column. If the original data set has multiple columns of daily precipitation data, then the user must rearrange the data into a single column.
3. Review the data for any anomalies or erroneous data points, measurement error flags (indicated in the precipitation data attributes) and remove this data from the list.
4. Remove data for small rainfall events that are 0.1 inch or less (≤ 0.1 inch) from the data set. These rainfall events (≤ 0.1 inch) are to be deleted since

they do not typically cause runoff and can potentially cause calculation of 95th percentile of runoff-causing rainfall event to be inaccurate.

5. It is preferable to sort the rainfall data (> 0.1 inch) from smallest value to highest value. The 95th percentile rainfall depth is calculated using the spreadsheet function PERCENTILE and specifying the range and percentile value (in this case it is 95th percentile and the value to be used in the spreadsheet function is 0.95). If MS Excel is used, the function attributes are [=PERCENTILE (precipitation data range, 0.95)]. Alternatively, the user can apply available statistical packages to determine the same.
6. A typical plot of rainfall depth versus percentile is shown in Figure A-15.

Figure A-15 Plot of Typical Rainfall Depth vs Percentile



A-5 LID DESIGN.

A-5.1 Introduction.

LID strategies provide decentralized hydrologic source control for stormwater. LID implementation centers around selecting LID features which are distributed small-scale controls that can closely maintain or replicate hydrological behavior of the natural system for a design storm event.

Standard BMPs may be used in conjunction with LID features, depending on site conditions, to handle the peak rate of discharge for flood control. Follow published design criteria relative to achieving, maintaining, and emphasizing a positive exterior visual environment applicable to military installations.

A-5.2 Hydrologic Analysis.

Table A-6 gives representative runoff curve numbers and the calculated initial abstractions for selected soil types. The runoff generated from a project site and the initial abstraction of the site does not have a linear relationship. For this reason, the required design storage of LID features is calculated using Equation 3-2 and Equation 3-3 discussed in Chapter 3.

Runoff curve numbers are determined by land cover type, hydrologic condition, antecedent runoff condition (ARC), and hydrologic soil group (HSG). Curve numbers for various land covers based on an average ARC can be found in the TR-55 manual.

Table A-6 Initial Abstraction for Indicated Soil Types

Existing Site Conditions	Curve Number (CN)	Initial Abstraction (inches)
Woods - good condition, HSG B	55	1.64
Woods - poor condition, HSG D	83	0.41
Pasture, grasslands - good condition, HSG B	61	1.28
Pasture, grasslands - fair condition, HSG C	79	0.53
Open space - lawns, park in fair condition, HSG B	69	0.90
Residential districts - 1/3 acre, 30% impervious, HSG B	72	0.78
Residential districts - 1/3 acre, 30% impervious, HSG C	81	0.47
Industrial area - 72% impervious, HSG B	88	0.27

A-5.2.1 Mimic Existing (Pre-Development) Hydrologic Conditions.

The preceding table shows that the hydrology of a naturally wooded environment in good condition provides a maximum retention that in turn increases the water quality treatment of stormwater runoff. For redevelopment, the site is not set at maximum retention, but to maintain pre-development levels. However, the typical site development project results in the following adverse environmental impacts:

- Changes to existing land-use and land cover

- Changes to natural drainage patterns
- Clear cutting of the native vegetation
- Soil compaction due to the use of heavy construction vehicles on-site
- Increase in impervious area
- Drainage systems that quickly move the water downstream.

It is recognized that there are very many different existing development conditions (including everything from leveling and fill, to existing conditions that bear no resemblance to what came before). As a result, the post-development hydrologic conditions are worsened, and in many cases, the damage becomes irreversible. The goal, however, is to document a return to a realistic natural pre-development condition for the particular locale and setting. LID techniques mimic the natural systems by capturing runoff in bio-infiltration practices (such as shown by Figure A-16 below), structural solutions, reuse, or footprint reduction for a design storm event. The pre-development condition is the typical condition of the project site just prior to the project. Apart from the potential increase in impervious area, the primary impacts due to man-made development are soil compaction, and increased efficiency of drainage patterns. The two land development conditions of concern are:

- Pre-Development Condition
- Post-Development Condition

Figure A-16 Typical Bio-infiltration 'Rain Garden'

Note curb cut inlet. Design should be based on regional plants and growing conditions.

A-5.2.2 Time of Concentration for Pre- and Post-Development Conditions.

In order to mimic natural hydrologic patterns, the site designer should provide features that limit the rate at which runoff leaves the site. Maintaining T_c close to pre-development conditions is critical because the peak runoff rate and thereby the volume of runoff from individual lots, is inversely proportional to the T_c. Manage T_c by utilizing strategies such as reduction of impervious areas, maintaining natural vegetation, siting of impervious areas in poor draining soils, and disconnecting impervious areas.

Using traditional site planning techniques, the post-development T_c is invariably reduced. This is due to the curbs, channels, and pipes causing quicker drainage, resulting in higher peak flow rates. In order to mimic the natural hydrologic pattern, the site designer needs to provide features that slow down the runoff from the site. To maintain the T_c, use the following site planning techniques:

- Maintaining or increasing pre-development sheet flow length
- Preserving natural vegetation
- Increasing surface roughness
- Detaining flows
- Disconnecting impervious areas

- Reducing longitudinal slopes of swales and ditches.

Achieving a T_c close to pre-development conditions is often an iterative process and requires analyzing different combinations of the appropriate techniques.

A-5.2.3 Stormwater Flow Segments.

TR-55 Curve Number Methodology is well documented and is used widely in engineering practice to determine the T_c. The method presumes that runoff from rainfall moves through a watershed as sheet flow, shallow concentrated flow, pipe flow, channel flow, or some combination of these. T_c is the sum of travel flow times calculated separately for the consecutive flow segments along the longest flow path. These three flow segments along with their implications on T_c are detailed in the TR-55 manual. The use of TR-55 is recommended for calculating T_c. Other methodologies in accordance with applicable state or local stormwater regulations and based on site specific conditions may also be used.

A-5.2.4 LID Design Storm Event.

Storm events are a complex natural phenomenon, and methods to predict and control their impacts rely upon empirical and mathematical modeling of the event. In previous versions of this document, three principal approaches were analyzed in selecting the 95th percentile design storm event – (a) Prince George's County Methodology; (b) EPA Methodology; and (c) First-Flush Water Quality Volume. Over the years, the EPA Methodology of using the 95th percentile rainfall depth as the design storm event for design of LID features has been widely accepted and is adopted herein. For details pertaining to this refer to Section A-4.8 or EPA 841-B-09-001 for the EPA Methodology for calculating the 95th percentile rainfall event.

A-5.2.4.1 Design Storage of LID Features.

For the 95th percentile design storm event, the LID volume is equal to or greater than the total net increase in runoff from the pre- to post-development states. Typically, the total volume of stormwater runoff generated during the post-development conditions exceeds the total volume of stormwater runoff generated from the site during the pre-development conditions. The design storage volume of LID features would be the difference in total volume of stormwater runoff generated between pre- and post-development conditions.

Table A-7 illustrates the total depth of increase in stormwater runoff for a hypothetical representative site. The depth of increase in stormwater runoff calculated will be used in designing the LID features to handle all of the net increases in stormwater runoff generated from a parcel being developed (using Equation 3-3).

A-5.3 Design Objective and Pre-Development Hydrology.

The LID Storage Volume assures the most practical solution and provides the maximum value for achieving an improved water quality discharge downstream. In certain geographical areas on optimal sites, the site designer will be able to improve the efficiency of the LID features to handle a portion of the flood control element of stormwater. For other rainfall events, which exceed normal intensities, the runoff will be collected and conveyed to the conventional SWM facilities. The conventional SWM facilities should be designed to discharge or outfall over a 24-hour period to reduce the peak flow rate below the pre-development outflow rate. Further, outfall water quality is improved through an additional treatment from conventional SWM facilities. To design the LID features for gross increases in stormwater runoff over a range of storm events, for less frequent or high return period storm events, would be impractical. Conventional SWM facilities may be needed in addition to LID features to meet with state/local stormwater requirements.

A-5.4 Design Considerations.

A few of the most relevant design considerations are listed below. For a more detailed list, the reader is referred to published literature given in the references.

It is important to note that holding excess rainwater on-site that would ordinarily end up as runoff can be detrimental in some cases. Rainfall that is retained in excess of the initial abstraction can destabilize certain soils on slopes, impact sensitive coastal tidal zones, increase the need for mosquito control, and in certain riparian or usufructuary rights create an infringement. In many areas where shallow groundwater aquifers are used for water supply or irrigation, the designer must consider contamination issues.

A-5.4.1 Develop LID Control Strategies.

Use hydrology as a design element. To minimize the runoff potential of the development, the hydrologic evaluation should be an ongoing part of the design process. An understanding of site drainage can suggest locations for both green areas and potential building sites. An open drainage system can help integrate the site with its natural features, creating a more aesthetically pleasing landscape.

a. Determine the state regulatory design storms. Regulatory requirements for design storms may also be stipulated in local ordinances, and these may limit or constrain the use of LID techniques or necessitate those structural controls be employed in conjunction with LID techniques.

b. Determine LID volumes using 95th percentile design storm and TR-55 Curve Number methodologies.

c. Evaluate current conditions. Analyze site with traditional hand methods or computer simulations. Use the results of modeling to estimate baseline values for the four evaluation measures: runoff volume, peak runoff rate, flow frequency and duration, and water quality.

d. Evaluate site planning benefits and compare with baseline values. The modeling analysis is used to evaluate the cumulative hydrologic benefit of the site planning process in terms of the four evaluation measures.

e. Evaluate the need for LID IMPs. If site planning is not sufficient to meet the site's LID objectives, additional hydrologic control needs may be addressed using LID features. After LID features are selected for the site, a second-level hydrologic evaluation can be conducted that combines the LID IMPs with the controls provided by the planning techniques. Results of this hydrologic evaluation are compared with the baseline conditions to verify that the site LID objectives have been achieved. If not, additional LID features are located on the site to achieve the optimal condition.

f. Evaluate supplemental needs. If supplemental control for either volume or peak flow is still needed after the use of LID IMPs, selection of additional management techniques should be considered. For example, where flood control or flooding problems are key design objectives, or where site conditions, such as poor soils or a high groundwater table limit the use of LID features, additional conventional end-of-pipe methods, such as large detention ponds or constructed wetlands, should be considered. In some cases, their capacity can be reduced significantly using LID features upstream. It may be helpful to evaluate several combinations of LID features and conventional stormwater facilities to determine which combination best meets the stated objectives. Use of hydrologic evaluations can assist in identifying the alternative solutions prior to detailed design and construction costs.

g. For residential areas, Prince George’s County, Maryland, has developed a detailed illustration of an approach for conducting a hydrologic evaluation based on the TR-55 method. The effect of LID features should be reflected in the curve numbers and times of concentration selected for the analysis. A full description of this process is available from Prince George’s County (*Low-Impact Development Hydrologic Analysis*)

A-5.4.2 LID Concept Design or Master Plan.

1. Maximize the efficiency of the existing site. Place impervious areas in poorer soils and retain existing trees where practical.
2. Sketch a design concept that distributes the LID practices appropriately around the project site. Keep in mind the multifunctional capability of LID technologies (that is, parking lot with detention facility underground).
3. Develop a master plan that identifies all key control issues (water quality, water quantity, water conservation) and implementation areas. Specify specific LID technologies and any connections they have to stormwater overflow units and subsurface detention facilities.

A-5.4.3 Develop Landscaping Plans to Maximize Efficiency of LID Features and Reduce Maintenance.

1. Hardy, native plantings should be used.
2. In areas where soils have low infiltration rates, as determined by percolation tests, average depth of bio-infiltration practices is determined such that the volume held would infiltrate within stated limits. For example, if the state criteria indicates 72 hours in soils with a low

permeability rate (hydrologic soil groups C and D) of 0.05 inches/hour (1.3 mm/hr), the depth of infiltration basin = 72 hrs x 0.05 in/hr (1.3 mm/hr) = 3.6 inches (93.6 mm). Conservatively, the designer may opt to restrict this depth to 3.0 inches (75 mm) and provide a larger area to satisfy the LID volume requirement. The designer may also want to incorporate other LID practices, such as footprint reduction of impervious surfaces and permeable pavers, in conjunction with sizing of bio-infiltration facilities. (Verify all actual design parameters with state BMP manual.)

3. Flood control is based on protecting life and property. Flood control criteria are ultimately determined locally based on drainage needs and flood risk of any particular area and may go beyond LID design criteria to achieve the necessary level of flood protection.
4. If project site has limited land area for bio-infiltration practices, in order to satisfy the LID volume criteria, a combination of structural practices such as rain barrels and cisterns may be employed in addition to bio-infiltration practices. At any time, the outflow from the structural practices should be controlled to the sum total of assimilating capacity of bio-infiltration practices provided downstream. For example, if a downstream bioretention facility is of size 600 sq.ft, in soil type C with an infiltration rate of 0.15 in/hr (3.8 mm/hr), then the cisterns or rain barrels provided on site will discharge into bioretention facility at a rate = 0.15 in/hr * 600 sq.ft /(12 in/ft * 3600 sec/hr) = 0.0021 cfs.
5. LID features should be incorporated into the site plan at locations as close as possible to the origin of surface runoff from impervious areas. For example, runoff from roof drains is to be collected around the building (minimum building offsets should comply with UFC 4-010-01), and runoff from parking lots will be held in traffic islands and along the perimeter.
6. Plant bioretention facilities with native vegetation; refer to Landscape Architect, local plant specialists, or horticulturists.
7. Design positive overflow system to capture excess rainfall-runoff.

A-5.4.4 Operation and Maintenance Procedures.

Operation and Maintenance Support Information documentation (OMSI) is critical to ensure LID features are maintained and continue to function properly. LID features should be viewed as environmental systems that have specific maintenance requirements. The O&M procedures for each of the LID practices implemented in the site plan should be provided as part of the OMSI documents. Different types of LID features will have different maintenance requirements, but some general principles will apply:

- Keep LID features and flow paths clear of debris and trash.
- Use native, drought-tolerant plantings that can tolerate periods of saturation. Vegetation should be watered regularly during dry periods. Use special care in selecting plants in areas of tidal influence.

- Consider impact on plants by road salts.
- Grassed areas should be mowed regularly using a longer length cut.
- Plantings should be pruned as needed.
- Deep raking and tilling of depression storage should be done on a yearly basis or as indicated.

A-5.5 Gaining Acceptance of LID Options.

A higher level of communication on LID projects should be maintained to keep stakeholders informed during the planning and design phase. From building tenant commands to O&M personnel, communicating intent and purpose is the key to successful LID implementation. In addition, for some period, feedback on implementation and program success of all new facilities may be required by the local Environmental Office.

Table A-7 Example Evaluations of Increased Post-Development Runoff Depth

Existing Site Conditions	Existing Site Composite CN	Design Storm Event 95th Percentile Rainfall EPA Methodology (inches)	Developed Conditions[2] Composite CN	Depth of Increase in Stormwater Runoff (inches)
Woods - good condition, HSG B	55	1.89[a]	76.5	0.37
Woods - poor condition, HSG D	83	1.38[b]	90.58	0.31
Pasture, grasslands - good condition, HSG B	61	1.89[a]	79.5	0.42
Pasture, grasslands - fair condition, HSG C	79	1.38[b]	88.5	0.31
Open space - lawns, park in fair condition, HSG B	69	1.89[a]	83.5	0.46
Residential districts - 1/3 acre, 30% impervious, HSG B	72	1.89[a]	85	0.47
Residential districts - 1/3 acre, 30% impervious, HSG C	81	1.38[b]	89.5	0.31
Industrial area - 72% impervious, HSG B	88	1.89[a]	93	0.34

1. In this example, regional refers to: a - Norfolk Region; b- Cincinnati Region.

2. The developed conditions composite curve number is calculated as equal to existing composite CN plus a 50% of maximum full development potential of the parcel. A full development potential is where the entire parcel is developed with impervious surface resulting in a composite curve number of 98. Here, it is assumed 50% of maximum full development and calculated as = existing CN+0.5*(98-existing CN).

Table A-8 Summary of Rainfall Analysis (1992 - 2021) – US Installations

	Rainfall Station Name	State	Station ID: GHCND (or GSOD)	Applicable DoDAAC[1] Numbers												Annual Rainfall Depth[2] (inches)	95th Percentile[3] (inches)	Rainy Days[4] (>0.1")	Years of Available Record (1992-2021)
				DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)				
1	YUMA WSO AP	Arizona	USW00003145	M62974	1											3.27	1.32	8	27
2	EL CENTRO 2 SSW	California	USC00042713	N60042	6											2.50	0.91	6	25
3	HETCH HETCHY	California	USC00043939	M64495	36											37.81	1.98	53	25
4	LEEMORE REEVES NAS	California	USW00023110	N44259	27											7.07	0.80	19	27
5	LOS ANGELES WSO AIRPORT	California	USW00023174	N61065	27	N69232	52	N67399	80							12.26	1.56	20	30
6	MONTEREY NWSFO	California	USC00045802	N61014	5											16.90	1.20	35	22
7	SAN DIEGO WSO AIRPORT	California	USW00023188	N62473	1	N00246	3	N63406	5	N00245	6	M00681	30			9.59	1.31	19	30
8	TRAVIS FIELD AFB	California	USW00023202	FA4427	1	FA4686	88									21.43	1.44	38	30
9	TWENTY NINE PALMS	California	69015093121	N67399	14	N68936	126	FA9300	102							2.81	1.16	6	23
10	VICTORVILLE PUMP PLANT	California	USC00049325	N3594A	60	M62204	30	FA9300	49	N68936	80					5.32	1.17	12	26
11	COLORADO SPRINGS WSO AP	Colorado	USW00093037	FA2550	0	FA2509	1									15.78	1.14	34	30
12	GROTON NEW LONDON AIRPORT	Connecticut	USW00014707	N44210	29											37.64	1.61	62	22
13	JACKSONVILLE WSO AP	Florida	USW00013889	N57061	19	N68931	18	N68248	25							52.64	2.03	74	30
14	KEY WEST WSO AIRPORT	Florida	USW00012836	N44222	2											39.76	1.95	59	30
15	MIAMI WSCMO AIRPORT	Florida	USW00012839	N30931	2.5	FA6648	23									67.04	2.33	87	30
16	PANAMA CITY 5 NE	Florida	USC00086842	N44223	9.5	FA4819	18	FA8651	65	N00204	97					60.65	2.30	73	26
17	TAMPA WSO AIRPORT	Florida	USW00012842	FA4814	8											49.65	2.18	67	30
18	ALBANY SW GEORGIA REGIONAL AP	Georgia	72216013869	M67004	9	FA4830	85									47.49	1.97	67	25
19	SAVANNAH WSO AIRPORT	Georgia	USW00003822	M00263	32	N44227	35									47.44	1.95	68	30
20	HONOLULU WSFO AP 703	Hawaii	USW00022521	N62813	1	N62742	3	N00318	10							16.37	2.11	25	30
21	LIHUE AIRPORT	Hawaii	USW00022536	N61064	1											36.03	1.90	61	30
22	BELLEVILLE SCOTT AFB	Illinois	72433813802	FA4407	1											43.19	1.65	70	30
23	CHICAGO OHARE WSO AP	Illinois	USW00094846	N65113	23											37.69	1.46	69	30
24	EVANSVILLE WSO AP	Indiana	USW00093817	N61018	85											48.27	1.81	74	30
25	MANHATTAN REGIONAL AIRPORT	Kansas	72455503936	SZ3586	10											33.26	1.79	53	15
26	FORT CAMPBELL AIRFIELD	Kentucky	74671013806	W34GL1	10											46.56	1.76	77	29
27	NEW ORLEANS WSMO AIRPORT	Louisiana	USW00012916	N44218	9											62.75	2.54	75	30
28	SHREVEPORT AP	Louisiana	USW00013957	FA4608	16											50.20	2.25	64	30

Table A-8 Summary of Rainfall Analysis (1992 - 2021) – US Installations (Cont'd.)

	Rainfall Station Name	State	Station ID: GHCND (or GSOD)	Applicable DoDAAC[1] Numbers												Annual Rainfall Depth[2] (inches)	95th Percentile[3] (inches)	Rainy Days[4] (>0.1")	Years of Available Record (1992-2021)
				DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)				
29	PORTLAND WSFO AP	Maine	USW00014764	N44214	24											47.68	1.65	78	30
30	BALTIMORE WSO ARPT	Maryland	USW00093721	N44201	15	N0417A	14									45.33	1.73	73	30
31	PATUXENT RIVER NAS	Maryland	USW00013721	N00019	0	N47370	33									45.47	1.74	70	27
32	GULFPORT BILOXI AIRPORT	Mississippi	USW00093874	N62604	4	FA3010	11									61.88	2.65	73	23
33	ALBUQUERQUE WSFO AIRPORT	New Mexico	USW00023050	FA7046	10											8.64	0.80	23	30
34	NIAGARA AIR RESERVE STATION	New York	USW00014733	FA6670	1											40.64	1.14	89	30
35	MOREHEAD CITY	North Carolina	USC00315830	M00146	16	M67001	34									60.52	2.32	78	29
36	WRIGHT PATTERSON AFB	Ohio	74570013840	FA8003	1											42.46	1.38	81	30
37	HARRISBURG CAPITAL CITY	Pennsylvania	USW00014751	N32414	9											41.16	1.47	73	21
38	PHILADELPHIA WSO AP	Pennsylvania	USW00013739	N00140	3											44.34	1.68	71	30
39	NEWPORT STATE AIRPORT	Rhode Island	USW00014787	N44211	2	N32411	2									42.04	1.60	70	23
40	CHARLESTON WSO AIRPORT	South Carolina	USW00013880	FA4418	1											52.78	2.08	72	30
41	ELLSWORTH AFB	South Dakota	72662524006	SZ3108	1											17.54	1.18	39	21
42	MEMPHIS WSFO	Tennessee	USW00013893	N44221	18											54.73	2.06	73	30
43	CORPUS CHRISTI WSO AP	Texas	USW00012924	N45974	27	N44215	10	N00216	17							31.69	2.52	39	30
44	LACKLAND AFB	Texas	72253512909	FA7037	1	FA8900	10	FA3002	24							28.91	2.13	41	24
45	NORFOLK WSO AIRPORT	Virginia	USW00013737	N62470	6	FA4521	20									48.99	1.89	72	30
46	WASHINGTON NATL WSO AP	Virginia	USW00013743	N00025	3	N61142	2	N33355	10	N44200	22	N48429	11	MMQQ50	25	42.27	1.61	71	30
47	WILLIAMSBURG 2 N	Virginia	USC00449151	N69212	10											51.50	1.77	79	30
48	SEATTLE TACOMA AP WBAS	Washington	USW00024233	N44255	17											39.55	1.08	90	30
49	SEATTLE SAND POINT	Washington	USW00094290	N68436	29	N68967	31									36.87	0.95	90	26
50	SPARTA	Wisconsin	USC00477997	W911SA	14											34.75	1.47	63	30

Note: [1] See Table A-10 for DoDAAC installation address

[2] Average Annual Rainfall Depth (inches) is averaged over number of years rainfall data is available from 1992 - 2021. In computing the Annual Rainfall Depth, all daily rainfall events (> 0.0 in) are included.

[3] 95th Percentile Rainfall Depth is computed for the most recent 30-year period (from 1992-2021), where available. The calculating 95th percentile rainfall depth daily rainfall depths greater than 0.1" (> 0.1 in) are used. Small rainfall events (≤ 0.1 inch) are lost due to abstractions and typically do not result in runoff.

[4] Average Annual Rainfall Days (> 0.1 inch) is averaged over number of years rainfall data is available from 1992 - 2021.

Table A-9 Summary of Rainfall Analysis (1992 - 2021) – Overseas Locations

	Rainfall Station Name	State	Station ID: GHCND (or GSOD)	Applicable DoDAAC[1] Numbers												Annual Rainfall Depth[2] (inches)	95th Percentile[3] (inches)	Rainy Days[4] (>0.1")	Years of Available Record (1992-2021)
				DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)	DoDAAC	(mi)				
51	BAHRAIN INT. AIRPORT, BA	Bahrain[5]	BA000041150	N63005	6											3.10	3.96	4	26
52	CAMP LEMONNIER	DjIbouti[6]	69675499999	N3379A	7											4.92	4.26	4	12
53	SOUDA AIRPORT	Greece	GR000167460	N66691	8											22.14	2.09	35	30
54	GUAM INTERNATIONAL AIRPORT, US	Guam	GQW00041415	N61755	12	N62395	11									99.75	2.06	152	30
55	GRAZZANISE, IT	Italy	ITM00016253	N62588	1											29.56	1.56	54	19
56	ISTRANA, IT	Italy	ITM00016098	FA5682	3											29.10	1.57	49	30
57	SIGONELLA, IT	Italy	ITW00033126	N62995	2											18.16	1.48	34	28
58	HACHINOHE, JA	Japan	JA000047581	N61060	10											38.03	1.85	61	28
59	YOKOHAMA, JA	Japan	JA000047670	N61054	11											61.87	2.67	73	28
60	BUSAN, KS	South Korea	KSM00047159	N32778	9											61.89	3.72	58	30
61	MORON DE LA FRONTERA, SP	Spain	SPE00120503	FA5575	5											20.04	1.42	39	30
62	ROTA, SP	Spain	SPE00119954	N62863	4											20.85	1.44	38	30

Note: [1] See Table A-10 for DoDAAC installation address

[2] Average Annual Rainfall Depth (inches) is averaged over number of years rainfall data is available from 1992 - 2021. In computing the Annual Rainfall Depth, all daily rainfall events (> 0.0 in) are included.

[3]95th Percentile Rainfall Depth is computed for the most recent 30-year period (from 1992-2021), where available. The calculating 95th percentile rainfall depth daily rainfall depths greater than 0.1" (> 0.1 in) are used. Small rainfall events (≤ 0.1 inch) are lost due to abstractions and typically do not result in runoff.

[4] Average Annual Rainfall Days (> 0.1 inch) is averaged over number of years rainfall data is available from 1992 - 2021.

[5] Bahrain average annual rainfall days (> 0.1 inch) = 4 days. For this reason, the 95th percentile rainfall depth computed is very high due to torrential storms that occur once or twice a year.

[6] Djibouti average annual rainfall days (> 0.1 inch) = 4 days. For this reason, the 95th percentile rainfall depth computed is very high due to torrential storms that occur once or twice a year.

Table A-10 DoDAAC Installation Address

DoDAAC Number	Installation Name	Address
FA2509	Peterson AFB	667 W Ent Ave, Colorado Springs, CO 80914
FA2550	Schriever AFB	210 Falcon Pkwy Ste 2116, Schriever AFB CO 80912-2116
FA3002	Randolph AFB	407 C St W, Randolph Air Force Base, TX 78150
FA3010	Keesler AFB	301 Fisher St, Biloxi MS 39534
FA4407	Us Air Force Scott AFB	201 E Winters St, Scott AFB IL 62225-5015
FA4418	Joint Base Charleston	101 E Hill Blvd, Charleston SC 29404-5021
FA4427	Travis Air Force Base	FA4427 60 CONS LGC, 350 Hangar Ave, Travis AFB CA 94535-2632
FA4521	Langley AFB	11 Nealy Avenue, Hampton VA 23665
FA4608	Barksdale AFB	801 Kenney Ave Bldg. 4400, Barksdale AFB LA 71110-2438
FA4686	Beale AFB	17855 Warren Shingle Rd, Beale Air Force Base, CA 95903
FA4814	MacDill AFB, FL	2610 Pink Flamingo Ave, Tampa FL 33621-5119
FA4819	Tyndall AFB	2580 Hwy 98, Panama City, FL 32403
FA4830	Moody AFB	4210 Bradley Cir, Moody AFB, GA 31699
FA6648	Homestead ARB	29050 Coral Sea Blvd, Homestead, FL 33039
FA6670	Niagara Air Reserve Station, Buffalo	800 Kirkbridge Dr, Niagara Falls NY 14304-5000
FA7037	US Air Force (USAF), San Antonio	102 Hall Blvd Bldg. 2000 Ste 258, San Antonio TX 78243-7091
FA7046	Kirtland AFB	1251 Wyoming Blvd Se, Kirtland AFB NM 87117-0001
FA8003	Wright Patterson AFB	1940 Allbrook Dr Bldg. 1, Wright Patterson AFB OH 45433-5344
FA8651	Eglin AFB	Eglin Pkwy, Eglin AFB, FL 32542
FA8900	Brooks AFB	3201 Sidney Brooks St, San Antonio TX 78235
FA9300	Edwards AFB	305 E Popson Ave, Edwards AFB, CA 93524
M00146	Marine Corps Air Station, Cherry Point	Cherry Point, NC 28533-0018
M00263	MX Marine Corps Regional	Contracting Office PO Box 5069, Marine Corps Recruit Depot/ERR, Parris Island, SC 29905-5069
M00681	NG Marine Corps Regional	Contracting Office PO Box 1609, Oceanside CA 92054-1609
M62204	Marine Corps Logistics Base, Barstow	PO Box 110340, Barstow CA 92311-5039
M62974	Marine Corps Air Station, Yuma	PO Box 99133, Station S-4/3KG, Yuma AZ 85369-9133
M64495	Marine Corps Mountain Warfare Training Center	Box 5009, Bridgeport CA 93517-5009
M67001	NB Marine Corps Regional Contracting Office	PSC Box 20004, Marine Corps Base, Camp Lejeune NC 28542-0004
M67004	Marine Corps Logistics Base (Code 89)	PO Drawer 43019, Albany GA 31704-3019
MMQQ50	Marine Corps Base Quantico	Marine Corps Base G4, 3250 Catlin Ave, Quantico VA 22134-5001
N00019	Naval Air Systems Command, Pax River	47123 Buse Road, Unit IPT, Patuxent River MD 20670-1547
N00025	NAVFAC Washington Navy Yard	1322 Patterson Avenue, Suite 1000, Washington DC 20374-5362

Table A-10 DoDAAC Installation Address (Cont'd.)

DoDAAC Number	Installation Name	Address
N00140	NAVSUP FLT LOG CTR Philadelphia	Naval Support Activity Philadelphia, 700 Robbins Ave, Philadelphia PA 19111-5083
N00204	Naval Air Station Pensacola	150 Hase Rd Suite A, Pensacola FL 32508-1051
N00216	NAS Corpus Christi	9604 Ocean Dr, Corpus Christi, TX 78418
N00245	NAVBASE San Diego	3455 Senn Rd, San Diego CA 92136
N00246	NAVBASE Coronado	4th St, Chula Vista CA 92118
N00318	Marine Corps Air Station Kaneohe Bay	MCBH Kaneohe Bay, HI 96863-5001
N0417A	Naval Support Facility Thurmont	PO Box 1000, Thurmont MD 21788-5001
N30614	Naval Outlying Landing Field	NOLF San Nicolas Island, NAWS Point Mugu CA 93042-5000
N30931	HQ USSOUTHCOM	3511 NW 91St Ave, Miami FL 33172-5000
N32411	NAVSTA Newport	8 Constitution Ave, Middletown, RI 02842
N32414	Naval Support Activity Mechanicsburg	5450 Carlisle Pike, Box 2020, Mechanicsburg PA 17055-0788
N33355	Naval Support Activity Bethesda	4655 Taylor Road, Bldg. 27, Room 308, Bethesda MD 20889
N3594A	Center For Seabees And Facilities	Engineering Bldg. 1444, 3502 Goodspeed Road Suite 1, Port Hueneme CA 93043-4336
N44200	NAVFAC Washington PWD South Potomac	Indian Head FEAD, 4474 McMahon Road Suite 3, Indian Head MD 20640-5035
N44201	NAVFAC Washington PWD, Annapolis FEAD	181 Wainwright Road, Annapolis MD 21402
N44210	NAVFAC Mid Atl PWD New London FEAD	135 Shark Blvd Bldg. 135 Box 26, Naval Submarine Base New London, Groton CT 06349-5026
N44211	NAVFAC Mid Atl PWD Newport FEAD	1 Simonpietri Drive, Newport RI 02841-1712
N44214	NAVFAC Mid Atlantic PWD Maine	FEAD ROICC, 437 Huey Drive Bldg. 53, Brunswick ME 04011
N44215	NAVFAC Southeast PWD Corpus Christi	8851 Ocean Dr Bldg. 19, Corpus Christi TX 78419-5525
N44218	NAVFAC Southeast PWD New Orleans	PW Dept Bldg. 552, New Orleans LA 70143-5000
N44219	NAVFAC Southeast PWD Meridian	229 Allen Rd, Bldg. 427 NAS Meridian, Meridian MS 39309-5427
N44221	PWD Mid-South	5722 Integrity Dr Bldg. 455, Millington TN 38054-5028
N44222	NAVFAC Southeast PWD Key West	PO Box 9018 Bldg. A 629, Key West FL 33040-9018
N44223	NAVFAC Southeast PWD Panama City	101 Vernon Ave, Bldg. 126, Panama City Beach FL 32407-7018
N44227	NAVFAC Southeast PWD Beaufort	PO Box 9310, Moore St Bldg. 658, Beaufort SC 29904-9310
N44251	NAVFAC Contracts (Guantanamo)	NAVFAC Southeast, PWD Guantanamo Bay Cuba, PSC 1005, Box 37, FPO AE 09593
N44255	Engineering Field Activity, Northwest	19917 7th Avenue NE, Poulsbo WA 98370-7570

Table A-10 DoDAAC Installation Address (Cont'd.)

DoDAAC Number	Installation Name	Address
N44259	NAVFAC Southwest PWD Lemoore	750 Enterprise Ave, NAS Lemoore CA 93246-6303
N45974	NAVFAC Southeast PWD Kingsville	201 Nimitz Ave Bldg. 4711, Kingsville TX 78363-5103
N47370	NAVFAC Washington PWD South Potomac	18329 Thomas Road, Dahlgren VA 22448-5000
N68248	Naval Submarine Base	Building 101, 1342 USS Simon Bolivar Road, Kings Bay, Ga 31547-2613
N48429	PWD South Potomac Site Andrews AFB	R53 Bainbridge St, Camp Springs MD 20762
N57061	US Naval Forces Southern Command	PO Box 280003, Mayport FL 32228-0003
N60042	Naval Air Facility El Centro	1605 3Rd Street Bldg. 214, El Centro CA 92243-5001
N61014	NSA Monterey	271 Stone Rd, Monterey CA 93943
N61018	NSA Crane	300 Hwy 361, Bldg. 3219, Crane IN 47522-5001
N61064	Pacific Missile Range Facility	Kekaha, HI 96752
N61065	Naval Weapons Station Seal Beach	Naval Weapons Station, 800 Seal Beach Boulevard, Seal Beach CA 90740-5000
N61142	Joint Base Anacostia Bolling	20 MacDill Blvd, Washington DC 20032-7711
N62470	NAVFAC - Atlantic Division	1510 Gilbert Street, Norfolk VA 23511-2699
N62473	NAVFAC Southwest	1220 Pacific Highway, San Diego CA 92132-5000
N62604	Naval Construction Battalion Center	5200 CBC 2nd Street, Gulfport MS 39501-5001
N62742	NAVFAC - Pacific Division	Building 258, Makalapa Drive, Pearl Harbor HI 96860-7300
N63406	NAVBASE Point Loma	140 Sylvester Rd, San Diego CA 92106
N65113	Navy Public Works Center	210 Decatur Avenue, Building 1A, Great Lakes IL 60088-5600
N67399	Twentynine Palms MCAGCC	Marine Corps Air-Ground Combat Ctr (MCAGCC), I And L, Box 788108, Twentynine Palms CA 92278-8108
N68248	Naval Submarine Base	Building 101, 1342 USS Simon Bolivar Road, Kings Bay GA 31547-2613
N68436	Naval Base Kitsap	120 South Dewey St, Bremerton WA 98314
N68931	FEC Southeast WCF	Det Box 30, Jacksonville FL 32212-0030
N68936	Naval Air Warfare Center	Weapons CT 25400E D, 429 E Bowen Rd Stop 4015, China Lake CA 93555-6018
N68967	NAVSTA Everett	2000 W Marine View Dr, Everett WA 98207
N69212	Naval Weapons Station	WPNSTA 160 Main Rd, Yorktown VA 23691-5111
N69232	NAVBASE Ventura County Pt Mugu	311 Main Rd Ste 1, Point Mugu NAWC, CA 93042
SZ3108	Ellsworth AFB	630 Twining St, Ellsworth AFB SD 57706-4920
SZ3586	DLA Disposition Services Riley	Camp Funston Bldg. 1950, Fort Riley KS 66442-2490
W34GL1	Fort Campbell, KY	CRP Bldg. 5207, 8th and Desert Storm, Fort Campbell KY 42223
W911SA	Us Army, Fort McCoy	Bldg. 1108 South R Street, Fort McCoy WI 54656-5142

Table A-10 DoDAAC Installation Address (Cont'd.)

DoDAAC Number	Installation Name	Address
OVERSEAS LOCATIONS		
FA5575	US Air Force	Base Aérea, 41600 Arahal, Sevilla, Spain
FA5682	US Air Force	600 Via Pordenone 89/B Area E, 33081 Aviano IT
N32778	US Navy, Fleet Activities Chinhae	1 Hyeon-Dong, Bldg. 606, Chinhae-Gu, Changwon-Si, Gyeongsangnam-Do Korea, Republic Of KR 51698
N3379A	Camp Lemonier Djibouti	Horn Of Africa, Camp Lemonier DJ; City - Camp Lemonier
N61054	US Navy, Commander Fleet Act Yokosuka	1 Banchi Tomari Cho Us Naval Base, Yokosuka JP 238-0001
N61060	Naval Air Facility Misawa Japan	1 Chome Hirahata Misawa, Aomori JP 033-0012
N61755	Naval Base Guam	Building 3190, Sumay Drive, Santa Rita Guam GU 96915
N62395	JK Navy Public Works Center, (Mariana Islands, Guam)	PSC 455, Box 195, FPO AP, GU 96540-2937
N62588	Naval Support Activity Naples	PSC 817 Box 1, FPO AE 09622-0000; Di Capodichino Bldg. 415; 80144 Napoli Italy IT
N62863	US Naval Station Rota Spain	Bldg. 55 Naval Station Rota, 11520 Rota ES, Spain, Rota
N62995	US Sigonella Naval Air Station	PSC 812 Box 1000, FPO AE 09627-1000
N63005	Naval Support Activity, Bahrain	Al Hidd Bh 115, Bahrain; City - Al Hidd
N66691	Naval Support Activity Souda Bay	Supply Dept Bldg. 6, Mouzouras Road Comm 30 28210 21256, Chania Crete GR 73100

This Page Intentionally Left Blank

APPENDIX B GLOSSARY

B-1 ACRONYMS AND ABBREVIATIONS.

ARC	Antecedent Runoff Condition
Bio	Biological
BMP	Best Management Practice
CN	Curve Number
CWA	Clean Water Act
DoD	Department of Defense
DoDAAC	Department of Defense Activity Address Code
EISA	Energy Independence and Security Act
EPA	United States Environmental Protection Agency
GHCN	Global Historical Climate Network
GSOD	Global Summary of the Day
HN	Host Nations
HSG	Hydrologic Soil Group
I_a	Initial Abstraction
IMP	Integrated Management Practice
LID	Low Impact Development
NCEI	National Centers for Environmental Information
NEH	National Engineering Handbook of Hydrology
NPDES	National Pollutant Discharge Elimination System
NOAA	National Oceanic and Atmospheric Administration
NRCS	USDA Natural Resources Conservation Service (formerly SCS)
O&M	Operations and Maintenance
OMSI	Operation and Maintenance Support Information
PGDER	Prince George's County Department of Environmental Resources

SCS USDA Soil Conservation Service

SWM Stormwater Management

T_c Time of Concentration

TR-55 NRCS Technical Release 55

UFC Unified Facilities Criteria

USDA United States Department of Agriculture

WMO World Meteorological Organization

B-2 DEFINITION OF TERMS.

95th Percentile Rainfall Event: The 95th percentile rainfall event represents a precipitation amount which 95 percent of all rainfall events for the period of record do not exceed. In more technical terms, the 95th percentile rainfall event is defined as the measured precipitation depth accumulated over a 24-hour period for the period of record that ranks as the 95th percentile rainfall depth based on the range of all daily event occurrences during this period.

The 24-hour period is typically defined as 12:00:00 am to 11:59:59 pm. In general, a 30-year period of rainfall data is recommended for such an analysis, with a required minimum period of 10 years. Small rainfall events that are 0.1 inch or less (that is, ≤ 0.1 inches) are excluded from the percentile analysis because this rainfall generally does not result in any measurable runoff due to absorption, interception, and evaporation by permeable, impermeable, and vegetated surfaces.

Building: DODI 4165.14, Enclosure 2, defines a building as: A roofed and floored facility enclosed by exterior walls and consisting of one or more levels that is suitable for single or multiple functions and that protects human beings and their properties from direct harsh effects of weather such as rain, wind, sun, etc.

Federal Facility: Section 401(8) of EISA states: The term “Federal facility” means any building that is constructed, renovated, leased, or purchased in part or in whole for use by the Federal Government.

Low Impact Development (LID): LID is a stormwater management strategy designed to maintain site hydrology and mitigate the adverse impacts of stormwater runoff and nonpoint source pollution.

LID actively manages stormwater runoff by mimicking a project site’s pre-development hydrology using design techniques that infiltrate, store, and evaporate runoff close to its source of origin. LID strategies provide decentralized hydrologic source control for stormwater runoff. In short, LID seeks to manage the rain, beginning at the point where it falls. The LID features are distributed small-scale controls that closely mimic the hydrological behavior of the pre-project sites for a design storm event.

Pre-Development: pre-project conditions that exist at the beginning of design. Where phased development occurs, the existing conditions at the time prior to the first phase being submitted will establish pre-development conditions.

This Page Intentionally Left Blank

APPENDIX C REFERENCES

DEPARTMENT OF DEFENSE

DODI 4165.14 *Real Property Inventory and Forecasting*

ENVIRONMENTAL PROTECTION AGENCY

EPA 841-B-09-001, *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act*, December 2009
https://www.wbdg.org/ffc/epa/criteria/epa-841-B-09-001

SWMM, Storm Water Management Model, July 2010
https://www.epa.gov/water-research/storm-water-management-model-swmm

Low-Impact Development Design Strategies, An Integrated Design Approach, Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division, January 2000.
https://www.princegeorgescountymd.gov/DocumentCenter/View/86/Low-Impact-Development-Design-Strategies-PDF

Low-Impact Development Hydrologic Analysis, Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division, July 1999.
https://www.princegeorgescountymd.gov/DocumentCenter/View/87/Low-Impact-Development-Hydrologic-Analysis-PDF

NATURAL RESOURCES CONSERVATION SERVICE

TR-55, *Urban Hydrology for Small Watersheds* June 1986
https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=22162.wba

WinTR-20*, Watershed Hydrology*, March 2015

Part 630 Hydrology, National Engineering Handbook of Hydrology, Chapter 4 (NEH-4), 2019

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc

UFC 1-200-01, *DoD Building Code*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 3-201-01, *Civil Engineering*

UFC 3-260-01, *Airfield and Heliport Planning and Design*

UFC 3-420-01, *Plumbing Systems*

UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*

UFC 4-010-06, *DoD Cybersecurity Of Facility-Related Control Systems*

UFC 3-220-01
1 November 2012
Change 2, 17 October 2024

UNIFIED FACILITIES CRITERIA (UFC)

GEOTECHNICAL ENGINEERING

UFC 3-220-01
1 November 2012
Change 2, 17 October 2024

GEOTECHNICAL ENGINEERING

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	11/03/2021	Update to referenced International Building Code 2018 (IBC 2018) as implemented by UFC 1-200-01. Clarifications to requirements not addressed by the current Building Code. Appendix A, B, C, and D updated links.
2	10/17/2024	Update to reference the International Building Code 2021 (IBC 2021) as implemented by UFC 1-200-01. Update to Chapter 2-1.1 to clarify requirements of individuals responsible for design and studies. Update to Chapter 2-4.2.5 to include use of geophysics. Update Chapter 2-4.2.9 to address effects of site grade changes.

This UFC supersedes UFC 3-220-01, dated 1 November 2012.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

JAMES C. DALTON, P.E.
Chief, Engineering and Construction
U.S. Army Corps of Engineers

JOSEPH E. GOTT, P.E.
Chief Engineer
Naval Facilities Engineering Command

SCOTT HARTFORD, Colonel, USAF, P.E.
Acting Director
Facilities Engineering Center of Excellence
AF Civil Engineer Center

MICHAEL McANDREW
Director, Facilities Investment and Management
Office of the Deputy Under Secretary of Defense
(Installations and Environment)

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY SHEET

Document: UFC 3-220-01, *Geotechnical Engineering*

Superseding: UFC 3-220-01, *Geotechnical Engineering,* dated 1 November 2012.

Description of Changes: This UFC adopts and modifies the provisions of the International Building Code 2021 (IBC 2021) consistent with the scope of current military requirements and procedures.

Reasons for Changes:

- The updated UFC is designed to be consistent with and to supplement the guidance contained in the IBC 2021 as modified and implemented by UFC 1-200-01.

- Clarification of requirements not addressed by IBC 2021 are added and use additional industry standards.

Impact: Changes to this document further reduce interpretation and ambiguity that could potentially lead to design and construction conflicts. Increase to costs of DoD facilities are not expected as a result of these changes.

Unification Issues: There are no unification issues.

TABLE OF CONTENTS

TABLES

CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

UFC 1-200-01, "DoD Building Code" adopts and modifies **\2** International Building Code 2021 (IBC 2021) as the building code for DoD. This UFC adopts the updated International Building Code 2021 (IBC 2021) as the basis for use in geotechnical engineering design requirements. Chapter 2 of this UFC further modifies the IBC for specific geotechnical engineering design requirements and is organized by the IBC chapter that each section modifies. The required IBC 2021 section modifications are one of four actions, according to the following legend:

> **[Addition]** – New section added, includes new section number not shown in IBC 2021.
>
> **[Deletion]** – Delete referenced IBC 2021 section.
>
> **[Replacement]** – Delete referenced IBC 2021 section or noted portion and replace it with the narrative shown.
>
> **[Supplement]** – Add narrative shown as a supplement to the narrative shown in the referenced section of IBC 2021. ***/2/***

Effort has been made to adopt non-government standards to the greatest practical extent when they appear to cover the topics and/or the information contained in the former manuals, or when they provide new and innovative methods for geotechnical engineering practices. When non-government criteria does not exist or there is insufficient coverage of the topic in the non-government criteria and where there are unique Department of Defense (DoD) requirements, the existing government criteria from DoD publications are either referenced or have been inserted totally in the document.

1-2 PURPOSE AND SCOPE.

This Unified Facilities Criteria (UFC) provides technical guidance and minimum technical requirements for geotechnical engineering and design of DoD facilities worldwide for all service elements. This guidance and the technical requirements are based on the IBC **\2** 2021 ***/2/*** and the requirements in UFC 1-200-01. This UFC shall be used by geotechnical engineers to develop military construction contract documents for design and construction of DoD facilities. Project conditions may dictate the need for designs that exceed these requirements. This document shall not supersede higher level mandates such as Public Laws (PL), Executive Orders (E.O.), Regulations (CFR), DoD Directives (DoDD) and DoD Instructions (DoDI) unless a specific exemption has been obtained. If a condition or application occurs for which guidance is not provided, the *registered design professional* shall obtain guidance from the *building official* at the earliest stage of design and prior to commission of any act not easily revise without cost to the Government.

1-3 REISSUES AND CANCELS.

This UFC reissues and cancels UFC 3-220-01, Change 1, 3 November 2021.

1-4 APPLICABILITY.

This UFC applies to all service elements and contractors involved in the planning, design and construction of DoD facilities worldwide. For construction outside of the U.S., the design shall comply with the more stringent of the UFC and the Host Nation requirements and regulations.

1-5 GENERAL BUILDING REQUIREMENTS.

UFC 1-200-01, "DoD Building Code," provides applicability of model building codes and government-unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, sustainability, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein. In addition, comply with all contract documents specific requirements.

1-6 REFERENCES.

Appendix A contains a list of references used in this document. The publication date of the code or standard is not included in this document. In general, the latest available issuance of the reference is to be used.

1-7 BEST PRACTICES.

Appendix B identifies background information and practices considered by the DoD as being acceptable for accomplishing certain geotechnical design and engineering services. The Engineer of Record (EoR) or Designer of Record (DoR) is expected to review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from the UFGS or Unified Facilities Criteria, the UFGS and the UFC shall prevail.

1-8 SUPPLEMENTAL RESOURCES.

Appendix C provides a list of reliable sources for information on subjects related to geotechnical engineering, design and construction. These resources are valuable tools to the geotechnical engineer for additional information on topics pertinent to and affiliated with geotechnical engineering.

The glossary in Appendix D contains acronyms, abbreviations, and definitions for terms used in this document.

CHAPTER 2 MODIFICATIONS TO IBC

2-1 CHAPTER 2 DEFINITIONS.

2-1.1 Section 202 DEFINITIONS. [Replacement]

Replace the

\1 Registered Design Professional: A registered design professional, as referred to in this document, is an individual licensed to practice engineering in the project area, knowledgeable in soil mechanics and experienced with the geotechnical conditions and construction practices in the project vicinity. This is the individual referred to as the Engineer of Record (EoR) or Designer of Record (DoR) for the geotechnical portion of the design in other Department of Defense construction requirement documents. **/1/ \2** Under special circumstances, such as conducting engineering or scientific studies not directly related to design, an expert in the field of study who is not licensed in the project jurisdiction may be utilized provided that the individual's credentials are submitted and approved in advance by the *building official*. **/2/**

2-2 CHAPTER 16 STRUCTURAL DESIGN.

2-2.1 Section 1613 EARTHQUAKE LOADS.

2-2.1.1 1613.1 Scope. [Supplement]

Insert the following after the first sentence:

Unless approved by the *building official*, the assessment of liquefaction potential must be based on the Summary Report and supporting documentation contained in NCEER-97-0022, Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils. An acceptable factor of safety associated with liquefaction potential shall meet or exceed those listed in TABLE 2-1 below or conform to local code requirements, whichever is greater. Risk Category is as indicated in Table 1604.5 of IBC **\2** 2021 **/2/**.

TABLE 2-1 MINIMUM FACTOR OF SAFETY FOR LIQUEFACTION

Risk Category	Factor of Safety
I & II	1.0
III & IV	1.1

Factor of safety values stated for risk categories I & II are to prevent structural collapse. Factor of safety values stated for risk categories III & IV are to prevent major non-repairable structural damage. Factor of safety values stated are minimums for an extreme event and some structures or conditions may require a factor of safety in excess of those indicated.

2-2.1.2 1613.2.2 Site class definitions. [Replacement]

Replace the following sentence:

“Where the soil properties are not known in sufficient detail to determine the site class, Site Class D, subjected to the requirements of Section 1613.2.3, shall be used unless the *building official* or geotechnical data determines that Site Class E or F soils are present at the site.”

With:

If the *building official* does not provide an assumed site class, or where the soil properties are not known in sufficient detail to determine the site class, Site Class D shall be assumed for preliminary purposes. However, the registered design professional shall be responsible for verification of the site class used for design. **\1** Verify the site class by assessing the strength and stiffness of the subsurface profile to a depth of 30.5 m (100 ft) using one or more methods specified in ASCE 7. Use applicable data to assess liquefaction potential.

Further, the new ‘requirements’ of IBC **\2** 2021 **/2/** Section 1613.2.3, read “Where Site Class D is selected as the default site class per Section 1613.2.2, the value of Fa shall be not less than 1.2. Where the simplified design procedure of ASCE 7 Section 12.14 is used, the value of Fa shall be determined in accordance with ASCE 7 Section 12.14.8.1, and the values of Fv, SMS and SM1 need not be determined.” These requirements should be included in the replacement. **/1/**

2-3 CHAPTER 17 SPECIAL INSPECTIONS AND TESTS. [REPLACEMENT]

Replace all paragraphs in this chapter relating to soils and foundations with the following:

All special inspections and testing shall be performed and documented as prescribed in the contract documents.

2-4 CHAPTER 18 SOILS AND FOUNDATIONS.

2-4.1 Section 1801 GENERAL.

2-4.1.1 1801.1 Scope. [Replacement]

Replace the current paragraph with the following:

The provisions of this chapter shall apply to Geotechnical Engineering for construction of military facilities. All exceptions must be approved by the *building official* (as defined in UFC 1-200-01). NAVFAC projects shall also conform to the provisions contained in

FC 1-300-09N, Navy and Marine Corps Design Procedures. If conflicts occur with the requirements in this document, the requirements of this document shall take precedence.

2-4.2 Section 1803 GEOTECHNICAL INVESTIGATIONS.

2-4.2.1 1803.1 General. [Supplement]

Add the following after the first sentence:

In addition: All site work, including topographic/hydrographic and soil surveys, shall be coordinated with representatives of the Public Works, Utilities and Energy team, base engineering and other design personnel. During execution of field investigation work, the *registered design professional* shall be responsible for obtaining necessary permits, and complying with applicable laws, codes, and regulations, including OSHA regulations. **\1** The exact location of the geotechnical excavation, whether by drilling or digging, shall be approved by the appropriate authorities, be it the local utility service or by a company hired by the geotechnical engineering firm to locate or “scope” utilities. **/1/** The *registered design professional* shall be responsible for all damages to persons and property that occur as a result of their fault or negligence. The *registered design professional* shall take proper safety precautions to protect all persons and property from physical hazards and unsafe conditions. Upon completion of field investigation, return the property to its original condition except as released in writing by the client activity.

Add the following to the end of the paragraph:

The qualifications of the geotechnical testing laboratory and personnel shall meet ASTM D3740, “Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction”. Adherence to the requirements in the ASTM D420, “Standard Guide to Site Characterization for Engineering Design and Construction Purposes” shall be required for all foundation and soils investigations. See IBC Section 1613 for requirements and procedure to determine site class. **\1** Follow IBC revisions contained within this UFC document. **/1/**

2-4.2.2 1803.2 Investigations required. [Supplement]

Add the following to the end of the paragraph:

Investigations and evaluations (including soil borings, test pits, ground penetrating radar surveys, seismic refraction surveys, and electrical resistivity testing, laboratory testing) shall be in accordance with ASTM D420 and other applicable ASTM standards to the fullest practical extent. The soil classification and investigation shall be supervised by a registered professional engineer. Where ASTM methods are not applicable, procedures and apparatus used shall be in accordance with generally accepted engineering practice.

2-4.2.3 1803.3.1 Scope of Investigation. [Supplement]

Add the following to the end of the paragraph:

Architecture and engineering firms preparing, planning or designing documents shall contact the *building official* to determine if there are files pertaining to the existing geotechnical and seismic conditions or past design approaches for facilities, structures, or pavements that are applicable to the current project. For Design-Build contracts, any relevant Government provided geotechnical or pavement information that is available will be furnished in the Design-Build RFP. Unless approved otherwise by the *building official*, Cone Penetration Test (CPT) holes shall be performed in accordance with ASTM D5778, “Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils” and the soil classification shall be substantiated by visual and laboratory testing of samples recovered from ASTM D1586, “Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils” **\1** and ASTM D1587, "Standard Practice for Thin-Walled Tube Sampling of Fine-Grained Soils", ASTM D3550, “Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils” soil borings. SPT tests and tube samples must be conducted continuously to a depth of 3.7m (12 ft), or 3.7m (12 ft) below the lowest floor elevation, foundation, whichever is greater. Investigate to a depth of 6.2m (20 ft) below the lowest anticipated deep foundations or deeper as determined by the registered design professional. ***/1/*** If geophysical methods including seismic (sonic) methods, electrical and electro-magnetic procedures, gravitational field techniques, and magnetic field methods, are contemplated; then a site visit is required by the *registered design professional* early in the site characterization process.

2-4.2.4 1803.5.4 Ground-water table. [Replacement]

Replace the paragraph with the following:

When encountered, provide the stabilized groundwater elevation with the anticipated variation with the local causes for variation (e.g., seasonal, tidal, etc.). The stabilized groundwater elevation will be measured after 24 hours unless determined otherwise by the *registered design professional*. If drilling techniques are used that prevent the measurement of the water table levels, the Contractor shall install at least two piezometers per drilling site to more accurately measure the depth to the water table. A sufficient number of readings (locations) shall be obtained to establish a representative groundwater depth profile for the project site. Piezometers are required for storm water pond investigations. Piezometers are not required if the ground water levels can be accurately measured during drilling operations or there is good evidence that the water table is not within the depth of the borings or zone of influence for the foundation or structure.

2-4.2.5 1803.5.6 Rock strata. [Supplement]

Add the following to the end of the paragraph:

Limestone areas suspected of containing solution channels or cavities or other areas suspected to have karst topography or subsurface voids shall be investigated by **\2** a combination of boring, probing, test pits and geophysical methods /**2**/ as determined by the *registered design professional*. A sufficient number of borings, probes and/or test pits shall be performed to verify the subsurface conditions as being adequate to support foundations. Unless specified otherwise in the contract requirements, the investigation shall determine, (a) the depth of overburden in areas of foundations and excavations; (b) the type and hardness of material encountered; and (c) the degree of difficulty expected to be encountered in excavation. Design of foundations in rock shall include bearing capacity, settlement, sliding stability analyses and consideration of the effects of seepage and grouting to prevent seepage. Rock- Mass Classification shall be determined by one of the systems proposed in ASTM D5878, "Standard Guides for Using Rock-Mass Classification Systems for Engineering Purposes".

2-4.2.6 1803.5.11 Seismic Design Categories C through F. [Supplement]

Add the following to the end of the paragraph:

\1 Refer to UFC 3-301-02 for Risk Category V structures, and to UFC 3-301-01 for all other structures. **/1/**

2-4.2.7 1803.5.12 Seismic Design Categories D through F. [Supplement]

Add the following to the end of the paragraph:

\1 Refer to UFC 3-301-02 for Risk Category V structures, and to UFC 3-301-01 for all other structures. **/1/**

2-4.2.8 1803.6 Reporting. [Replacement]

Replace the first paragraph with the following:

A geotechnical report must be provided to the *building official* by the *registered design professional* on all contracts unless waived by the *building official*. Unless directed otherwise, provide the report electronically in PDF format and two (2) print copies of the report. The PDF copy of the report shall be produced directly from the report's authoring software. All Geotechnical Reports shall be signed and sealed by the *registered design professional*. **\1** Include in-situ testing data source files with the electronic submittal of the geotechnical report. **/1/**

Replace item 1 with the following:

Plot(s) indicating the location of all testing, samples or investigations. The plot(s) shall be to scale and shall clearly indicate the location of each test, etc. on the project site as well as the location of the project on the facility.

Replace item 4 with the following:

When encountered, provide the stabilized groundwater level and identify any factors that influence the groundwater elevation (i.e., tidal or seasonal variation, etc.) and any potential influence of groundwater on the project during both design and during construction.

2-4.2.9 1803.6 Reporting. [Supplement]

Add the following to the end of the section:

11. Seismic site classification and liquefaction potential.
12. Global Positioning System (GPS) coordinates, with an accuracy of at least 3 feet (1 m) for each soil boring, coring or test pit location, referenced to the datum and stated in coordinates required by the *building official*. Reference WGS84 and state in degrees of latitude and longitude for Navy projects.
13. Gradation, moisture content and/or Atterberg tests results per stratum exceeding 1.5 m (5 ft) thickness.
14. Soil corrosivity test results with recommended mitigation construction practices.
15. Observed indication of soil or groundwater contamination.
16. Structural properties tests (i.e. hydraulic conductivity, consolidation, shear strength, triaxial shear, collapse/swell potential, etc.) and dynamic tests (cyclic loading, resonant column, ultrasonic pulse, etc.) when required to support particular design problems.
17. The professional seal and signature of the *registered design professional*.
18. For Cone Penetration Tests (CPT), presentation of results shall include soil stratigraphy in a manner discernable in black and white prints, similar to those provided for soil borings, unless otherwise stated in the contract documents. Include tabulated CPT data.
19. Report the occurrence of permafrost and the accommodations that must be made for the design of the project.
20. When rock is encountered, classify rock in accordance with ASTM D5878, “Standard Guide for Using Rock-Mass Classification Systems for Engineering Purposes” and report the characteristics determined for the specific engineering purpose of the investigation.
21. Provide hammer type used for SPT testing (i.e. manual or automatic) and corrected “N” values with uncorrected values in parenthesis. Supporting information must include energy ratio and supporting calibration data.
22. Provide written and graphic subsurface profiles. Profiles must indicate the elevation of features and based on the report data. Profiles must provide soil and rock stratigraphy, groundwater data, penetration resistance data and all other pertinent data.
23. Site preparation recommendations with any special precautions (e.g., soft soil conditions, high groundwater, etc.) including any equipment limitations and any special requirements (e.g., over-excavation and replacement) and any special

precautions. **\2** Address the effects of site grade increases/decreases. **/2/**

24. Recommended pavement section(s) with a discussion of the variables (e.g., subgrade CBR and modulus k) used to determine the pavement section(s).

25. **\1** Calculations to support all conclusions, recommendations, and analyses. Include references, factor of safety used, soil model, etc. **/1/**

2-4.3 Section 1804 EXCAVATION, GRADING AND FILL.

2-4.3.1 1804.1 Excavation near foundations. [Supplement]

Add at the end of this paragraph:

There shall be no excavation in the proximity of an existing foundation without approval of the *building official*. Prior to excavation, provide calculations verifying there will be no loss of support for all excavations closer than the excavation depth to an existing foundation.

2-4.4 Section 1805 DAMPPROOFING AND WATERPROOFING.

2-4.4.1 1805.1.3 Ground-water control. [Replacement]

Replace the first sentence with the following:

Where the ground-water table is lowered and maintained at an elevation 12 inches (305 mm) or more below the bottom of the lowest floor or working level, the floor and walls shall be dampproofed in accordance with Section 1805.2.

Add the following to the end of the paragraph:

Since permanent groundwater control systems must operate continuously without interruption, they shall be conservatively designed and mechanically simple to avoid the need for complicated control equipment subject to failure and the need for operation personnel. When temporary dewatering is required during construction, the dewatering shall be in accordance with UFC 3-220-05, “Dewatering and Groundwater Control” and the groundwater shall be maintained a minimum of 12 inches (305 mm) below the working level or base of the excavation. The *registered design professional* shall provide all documentation required by the *building official* to ensure the dewatering procedure does not cause damage to any existing structures, utilities or pavements and ensure the process complies with applicable safety requirements.”

2-4.4.2 1805.4.3 Drainage discharge. [Supplement]

Add the following to the end of the paragraph:

Sedimentation and erosion control shall be incorporated in all new construction projects.

2-4.5 Section 1806 PRESUMPTIVE LOAD-BEARING VALUES OF SOILS.

2-4.5.1 1806.1 Load combinations. [Supplement]

Add to the beginning of the paragraph:

Unless otherwise provided or required in the contract documents, load bearing values shall be based on site specific analysis determined by a *registered design professional* as a result of a geotechnical investigation for all structures except minor construction such as equipment or storage sheds less than 55.75 sq m (600 sf). Use the factors of safety provided in Tables 2-2 and 2-3 in developing the allowable bearing values for site specific designs.

TABLE 2-2 MINIMUM FACTORS OF SAFETY (FS) FOR FOUNDATIONS IN ROCK

LOADING CONDITION		FACTOR OF SAFETY (FS)
Bearing		
	Structural Foundations (DL+LL)	3.0
Sliding		
	Dams, Basin Walls	2.5
	Static Loading	2.0
	Seismic Loading	1.3
	Retaining Walls on Rock	1.5
Rock Slopes		
	Severe Consequence of Failure	2.0
	Minor Consequence of Failure	1.3
	Seismic Loading	1.1
Rock Anchorage		
	Based on Unit Weight of Rock Mass	1.5
	Based on Rock Mass Cohesion Intercept	4.0
\1\Pile Foundations Anchored in Rock /1/		
	For pile groups, end bearing piles resting in bedrock may have an efficiency of 1. Buoyancy should be considered in tensile resistance to pull out. The possibility of buckling below the mudline should be evaluated for high capacity piles driven through soft soils to bedrock.	3
\1\ Drilled Shafts/Piers/ Caissons Anchored in Rock /1/		
	Socket into the rock effects the load transfer. Inspection of the bottom of the hole may be needed to ensure the bearing stratum is what was anticipated. For piers extending into Rock assume no load transfer takes place along the soil pier interface. For piers likely to be subjected to tensile loads, reinforcement should be continued for the entire length of the pier.	2.5-4 Depending on uncertainties in loading, stratification, and verification testing.

TABLE 2-3 MINIMUM FACTORS OF SAFETY (FS) FOR FOUNDATIONS IN SOIL

STRUCTURE		FACTOR OF SAFETY (FS)*
Retaining		
	Walls	3.0
	Temporary Braced Excavations	>2
Bridges		
	Railway	4.0
	Highway	3.5
Buildings		
	Silos	2.5
	Warehouse	2.5*
	Apartments, Office	3.0
	Light Industrial, Public	3.5
Footings, Other		3
Mats		>3
\1\ Deep Foundations /1/		
	With static load tests	2
	With dynamic pile analysis including signal matching	2.25 (Compression) 3.0 (Tension)

Notes for Table 2-3:

* Use FS >3 for projects that require extreme limitations on total and differential movements such as super-flat warehouse floors that are needed to accommodate modern transport equipment.

These FS's are conservative and will generally limit settlement to acceptable values, but economy may be sacrificed in some cases.

FS selected for design depends on the extent of data available on subsoil characteristics and their variability. A thorough and extensive subsoil investigation and extensive testing may permit use of a smaller FS. Use of a FS less than the minimum listed above requires formal approval by the Building Official.

FS should generally be $\geq$ 2.5 and never less than 2.

2-4.5.2 1806.2 Presumptive load-bearing values. [Deletion]

Delete the exception statement at the end of this paragraph.

2-4.6 Section 1807 FOUNDATION WALLS, RETAINING WALLS AND EMBEDDED POSTS AND POLES.

2-4.6.1 1807.1.3 Rubble Stone Foundation Walls. [Replacement]

Replace the paragraph with the following:

Rubble stone foundation walls are not allowed.

2-4.6.2 1807.1.4 Permanent Wood Foundation Systems. [Replacement]

Replace the paragraph with the following:

Permanent wood foundation systems are not allowed. **\1** Timber piles are allowed where deemed appropriate by the *registered design professional* and approved by the *building official*. **/1/**

2-4.6.3 1807.2.3 Safety factor. [Replacement]

Replace last sentence in paragraph with the following:

The factor of safety against sliding, calculated as the ratio of forces resisting movement to the horizontal component of earth plus water pressure on the back wall, whether in soil or rock shall be not less than 2.0. In rock, the sliding seismic loading factor of safety is 1.3.

2-4.6.4 1807.3.2.3 Vertical load. [Replacement]

Replace the paragraph with the following:

The resistance to vertical loads shall be determined by the *registered design professional* based on an analysis of the site soil conditions. The presumptive allowable soil-bearing pressures set forth in Table 1806.2 may be used for preliminary design purposes and for minor construction (e.g., non-critical equipment pad or shed, etc.) where a site investigation is not warranted.

2-4.7 Section 1808 FOUNDATIONS.

2-4.7.1 1808.2 Design for capacity and settlement. [Supplement]

Add the following at the end of this paragraph:

The ultimate bearing capacity shall be evaluated using the results from the geotechnical investigation and appropriate in-situ and laboratory analyses.

\1 Foundation settlements shall be estimated using deformation analyses based on the results of laboratory or in situ testing. The soil parameters used in the analyses shall be chosen to reflect the loading history of the ground, the construction sequence and the effect of soil layering. Both total and differential settlements, including time effect, shall be considered. Ultimate bearing capacity and settlement analysis shall be performed using a minimum of three (3) widely accepted methods of analysis. The guidance provided in Appendix B shall be utilized for the determination of widely accepted methods of analysis. **/1/** Foundations shall be designed such that the net allowable bearing capacity of the soil is not exceeded, and that total and differential settlement is limited to acceptable values, as defined below. Except for minor construction (e.g., equipment sheds, storage sheds, etc. less than 55.75 sq m (600 sf)) minimum width of individual column or pier foundations shall be 610 mm (24 inches) and continuous footings shall be 457 mm (18 inches) wide or 203 mm (8 inches) wider than the supported wall, whichever is greater.

Design of foundations in rock shall include bearing capacity, settlement and sliding stability analyses, and consider the effects of seepage and grouting to control seepage.

Using statistical analyses, compute total settlement at a sufficient number of points to establish the overall settlement pattern. In no case shall total settlement be computed at less than two (2) points. Determine the greatest difference in settlement between adjacent foundation units from this pattern. Designs shall incorporate measures that limit total and differential settlement to levels that prevent structural or cosmetic damage or impairment of the serviceability and function of the facility or structures, including affected drainage and utilities.

\1 Unless approved by the *building official*, total post construction settlement may not exceed tolerable limits based on building type and dimension, or 25.4 mm (1 in.), whichever is less. Differential settlements shall not result in an angular distortion in excess of 1/500. The angular distortion is defined as the difference in settlement between two points divided by the distance between the points. Acceptable values for total and differential settlement shall give consideration to the purpose and design life of the facility, the materials used for construction, the conditions (environmental, subsurface and external forces) that the facility will be exposed to, and any project-specific requirements. Reference guidance in Appendix B-3.7 for typical limits based on building type and materials. **/1/**

Slab-on-grade concrete floors shall be designed so that any settlement of the floor shall not result in harmful distortion of the floor or misalignment of the floor with any other building components (such as doorways, trenches or structural elements) or building utilities.

2-4.7.2 1808.3 Design loads. [Supplement]

Add the following to the end of the paragraph:

Consideration of possible future events such as dewatering and flooding due to storms is also required.

2-4.7.3 1808.4 Vibratory loads. [Supplement]

Add the following to the end of the paragraph:

Design foundations in accordance with ACI 351.3R, “Foundations for Dynamic Equipment” and ACI 350.4R, “Design Considerations for Environmental Engineering Concrete Structures”.

2-4.7.4 1808.6 Design for expansive soils. [Supplement]

Add the following to the end of the first paragraph:

Surface soils shall be examined for gilgai whenever expansive soils are suspected.

2-4.7.4.1 1808.6.2 Slab-on-ground foundations. [Supplement]

Add the following at the end of this paragraph:

Structurally supported slabs cast on the ground or above ground shall provide support for all under slab utilities to accommodate their in-service dead and live load using structurally supported trenches and/or stainless steel hangars.

2-4.7.4.2 1808.6.4 Stabilization. [Supplement]

Add the following to the end of the paragraph:

Construction techniques that promote a constant moisture regime in the foundation soils during and following construction shall be used.

2-4.7.5 1808.7.5 Alternate setback and clearance. [Replacement]

Replace the paragraph with the following:

Alternate setback and clearances are permitted subject to the approval of the *building official*. For consideration, the contractor must provide the recommendation of a *registered design professional* substantiated with the results of an investigation that demonstrates the intent of this section has been satisfied.

2-4.7.6 1808.8.6 Seismic requirements. [Deletion]

Delete exceptions at end of paragraph.

2-4.7.7 1808.8.7 Concrete reinforcement. [Addition]

For footings over 0.914 m (3 ft) thick, the minimum ratio of reinforcement area to gross concrete area in each direction shall be 0.0015, with not less than one-half nor more than two-thirds of the total reinforcement required placed in any one face. Minimum bar size shall be #13M (No. 4) with a maximum spacing of 305 mm (12 inches).

2-4.8 Section 1809 SHALLOW FOUNDATIONS.

2-4.8.1 1809.4 Depth and width of footings. [Replacement]

Replace the paragraph with the following:

The minimum depth of footings below the finished ground surface shall be 457 mm (18 inches). Spacing between footings shall be at least 1.5 times the width of the larger foundation to minimize any reduction in bearing capacity due to overlapping zones of influence. The most appropriate foundation types shall be designed, in a preliminary manner and foundation type selection based on a detailed cost comparison of these designs. The minimum footing size shall be as indicated in paragraph 1808.2 revisions in this UFC.

2-4.8.2 1809.5 Frost Protection. [Deletion]

Delete the exception statements at the end of this paragraph.

2-4.8.3 1809.5 Frost Protection. [Replacement]

Replace the last sentence of the paragraph with the following:

Shallow foundations shall not bear on frozen soil unless such frozen condition is of a permanent character and specifically allowed by the contract documents.

2-4.8.3.1 1809.5.1 Frost line depth. [Addition]

Depths to the frost line at specific locations within the United States, its territories and possessions, and at specific locations outside of the United States are identified in UFC 3-301-01, "Structural Engineering". At locations where frost depths are not provided, use the more stringent of the nearest listed location and the local building code requirement. Conflicts shall be brought to the *building official*'s attention at the earliest stage of design. Additional guidance on frost depth determination and design can be found in Appendix B.

2-4.8.4 1809.9 Masonry-unit footings. [Replacement]

Replace this subsection paragraph with the following sentence:

Masonry-unit footings are not permitted.

2-4.8.5 1809.11 Steel grillage footings. [Replacement]

Replace this subsection paragraph with the following sentence:

Steel grillage footings are not permitted.

2-4.8.5.1 1809.12 Timber footings. [Replacement]

Replace this subsection paragraph with the following sentence:

Timber footings are not permitted. **\1** Treated timber piling is allowed. **/1/**

2-4.9 Section 1810 DEEP FOUNDATIONS.

2-4.9.1 1810.1 General. [Supplement]

Add the following to the end of this paragraph:

Applied loads shall not cause excessive vertical and lateral displacements of the pile or drilled shaft. See Section 1808.2 including revisions in this UFC.

2-4.9.2 1810.2 Analysis. [Supplement]

Add the following to the end of this paragraph:

Applied loads shall not cause excessive vertical and lateral displacements of the pile or drilled shaft. See Section 1808.2 including revisions in this UFC.

2-4.9.3 1810.2.5 Group effects. [Supplement]

Add the following at the end of this paragraph:

See Section 1808.2 including revisions in this UFC.

2-4.9.4 1810.3.2.1 Concrete. [Supplement]

Insert the following statement at the end of this paragraph:

Material specifications shall conform to ACI 543R, "Guide to Design, Manufacture, and Installation of Concrete Piles".

2-4.9.5 1810.3.2.5 Protection of materials. [Replacement]

Replace the first sentence of the paragraph to read:

Where boring records or site conditions indicate possible deleterious action on the materials used in deep foundation elements because of soil constituents, changing water levels or other factors, the *registered design professional* and/or the *Designer of Record* shall evaluate materials, methods or processes to adequately protect these foundation materials and provide recommendations for approval by the *building official*.

2-4.9.6 1810.3.3.1.6 Uplift capacity for grouped deep foundation elements. [Supplement]

After ". . . largest single element", add the following:

"with the optimum pile spacing being 3 to 3.5B (Vesic 1967) or greater than 0.02L + 2.5B, where L is the pile length in feet and B equals the least horizontal dimension of the largest single deep foundation element."

2-4.9.7 1810.4.4 Pre-excavation. [Replacement]

Replace first sentence in the paragraph to read:

The use of jetting, augering or other methods of pre-excavation shall be evaluated by the *registered design professional* and subject to the approval of the *building official*.

2-4.9.8 1810.4.13 Noise. [Addition]

The entire matter of allowable noise disturbance is subjective and shall be carefully evaluated before seeking special methods to reduce its effect.

2-1.1.1.1 1810.4.14 Airfield Clearance. [Addition]

Cranes and other tall equipment used to install deep foundations or site improvement features (e.g., wicks, sand drains, etc.) shall comply with the requirements of UFC 3-260-01, "Airfield and Heliport Planning and Design" including equipment height, clearance and marking requirements.

2-4.10 Section 1811 SLOPE STABILITY. [Addition]

2-4.10.1 1811.1 General. [Addition]

Slopes shall be designed and constructed in accordance with Section 1811.2.

2-4.10.2 1811.2 Geotechnical Investigations and stability analyses. [Addition]

Follow guidelines established in Section1803 as modified herein and with special emphasis on ground water and seepage site information. Liquefaction is a major concern for slope stability and shall be investigated thoroughly. Several methods of stability analyses shall be employed to ensure greater accuracy and safety in final design. Structural properties testing shall be accomplished for slopes where consequences of failure endanger human life and/or high value structures. Safety factors used in design of new construction or evaluation of existing conditions shall be evaluated by the *registered design professional* and subject to the approval of the *building official* at the earliest stages of the design/evaluation. Acceptable values for factors of safety shall be derived from guidance in Best Practices document EM 1110-2-1902, "Slope Stability", and evaluation of the conditions (environmental, subsurface and external forces) that the facility will be exposed to, and any project-specific requirements.

2-4.11 Section 1812 GEOSYNTHETICS. [Addition]

2-4.11.1 1812.1 General. [Addition]

Applications using geosynthetics shall be designed and constructed using the most current industry accepted practices and standards, along with applicable guidance from Best Practices document UFC 3-220-08FA, "Engineering Use of Geotextiles". Safety factors shall be applied as stated herein for the type of structure being designed.

2-4.11.2 1812.2 Geosynthetics design and use in construction. [Addition]

Geosynthetics functions include pavement reinforcement, separation, filtration (water and gases), drainage, reinforced embankments, impermeable liners, railroads, erosion and sediment control, and earth retaining walls. **\1** For landfill design and construction, follow guidance from applicable Environmental Protection Agency (EPA) and Geosynthetic Research Institute (GRI) publications. **/1/**

Geosynthetics must be manufactured for the purpose intended, whether woven, non-woven, method of bonding, whether made from polypropylene, polyester, polyethylene, polyamide (nylon), polyvinylidene chloride, fiberglass or bonded with clay. Strength considerations vary from very low as in non-woven fabrics to very high tensile strength as geogrids. Durability must be considered in exposure to sunlight, ground water, chemicals (landfill liners), asphalt (pavement applications), and temperature of the environment. In drainage design the apparent opening size is important in maintaining drainage and filtration. In construction, important factors are making connections whether in overlapping edges and ends or sewing seams at these intersections and the exposure to sunlight before and after installation.

2-5 CHAPTER 33 SAFEGUARDS DURING CONSTRUCTION.

2-5.1 Section 3304 SITE WORK. [Replacement]

Replace this section with the following:

All site work shall be performed and documented as prescribed in the approved contract documents.

\1 Designer must consider the differential settlement of the site in relation to the structure or critical areas to ensure that utility connections will not fail. **/1/**

This Page Intentionally Left Blank

APPENDIX A REFERENCES

AMERICAN CONCRETE INSTITUTE

www.concrete.org

ACI 543R, Guide to Design, Manufacture, and Installation of Concrete Piles

ACI 350.4R, Design Considerations for Environmental Engineering Concrete Structures

ACI 351.3R, Foundations for Dynamic Equipment

AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE)

ASCE 7, Minimum Design Loads for Buildings and Other Structures

ASCE 32-01, Design and Construction of Frost-Protected Shallow Foundations

ASCE 41, Seismic Evaluation and Retrofit of Existing Buildings

ASTM INTERNATIONAL

http://www.astm.org/

ASTM D420, Standard Guide to Site Characterization for Engineering Design and Construction Purposes

ASTM D1586, Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils

ASTM D1587, Standard Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes

ASTM D3550, Standard Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils

ASTM D3740, Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

ASTM D5778, Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils

ASTM D5878, Standard Guides for Using Rock-Mass Classification Systems for Engineering Purposes

INTERNATIONAL CODE COUNCIL

http://www.iccsafe.org/

International Building Code – 2021 Edition

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

http://www.buffalo.edu/mceer/catalog.host.html/content/shared/www/mceer/publications/NCEER-97-0022.detail.html

NCEER-97-0022, Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils

UNIFIED FACILITIES CRITERIA

http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

UFC 1-200-01, DoD Building Code

FC 1-300-09N, Navy and Marine Corps Design Procedures

UFC 3-220-05, Dewatering and Groundwater Control

UFC 3-220-08FA, Engineering Use of Geotextiles

UFC 3-220-10, Soil Mechanics (DM 7.1)

UFC 3-260-01, Airfield and Heliport Planning and Design

UFC 3-301-01, Structural Engineering

U.S. ARMY CORPS OF ENGINEERS

https://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/?udt_43544_param_page=1

EM 1110-2-1902, Slope Stability

VESIC, A.S.

Ultimate Loads and Settlements of Deep Foundations in Sand, Proc., Symposium on Bearing Capacity and Settlement of Foundations, Duke University, Durham, N.C. 1967, p. 53

APPENDIX B BEST PRACTICES

B-1 INTRODUCTION.

This appendix identifies background information and practices considered by the DoD as being acceptable for accomplishing certain geotechnical design and engineering services. The Designer of Record (DoR) is expected to review and interpret this guidance and apply the information according to the needs of the project. If a Best Practices document has guidelines or requirements that differ from the UFGS or Unified Facilities Criteria, the UFGS and the UFC shall prevail.

B-2 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide provides additional information and discussion on practice and facility design, including a holistic approach to integrated design of facilities.

The WBDG website provides access to all Construction Criteria Base (CCB) criteria, standards and codes for the DoD Military Departments, National Aeronautics and Space Administration (NASA), and others. These include, Unified Facilities Criteria (UFC), Unified Facilities Guide Specifications (UFGS) and other construction criteria. For approved Government employees, it also provides access to non-government standards.

B-3 GEOTECHNICAL ENGINEERING RELATED GUIDANCE.

The following documents provide guidance on the specific topics indicated. Obtain the indicated UFC documents from the WBDG, the EM documents from http://publications.usace.army.mil/publications/ and ETL documents from https://www.publications.usace.army.mil/USACE-Publications/Engineer-Technical-Letters/.

B-3.1 UFC 3-130-04 FOUNDATION FOR STRUCTURES: ARCTIC AND SUBARCTIC CONSTRUCTION

B-3.2 UFC 3-130-06 CALCULATION METHODS FOR DETERMINATION OF DEPTH OF FREEZE AND THAW IN SOIL: ARCTIC AND SUBARCTIC

B-3.3 UFC 3-220-04FA BACKFILL FOR SUBSURFACE STRUCTURES

B-3.4 UFC 3-220-05 DEWATERING AND GROUNDWATER CONTROL

B-3.5 UFC 3-220-08FA ENGINEERING USE OF GEOTEXTILES

B-3.6 UFC 3-220-10 SOIL MECHANICS (DM 7.1)

B-3.7 USACE EM 1110-1-1904 Engineering and Design: SETTLEMENT

ANALYSIS

B-3.8 USACE EM 1110-1-1905 Engineering and Design: BEARING CAPACITY OF SOILS

B-3.9 USACE EM 1110-1-2907 Engineering and Design: ROCK REINFORCEMENT

B-3.10 USACE EM 1110-1-2908 Engineering and Design: ROCK FOUNDATIONS

B-3.11 USACE EM 1110-2-1421 Engineering and Design: GROUNDWATER HYDROLOGY

B-3.12 USACE EM 1110-2-1901 Engineering and Design: SEEPAGE ANALYSIS AND CONTROL FOR DAMS CH 1

B-3.13 USACE EM 1110-2-1902, Engineering and Design: SLOPE STABILITY

B-3.14 USACE EM 1110-2-2502 Engineering and Design: RETAINING AND FLOOD WALLS

B-3.15 USACE EM 1110-2-2503 Engineering and Design: DESIGN OF SHEET PILE CELLULAR STRUCTURES COFFERDAMS & RETAINING STRUCTURES

B-3.16 USACE EM 1110-2-2504 Engineering and Design: DESIGN OF SHEET PILE WALLS

B-3.17 USACE EM 1110-1-3500 Engineering and Design: CHEMICAL GROUTING

B-3.18 USACE EM 1110-1-1802 Engineering and Design: GEOPHYSICAL EXPLORATION FOR ENGINEERING AND ENVIRONMENTAL INVESTIGATIONS

B-3.19 USACE EM 1110-1-1804 Engineering and Design: GEOTECHNICAL INVESTIGATIONS, ENG 1836, ENG 1836A

B-3.20 USACE EM 1110-1-2909 Engineering and Design: GEOSPATIAL DATA AND SYSTEMS

B-3.21 USACE EM 1110-2-1908 Engineering and Design: INSTRUMENTATION FOR EMBANKMENT DAMS AND LEVEES

B-3.22 USACE EM 1110-2-1909 Engineering and Design: CALIBRATION OF LABORATORY SOILS TESTING EQUIPMENT

B-3.23 USACE EM 1110-2-1911 Engineering and Design: CONSTRUCTION CONTROL FOR EARTH AND ROCK- FILL DAMS

B-3.24 USACE ETL 1110-2-352 Engineering and Design: STABILITY OF GRAVITY WALLS, VERTICAL SHEAR

B-3.25 USACE ETL 1110-2-544 Engineering and Design: GEOTECHNICAL ANAYLSIS BY THE FINITE ELEMENT METHOD

B-3.26 USACE ETL 1110-2-547 Engineering and Design: INTRODUCTION TO PROBABILITY AND RELIABILITY METHODS FOR USE IN GEOTECHNICAL ENGINEERING

B-3.27 American Society of Civil Engineers, SEI/ASCE 32-01 Design and Construction of Frost-Protected Shallow Foundations and ASCE 20-96, Standard Guidelines for the Design and Installation of Pile Foundations

B-3.28 Transportation Research Board, NCHRP Program Report VOL. 343, Engineering Manual for Shallow Foundations, Driven Piles, Drilled Shafts, Retaining Walls, and Abutments

B-3.29 A Study of Bearing Capacity of Deep Foundations, Georgia Institute of Technology, Atlanta, 1967

This Page Intentionally Left Blank

APPENDIX C SUPPLEMENTAL RESOURCES

INTRODUCTION

The following references are reliable sources for information related to geotechnical engineering and design. These sources provide direction for specific geotechnical applications not addressed in this UFC or provide additional information to guide or aid the designer in the various phases of the design. This list is provided for the convenience of the designer and may not include references for all specific applications relevant to all projects. The designer is responsible for insuring the design conforms to all criteria relevant to the project.

UNIFIED FACILITIES CRITERIA

http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

UFC 3-220-06, GROUTING METHODS AND EQUIPMENT

UFC 3-250-11, SOIL STABILIZATION FOR PAVEMENTS

ARMY CORPS OF ENGINEERS PUBLICATIONS

http://publications.usace.army.mil/publications/

https://discover.dtic.mil/

USACE EM 1110-2-2300 Engineering and Design: GENERAL DESIGN AND CONSTRUCTION CONSIDERATIONS FOR EARTH AND ROCK-FILL DAMS

USACE EM 1110-3-136 Engineering and Design: DRAINAGE AND EROSION CONTROL-MOBILIZATION CONSTRUCTION

USACE EM 1110-3-137 Engineering and Design: SOIL STABILIZATION FOR PAVEMENTS-MOBILIZATION CONSTRUCTION

USACE ER 1110-1-261 Engineering and Design: QUALITY ASSURANCE OF LABORATORY TESTING PROCEDURES

USACE ETL 1110-1-138 Engineering and Design: STANDARD PENETRATION TEST

USACE ETL 1110-1-185 Engineering and Design: GUIDELINES ON GROUND IMPROVEMENT FOR STRUCTURES

USACE ETL 1110-2-282 Engineering and Design: ROCK MASS CLASSIFICATION DATA REQUIREMENT FOR RIPPABILITY

NON-GOVERNMENT INDUSTRY PUBLICATIONS

ADSC: The International Association of Foundation Drilling, 8445 Freeport Parkway, Suite 325, Irving, TX 75063, Telephone: 469-359-6000, Website: www.adsc-iafd.com

Caterpillar Tractor Company, Handbook of Ripping, 8th Edition, Peoria, IL

Cambridge University Press, The Edinburgh Building, Cambridge, CB2 8RU, UK Rock Mechanics and Engineering, by C. Jaeger

Center for Geotechnical Research, Virginia Tech, Blacksburg, VA 24061, Dr. George Filz, Director, E-mail: filz@vt.edu, Phone: 540-231-7151 Website: https://cgpr.cee.vt.edu/

Deep Foundations Institute, 326 Lafayette Avenue, Hawthorne, NJ 07506 Telephone: 973-423-4030, Website: www.dfi.org

Elsevier Publications, The Boulevard, Langford Land, Kidlington Oxford, Engineering Rock Mechanics (Pt. 1, 2) by J.A. Hudson, J.P. Harrison

Geosynthetics Specifiers Guide, Geosynthetics Magazine, Geosynthetic Materials Association,1801 County Road B, West, Roseville, MN 55113, Telephone: 651-222-2508, Website: http://geosyntheticsmagazine.com/

The Geotechnical Directory website: www.geotechnicaldirectory.com

The Geotechnical and Geoenvironmental Software Directory, Website http://www.ggsd.com/

ISEE Blasters' Handbook, International Society of Explosive Engineers, 30325 Bainbridge Road, Cleveland, OH 44139, Telephone: 440-349-4400, Website: http://www.isee.org

Pile Buck, Inc., P.O. Box 64-3929 Vero Beach, FL 32964, Telephone: 772-492-1056, Website: http://www.pilebuck.com/

Transportation Research Board, NCHRP Program Report VOL. 343, Engineering Manual for Shallow Foundations, Driven Piles, Drilled Shafts, Retaining Walls, and Abutments, Website: http://www.trb.org/Publications/PubsNCHRPProjectReportsAll.aspx

APPENDIX D GLOSSARY

ACRONYMS

AFCEC	Air Force Civil Engineering Center
BIA	Bilateral Infrastructure Agreement
DoD	Department of Defense
DoR	Designer of Record – The responsible designer whose seal is placed on the design documents (Navy, Marine Corps)
EoR	Engineer of Record – Same as DoR (Army, Air Force)
ft	foot
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HNFA	Host Nation Funded Construction Agreements
NAVFAC	Naval Facilities Engineering Systems Command
SOFA	Status of Forces Agreements
sq m	square meter
sf	square foot
TBD	To Be Determined
UFC	Unified Facilities Criteria
U.S.	United States
USACE	United States Army Corps of Engineers

UFC 3-220-04FA
16 January 2004

UNIFIED FACILITIES CRITERIA (UFC)

BACKFILL FOR SUBSURFACE STRUCTURES

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

UNIFIED FACILITIES CRITERIA (UFC)

BACKFILL FOR SUBSURFACE STRUCTURES

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes TM 5-818-4, dated 1 June 1983. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TM 5-818-4, dated 1 June 1983.

FOREWORD

\1\
The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: Criteria Change Request (CCR). The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://dod.wbdg.org/.

Hard copies of UFC printed from electronic media should be checked against the current electronic version prior to use to ensure that they are current.

AUTHORIZED BY:

DONALD L. BASHAM, P.E.
Chief, Engineering and Construction
U.S. Army Corps of Engineers

DR. JAMES W WRIGHT, P.E.
Chief Engineer
Naval Facilities Engineering Command

KATHLEEN I. FERGUSON, P.E.
The Deputy Civil Engineer
DCS/Installations & Logistics
Department of the Air Force

Dr. GET W. MOY, P.E.
Director, Installations Requirements and Management
Office of the Deputy Under Secretary of Defense (Installations and Environment)

ARMY TM 5-818-4
AIR FORCE AFM 88-5, Chap. 5

BACKFILL FOR SUBSURFACE STRUCTURES

DEPARTMENTS OF THE ARMY AND THE AIR FORCE
JUNE 1983

TECHNICAL MANUAL
No. 5-818-4
AIR FORCE MANUAL
NO. 88-5, CHAPTER 5

HEADQUARTERS
DEPARTMENTS OF THE ARMY
AND THE AIR FORCE
WASHINGTON, DC, *1 June 1983*

BACKFILL FOR SUBSURFACE STRUCTURES

LIST OF FIGURES

*This manual supersedes TM 5-818-4/AFM 88-5, Chapter 5, 7 June 1969.

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1-1. Background. Military facilities for the Army and Air Force have included construction of buildings and other structures partially below ground surface. In more recent years, missile launching and support structures, fallout and blast-protection shelters, and command-control centers have been constructed below ground surface. Many of these structures were constructed using cut-and-cover procedures and required backfilling within confined areas using various types of soil.

a. Numerous deficiencies in backfilling operations occurred in some of the earlier missile-launch construction programs and caused conditions that jeopardized the proper functioning of those structures. Measures to correct deficiencies were both time consuming and costly. It was recognized that critical areas must be delineated and the causes of the deficiencies be determined and corrected.

b. Measures were taken to alleviate the overall backfilling problems. These measures were progressive modification of design and configuration of structures, more detailed instructions to the construction personnel, and close control during construction to ensure that proper construction practices were being followed.

(1) Some of the problem areas were eliminated by modification of design and configuration of structures to allow easier placement of backfill and to permit access of compaction equipment so that required densities could beachieved.

(2) Construction personnel were issued more detailed field directives covering some of the particularly difficult phases of backfill placement.

(3) Inspector training programs were conducted to point out critical areas and emphasize proper backfill procedures and the need for continuous surveillance and close control.

c. The advent of energy efficient structures, partially embedded below ground level, had increased the use of backfill. In addition, the ever increasing need for fuel conservation requires maximum use of all excavated or onsite materials for backfill to reduce fuel needed for hauling in better materials from offsite. Thus, innovative planning and design and good construction control using rapid check tests are imperative for all backfill operations.

1-2. Purpose and scope. This manual is for the guidance of designers, specification writers, and especially field personnel engaged in designing, planning, and conducting earthwork operations around major deep-seated or subsurface structures.

a. The greatest deficiencies in earthwork operations around deep-seated or subsurface structures occur because of improper backfilling procedures and inadequate construction control during this phase of the work. Therefore, primary emphasis in this manual is on backfilling procedures. Design and planning considerations, evaluation and selection of materials, and other phases of earthwork construction are discussed where pertinent to successful backfill operations.

b. Although the information in this manual is primarily applicable to backfilling around large and important deep-seated or buried structures, it is also applicable in varying degrees to backfilling operations around all structures, including conduits.

CHAPTER 2

PLANNING AND DESIGN OF STRUCTURES AND EXCAVATIONS TO ACCOMMODATE BACKFILL OPERATIONS

2-1. General. Many earthwork construction problems can be eliminated or minimized through proper design, thorough planning, and recognition of problem areas effecting backfill operations. Recognition and consideration must be given in planning to design features that will make backfilling operations less difficult to accomplish. Examples of problem areas and how forethought in design and planning can help to eliminate backfill deficiencies are presented in the following paragraphs.

2-2. Effect of excavation and structural configuration on backfill operations. Some of the problems encountered in earthwork construction are related to the excavation and the configuration of the structures around which backfill is to be placed. It is the designer's responsibility to recognize these problems and to take the necessary measures to minimize their impact on the backfill operations.

a. *Open zones.* An open zone is defined as a backfill area of sufficient dimensions to permit the operation of heavy compaction equipment without endangering the integrity of adjacent structures around which compacted backfill operations are conducted. Figure 2-1 shows examples of open zones. In these zones where large compaction equipment, can operate, it is generally not too difficult to obtain the desired density if appropriate materials and proper backfill procedures are used. For areas that can be economically compacted by heavy equipment, the designer can avoid problems by including in the design provisions sufficient working space between structures or between excavation slopes and structures to permit access by the heavy compaction equipment. Generally, a working space of at least 12 feet between structure walls and excavation slopes and at least 15 feet between structures is necessary for heavy equipment to maneuver. In addition to maneuvering room, the designer must also consider any adverse loading caused by the operation of heavy equipment too close to structure walls, as discussed in paragraph *2-3d.*

b. Confined zones. Confined zones are defined as areas where backfill operations are restricted to the use of small mechanical compaction equipment (fig. 2-2) either because the working room is limited or because heavy equipment (fig. 2-1) would impose excessive soil pressures that could damage the structure. Most deficiencies in compacted backfill around subsurface structures have occurred in confined zones where required densities are difficult to achieve because of restricted working room and relatively low compaction effort of equipment that is too lightweight. The use of small equipment to achieve required compaction is also more expensive than heavy equipment since thinner lifts are required. However, because small compaction equipment can operate in spaces as narrow as 2 feet in width, such equipment is necessary to achieve the required densities in some areas of most backfill projects. Therefore, the designer should plan structure and excavation areas to minimize the use of small compaction equipment.

c. Structure configuration. The designer familiar with backfilling operations can avoid many problems associated with difficult to reach confined zones, which are created by structural shapes obstructing the placement and compaction of backfill, by considering the impact of structural shape on backfill operations. In most cases, structural shapes and configurations that facilitate backfill operations can be used without significantly affecting the intended use of the structure.

(1) *Curved bottom and wall structures.* Areas below the spring line of circular, elliptical, and similar shaped structures are difficult to compact backfill against because compaction equipment cannot get under the spring line. If possible, structures should be designed with continuously curved walls and flat floors such as in an igloo-shaped structure. For structures where a curved bottom is required to satisfy the intended function, it may be advisable for the designer to specify that a template shaped like the bottom of the structure be used to guide the excavation below the spring line so that uniform foundation support will be provided.

(2) Complex structures. Complex structures have variable shaped walls and complex configurations in plan and number of levels. These structures can also be simple structures interconnected by access shafts, tunnels, and utility conduits. Because of their irregular shapes and configurations the different types of structures significantly increase excavation and backfill problems.

(a) Typical examples of complex structures are stepped multilevel structures and multichambered structures with interconnecting corridors (fig. 2-3). Complex structures are generally more difficult to

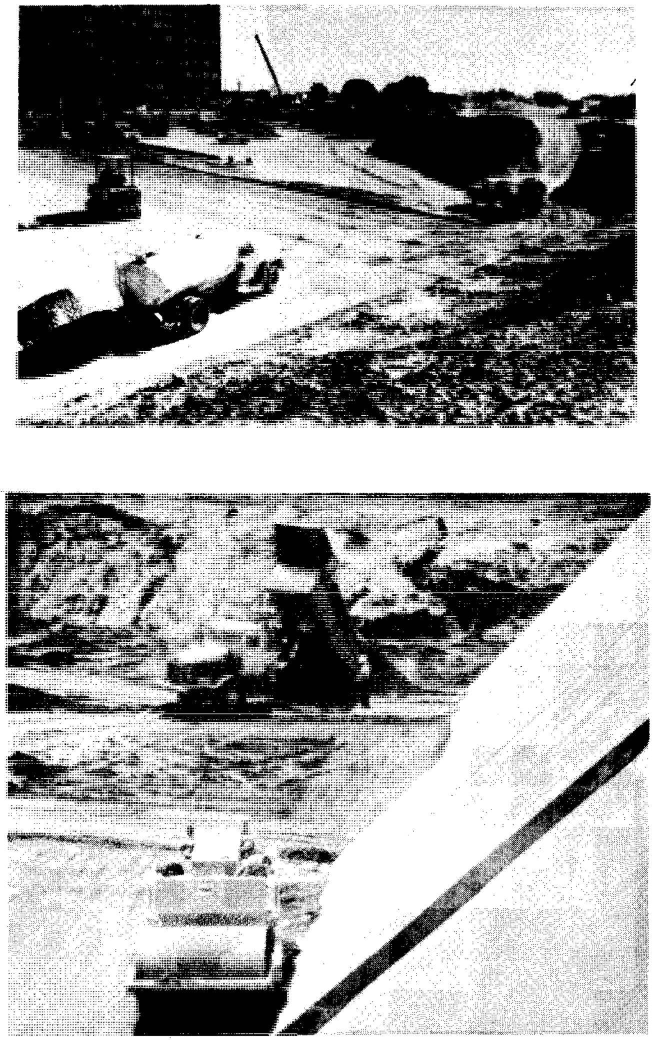


Figure 2- 1. Open backfill zones.

compact backfill around and are more likely to have settlement problems (para 2-3a). Although the multi-level step structure (fig. 2-3a) is not particularly difficult to compact backfill around, at least for the first level, the compaction of backfill over the offset structure will generally require the use of small equipment. Small equipment will also be required for compaction of backfill around and over the access corridor and between the two chambers (fig. 2-3b). Where possible, the design should accommodate intended functions into structures with uniformly shaped walls and a simple configuration.

(b) Where structures of complex configurations are necessary, construction of a three-dimensional model during the design and planning phases will be extremely beneficial. From the model, designers can more easily foresee and eliminate areas in which it would be difficult to place and compact backfill.

d. Service conduits. Since compaction of backfill is difficult around pipes and conduits, utility lines should be grouped together or placed in a single large conduit where feasible rather than allowed to form a haphazard maze of pipes and conduits in the backfill. Utility lines should be run either horizontally or vertically wherever possible. Plans for horizontally run appurtenances, such as utility lines, access tunnels, and blast-delay tubing, should be coordinated with the excavation plans so that wherever feasible these appurtenances can be supported by undisturbed soils rather than by compacted backfill.

e. Excavation plans. The excavation plans should be developed with the backfill operations and the structure configurations in mind. The excavation and all completed structures within the excavation should be conducive to good backfill construction procedures, and access should be provided to all areas so that compaction equipment best suited to the size of the area can be used. The plans for excavation should also provide for adequate haul roads and ramps. Positive excavation slopes should be required in all types of soil de-

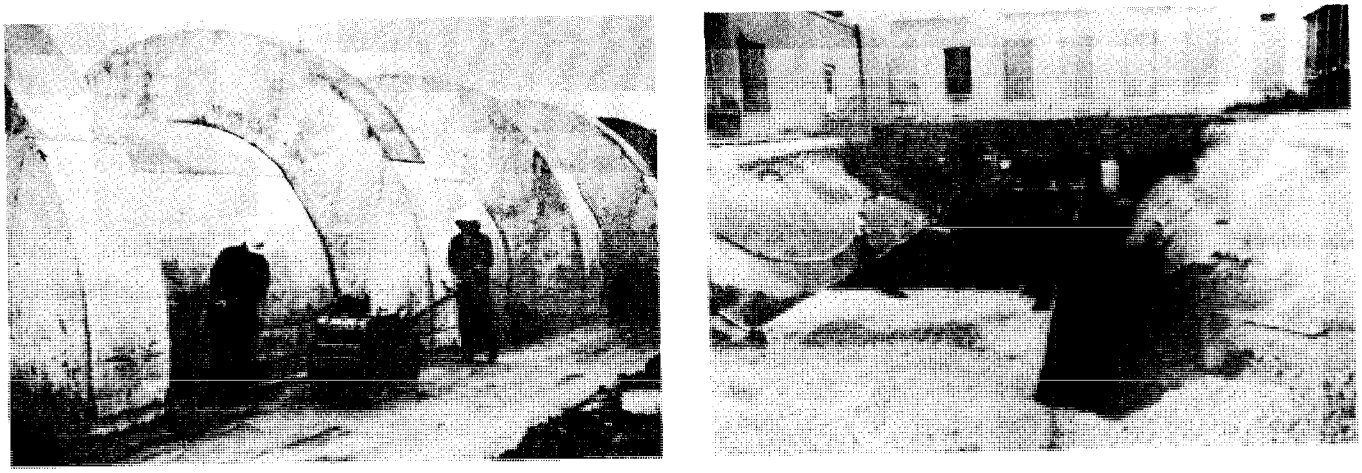
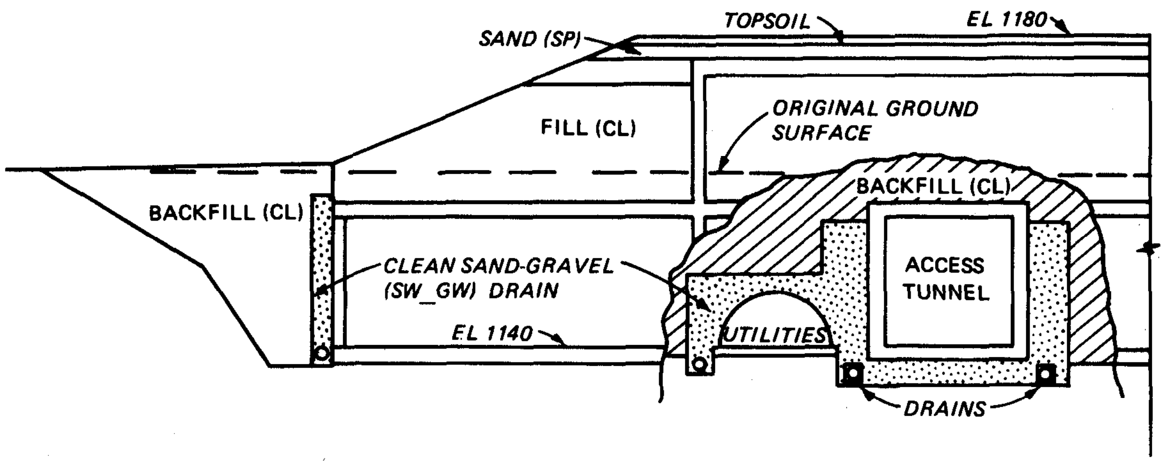
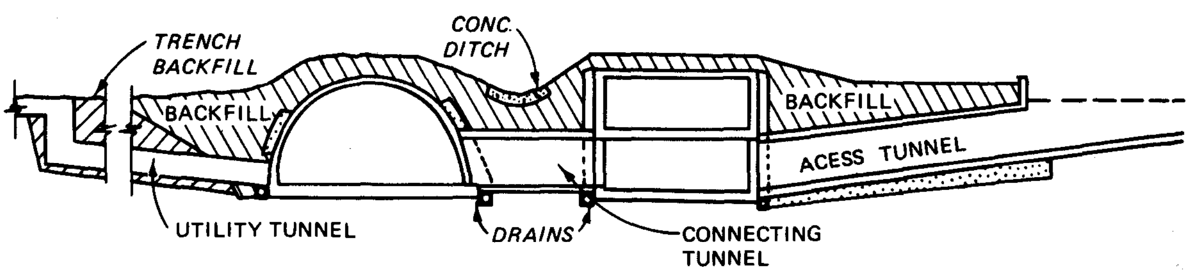


Figure 2-2. Confined backfield zones.



(a) TWO-STORY STRUCTURE



(b) CONNECTING STRUCTURES

Figure 2-3. Complex structures.

posits to facilitate compaction of backfill against the slope and to ensure good bond between the backfill and the excavation slopes. Loose material should be removed from the excavation slopes; in some cases, benches may be required to provide a firm surface to compact backfill against.

f. Lines and grades. Care should be exercised in planning lines and grades for excavation to ensure that uniform, adequate support is provided at the foundation level of important structures. Generally, foundations consisting of part backfill and part undisturbed materials do not provide uniform bearing and should be avoided wherever possible. The foundation should be overexcavated where necessary, and backfilled with compacted select material to provide uniform support for the depth required for the particular structure. Where compacted backfill is required beneath a structure, the minimum depth specified should be at least 18 inches.

g. Thin- walled metal structures. Thin-walled, corrugated metal structures are susceptible to deflections of structural walls when subjected to backfill loads. Adverse deflections can be minimized by planning backfill operations so that compacted backfill is brought up evenly on both sides of the structure to ensure uniform stress distribution. Temporary surcharge loads applied to the structure crown may also be required to prevent vertical distortions and inward deflection at the sides.

2-3. Backfill problem areas. Other features that have the potential to become problem areas are discussed in the following paragraphs. These potential problem areas have to be considered during the planning and design phases to minimize deficiencies in structure performance associated with backfill placement and to make backfilling operations less difficult.

a. Settlement and downdrag. In the construction of underground structures and particularly missile-launch-site facilities, tolerances to movement are often considerably less than those in normal construction. The design engineer must determine and specify allowable tolerances in differential settlement and ensure that differential settlement is minimized and/or accommodated. Settlement analysis procedures are outlined in TM 5-818-l/AFM 88-3, Chapter 7. See appendix A, References.

(1) *Critical zones.* Critical backfill zones are those immediately beneath most structures. Consolidation and swelling characteristics of backfill materials should be thoroughly investigated so that materials having unfavorable characteristics will not be used in those zones. Some settlement can be expected to take place, but it can be minimized by requiring a higher than normal compacted density for the backfill. Cohesive backfill compacted at a water content as little as 3 to 4 percentage points below optimum may result in large settlements caused by collapse of nonswelling soil material or heave of swelling materials upon saturation after construction. Compacting cohesive backfill material at optimum water content or slightly on the wet side of optimum generally will reduce the amount of settlement and swelling that would occur. The reduction should be confirmed by consolidation and swell tests on compacted specimens (para 3-2b(4)).

(2) *Service conduits.* Settlement within the backfill around structures will also occur. A proper design will allow for the estimated settlement as determined from studies of consolidation characteristics of the compacted backfill. Where service conduits, access corridors, and similar facilities connect to the structure oversize sleeves, flexible connections and other protective measures, as appropriate, may be used to prevent damage within the structure.

(3) *Differential settlement.* Complex structures are more susceptible to differential settlement because of the potential for large variations in loads carried by each component foundation. In the multilevel stepped structure (fig. 2-3a), the foundation supporting the lower level offset component must also support the volume of backfill over that part of the structure. Measures must be taken to ensure that the proper functioning of all elements is not hampered by differential settlement. The increased cost of proper design and construction where unusual or difficult construction procedures are required is insignificant when compared with the cost of the structure. The cost of remedial measures to correct deficiencies caused by improper design and construction usually will be greater than the initial cost required to prevent the deficiencies.

(4) *Downdrag.* In addition to conventional service loads, cut and cover subsurface structures are susceptible to downdrag frictional forces between the structure and the backfill that are caused by settlement of the backfill material adjacent to and around the structure. Downdrag loads can be a significant proportion of the total vertical load acting on the structure and must be considered in the structure settlement analysis. Structure-backfill friction forces may also generate significant shear forces along the outer surface of structures with curve-shaped roofs and walls. The magnitude of the friction forces depends upon the type of backfill, roughness of the structure's surface, and magnitude of earth pressures acting against the structure. Techniques for minimizing downdrag friction forces generally include methods that reduce the structure surface roughness such as coating the structure's outer surface with asphalt or sandwiching a layer of polyethylene sheeting between the structure's outer surface and fiberboard (blackboard) panels. Backfill settlement and associated downdrag can also be mini-

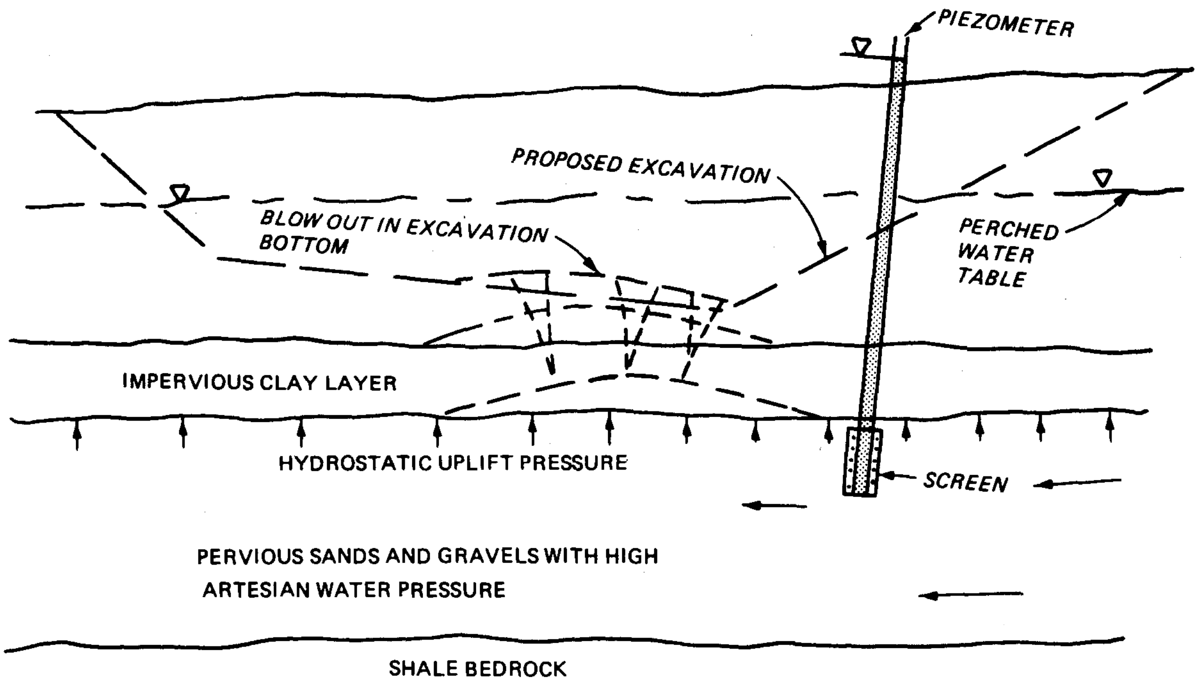


Figure 2-4. Excavation subject to bottom heave.

mized by requiring higher backfill densities adjacent to the structure.

b. Groundwater. Groundwater is an important consideration in planning for construction of subsurface structures. If seepage of groundwater into the excavation is not adequately controlled, backfilling operations will be extremely difficult. The groundwater level must be lowered sufficiently (at least 2 to 3 feet for granular soils and as much as 5 to 10 feet for fine-grained soils below the lowest level of backfilling) so that a firm foundation for backfill can be established. If the level is not lowered, the movement of hauling or compaction equipment may pump seepage water through the backfill, or the initial backfill layers may be difficult to compact because of an unstable foundation. Since the proper water content of the backfill is essential for achieving proper compaction, prevention of groundwater seepage into the excavation during backfilling operations is mandatory. Figure 3-14 of EM 1110-2-1911 shows a method for dewatering rock foundations.

(1) The contractor is generally responsible for the design, installation, and operation of dewatering equipment. The Corps of Engineers is responsible for specifying the type of dewatering system and evaluating the contractor's proposed dewatering plan. Since the dual responsibility of the contractor and the Corps relies on a thorough understanding of groundwater conditions, inadequate dewatering efforts can be minimized by adequate planning and implementation of groundwater investigations.

(2) The possibility of hydraulic heave in cohesive material must also be investigated to ensure stability of the excavation floor. Hydraulic heave may occur where an excavation overlies a confined permeable stratum below the groundwater table (fig. 2-4). If the upward hydrostatic pressure acting at the bottom of the confining layer exceeds the weight of overburden between the bottom of the excavation and the confining layer, the bottom of the excavation will rise bodily even though the design of the dewatering system is adequate for control of groundwater into the excavation. To prevent heave, the hydrostatic pressure beneath the confined stratum must be relieved.

(3) Subsurface structures located in part or wholly below the groundwater table require permanent protection against groundwater seepage. The type of protection may range from simple impermeable barriers to complex permanent dewatering systems.

(4) Dewatering and groundwater control procedures are described in TM 5-818-5/NACFAC P-418/AFM 88-5, Chapter 6.

c. Gradation and filter criteria for drainage materials. Groundwater control is often accomplished by ditches positioned to intercept the flow of groundwater and filled with permeable granular material. The water is generally collected in perforated pipes located at the bottom of the ditch and pumped to a suitable discharge area. Such drainage systems are referred to as filter drains. The gradation of the granular filter material is critical for the functioning of the system. Selection of the proper gradation for the filter material is dependent upon the gradation of the material that is being drained. Drainage of silts and clays usually requires a graded filter made up of several layers of granular material with each layer having specific requirements for maximum grain size and gradation. Details on the design of filter drains are presented in TM 5-818-5/NAVFACP-418/AFM 88-5, Chapter 6.

(1) *Selected material.* If materials at the jobsite do not meet the designed filter requirements, select material must be purchased from commercial sources and shipped to the jobsite. Filter material must be stockpiled according to gradation. For graded filter systems, the materials must be placed with care to minimize mixing of individual components.

(2) *Filter cloths.* Both woven and nonwoven filter cloths, which have been found satisfactory for use as a filter media for subsurface drains, are available. When granular filter materials are not economically available, a single wrap of filter cloth around a pipe may be used in lieu of a coarser backfill. When available granular filter material is too coarse to satisfy filter criteria for the protected soil, a single layer of filter cloth may be used adjacent to the protected soil. To reduce the chance of clogging, no filter cloth should be specified with an open area less than 4 percent and or equivalent opening size (EOS) of less than the No. 100 sieve (0.0059 inch). A cloth with openings as large as allowable should be specified to permit drainage and prevent clogging. Additional information on airfield drainage is contained in TM 5-820-2/AFM 88-5, Chapter 2.

(3) *Other uses.* Filter cloth can also provide protection for excavated slopes and serve as a filter to prevent piping of fine-grained soils. In one project, sand was not available for backfill behind a wall and coarse gravel had to be used to collect seepage. The filter cloth used to protect the excavated slope served as a filter against piping of the natural silty clay under seepage gradients out of the excavated slope after the coarse gravel backfill was placed.

d. Earth pressures. The rationale design of any structure requires the designer to consider all loads acting on the structure. In addition to normal earth pressures associated with the effective pressure distribution of the backfill materials, subsurface cut-and-cover structures may also be subjected to surcharge loads caused by heavy equipment operating close to the structure and by increased permanent lateral earth pressures caused by compaction of backfill material with heavy equipment. Procedures for predicting normal earth pressures associated with the effective pressure of backfill materials are discussed in TM 5-818-1/AFM 88-3, Chapter 7, EM 1110-2-2902, and EM 1110-2-2502.

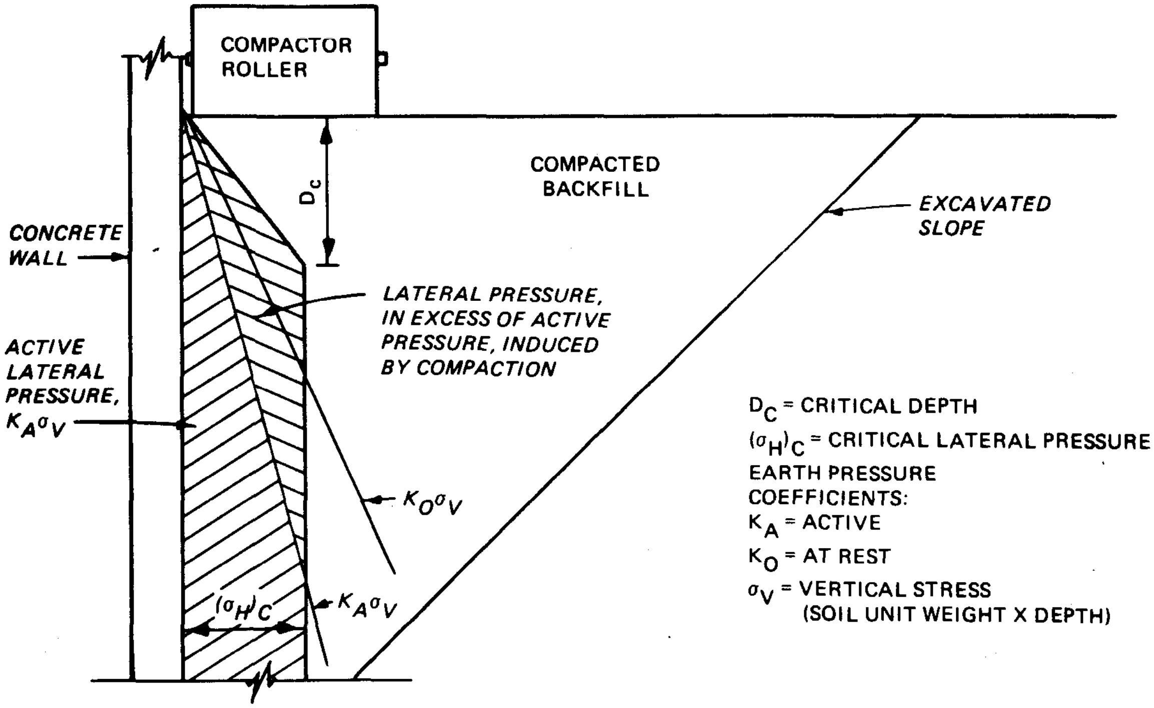
(1) Exact solutions for surcharge earth pressures generated by heavy equipment (or other surcharge loads) do not exist. However, approximations can be made using appropriate theories of elasticity such as Boussinesq's equations for load areas of regular shape or Newmark's charts for irregular shaped load areas as given in NAVFAC DM-7. As a conservative guide, heavy-equipment surcharge earth pressures may be minimized by specifying that heavy compaction equipment maintain a horizontal distance from the structure equivalent to the height of the backfill above the structure's foundation.

(2) Compaction-induced earth pressures can cause a significant increase in the permanent lateral earth pressures acting on a vertical wall of a structure (fig. 2-5a). This diagram is based on the assumption that the equipment can operate to within 6 inches of the wall. Significant reductions in lateral pressures occur as the closest allowable distance to the wall is increased (fig. 2-5b). For an operating distance 5 feet from the wall, the induced horizontal earth pressure is much less than that caused by the backfill. The magnitude of the increase in lateral pressure is dependent, among other factors, on the effective weight of the compaction equipment and the weight, earth pressure coefficient, and Poisson's ratio of the backfill material. Compaction-induced earth pressures against walls are also described in TM 5-818-l/AFM 88-3, Chapter 7, and EM 1110-2-2502.

(3) The designer must evaluate the economics of the extra cost of structures designed to withstand very close-in operation of heavy compaction equipment versus the extra cost associated with obtaining required compaction of backfill in thin lifts with smaller compaction equipment. A more economical alternative might be to specify how close to the walls different weights of compaction equipment can be operated.

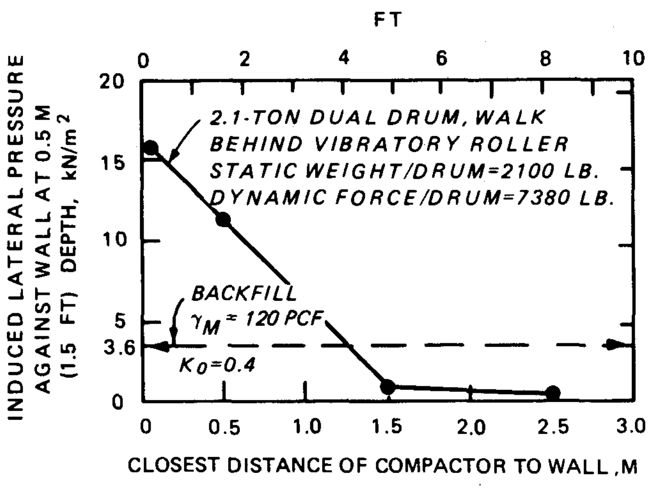
(4) One method of reducing lateral earth pressures behind walls has been to use about 4 feet of uncompacted granular (sand or gravel) backfill above the base of the wall. Soil backfill can then be compacted in layers above the granular backfill. Compression of the granular material prevents the buildup of excessive lateral pressures against the wall.

e. Structural backfill. Structural backfill is defined as the compacted backfill required over and around a structure to prevent damage from heavy equipment operating over or near the structure. This backfill must be compacted using small compaction equipment, such as mechanical rammers or vibratory-plate compactors, or intermediate size equipment such as walk-behind, dual-drum vibratory rollers. The horizontal and vertical distances from the structure for which structural backfill is required should be deter-



COMPACTION EQUIPMENT	CRITICAL DEPTH D_c, FT	$(\sigma_H)_c$ psf
10–TON SMOOTH WHEEL ROLLER	1.9	420
3.2–TON VIBRATORY ROLLER	1.7	400
1.4–TON VIBRATORY ROLLER	1.2	260
400–KG VIBRATORY PLATE	1.5	340
120–KG VIBRATORY PLATE	1.0	240

a. MAXIMUM INDUCED LATERAL PRESSURES



b. EFFECT OF DISTANCE FROM WALL

Figure 2-5. Excess lateral pressure against vertical walls induced by compaction.

mined from estimates of loads acting on the structure caused by heavy equipment and on the strength of the embedded structure members as discussed in *d* above. A 2-foot cover over small utility conduits and pipes is adequate protection where proper bedding procedures are followed. The minimum cover requirements over larger diameter (6 inches or greater), rapid and flexible pipes are presented in appendix II of TM 5-820-4/AFM 88-5, Chapter 4.

f. Slopes and bracing. Where open excavation is planned, consideration should be given to the slopes to which the materials to be encountered can be cut and remain stable. The stability analysis should include the strength of the materials, groundwater conditions, and any surcharge load that may be imposed as the result of stockpiles being placed or equipment operating near the crest of the excavation. Slope stability evaluation procedures are described in TM 5-818-1/AFM 88-3, Chapter 7. Shoring and bracing should be used to support excavation slopes where it is not feasible to excavate to stable slopes (TM 5-818-l/AFM 88-3, Chapter 7). Requirements for shoring and bracing safety are presented in EM 385-l-l.

g. Bedding for curved-bottom structures. Foundations for pipes, conduits, access tunnels, fuel and water storage tanks, and other curved-bottom structures constructed within the backfill are considered critical zones that require special attention. Any bedding material used should be free of stones or other large particles that would lead to nonuniform bearing. One of the most important functions of any bedding procedure is to provide firm support along the full length of the structure. For areas where it is difficult to perform field density control tests because of limited working space, a procedure to ensure that proper compaction is obtained must be employed. Several methods of obtaining adequate bedding are discussed in paragraph 5-1c (2).

h. Cold weather construction. Cold weather can have a very adverse effect on backfilling operations and can cause considerable delay. If possible, the project should be planned to complete backfilling operations prior to any extended period of freezing temperatures. The contractor and the resident engineer must keep up to date with weather data so that the contractor can plan the equipment and construction force required to meet the construction schedule and to protect the work already accomplished.

(1) The designer must establish definite limitations and requirements regarding placement of backfill when the ambient temperature is below freezing. Most inorganic soils, particularly silts and lean clays, containing 3 percent, by weight, or more of particles finer than 0.02 millimetre in diameter are frost susceptible. Such soils, when frozen in the presence of an available source of water, develop segregated ice in the form of lenses, layers, veins, or masses commonly, but not always oriented normal to the direction of heat loss. The expansion of the soil mass resulting from ice segregation is called frost heave. Frost heave of soil under and against structures can cause detrimental effects, which can be compounded during subsequent thawing by differential movement, loss of density, and loss of shear strength. Soils of this type should not be placed during or immediately prior to freezing temperatures and must not be placed in critical areas. Nonfrost susceptible soils should be used at the finished grade to the depth of frost penetration when the finished grade serves as a load-bearing surface.

(2) Additives, such as calcium chloride, can be used to lower the freezing temperature of soil water, but such additives will ordinarily also change the compaction and water content requirements. Therefore, additives must not be used without prior investigation to determine their effect on compaction and water content requirements. Dry sand or sand-gravel mixtures can be placed satisfactorily when temperatures are below freezing without serious effects.

(3) Protection must be provided for in-place permanent backfill in critical areas, such as those around and under structures and embedded items already placed. To preclude structural damage from possible frost heave, backfill materials around such structures should be insulated with a protective covering of mulch, hay, or straw. In some instances, loose lifts of soil can be used for insulation. However, rock or sand is too porous to provide sufficient insulation and too permeable to resist water penetration. If soil is to be used as an insulating material, a material completely foreign to the permanent fill, such as straw or building paper, should be laid down prior to placement of the insulation fill so that there will be a marked distinction between the permanent and the temporary insulation fills. In this way, when the insulation fill is removed, the stripping limits can be readily discerned.

(4) Flooding of the excavation has also been used successfully to prevent frost penetration of the in-place permanent backfill. However, consideration must be given to possible detrimental effects of saturating in-place backfill and the delay of removing the water at the beginning of the next construction season if it freezes into a solid mass of ice.

(5) Concrete walls and floors of completed structures provide poor insulation for the fill around and beneath these structures. Therefore, these structures should be enclosed as much as possible and kept closed during the winter when construction is halted because of adverse freezing weather. Reinforcing steel protruding from a partially completed structure will conduct cold through the concrete and increase the rate and depth of frost penetration beneath the structure.

Every effort should be made to schedule construction so that this condition will be kept to a minimum, and protection must be required where necessary.

i. Seismic zones. The design considerations for subsurface structures subjected to dynamic loads caused by seismic activity or explosive devices are beyond the scope of this manual. Design details are provided in TM 5-818-1/AFM 88-3, Chapter 7, and ER 1110-2-1806. Specific problems relating to backfill operations are primarily limited to possible potential for dynamically induced liquefaction. Certain materials are particularly susceptible to liquefaction; these include saturated gravels, sands, silts, and clayey sands and gravel. Where these materials are used as backfill, the potential for liquefaction can be minimized by requiring a high degree of compaction, particularly in critical areas such as beneath footings and under the spring line of curved wall structures. The requirements for materials susceptible to liquefaction are discussed in paragraph 3 - 3d.

2-4. Instrumentation. For important structures of unique design or for structures where the potential for postconstruction distress exists, instrumentation of the structure should be considered. The instrumentation program may include monitoring the amount and rate of settlement, movement of retaining walls and other structural elements, development of stresses within the structure, and development of hydrostatic and earth pressures against the structure. Analysis of the data will furnish a check on design assumptions and indicate what measures must be taken to relieve or correct undesirable conditions before distress develops. Information of this nature can also be of significant value in future design and construction.

a. Requirements. Specific requirements for instruments are ruggedness, reliability over the projected service life, and simplicity of construction, installation, and observation. Other important considerations in selecting the type of instruments are cost and availability. Manufacturers of devices considered for installation should be asked to provide a list of projects on which their devices have been installed, and previous users of new equipment should be contacted to ascertain their operating experiences.

b. Installation and observation of instrumentation. A rational instrumentation program must use the proper type of instruments and have the instruments installed properly at critical locations. Valid readings often depend on techniques and procedures used in installing and observing the instrumentation.

(1) Schedules for observations are generally established by the design office. Initial observations should be checked to assure their validity and accuracy, since these readings usually form the basis to which subsequent observations are related. Observations should be plotted immediately after each set of readings is taken and evaluated for reasonableness against previous sets of readings. In this way, it is often possible to detect errors in readings and to obtain check readings before significant changes in field conditions occur.

(2) EM 1110-2-1908 discusses in detail various types of instrumentation devices; procedures for installation, observation, and maintenance; collection, recording, analysis, and reporting of data; and possible source of error and causes of malfunctions.

2-5. Optimum cost construction. The designer should consider all details of the construction process to ensure a safe and operational facility at the lowest possible cost.

a. Energy requirements. The consideration of energy requirements is important not only for economical reasons but also for the critical need to conserve energy wherever possible. It should not be the intent of the design engineer to unduly restrict the competitive nature of current contractural procedures. Nevertheless, there are certain alternatives that the designer may specify that potentially could lead to more energy efficient construction with cost saving being reflected in bid prices. Some of the possible alternatives that should be considered are discussed below.

(1) Sources of suitable select backfill material should be located as close to the project site as possible. The source may be either a borrow area or a commercial vendor.

(2) Hauling routes to and from the source of backfill and the project site should follow the most direct route.

(3) Only compaction equipment that will compact the specific backfill to the required density in an efficient manner should be approved for use. For large projects, the designer may require that the contractor demonstrate the capabilities of the equipment he intends to use prior to construction.

(4) If possible, material from excavations or within the immediate vicinity of the project site should be used as backfill, even though such material may be marginally suitable. The engineering characteristics of marginal material may be enhanced by the use of additives (para 3-3d).

(5) The energy requirements for adequate cold weather protection of construction personnel and structures can be considerable. For project sites subject to seasonal cold weather, construction should not, if possible, be scheduled during extreme cold weather periods.

b. Value engineering. Potential cost savings may be realized by encouraging the contractor to participate in value engineering, whereby the contractor shares any project saving derived from realistic cost-saving suggestions submitted.

CHAPTER 3

EVALUATION, DESIGN, AND PROCESSING OF BACKFILL MATERIALS

3-1. General. The evaluation, design, and proper processing of backfill materials are extremely important phases of the preconstruction operations. The purpose of the evaluation phase is to determine the engineering characteristics of potential backfill materials. The design phase must take into account the engineering characteristics required of the backfill and specify materials that, when compacted properly, will have these characteristics. Proper processing of the backfill material will ensure that desirable engineering. characteristics will be obtained as the material is placed.

3-2. Evaluation of backfill materlals. Evaluation of backfill materials consists of exploration, sampling, and laboratory testing to determine the engineering characteristics of potential backfill materials. Detailed instructions for exploration, sampling, laboratory testing, and foundation design are presented in TM 5-818-1/AFM 88-3, Chapter 7. However, to emphasize the need for an adequate investigation, some aspects of planning and investigation that should be considered are discussed in the following paragraphs.

a. Field exploration and sampling. Field exploration and sampling are extremely important to the design of foundations, selection of backfill, and planning for construction. A great amount of material will be available from required excavations, and the investigation for foundation conditions should include the sampling and evaluation of these materials for possible use as backfill. Where an adequate volume of suitable backfill cannot be obtained from the construction excavation, the exploration and sampling program must be expanded to find other sources of suitable material whether from nearby borrow areas or commercial sources.

(1) The purpose of the investigation is to delineate critical conditions and provide detailed information on the subsurface deposits so that proper design and construction, including backfilling operations, can be accomplished with minimum difficulty. Thus careful planning is required prior to the field exploration and sampling phase of the investigation. Available geologic and soil data should be studied, and if possible, preliminary borings should be made. Once a site has been tentatively selected, orientation of the structure to the site should be established. The engineer who plans the detailed field exploration program must have knowledge of the structure, i.e., its configuration and foundation requirements for design loads and settlement tolerances. The planning engineer should also know the type and quantity of backfill required. The importance of employing qualified field exploration personnel cannot be overemphasized. The exploration crews should be supervised in the field by a soils engineer or geologist familiar with the foundation and backfill requirements so that changes can be made in the exploration program where necessary to provide adequate information on subsurface conditions.

(2) The field engineer should also know the location of significant features of the structure so that sampling can be concentrated at these locations. In addition, he should have an understanding of the engineering characteristics of subsurface soil and rock deposits that are important to the design of the structure and a general knowledge of the testing program so that the proper type and quantity of samples will be obtained for testing.

(3) From the samples, the subsurface deposits can be classified and boring logs prepared. The more continuous the sampling operation, the more accurate will be the boring logs. All borings should be logged with the description of the various strata encountered as discussed in TM 5-818-1/AFM 88-3, Chapter 7. Accurate logging and correct evaluation of all pertinent information are essential for a true concept of subsurface conditions.

(4) When the exploratory borings at the construction site have been completed, the samples and logs of borings should be examined to determine if the material to be excavated will be satisfactory and in sufficient quantity to meet backfill requirements. Every effort should be made to use the excavated materials; however, if the excavated materials are not satisfactory or are of insufficient quantity, additional exploration should be initiated to locate suitable borrow areas. If borrow areas are not available, convenient commercial sources of suitable material should be found. Backfill sources, whether excavation, borrow, or commercial, should contain several times the required volume of compacted backfill.

(5) Groundwater studies prior to construction of subsurface structures are of the utmost importance, since groundwater control is necessary to provide a dry excavation in which construction and backfilling

operations can be properly conducted. Data on groundwater conditions are also essential for forecasting construction dewatering requirements and stability problems. Groundwater studies must consist of investigations to determine: groundwater levels to include any seasonal variations and artesian conditions; the location of any water-bearing strata; and the permeability and flow characteristics of water-bearing strata. Methods for investigating groundwater conditions are described in TM 5-818-1/AFM 88-3, Chapter 7, and TM 5-818-5/NAVFACP-418/AFM 88-5, Chapter 6.

b. Laboratory testing. The design of any foundation is dependent on the engineering characteristics of the supporting media, which may be soil or rock in either its natural state or as compacted backfill. The laboratory testing program will furnish the engineer information for planning, designing, and constructing sub surface structures. Laboratory testing programs usually follow a general pattern and to some extent can be standardized, but they should be adapted to particular problems and soil conditions. Special tests and research should be utilized when necessary to develop needed information. The testing program should be well planned with the engineering features of the structure and backfill in mind; testing should be concentrated on samples from areas where significant features will be located but should still present a complete picture of the soil and rock properties. The laboratory test procedures and equipment are described in TM 5-818-1/AFM 88-3, Chapter 7, EM 1110-2-1906, and MIL-STD-621.

(1) *Identification and classification of soils. The* Unified Soil Classification System used for classifying soils for military projects (MIL-STD-619 and TM 5-818-1/AFM 88-3, Chap. 7) is a means of identifying a soil and placing it in a category of distinctive engineering properties. Table 3-1 shows the properties of soil groups pertinent to backfill and foundations. Using these characteristics, the engineer can prepare preliminary designs based on classification and plan the laboratory testing program intelligently and economically.

(a) The Unified Soil Classification System classifies soils according to their grain-size distribution and plasticity characteristics and groups them with respect to their engineering behavior. With experience, the plasticity and gradation properties can be estimated using simple, expedient tests (see table 2-2 and 2-3 of TM 5-818-1/AFM 88-3, Chap. 7 or AFM 89-3, Chap. 2) and these estimates can be confirmed using simple laboratory tests. The principal laboratory tests performed for classification are grain-size analyses and Atterberg limits.

(b) The engineering properties in table 3-1 are based on “Standard Proctor” (CE 25) maximum density except that the California Bearing Ratio (CBR) and the subgrade modulus are based on CE 55 maximum density. This information can be used for initial design studies. However, for final design of important structures, laboratory tests are required to determine actual performance characteristics, such as CE 55 compaction properties, shear strength, permeability, compressibility, swelling characteristics, and frost susceptibility where applicable, under expected construction conditions.

(c) The Unified Soil Classification System is particularly useful in evaluating, by visual examination, the suitability of potential borrow materials for use as compacted backfill. Proficiency in visual classification can be developed through practice by comparing estimated soil properties with results of laboratory classification tests.

(2) *Compaction testing.* Compaction test procedures are described in detail in MIL-STD-621 and ASTM D 1557 (app. A). It is important that the designer and field inspection personnel understand the basic principles and fundamentals of soil compaction. The principles of soil compaction are discussed in appendix B of this manual.

(a) The purpose of the laboratory compaction tests are to determine the compaction characteristics of available backfill materials. Also, anticipated field density and water content can be approximated in lab oratory-compacted samples in order that other engineering properties, such as shear strength, compressibility, consolidation, and swelling, can be studied. For most soils there is an optimum water content at which a maximum density is obtained with a particular compaction effort. A standard five-point compaction curve relating density and water content (fig. B-1, app. B) can be developed by the procedures outlined in MIL-STD-621.

(b) The impact compaction test results normally constitute the basis on which field compaction control criteria are developed for inclusion in the specifications. However, for some cohesionless soils, higher densities can be obtained by the vibratory compaction method (commonly referred to as maximum relative density), described in appendix XII of EM 1110-2-1906. The required field compaction is generally specified as a percentage of laboratory maximum dry density and referred to as percent CE 55 maximum density. Water content is an important controlling factor in obtaining proper compaction. The required percentage of maximum dry density and the compaction water content should be selected on the basis of the engineering characteristics, such as compression moduli, settlement, and shear strength, desired in the compacted backfill. It should be noted that these characteristics could be adversely effected by subsequent increases in

water content after placement. This situation could result from an increase in the groundwater level after construction.

(c) Density control of placed backfill in the field can be facilitated by the use of rapid compaction check tests (para 7-5c). A direct rapid test is the one-point impact compaction test. Rapid indirect tests, such as the Proctor needle penetration for cohesive soils or the cone resistance load for cohesionless soils, can also be used when correlations with CE 55 maximum density have been established.

(3) *Shear strength testing.* When backfill is to be placed behind structure walls or bulkheads or as foundation support for a structure, and when fills are to be placed with unrestrained slopes, shear. tests should be performed on representative samples of the backfill materials compacted to expected field densities and water contents to estimate as-constructed shear strengths. The appropriate type of test required for the conditions to be analyzed is presented in TM 5-818-1/AFM 88-3, Chapter 7. Procedures for shear strength testing are described in EM 1110-2-1906.

Table 3-1. Typical Engineering Properties of Compacted Materials[a]

Group Symbol	Soil Type	Range of Maximum Dry Unit Weight, pcf	Range of Optimum Water, Content Percent	Typical Value of Compression At 2.5 ksf (20 psi) Percent of Original Height	At 7.2 ksf (50 psi)	Typical Strength Characteristics Cohesion (As Compacted) psf	Cohesion (Saturated) psf	φ (Effective Stress Envelope) deg	Typical Coefficient of Permeability ft/min	Range of CBR Values	Range of Subgrade Modulus k lb/cu in.	Potential Frost Action[b]
GW	Well-graded clean gravels, gravel-sand mixtures	125-135	11-8	0.3	0.6	0	0	>38	5×10^{-2}	40-80	300-500	None to very slight
GP	Poorly graded clean gravels, gravel-sand mix	115-125	14-11	0.4	0.9	0	0	>37	10^{-1}	30-60	250-400	None to very slight
GM	Silty gravels, poorly graded gravel-sand-silt	120-135	12-8	0.5	1.1	—	—	>34	$>10^{-6}$	20-60	100-400	Slight to medium
GC	Clayey gravels, poorly graded gravel-sand-clay	115-130	14-9	0.7	1.6	—	—	>31	$>10^{-7}$	20-40	100-300	Slight to medium
SW	Well-graded clean sands, gravelly sands	110-130	16-9	0.6	1.2	0	0	38	$>10^{-3}$	20-40	200-300	None to slight
SP	Poorly graded clean sands, sand-gravel mix	100-120	21-12	0.8	1.4	0	0	37	$>10^{-3}$	10-40	200-300	None to slight
SM	Silty sands, poorly graded sand-silt mix	110-125	16-11	0.8	1.6	1050	420	34	5×10^{-5}	10-40	100-300	Slight to medium
SM-SC	Sand-silt clay mix with slightly plastic fines	110-130	15-11	0.8	1.4	1050	300	33	2×10^{-6}	—		
SC	Clayey sands, poorly graded sand-clay mix	105-125	19-11	1.1	2.2	1550	230	31	5×10^{-7}	5-20	100-300	Slight to high
ML	Inorganic silts and clayey silts	95-120	24-12	0.9	1.7	1400	190	32	10^{-5}	15 or less	100-200	Medium to very high
ML-CL	Mixture of inorganic silt and clay	100-120	22-12	1.0	2.2	1350	460	32	5×10^{-7}	—	100-200	
CL	Inorganic clays of low to medium plasticity	95-120	24-12	1.3	2.5	1800	270	28	10^{-7}	15 or less	50-200	Medium to high
OL	Organic silts and silt-clays, low plasticity	80-100	33-21	—	—	—	—	—	—	5 or less	50-100	Medium to high
MH	Inorganic clayey silts, elastic silts	75-95	40-24	2.0	3.8	1500	420	25	5×10^{-7}	10 or less	50-100	Medium to very high
CH	Inorganic clays of high plasticity	80-105	36-19	2.6	3.9	2150	230	19	10^{-7}	15 or less	50-150	Medium
OH	Organic clays and silty clays	75-100	45-21	--	—	—	—	—	—	5 or less	25-100	Medium

Notes: 1. All properties are for condition of "standard Proctor" maximum density, except values of k and CBR which are for CE55 maximum density.
2. Typical strength characteristics are for effective strength envelopes and are obtained from USBR data.
3. Compression values are for vertical loading with complete lateral confinement.
4. (>) indicates that typical property is greater than the value shown. (—) indicates insufficient data available for an estimate.

[a] After DM-7.
[b] From TM 5-818-2/AFM 88-6, Chapter 4.

(4) *Consolidation and swell testing.* The rate and magnitude of consolidation under a given load are influenced primarily by the density and type of soil and the conditions of saturation and drainage. Fine-grained soils generally consolidate more and at a slower rate than coarse-grained soils. However, poorly graded, granular soils and granular soils composed of rounded particles will often consolidate significantly under load but usually at a relatively fast rate.

(a) The procedure for the consolidation test is outlined in EM 1110-2-1906. The information obtained in this test can be used in settlement analyses to determine the total settlement, the time rate of settlement, and the differential settlement under varying loading conditions. Consolidation characteristics are important considerations in selection of backfill materials. The results of consolidation tests performed on laboratory compacted specimens of backfill material can be used in determining the percent compaction to be required in the specifications.

(b) Swelling characteristics can be determined by a modified consolidation test procedure. The degree of swelling and swelling pressure should be determined on all backfill and foundation materials suspected of having swelling characteristics. This fact is particularly important when a considerable overburden load is removed by excavation or when the compacted backfill with swelling tendencies may become saturated upon removal of the dewatering system and subsequent rise of the groundwater level. The results of swelling tests can be used to determine the suitability of material as backfill. When it is necessary to use backfill materials that have a tendency to swell upon saturation because more suitable materials are unavailable, the placement water content and density that will minimize swelling can be determined from a series of tests. TM 5-818-1/AFM 88-3, Chapter 7, and FHWA-RD-79-51 (app. A) provide further information applicable to compacted backfills.

(5) *Permeability tests.* Permeability tests to determine the rate of flow of water through a material can be conducted in the laboratory by procedures described in EM 1110-2-1906. Permeability characteristics of fine-grained materials at various densities can also be determined from consolidation tests.

(a) Permeability characteristics for the design of permanent drainage systems for structures founded below the groundwater level must be obtained from laboratory tests. The tests should be performed on representative specimens of backfill materials compacted in the laboratory to densities expected in the field.

(b) In situ material permeability characteristics for the design of construction excavation dewatering systems can also be approximated from laboratory tests on representative undisturbed samples. Laboratory permeability tests on undisturbed samples are less expensive than in situ pumping tests performed in the field; however, laboratory tests are less accurate in predicting flow characteristics.

(6) *Slake durability of shales.* Some clay shales tend to slake when exposed to air and water and must be protected immediately after they are exposed. The extent of slaking also governs the manner in which they are treated as a backfill material (para 3-3c). Slaking characteristics can be evaluated by laboratory jar-slake tests or slake-durability tests.

(a) The jar-slake test is qualitative with six descriptive degrees of slaking determined from visual observation of ovendried samples soaked in tap water for as long as 24 hours. The jar-slake test is not a standardized test. One version of the jar-slake test is discussed in FHWA-RD-78-141. Six suggested values of the jar-slake index I_J are listed below:

I_J	Behavior
1	Degrades into pile of flakes or mud
2	Breaks rapidly and forms many chips
3	Breaks rapidly and forms few chips
4	Breaks slowly and forms several fractures
5	Breaks slowly and develops few fractures
6	No change

Shales with I_J values of 1 to 3 should be protected when occurring in excavated slopes and compacted as soil if used for backfill.

(b) The slake-durability test is a standardized test that gives a quantitative description in percent by weight of material remaining intact at the conclusion of the test. Details of the test are presented in FHWA-RD-78-141.

(7) *Dynamic tests for special projects.* The dynamic analysis of projects subject to seismic or blast induced loading conditions requires special dynamic tests on both in situ and backfill materials. Tests required for dynamic analysis include: cyclic triaxial tests; in situ density measurements; and tests to determine shear wave velocities, shear modulus, and damp ing (ER 1110-2-1806).

(8) *In situ water content.* The in situ water content, including any seasonal variation, must be determined prior to construction for materials selected for use as backfill. Natural in situ water contents will determine the need for wetting or drying the backfill material before placement to obtain near optimum water contents for placement and compaction. ASTM D 2216 discusses the test method for determining water content.

3-3. Selection of backfill materials. Selection of backfill materials should be based upon the engineering properties and compaction characteristics of the materials available. The results of the field exploration and laboratory test programs should provide adequate information for this purpose. The materials may come from required excavation, adjacent borrow pits, or commercial sources. In selecting materials to be used, first consideration should be given to the maximum use of materials from required excavation. If the excavated materials are deficient in quality or quantity, other sources should be considered. Common backfill having the desired properties may be found in borrow areas convenient to the site, but it may be necessary to obtain select backfill materials having particular gradation requirements, such as filter sands and gravels and pipe or conduit bedding materials from commercial sources.

a. Primary considerations. Primary considerations for borrow material sources are suitability and quantity. Accessibility and proximity of the borrow area to the jobsite should also be considered. The water contents of the borrow area material should be determined seasonally, and a source of water should be located if the natural water contents are considerably less than the required placement water content. If several sources of suitable backfill are available, other factors to be considered in selecting the borrow materials are ease of loading and spreading and the means for adding or reducing water. The need for separating or mixing soil strata from excavation or borrow sources should be considered if necessary to provide reasonably uniform engineering properties throughout the compacted backfill.

b. Compaction characteristics. If compaction characteristics of the major portion of the backfill are relatively uniform, problems of controlling placement of backfill will be significantly reduced since the inspector will be able to develop more rapidly the ability to recognize the adequacy of the compaction procedures. In addition, the frequency of testing for compaction control could be reduced. When available backfill materials are unusual, test sections of compacted backfill are sometimes justified to develop placement procedures and to determine the engineering characteristics to be expected in field-compacted materials.

c. Workability. An important factor in choosing backfill materials is the workability or ease with which the soil can be placed and compacted. Material characteristics that effect workability include: the ease of adjusting water contents in the field by wetting or aeration; the sensitivity to the compaction water content with respect to optimum; and the amount of compaction effort required to achieve specified densities.

d. Types of backfill material. A discussion of the many types of backfill and their compaction characteristics is beyond the scope of this manual since soil types will vary on each project. However, the compaction characteristics of several rather broad categories of backfill (table 3-1) are discussed briefly. MIL-STD-619 should be studied for more detailed information.

(1) *Coarse-grained soils.* Coarse-grained soils include gravelly and sandy soils and range from clayey sands (SC) through the well-graded gravels of gravel-sand mixtures (GW) with little or no fines (table 3-l). They will exhibit slight to no plasticity. All of the well-graded soils falling in this category have fairly good compaction characteristics and when adequately compacted provide good backfill and foundation support.

(a) One difficulty that might arise with soils in this category would be in obtaining good compaction of the poorly graded sands and gravels. These poorly graded materials may require saturation with downward drainage and compaction with greater compaction effort to achieve sufficiently high densities. Also, close control of water content is required where silt is present in substantial amounts. Coarse-grained materials compacted to a low relative density are susceptible upon saturation to liquefaction under dynamic loads.

(b) For sands and gravelly sands with little or no fines, good compaction can be achieved in either the air-dried or saturated condition. Downward drainage is required to maintain seepage forces in a downward direction if saturation is used to aid in compaction. Consideration may be given to the economy of adding cement to stabilize moist clean sands that are particularly difficult to compact in narrow confined areas. However, the addition of cement may produce zones with greater rigidity than untreated adjacent backfill and form “hard spots” resulting in nonuniform stresses and deformations in the structure.

(c) Cohesionless materials are well suited for placement in confined areas adjacent to and around structures where heavy equipment is not permitted and beneath and around irregulary shaped structures, such as tunnels, culverts, utilities, and tanks. Clean, granular, well-graded materials having a maximum size of 1 inch with 95 percent passing the No. 4 sieve and 5 percent or less passing the No. 200 sieve are excellent for use in these zones. However, a danger exists of creating zones where seepage water may accumulate and saturate adjacent cohesive soils resulting in undesirable consolidation or swelling. In such cases, provisions for draining the granular backfill, sealing the surface, and draining surface water away from the structure are necessary.

(2) *Fine-grained soils of low to medium plasticity.* Inorganic clays (CL) of low to medium plasticity (gravelly, sandy, or silty clays and lean clays) and inorganic silts and very fine sands (ML) of low plasticity (silty or clayey fine sands and clayey silts) are included in this category. The inorganic clays are relatively impervious and can be compacted fairly easily with heavy compac-

tion equipment to provide a good stable backfill. Soils in the CL group can be compacted in confined areas to a fairly high degree of compaction with proper water content and lift thickness control. The clayey sands of the SC group and clayey silts of the ML group can be compacted to fairly high densities, but close control of water content is essential and sometimes critical, particularly on the wet side of optimum water content. Some ML soils, if compacted on the dry side of optimum, may lose considerable strength upon saturation after compaction. Considerable settlement may occur. Caution must therefore be exercised in the use of such soils as backfill, particularly below the groundwater level. Also, saturated ML soils are likely to be highly susceptible to liquefaction when dynamically loaded. Where such soils are used as backfill in seismic prone areas, laboratory tests should be conducted to determine their liquefaction potential (see para. 17-5 and 17-6, TM 5-818-1/AFM 88-3, Chap. 7).

(3) *Rock.* The suitability of rock as backfill material is highly dependent upon the gradation and hardness of the rock particles. The quantity of hard rock excavated at most subsurface structure sites is relatively small, but select cohesionless materials may be difficult to find or may be expensive. Therefore, excavated hard rock may be specified for crusher processing and used as select cohesionless material.

(4) *Shale.* Although shale is commonly referred to as rock, the tendency of some shales to breakdown under heavy compaction equipment and slake when exposed to air or water after placement warrants special consideration.

(a) Some soft shales break down under heavy compaction equipment causing the material to have entirely different properties after compaction than it had before compaction. This fact should be recognized before this type of material is used for backfill. Establishing the proper compaction criteria may require that the contractor construct a test fill and vary the water content, lift thickness, and number of coverages with the equipment proposed for use in the backfill operation. This type of backfill can be used only in unrestricted open zones where heavy towed or self-propelled equipment can operate.

(b) Some shales have a tendency to break down or slake when exposed to air. Other shales that appear rock-like when excavated will soften or slake and deteriorate upon wetting after placement as rockfill. Alternate cycles of wetting and drying increases the slaking process. The extent of material breakdown determines the manner in which it is treated as a backfill material. If the material completely degrades into constituent particles or small chips and flakes, it must be treated as a soil-like material with property characteristics similar to ML, CL, or CH materials, depending upon the intact composition of the parent material. Complete degradation can be facilitated by alternately wetting, drying, and disking the material before compaction A detailed discussion on the treatment of shales as a fill material is given in FHWA-RD-78-141.

(5) *Marginal materials.* Marginal materials are these materials that because of either their poor compaction, consolidation, or swelling characteristics would not normally be used as backfill if sources of suitable material were available. Material considered to be marginal include fine-grained soils of high plasticity and expansive clays. The decision to use marginal materials should be based on economical and energy conservation considerations to include the cost of obtaining suitable material whether from a distant borrow area or commercial sources, possible distress repair costs caused by use of marginal material, and the extra costs involved in processing, placing, and adequately compacting marginal material.

(a) The fine-grained, highly plastic materials make poor backfill because of the difficulty in handling, exercising water-content control, and compacting. The water content of highly plastic fine-grained soils is critical to proper compaction and is very difficult to control in the field by aeration or wetting. Furthermore, such soils are much more compressible than less-plastic and coarse-grained soils; shear strength and thus earth pressures may fluctuate between wide limits with changes in water content; and in cold climates, frost action will occur in fine-grained soils that are not properly drained. The only soil type in this category that might be considered suitable as backfill is inorganic clay (CH). Use of CH soils should be avoided in confined areas if a high degree of compaction is needed to minimize backfill settlement or to provide a high compression modulus.

(b) The swelling (and shrinking) characteristics of expansive clay vary with the type of clay mineral present in the soil, the percentage of that clay mineral, and the change in water content. The active clay minerals include montmorillonite, mixed-layer combinations of montmorillonite and other clay minerals, and under some conditions chlorites and vermiculites. Problems may occur from the rise of groundwater, seepage, leakage, or elimination of surface evaporation that may increase or decrease the water content of compacted soil and lead to the tendency to expand or shrink. If the swelling pressure developed is greater than the restraining pressure, heave will occur and may cause structural distress. Compaction on the wet side of optimum moisture content will produce lower magnitudes of swelling and swell pressure. Expansive clays that exhibit significant volume increases should not be used as backfill where the potential for structural damage might exist. Suitability should be based upon laboratory swell tests (TM 5-818-1/AFM 88-3, Chapter 7).

(c) Additives, such as hydrated lime, quicklime, and fly ash, can be mixed with some highly plastic clays to improve their engineering characteristics and permit the use of some materials that would otherwise be unacceptable. Hydrated lime can also be mixed with some expansive clays to reduce their swelling characteristics (TM 5-818-1/AFM 88-3, Chapter 7). Lab oratory tests should be performed to determine the amount of the additive that should be used and the characteristics of the backfill material as a result of using the additive. Because of the complexity of soil-additive systems and the almost complete empirical nature of the current state of the art, trial mixes must be varified in the field by test fills.

(6) *Commercial by-products. The* use of commercial by-products, such as furnace slag or fly ash as backfill material, may be advantageous where such products are locally available and where suitable natural materials cannot be found. Fly ash has been used as a lightweight backfill behind a 25-foot-high wall and as an additive to highly plastic clay. The suitability of these materials will depend upon the desirable characteristics of the backfill and the engineering characteristics of the products.

3-4. Processing of backfill materials. The construction of subsurface structures often requires the construction of elements of the structure within or upon large masses of backfill. The proper functioning of these elements are often critically affected by adverse behavioral characteristics of the backfill. Behavioral characteristics are related to material type, water content during compaction, gradation, and compaction effort. While compaction effort may be easily controlled during compaction, it is difficult to control material type, water content, and gradation of the material as it is being placed in the backfill; control criteria must be established prior to placement.

a. Material type. Backfill material should consist of a homogeneous material of consistent and desirable characteristics. The field engineer must ensure that only the approved backfill material is used and that the material is uniform in nature and free of any anomalous material such as organic matter or clay pockets. Stratified material should be mixed prior to placing to obtain a uniform blend. Excavated material to be used as backfill should be stockpiled according to class or type of material.

b. Water content. While water content can be adjusted to some extent after placing (but before compacting), it is generally more advantageous to adjust the water content to optimum compaction conditions before placing. Adjustment of water content can be accomplished by aeration (disking or turning) or sprinkling the material in 12- to 18- inch layers prior to placing or stockpiling. If the material is stockpiled, provisions should be made to maintain a constant moisture content during wet or dry seasons.

c. Ensuring gradation. Some backfill materials consisting of crushed rock, gravel, or sand require limitations on maximum and minimum particle-size or gradation distributions. Where materials cannot be located that meet gradation criteria, it may be advantageous to require processing of available material by sieving to obtain the desired gradation.

CHAPTER 4

EARTHWORK: EXCAVATION AND PREPARATION FOR FOUNDATIONS

4-1. Excavation.

a. General. In general, excavation for subsurface structures will consist of open excavation and shaft and tunnel excavation. Where excavation to great depths is required, a variety of soils and rock may be encountered at a single site. Soils may range through a wide spectrum of textures and water contents. Rock encountered may vary from soft rock, very similar to a firm soil in its excavation requirements, to extremely hard rock requiring extensive blasting operations for removal. Groundwater may or may not be present. The groundwater conditions and the adequacy of groundwater control measures are important factors in excavation, in maintaining a stable foundation, and in backfilling operations. The extent to which groundwater can be controlled also influences the slopes to which the open excavation can be cut, the bracing required to support shaft and tunnel excavation, and the handling of the excavated material.

b. Good construction practices, and problems. A majority of the problems encountered during excavation are related to groundwater conditions, slope stability, and adverse weather conditions. Many of the problems can be anticipated and avoided by preconstruction planning and by following sound construction practices.

(1) *Groundwater.* Probably the greatest source of problems in excavation operations is groundwater. If the seepage of groundwater into an excavation is adequately controlled, other problems will generally be minor and can be easily handled. Several points should be recognized that, if kept in mind, will help to reduce problems attributable to groundwater. In some instances, groundwater conditions can be more severe than indicated by the original field exploration investigation since field explorations provide information only for selected locations and may not provide a true picture of the overall conditions.

(a) If groundwater seepage begins to exceed the capacity of the dewatering system, conditions should not be expected to improve unless the increased flow is known to be caused by a short-term condition such as heavy rain in the area. If seepage into the excavation becomes excessive, excavation operations should be halted until the necessary corrective measures are determined and effected. The design and evaluation of dewatering systems require considerable experience that the contractor or the contracting office often do not possess, and the assistance of specialists in this field should be obtained.

(b) Groundwater without significant seepage flow can also be a problem since excess hydrostatic pressures can develop below relatively impervious strata and cause uplift and subsequent foundation or slope instability. Excess hydrostatic pressures can also occur behind sheet pile retaining walls and shoring and bracing in shaft and tunnel excavations. Visual observations should be made for indications of trouble, such as uncontrolled seepage flow, piping of material from the foundation or slope, development of soft wet areas, uplift of ground surface, or lateral movements.

(c) Accurate daily records should be kept of the quantity of water removed by the dewatering system and of the piezometric levels in the foundation and beneath excavation slopes. Separate records should be kept of the flow pumped by any sump-pump system required to augment the regular dewatering system to note any increase of flow into the excavation. Flowmeters or other measuring devices should be installed on the discharge of these systems for measurement purposes (TM 5-818-5/NAVFAC P-418/AFM 88-5, Chap. 6). These records can be invaluable in evaluating "Changed Condition" claims submitted by the contractor. The contractor should be required to have "standby" equipment in case the original equipment breaks down.

(2) *Surface water.* Sources of water problems other than groundwater are surface runoff into the excavation and snow drifting into the excavation. A peripheral, surface-drainage system, such as a ditch and berm, should be required to collect surface water and divert it from the excavation, In good weather there is a tendency for the contractor to become lax in maintaining this system and for the inspection personnel to become lax in enforcing maintenance. The result can be a sudden filling of the excavation with water during a heavy rain and consequent delay in construction. The surface drainage system must be constantly maintained until the backfill is complete. Drifting snow is a seasonal and regional problem, which can best be controlled by snow fences placed at strategic locations around the excavation,

(3) *Slope integrity.* Another area of concern during excavation is the integrity of the excavation

slopes. The slopes may be either unsupported or supported by shoring and bracing. The lines and grades indicated in the plans should be strictly adhered to. The contractor may attempt to gain additional working room in the bottom of the excavation by steepening the slopes; this change in the plans must not be allowed.

(a) Where shoring and bracing are necessary to provide a stable excavation, and the plans and specifications do not provide details of these requirements, the contractor should be required to submit the plans in sufficient detail so that they can be easily followed and their adequacy checked. The first principle of excavation stabilization, using shoring and bracing, is that the placing of supports should proceed with excavation. The excavation cut should not be allowed to yield prior to placing of shoring and bracing since the lateral pressures to be supported would generally be considerably greater after yield of the unshored cut face than if no movement had occurred prior to placement of the shoring. Excavation support systems are discussed in TM 5-818-1/AFM 88-3, Chapter 7. All safety requirements for shoring and bracing as contained in EM 385-1-1 should be strictly enforced.

(b) The inspector must be familiar with stockpiling requirements regarding the distance from the crest of the excavation at which stockpiles can be established and heavy equipment operated without endangering the stability of the excavation slopes. He must also know the maximum height of stockpile *or* weight of equipment that can be allowed at this distance.

(c) Excessive erosion of the excavation slopes must not be permitted. In areas subject to heavy rainfall, it may be necessary to protect excavation slopes with polyethylene sheeting, straw, silt fences, or by other means to prevent erosion. Excavation slopes for large projects that will be exposed for several seasons should be vegetated and maintained to prevent erosion.

(4) *Stockpiling excavated material.* Generally, procedures for stockpiling are left to the discretion of the contractor. Prior to construction, the contractor must submit his plans for stockpiling to the contracting officer for approval. In certain cases, such as where there are different contractors for the excavation and the backfill phases, it may be necessary to include the details for stockpiling operations in the specifications. In either case, it is important that the stockpiling procedures be conducive to the most advantageous use of the excavated materials.

(a) As the materials are excavated, they should be separated into classes of backfill and stockpiled accordingly. Thus the inspection personnel controlling the excavation should be qualified to classify the material and should be thoroughly familiar with backfill requirements. Also, as the materials are placed in stockpiles, water should be added or the materials should be aerated as required to approximate optimum water content for compaction. Field laboratory personnel can assist in determining the extent to which this is necessary. The requirements of shaping the stockpile to drain and sealing it against the entrance of undesirable water by rolling with spreading equipment or covering with polyethylene sheeting should be enforced. This step is particularly important for cohesive soils that exhibit poor draining characteristics and tend to remain wet if once saturated by rains. Stockpiles must be located over an area that is large enough to permit processing and where they will not interfere with peripheral drainage around the excavation and will not overload the slopes of the excavation.

(b) In cases where significant energy and cost saving can be realized, special stockpiling requirements should be implemented. An example would be *a* large project consisting of a number of excavation and backfilling operations. The excavation material from the first excavation could be stockpiled for use as backfill in the last excavation. The material from the intermediate excavations could in turn be immediately used as backfill for the first, second, etc., phases of the project and thereby eliminate double handing of excavated backfill for all but the first-phase excavation.

(5) *Protection of exposed material.* If materials that are exposed in areas, such as walls of a silo shaft, foundation support, or any other area against which concrete will be placed, are susceptible to deterioration or swell when exposed to the weather, they should be properly protected as soon after exposure as possible. Depending on the material and protection requirements, this protection may be pneumatic concrete, asphalt spray, or plastic membrane (TM 5-818-1/AFM 88-33, Chap. 7). In the case of a foundation area, the contractor is required to underexcavate leaving a cover for protection, as required, until immediately prior to placement of the structure foundation. Any frost-susceptible materials encountered during excavation should be protected (para 2-3h (3) and (4)) if the excavation is to be left open during an extended period of freezing weather.

(6) *Excavation record.* As the excavation progresses, the project engineer should keep a daily record of the type of material excavated and the progress made. This record would be of value if subsequent claims of "Changed Conditions" are made by the contractor.

4-2. Foundation preparation.

a. General. In this manual, preparation applies to foundations for backfill as well as those for structures to be placed in the excavation. Generally, if proper excavation procedures have been followed, very little additional preparation will be required prior to backfill placement.

b. Good construction practices, and problems. As mentioned previously, the problems associated with foundation preparation are greatly reduced by following such proper excavation procedures as maintaining a dry excavation and planning ahead. The principles of good foundation preparation are simple, but enforcing the provisions of the specifications concerning the work is more difficult. Inspection personnel must recognize the importance of this phase of the work since, if not properly controlled, problems can result.

(1) It is most important that a stable foundation be provided. Thus it may be necessary, particularly in the case of sensitive fine-g-rained materials, to require that the final excavation for footings be carefully done with hand tools and that no equipment be allowed to operate on the final cut surface. To provide a working platform on which to begin backfill placement on these sensitive materials, it may be necessary to place an initial layer of granular material.

(2) If the foundation is to be supported on rock, the soundness of the exposed rock should be checked by a slaking test (soaking a piece of the rock in water to determine the resulting degree of deterioration (para 3-2b (6)) and visual observation to determine if the rock is in a solid and unshattered condition. If removal of rock below the foundation level is required, the space should be filled with concrete. A qualified geological or soils engineer should inspect the area if it is suspected that the material will deteriorate or swell when exposed to the weather. If necessary, the materials must be protected from exposure using the methods previously discussed in paragraph 4-1b (5).

(3) Before placement of any structure foundation is begun, the plans should be rechecked to ensure that all required utilities and conduits under or adjacent to the foundation have been placed, so that excavating under or undermining the foundation to place utilities and conduits will not become necessary later.

(4) Occasionally, it may be found upon completion of the excavation that if a structure were placed as shown on the plans, it would be supported on two materials with drastically different consolidation charactertistics, such as rock and soil, rock and backfill, or undisturbed soil and backfill. This situation could occur because the predesign subsurface information was inadequate, because the structure was relocated or reoriented by a subsequent change in the plans, because of an oversight of the design engineer, or because of the excavation procedures followed by the contractor. Regardless of the reason, measures such as overexcavation and placement of subsequent backfill should be taken, where possible, and in coordination with the design office to provide a foundation of uniform material. Otherwise, the design office should evaluate the differences in foundation conditions for possible changes to the structural foundation elements.

(5) Preparing the area to receive the backfill consists of cleaning, leveling, and compacting the bottom of the excavation if the foundation is in soil. All debris and foreign material, such as trash, broken concrete and rock, boulders, and forming lumber, should be removed from the excavation. All holes, depressions, and trenches should be filled with the same material as that specified to be placed immediately above such a depression, unless otherwise designated, and compacted to the density specified for the particular material used. If the depression is large enough to accommodate heavy compacting equipment, the sides of the depression should have a positive slope and be flat enough for proper operation of compaction equipment. After the area is brought to a generally level condition by compacting in lifts in accordance with specifications, the entire area to receive backfill should be sacrificed to the depth specified, the water content adjusted if necessary, and the area compacted as specified. If the foundation is in rock, the area should be leveled as much as possible and all loose material removed.

(6) All work in the excavation should be accomplished in the dry; therefore, the dewatering system should be operated for the duration of this work. Under no circumstances should the contractor be allowed to dry an area by dumping a thick layer of dry material over it to blot the excess water. If soil exists at the foundation level and becomes saturated, it cannot be compacted. The saturated soil will have to be removed and replaced or drained sufficiently so that it can be compacted. Any frozen material in the foundation should be removed before placement of concrete footings or compacted backfill.

CHAPTER 5

BACKFILL OPERATIONS

5-1. Placement of backfill.

a. General. Backfill construction is the refilling of previously excavated space with properly compacted material. The areas may be quite large, in which case the backfilling operation will be similar to embankment construction. On the other hand, the areas may be quite limited, such as confined areas around or between and beneath concrete or steel structures and areas in trenches excavated for utility lines. Prior to construction of the backfill, the inspection personnel should become thoroughly familiar with the various classes of backfill to be used. They should be able to readily identify the materials on sight, know where the various types of material should be placed, and be familiar with the compaction characteristics of the soil types. Compaction characteristics of various soil types are discussed in appendix B.

b. Good construction practices, and problems. Problems with placement of backfill will vary from one construction project to another. The magnitude of the problems will depend on the type of materials available such as backfill, density requirements, and the configuration of the areas in which compaction is to be accomplished. Problems should be expected during the initial stages of backfill compaction unless the contractor is familiar with compaction characteristics of backfill materials. The inspector can be of great assistance to the contractor during this period by performing frequent water content and density checks. The information from these checks will show the contractor the effects of the compaction procedures being used and point out any changes that should be made.

(1) *Backfilling procedures.* Problems associated with the compaction of backfill can be minimized by following good backfilling procedures. Good backfilling procedures include: processing the material (para. 3-4) before it is placed in the excavation; placing the material in a uniformly spread loose lift of the proper thickness suited to the compaction equipment and the type of material to be used; applying the necessary compaction effort to obtain the required densities; and ensuring that these operations are not performed during adverse weather. Proper bond should be provided between each lift and also between the backfill and the sides of the excavation.

(2) *Compaction equipment, backfill material,* and *zones.* The type of compaction equipment used. to achieve the required densities will usually depend upon the type of backfill material being compacted and the type of zone in which the material is placed.

(a) In open zones, coarse-grained soils that exhibit slight plasticity (clayey sands, silty sands, clayey gravels, and silty gravels) should be compacted with either sheepsfoot or rubber-tired rollers; close control of water content is required where silt is present in substantial amounts. For sands and gravelly sands with little or no fines, good compaction results are obtained with tractor compaction. Good compaction can also be achieved in gravels and gravel-sand mixtures with either a crawler tractor or rubber-tired and steel-wheeled rollers. The addition of vibration to any of the means of compaction mentioned above will usually improve the compaction of soils in this category. In confined zones, adequate compaction of cohesionless soils in either the air-dried or saturated condition can be achieved by vibratory-plate compactors with a static weight of at least 100 pounds. If the material is compacted in the saturated condition, good compaction can be achieved by internal vibration (for example, by using concrete vibrators). Downward drainage is required to maintain seepage forces in a downward direction if the placed material is saturated to aid in compaction.

(b) Inorganic clays, inorganic silts, and very fine sands of low to medium plasticity are fairly easily compacted in open zones with sheepsfoot or rubber-tired rollers in the 15,000-pound and above wheel-load class. Some inorganic clays can be adequately compacted in confined zones using rammer or impact compactors with a static weight of at least 100 pounds provided close control of lift thickness and water content is maintained.

(c) Fine-grained, highly plastic materials, though not good backfill materials, can best be compacted in open zones with sheepsfoot rollers. Sheepsfoot rollers leave the surface of the backfill in a rough condition, which provides an excellent bond between lifts. In confined areas the best results, which are not considered good, are obtained with rammer or impact compactors.

(3) *Lift thickness.* The loose-lift thickness will depend on the type of backfill material and the compaction equipment to be used.

(a) As a general rule, a loose-lift thickness that will result in a 6-inch lift when compacted can be al-

lowed for most sheepsfoot and pneumatic-tired rollers. Cohesive soils placed inapproximately lo-inch loose lifts will compact to approximately 6 inches, and cohesionless soils placed in approximately 8-inch base lifts will compact to 6 inches. Adequate compaction can be achieved in cohesionless materials of about 12- to 15-inch loose-lift thickness if heavy vibratory equipment is used. The addition of vibration to rolling equipment used for compacting cohesive soils generally has little effect on the lift thickness that can be compacted, although compaction to the desired density can sometimes be obtained by fewer coverages of the equipment.

(b) In confined zones where clean cohesionless backfill material is used, a loose-lift thickness of 4 to 6 inches and a vibratory plate or walk-behind, dual-drum vibratory roller for compaction is recommended. Where cohesive soils are used as backfill in confined zones, use of rammer compactors and a loose-lift thickness of not more than 4 inches should be specified. Experience has shown that "two-by-four" wood rammers, or single air tampers (commonly referred to as "powder puffs" or "pogo sticks") do not produce sufficient compaction.

(4) *Density requirements.* In open areas of backfill where structures will not be constructed, compaction can be less than that required in more critical zones. Compaction to 90 percent of CE 55 maximum dry density as obtained by MIL-STD-621 should be adequate in these areas. If structures are to be constructed on or within the backfill, compaction of cohesionless soils to within 95 to 100 percent of CE 55 maximum dry density and of cohesive soils to at least 95 percent of CE 55 should be required for the full depth of backfill beneath these structures. The specified degree of compaction should be commensurate with the tolerable amount of settlement, and the compaction equipment used should be commensurate with the allowable lateral pressure on the structure. Drainage blankets and filters having special gradation requirements should be compacted to within 95 to 100 percent of CE 55 maximum dry density. Table 5-1 gives a summary of type of compaction equipment, number of coverages, and lift thickness for the specified degree of compaction of various soil types (TM 5-818-1/AFM 88-3, Chap. 7).

(5) *Cold weather.* In areas where freezing temperatures either hamper or halt construction during the winter, certain precautions can and should be taken to prevent damage from frost penetration and subsequent thaw. Some of these precautions are presented below.

(a) Placement of permanent backfill should be deferred until favorable weather conditions prevail. However, if placement is an absolute necessity during freezing temperatures, either dry, cohesionless, non-frost-susceptible materials or material containing additives, such as calcium chloride, to lower the freezing temperature of the soil water should be used. Each lift should be checked for frozen material after compaction and before construction of the next lift is begun. If frozen material is found, it should be removed; it should not be disked in place. Additives should not be used indiscriminately since they will ordinarily change compaction and water content requirements. Prior laboratory investigation should be conducted to determine additive requirements and the effect on the compaction characteristics of the backfill material.

(b) Under no circumstances should frozen material, from stockpile or borrow pit, be placed in backfill that is to be compacted to a specified density.

(c) Prior to halting construction during the winter, the peripheral surface drainage system should be checked and reworked where necessary to provide positive drainage of surface water away from the excavation.

(d) Foundations beneath structures and backfill around structures should not be allowed to freeze, because structural damage will invariably develop. Structures should be enclosed as much as possible and heated if necessary. Construction should be scheduled so as to minimize the amount of reinforcing steel protruding from a partially completed structure since steel will conduct freezing temperatures into the foundation.

(e) Permanent backfill should be protected from freezing as discussed in paragraphs 2-3h (3) and (4). Records should be made of all temporary coverings that must be removed before backfilling operations are resumed. A checklist should be maintained to ensure that all temporary coverings are removed at the beginning of the next construction season.

(f) During freezing weather, records should be kept of the elevation of all critical structures to which there is the remotest possibility of damage or movement due to frost heave and subsequent thaw. It is important that frost-free bench marks be established to which movement of any structure can be referenced. Bench marks also should be established on the structures at strategic locations prior to freezing weather.

(g) At the beginning of the following construction season and after the temporary insulating coverings are removed, the backfill should be checked for frozen material and ice lenses, and the density of the compacted material should be checked carefully before backfilling operations are resumed. If any backfill has lost its specified density because of freezing, it should be removed.

(6) *Zones having particular gradation requirements.* Zones that have particular gradation requirements include those needed to conduct and control seepage, such as drainage blankets, filters, and zones

Table 5-1. Summary of Compaction Criteria [a]

Soil Group	Soil Types		Degree of Compaction	Equipment	No. of Passes or Coverages	Comp. Lift Thick., in.	Placement Water Content	Field Control
				Fill and Backfill — Typical Equipment and Procedures for Compaction				
Pervious (Free-Draining)	GW GP SW SP	Compacted	90 to 95% of CE 55 maximum density; 75 to 85% of relative density	Vibratory rollers and compactors	Indefinite	Indefinite	Saturate by flooding	Control tests at intervals to determine degree of compaction or relative density
				Rubber-tired roller[b]	2-5 coverages	12		
				Crawler-type tractor[c]	2-5 coverages	8		
				Power hand tamper[d]	Indefinite	6		
		Semicompacted	85 to 90% of CE 55 maximum density; 65 to 75% of relative density	Rubber-tired roller[b]	2-5 coverages	14	Saturate by flooding	Control tests as noted above, if needed
				Crawler-type tractor[c]	1-2 coverages	10		
				Power hand tamper[d]	Indefinite	8		
				Controlled routing of construction equipment	Indefinite	8-10		
Semipervious and Impervious	GM GC SM SC ML CL OL OH MH CH OH	Compacted	90 to 95% of CE 55 maximum density	Rubber-tired roller[b]	2-5 coverages	8	Optimum water content	Control tests at intervals to determine degree of compaction
				Sheepsfoot roller[e]	4-8 passes	6		
				Power hand tamper[d]	Indefinite	4		
		Semicompacted	85 to 90% of CE 55 maximum density	Rubber-tired roller[b]	2-4 coverages	10	(A) Optimum water content (B) By observation; wet side-maximum water content at which material can satisfactorily operate, dry side-minimum water content required to bond particles and which will not result in voids or honeycombed material	(A) Control tests as noted above, if needed (B) Field control exercised by visual inspection of action of compacting equipment
				Sheepsfoot roller[e]	4-8 passes	8		
				Crawler-type tractor[c]	3 coverages	6		
				Power hand tamper[d]	Indefinite	6		
				Controlled routing of construction equipment	Indefinite	6-8		

Note: The above requirements will be adequate in relation to most construction. In special cases where tolerable settlements are unusually small, it may be necessary to employ additional compaction equivalent to 95 to 100% of compaction effort. A coverage consists of one application of the wheel of a rubber-tired roller or the threads of a crawler-type tractor over each point in the area being compacted. For a sheepsfoot roller, one pass consists of one movement of a sheepsfoot roller drum over the area being compacted.

a From TM 5-818-1.
b Rubber-tired rollers having a wheel load between 18,000 and 25,000 lb and a tire pressure between 80 and 100 psi.
c Crawler-type tractors weighing not less than 20,000 lb and exerting a foot pressure not less than 6-1/2 psi.
d Power hand tampers weighing more than 100 lb; pneumatic or operated by gasoline engine.
e Sheepsfoot rollers having a foot pressure between 250 and 500 psi and tamping feet 7 to 10 in. in length with a face area between 7 and 16 sq in.

susceptible to frost penetration. Drainage zones are often extremely important to the satisfactory construction and subsequent performance of the structure. To maintain the proper functioning of these zones, care must be taken to ensure that the material placed has the correct gradation and is compacted according to specifications.

c. Special problems. In open zones, compaction of backfill will not generally present any particular problems if proper compaction procedures normally associated with the compaction of soils are exercised and the materials available for use, such as backfill, are not unusually difficult to compact. The majority of the problems associated with backfill will occur in confined zones where only small compaction equipment producing a low compaction effort can be used or where because of the confined nature of the backfill zone even small compaction equipment cannot be operated effectively.

(1) Considerable latitude exists in the various types of small compaction equipment available. Unfortunately, very little reliable information is available on the capabilities of the various pieces of equipment. Depending upon the soil type and working room, it may be necessary to establish lift thickness and compaction effort based essentially on trial and error in the field. For this reason, close control must be maintained particularly during the initial stages of the backfill until adequate compaction procedures are established.

(2) Circular, elliptical and arched walled structures are particularly difficult to adequately compact backfill beneath the under side of haunches because of limited working space. Generally, the smaller the structure the more difficult it is to achieve required densities. Rock, where encountered, must be removed to a depth of at least 6 inches below the bottom of the structure and the overdepth backfilled with suitable material before foundation bedding for the structure is placed. Some alternate bedding and backfill placement methods are discussed below.

(a) One method is to bring the backfill to the planned elevation of the spring line using conventional heavy compaction equipment and methods. A template in the shape of the structure to be bedded is then used to reexcavate to conform to the bottom contours of the structure. If the structure is made of corrugated metal, allowance should be made in the grade for penetration of the corrugation crests into the backfill upon application of load. Success of this method of bedding is highly dependent on rigid control of grade during reexcavation using the template. This procedure is probably the most applicable where it is necessary to use a cohesive backfill.

(b) Another method of bedding placement is to sluice a clean granular backfill material into the bed after the structure is in place. This method is particularly adapted to areas containing a maze of pipes or conduits. Adequate downward drainage, generally essential to the success of this method, can be provided by sump pumps or, if necessary, by pumping from well points. Sluicing should be accompanied by vibrating to ensure adequate soil density. Concrete vibrators have been used successfully for this purpose. This method should be restricted to areas where conduits or pipes have been placed by trenching or in an excavation that provides confining sides. Also, this method should not be used below the groundwater table in seismic zones, since achieving densities high enough to assure stability in a seismic zone is difficult.

(c) Another method is to place clean, granular bedding material with pneumatic concrete equipment under the haunches of pipes, tunnels, and tanks. The material is placed wet and should have an in-place water content of approximately 15 to 18 percent. A nozzle pressure of 40 pounds per square inch is required to obtain proper density. Considerable rebound of material (as much as 25 percent by volume when placed with the hose nozzle pointed vertically downward and 50 percent with the nozzle pointed horizontally) occurs at this pressure. Rebound is the material that bounces off the surface and falls back in a loose state. However, the method is very satisfactory if all rebound material is removed. The material can be effectively removed from the backfill by dragging the surface in the area where material is being placed with a flat-end shovel. Two or three men will be needed for each gunite hose operated.

(d) For structures and pipes that can tolerate little or no settlement, lean grouts containing granular material and various cementing agents, such as portland cement or fly ash, can be used. This grout may be placed by either method discussed in (b) and (c) above. However, grouts may develop hard spots (particularly where the sluice method is used that could cause segregation of the granular material and the cementing agent), which could generate stress concentrations in rigid structures such as concrete pipes. Stress concentrations may be severe enough to cause structural distress. If lean grouts are used as backfill around a rigid structure, the structure must be designed to withstand any additional stress generated by possible hard spots.

5-2. Installation of instruments. Installation of instrumentation devices should be supervised, if not actually done, by experienced personnel from within the Corps of Engineers or by firms that specialize in instrumentation installation. The resident engineer staff must be familiar with the planned locations of all instruments and necessary apparatus or structures (such as trenches and terminal houses) so that necessary arrangements and a schedule for installation can be made with the contractor and with the office or firm that will install the devices. Inspectors should inspect any instrumentation furnished and installed by the contractor. Records must be made of the exact locations and procedures used for installation and initial observations. Inspectors should ensure that necessary extensions are added for the apparatus (such as lead lines and piezometer tubes) installed within the backfill as the backfill is constructed to higher elevations. Care must be used in placing and compacting backfill around instruments that are installed within or through backfill. Where necessary to prevent damage to instruments, backfill must be placed manually and compacted with small compaction equipment such as rammers or vibratory plates.

5-3. Postconstruction distress. Good backfill construction practices and control will minimize the potential for postconstruction distress. Nevertheless, the possibility of distress occurring is real, and measures must be taken to correct any problems before they become so critical as to cause functional problems with the facility. Therefore, early detection of distress is essential. Some early signs of possible distress include: settlement or swelling of the backfill around the structure; sudden or gradual change of instrumentation data; development of cracks in structural walls; and adverse seepage problems. Detailed construction records are important for defining potential distress areas and assessing the mechanisms causing the distress.

CHAPTER 6

SPECIFICATION PROVISIONS

6-1. General.

a. The plans and specifications define the project in detail and show how it is to be constructed. They are the basis of the contractor's estimate and of the construction contract itself. The drawings show the physical characteristics of the structure, and the specifications cover the quality of materials, workmanship, and technical requirements. Together they form the guide and standard of performance that will be required in the construction of the project. Once the contract is let, the plans and specifications are binding on both the Contracting Officer and the contractor and are changed only by written agreement. For this reason, it is essential that the contractor and the Contracting Officer's representative anticipate and resolve differences that may arise in interpreting the intent and requirements of the specifications. The ease with which this can be accomplished will depend on the clarity of the specifications and the background and experience of the individuals concerned. Understanding of requirements and working coordination can be improved if unusual requirements are brought to the attention of prospective bidders and meetings for discussion are held prior to construction. Situations will undoubtedly arise that are not covered by the specifications, or conditions may occur that are different from those anticipated. Close cooperation is required between the contractor and the inspection personnel in resolving situations of this nature; if necessary, to be fair to both parties a change order should be issued.

b. Preparation of contract specifications is easier if an outline of general requirements is available to the specification writer. However, it would be virtually impossible to prepare a guide specification that anticipates all problems that may occur on all projects. Therefore, contract specifications must be written to satisfy the specific requirement of each project. Some alternate specification requirements that might be considered for some projects are discussed below.

6-2. Excavation. The section of the specifications dealing with excavation contains information on drainage, shoring and bracing, removal and stockpiling, and other items, and refers to the plans for grade requirements and slope lines to be followed in excavating overburden soils and rock.

a. Drainage. For some projects the specifications will require the contractor to submit a plan of his excavation operations to the Contracting Officer for review. The plans and specifications will require that the excavation and subsequent construction and backfill be carried out in the dry. To meet this requirement, a dewatering system based on the results of groundwater studies may be included in the plans. Also, for some projects the specifications may require the contractor to submit his plan for controlling groundwater conditions. The specifications should likewise indicate the possibility of groundwater conditions being different from those shown in the subsurface investigation report due to seasonal or unusual variations or insufficient information, since the contractor will be held responsible for controlling the groundwater flow into the excavation regardless of the amount. To this end, the specifications should provide for requiring the contractor to submit a revised dewatering plan for review where the original dewatering plan is found to be inadequate.

b. Shoring and bracing. The specifications either will require the contractor to submit for review his plans for the shoring and bracing required for excavation or will specify shoring and bracing required by subsurface and groundwater conditions and details of the lines and grades of the excavation. In the latter case, the contractor may be given the option to submit alternate plans for shoring and bracing for review by the Contracting Officer. The plans will present the necessary information for the design of such a system if the contractor is allowed this option.

c. Stockpiling. Provisions for stockpiling materials from required excavation according to type of backfill may or may not be included in the specifications. Generally, procedures for stockpiling are left to the discretion of the contractor, and a thorough study should be made to substantiate the need for stockpiling before such procedures are specified. There are several conditions under which inclusion of stockpiling procedures in the specifications would be desirable and justified. Two such conditions are discussed in the following paragraphs.

(1) Under certain conditions, such as those that existed in the early stages of missile base construction where time was an important factor, it may be necessary or desirable to award contracts for the work in phases. As a result, one contractor may do the excavat-

ing and another place the backfill. It is probable that the excavation contractor will have little or no interest in stockpiling the excavated materials in a manner conducive to good backfilling procedures. When such a situation can be foreseen, the specifications should set forth stockpiling procedures. The justification for such requirements would be economy and optimum use of materials available from required excavation as backfill.

(2) The specifications will contain provisions for removing, segregating, and stockpiling or disposing of material from the excavation and will refer to the plans for locations of the stockpiles. The subsoil conditions and engineering characteristics requirements may state that the specifications must be quite definite concerning segregation and stockpiling procedures so that the excavated materials can be used most advantageously in the backfill. The specification may require that water be added to the material or the material be aerated as it is stockpiled to approximate optimum water content, that the stockpile be shaped to drain and be sealed from accumulation of excess water, and that the end dumping of material on the stockpile be prohibited to prevent segregation of material size or type along the length of the stockpile.

(3) An alternative to this latter action would be to specify the various classes of backfill required and leave the procedure for stockpiling the materials by type to the discretion of the contractor. In this case, the contractor should be required to submit a detailed plan for excavating and stockpiling the material. The plan should indicate the location of stockpiles for various classes of backfill so that the material can be tested for compliance with the specifications. The contractor may elect to obtain backfill material from borrow or commercial sources rather than to separate and process excavated materials. Then the specifications should require that stockpiles of the various classes of needed backfill be established at the construction site in sufficient quantity and far enough in advance of their use to allow for the necessary testing for approval unless conditions are such that approval of the supplier's stockpile or borrow source can be given.

6-3. Foundation preparation. The provisions for preparation for structures will generally not be grouped together in the specifications but will appear throughout the earthwork section of the specifications under paragraphs on excavation, protection of foundation materials, backfill construction, and concrete placement. When a structure is to be founded on rock, the specifications will require that the rock be firm, unshattered by blasting operations, and not deteriorated from exposure to the weather. The contractor will be required to remove shattered or weathered rock and to fill the space with concrete.

a. Specifications for structures founded on soil require the removal of all loose material and all unsuitable material, such as organic clay or silt, below the foundation grade. When doubt exists as to the suitability of the foundation materials, a soils engineer should inspect the area and his recommendations should be followed. When removal of rock material below the planned foundation level is required, the overexcavation will usually require filling with concrete. The specifications also require dewatering to the extent that no backfill or structural foundation is placed in the wet.

b. Specifications for preparation of the soil foundation to receive backfill require removing all debris and foreign matter, making the area generally level, and scarifying, moistening, and compacting the foundation to a specified depth, generally 12 inches. Specific provisions may or may not be given with respect to leveling procedures.

6-4. Backfill operations. The specifications define the type or types of material to be used for backfill construction and provide specific instructions as to where these materials will be used in the backfill, The percentage of CE 55 maximum dry density to be obtained, determined by a designated standard laboratory compaction procedure, will be specified for the various zones of backfill. The maximum loose-lift thickness for placement will also be specified. Because of the shape of the compaction curve (see discussion of compaction characteristics in Section B-1, app. B), the degree of compaction specified can be achieved only within a certain range of water contents for a particular compaction effort. Though not generally specified in military construction, the range of water contents is an important factor affecting compaction.

a. The specifications sometimes stipulate the characteristics and general type of compaction equipment to be used for each of the various types of backfill. Sheepsfoot or rubber-tired rollers, rammer or impact compactors, or other suitable equipment are specified for fine-grained, plastic materials. Noncohesive, free-draining materials are specified to be compacted by saturating the material and operating crawler-type tractor, surface or internal vibrators, vibratory compactors, or other similar suitable equipment. The specifications generally will prohibit the use of rock or rock-soil mixtures as backfill in this type of construction. However, when the use of backfill containing rock is permitted, the maximum size of the rock is given in the specifications along with maximum lift thickness, loading, hauling, dumping, and spreading procedures, type of compaction equipment, and method of equipment operation. The specifications should prohibit the use of rock or rock-soil mixtures as backfill in areas where heavy equipment cannot operate. Rock-soil mixtures having greater than 8 to 10 percent binder should be prohibited in all areas. In the case of backfill containing rock, the density is not generally specified. Obtaining adequate density is usually achieved by specifying the compaction procedures. The specifications may require that these procedures be developed in field test sections.

b. Specifications may also require specific equipment and procedures to ensure adequate bedding for round-bottom structures such as tunnels, culverts, conduits, and tanks. Procedures normally specified for placement of bedding for these types of structures are discussed in paragraph 5-1c (2).

c. The specifications will state when backfill may be placed against permanent concrete construction with respect to the time after completion; this time period is usually from 7 to 14 days. To provide adequate protection of the structures during backfill construction, the specifications require that the backfill be built up symmetrically on all sides and that the area of operation of heavy equipment adjacent to a structure be limited. Also, the minimum thickness of compacted materials to be placed over the structures by small compaction equipment, such as vibratory plate or rammer type, will be specified before heavy equipment is allowed to operate over the structure. The specifications require that the surface of the backfill be sloped to drain at all times when necessary to prevent ponding of water on the fill. The specifications also provide for groundwater control, so that all compacted backfill will be constructed in the dry. Where select, free-draining, cohesionless soils of high permeability are required in areas where compaction is critical, the specifications list gradation requirements. Gradation requirements are also specified for materials used for drains and filters.

d. Unusually severe specification requirements may be necessary for backfill operations in confined areas. The requirements may include strict backfill material-type limitation, placement procedures, and compaction equipment.

e. It is not the policy of the Government to inform the contractor of ways to accomplish the necessary protection from freezing temperatures. However, to ensure that adequate protection is provided, it may be necessary to specify that the contractor submit detailed plans for approval for such protection.

CHAPTER 7

CONSTRUCTION CONTROL

7-l. General. The heterogeneous nature of soil makes it the most variable construction material with which engineers are required to work. Research in soil mechanics and experience gained recently in constructing large earth embankments have provided additional knowledge toward understanding and predicting the behavior of a soil as a construction material. However, only with careful control can engineers ensure that backfill construction will satisfactorily fulfill the intended functions. Both the contractor and the Government share dual responsibility in achieving a satisfactory product. The contractor is responsible for inspection and tests through his quality control system. The Government's responsibility is assuring that the contractor's quality control system is achieving the desired results through its quality acceptance system.

a. *Contractor quality control.* The contractor is responsible for all of the activities that are necessary to ensure that the finished work complies with the plans and specifications to include quality control requirements, supervision, inspection, and testing. The construction contract special provisions explain the quality control system that the contractor must establish; the technical provisions specify the construction requirements with the tests, inspections, and submittals that the contractor must follow to produce acceptable work.

(1) Prior to construction, the contractor must submit for approval by the Contracting Officer his plan for controlling construction quality. The plan must contain all of the elements outlined in the special provisions and demonstrate a capability for controlling all of the construction operations specified in the technical provisions. The plan must include the personnel (whether contractor's personnel or outside private firm) and procedures the contractor intends to use for controlling quality, instructions and authority he is giving his personnel, and the report form he will use. The plan should be coordinated with his project construction schedule.

(2) During construction, the contractor is responsible for exercising day by day construction quality control in consonance with his accepted control plan. He must maintain current records of his quality control operations. Reports of his operations must be submitted at specified intervals and be in sufficient detail to identify each specific test.

(3) The prime contractor is responsible for the quality control of all work including any work by sub contractors.

b. *Corps acceptance control.* In contrast to the contractor's quality control, the Government is responsible for quality assurance, which includes: the checks, inspections, and tests of the products that comprise the construction; the processes used in the work; and the finished work for the purpose of determining whether the contractor's quality control is effective and he is meeting the requirements of the contract. These activities are to assure that defective work or materials are not incorporated in the construction.

c. *Coordination between Government and contractor.* The contractor's quality control does not relieve the Contracting Officer from his responsibility for safeguarding the Government's interest. The quality assurance inspections and tests made by the Government may be carried out at the same time and adjacent to the contractor's quality control operations. Quality control and quality assurance supplement one another and assist in avoidance of construction deficiencies or in early detection of such deficiencies when they can be easily corrected without requiring later costly tear out and rebuild. The remainder of this chapter discusses the Corps quality assurance activities.

7-2. Corps acceptance control organization.

a. *General.* Difficulties in construction of a compacted backfill can be attributed at least in part to inexperience of the control personnel in this phase of construction work or lack of emphasis as to the importance of proper procedure and control. Since it is essential that policies with regard to control be established prior to the initiation of construction, thorough knowledge of the capabilities of the control organization and of the intent of the plans and specifications is required. Control is achieved by a review of construction plans and specifications, visual inspection of construction operations and procedures, and physical testing. A well-organized, experienced inspection force can mean the difference between a good job and a poor one. A good field inspection organization must be staffed and organized so that inspection personnel and laboratory technicians are on the job when and where they are needed. Thus the organization must have knowledge of the construction at all times.

b. Inspection personnel training program. Prior to construction, the training, guidance, and support required to ensure that the inspection force is fully competent should be determined. If experience is lacking, training and supervision become more important and necessary.

(1) The training program for earthwork inspection personnel should consist of both classroom and field instruction. During the classroom sessions, the specifications should be studied, discussed, and interpreted as to the intent of the designer. The critical areas of compaction should be pointed out as well as the location of zoned and transitional areas. The inspection personnel should be instructed on the various zones of backfill, types of backfill, density requirements, and classification and compaction characteristics for each class of backfill. Inspection personnel should also be instructed as to approved sources of borrow for each type of backfill and borrow pit operations, such as loading procedures to provide uniform materials and prewetting to provide uniform moisture. The various types of backfill should be studied, so inspection personnel can recognize and readily identify these materials. Jar samples may be furnished for later reference and comparison; preferably these should be samples of the particular soils on which lab oratory compaction tests were performed in design studies. Instructions should be given as to water content control, lift thickness, and most suitable compaction equipment for each type of backfill. Inspection personnel should be capable of recommending alternate procedures to achieve the desired results when the contractor's procedure is unsuccessful.

(2) Inspection personnel should be made aware of the importance of their work by explaining the engineering features of the design on which the construction requirements are based. Every opportunity should be taken to assemble the inspection force for discussion of construction problems and procedures so that all can gain knowledge from the experience of others. Inspection personnel should be kept informed of all decisions and agreements pertinent to their work that are made at higher levels of administration. They should be advised of the limits of their authority and contact with contractor personnel.

(3) Field training of inspection personnel should include observation of their control techniques and additional instruction on elements of fieldwork requiring correction. Inspection personnel should be instructed in the telltale signs that give visual indications whether sufficient compaction is being applied and proper water content is being maintained (see para 7-5b *(4)* and EM 1110-2-1911 for discussion of telltale signs). They should develop the ability to determine from visual observations (based on correlations with tests on the project) that satisfactory compaction is being obtained so that considerable emphasis can be placed on such methods as a control procedure rather than relying on field tests alone. Inspection personnel should be capable of selecting locations at which field density and moisture determinations should be made. To meet this requirement they must be present almost continuously during compaction operations to observe and note areas where tests appear to be needed. Laboratory technicians should be made available to perform tests so that the inspection personnel will be free to observe the placement and compaction process on another portion of the backfill. Inspection personnel should be able to use expedient quick-check field apparatus such as the Proctor and hand-cone penetrometers (sec. B-3, app. B) to make a rapid check of the field water content to supplement acceptance testing and to serve as a guide in determining areas that should be tested. Inspection personnel should also be well versed in normal testing procedures so they can properly supervise testing or explain the procedure in case they are questioned by contractor personnel.

(4) It is necessary and important that inspection personnel ascertain their authority and responsibility at an early stage in the construction. Their policy should be one of firmness coupled with practicality. The quality of the work should not be compromised; however, unreasonable requirements and restrictions should not be placed on the contractor in enforcing the specifications. If the inspection personnel know their job and are fair and cooperative in dealing with the contractor, they will gain his or her respect and cooperation and be able to efficiently carry out their responsibilities.

b. Field laboratory facilities. The field laboratory is used for routine testing of construction materials (such as gradation, water content, compaction, and Atterberg limits tests) and for determining the adequacy of field compaction. The data obtained from tests performed by inspection personnel serve as a basis for determining and ensuring compliance with the specifications, for obtaining the maximum benefit from the materials being used, and for providing a complete record of the materials placed in every part of the project. The size and type of laboratory required are dependent on the magnitude of the job and the type of structures being built. Where excavation and backfill construction are extensive and widespread, the establishment of a centrally located field laboratory is generally beneficial. This laboratory in addition to having equipment for on-the-job control will provide a nucleus of experienced soils engineers or engineering technicians for general supervision and training of inspection personnel. Field control laboratories on the sites may be established as necessary during the excavation and backfill phases of the construction. They may be set up in an enclosed space allocated by the project officer or in mobile testing laboratories, such as pickup trucks with a camper and equipped with the necessary testing equipment for performance of field density tests, water content tests, and gradation tests. Another possibility is the use of large portable boxes in which equipment is stored. When special problems arise and the required testing equipment is not available at the site laboratory, the testing should be performed at the central laboratory.

7-3. Excavation control techniques. Control to obtain a satisfactory excavation is exercised by enforcement of approved plans, visual observations, a thorough knowledge of the contractor's plan of operation and construction schedule, the dimensions and engineering features of the structure(s) to be placed in the excavation, and vertical and horizontal control measurements to ensure that the proper line and grade requirements are met.

7-4. Foundation preparation control techniques. The main control technique for ensuring proper foundation preparation is visual inspection. Prior to backfill placement, all uncompacted fill should be removed from those portions of the excavation to be backfilled. The items included are road fills, loose material that has fallen into overexcavated areas adjacent to foundations, and construction ramps other than those required for access to the excavation. Identification of such items will be easier if the inspection personnel have charted the items on the plans as they *were* created, since they are not always easily discernible by visual inspection. It is desirable to control earth backfill placed in foundation leveling operations by water content and density tests. Care should be exercised to ensure that all subdrains required in the foundation are protected by filters and transitional zones that are adequate to prevent infiltration of fines from the surrounding backfill that might otherwise clog the drains and undermine structures.

7-5. Backfill quality acceptance control. The necessary authority to assure that compacted backfill is in compliance with the specifications is given in the specifications. The control consists of inspecting and testing materials to be used, checking the amount and uniformity of soil water content, maintaining the proper thickness of the lifts being placed, and determining the dry unit weight being obtained by the compaction process. While control consists of all of these things, good inspection involves much more.

a. Inspection activities. One of the best inducements to proper placement and compaction of backfill is the presence of the inspection personnel when backfill is being placed. However, to be of value the inspector must know his job. He should be familiar with all aspects of backfill operation, such as selection and availability of materials, processing, hauling, compaction, and inspection procedures. Some of the most common deficiencies in inspection personnel activities are as follows:

(1) Failing to enforce specification requirements for preparation of the area for backfill. Often temporary fills, the working platform, debris, and other undesirable materials are left in the excavation causing weak areas and resulting in greater consolidation in the backfill.

(2) Failing to be cognizant of detailed site-adapted plans for stockpiling and placing backfill at specific locations. Without knowledge of these plans, inspection personnel are sometimes forced to make engineering decisions beyond their capability, such as on-the-site approval of a new material or mixture of materials, and stockpile locations.

(3) Allowing processing of backfill material and adjustment of water content on the fill that should have been accomplished prior to placement. The results are the segregation of grain sizes and the nonuniform distribution of water content. All major processing, including crushing, raking, mixing, and adjusting of water content, must be done in the stockpile or borrow areas.

(4) Allowing lift thickness that is inconsistent with equipment capabilities and thicker than that allowed by specifications. Field density determinations will not necessarily detect this inconsistency.

(5) Allowing construction of backfill slopes that are too steep to obtain the full effect of compaction equipment.

(6) Failing to require that the fill be built up uniformly in a well-defined pattern. Since the contractor's next move cannot be predicted, the inspection personnel cannot adequately plan their operations, and it is difficult to determine which areas of backfill have been tested and approved when the backfill is built up in an unorganized manner.

(7) Allowing segregation of coarse-grained, noncohesive materials. This condition is caused by improper hauling, dumping, and spreading techniques.

(8) Allowing the use of compaction equipment not suited to material being compacted.

(9) Failing to perform sufficient field density testing in critical areas.

(10) Allowing material that is too wet or too dry to be compacted.

(11) Failing to require that intermediate backfill surfaces be shaped to drain during backfilling at other locations.

b. Inspection requirements. To properly control and inspect backfill operations, the inspection personnel must keep informed of the construction schedule at all times and be at the site where backfill is being placed.

The inspection personnel must be thoroughly familiar with *every* aspect of the earthwork section of the specifications and know boundary locations for the various zones of material. They should be able to readily identify the various classes of backfill and know their compaction characteristics and requirements. Good inspection personnel will also know the compaction capabilities of various types of equipment and the materials that each type is best suited to compact.

(1) To maintain adequate control of compaction operations, a staff of earthwork inspectors and laboratory personnel commensurate with the importance of the work and size of the operation is essential. There should be at least one inspector at the fill when backfill is being placed. His sole duty should be inspection of earthwork. Although he should be familiar with the testing procedures and capable of directing testing operations and selecting locations for testing, he should not be required to perform the tests. Laboratory technicians should be available for this purpose. A discussion of the methods and procedures for field density testing of the compacted fill is contained in section B-3, appendix B.

(2) The specifications should require that necessary processing of backfill materials be performed in the stockpile or borrow pit. Processing includes raking or crushing to remove oversize material, mixing to provide uniformity, and watering or aerating to attain a water content approximating optimum for compaction. An earthwork inspector is required at the stockpile or borrow pit to enforce these provisions. In addition, this inspector has the duties of classifying the materials, determining their suitability, and directing the zone of backfill in which they are to be placed. He is charged with the responsibility of seeing that the contractor uses the materials available for backfill in the most advantageous manner. Generally, the stockpile or borrow pit inspector relies upon visual inspection and experience to exercise control over these operations. Occasionally, he may require that appropriate tests be performed to confirm his judgment.

(3) The duties of the backfill inspector consist of checking the material for suitability as it is placed on the fill and spread, ensuring that any oversize material, roots, or trash found in the material is removed, checking the thickness of the lift prior to compaction, checking for uniformity and amount of water content, observing compaction operations, and directing or monitoring testing of the compacted material for compliance with density and water content requirements.

(4) There are many techniques and rule-of-thumb procedures that the earthwork inspector can and must resort to for assistance in his work. A few of them are discussed below; others can be ascertained by inspectors meeting together to discuss problems and corrective action.

(a) The thickness of loose lifts can be checked easily by probing with a calibrated rod just prior to compaction. Compaction of lifts too thick for the equipment will not normally be detected by performing density tests on the lift, since adequate compaction may be indicated by a test made in the upper portion of the lift and the lower portion may still have too low a density. It is therefore a requisite that lift thickness be controlled on a loos&thickness basis prior to compaction

(b) Checks for proper bond between layers can be made by digging through a lift after compaction and using a shovel to check this bond. If the soil can be separated easily along the plane between lifts, sufficient bond is not being provided. Backfill materials should not be placed on dried or smooth surfaces, as bond will be difficult to obtain.

(c) Inspection personnel should be thoroughly aware of areas where compaction is critical. These areas are the confined spaces around and adjacent to structures that are not accessible to the rolling and spreading equipment. Although the volume of backfill is usually rather small in these areas, a much higher frequency of check testing for density is required as well as a careful check of the quality and water content of the materials to be placed.

c. Compaction control tests. Compaction tests will have been performed on representative specimens obtained from exploratory sampling prior to construction. The selection of suitable backfill material are in fact generally made based on these and other tests. At least during the early phases of the backfill operation, density requirements are based on these and in some cases additional preconstruction compaction tests. Conditions may develop that require compaction tests during backfill operations to establish new density requirements. Generally, these changes are the results of backfill material deviations. The need for additional control tests may be ascertained from visual observation and changes in compaction characteristics during field compaction. For most backfill materials, quality acceptance compaction control tests must be performed according to the CE 55 test procedure specified in MIL-STD-621, the equivalent procedure in ASTM D 1557, or the two-point test procedure (app B). For some cohesionless soils where higher maximum dry densities can be obtained using the vibratory (relative density) compaction procedure, the specifications may require the vibratory test procedures as specified in EM 1110-2-1906 or ASTM D 2049. Field compaction control and rapid compaction check tests that are used to supplement the Corps acceptance control tests are discussed in appendix B.

d. Field moisture-density control techniques. Moisture-density control is the most important phase of backfill operations. The success of ensuring required backfill density often determines the functional service of the imbedded structure. Good control involves many techniques. An experienced inspector will not rely on any one technique but from experience will base his control on a combination of techniques. Moisture-density control techniques may be grouped into three categories: rule-of-thumb techniques, and indirect and direct moisture density measurements.

(1) *Rule-of-thumb methods.* Rule-of-thumb techniques are derived from experience and are based on visual observations and feel of the material. A rule-of-thumb for judging if the water content of a fine-grained, plastic material is near the optimum water content consists of rolling the material between the hands until it forms a thread approximately 1/8 inch in diameter. If the material at this stage tends to crack or crumble, it is in the proper water content range for compaction. It will be recognized that this method is similar to the method of determining the plastic limit of a soil. The methods are similar because the optimum water content for compaction of a cohesive soil roughly approximates the plastic limit of the soil.

(a) Another good indication of whether the proper water content has been obtained can be determined by observing the compacting equipment. When a sheepsfoot roller is being used and the soil sticks to the roller to any great extent, the material is being rolled too wet for the equipment being used; at optimum water content it may be expected that a few clods will be picked up by the roller but a general sticking will not occur. If the compacted fill does not definitely spring (noticeable to visual observation) under hauling and compaction equipment, it is probable that several lifts of fill have been placed too dry. The roller should roll evenly over the surface of the backfill if water content is uniform throughout the lift and should not ride higher on some portions of the backfill than on others. If on the first pass of a rubber-tired roller the tires sink to a depth equal to or greater than one-half the tire width, if after several passes the soil is rutting excessively, or if at any time during rolling the weaving or undulating (as opposed to normal "springing" of the surface) of the material is taking place ahead of the roller, either the tire pressure is too high or the water content of the material is too high. On the other hand, if the roller tracks only very slightly or not at all and leaves the surface hard and stiff after several passes, the soil is probably too dry. For most soils having proper water contents, the roller will track evenly on the first pass and the wheels will embed 3 to 4 inches. Some penetration should be made into soil at its proper water content, though the penetration will decrease as the number of passes increases. After several passes of a sheepsfoot roller, the roller should start walking out if adequate and efficient compaction is being obtained. Walking out means the roller begins bearing on the soil through its feet only-the drum is riding a few inches above the soil surface. If the roller walks out after only a few passes, the soil is probably too dry; if it does not walk out but continues churning up the material after the desired number of passes, the soil is too wet or the foot contact pressure is too high.

(b) A trained inspector will spend some time in the field laboratory, performing several compaction tests on each type of backfill material to become familiar with the differences in looks, feel, and behavior and learning to recognize when they are too dry or too wet, as well as when they are at optimum water content.

(2) *Indirect methods.* Indirect methods of determining the density and water content involve measurement of the characteristic of the material that has been previously correlated to the maximum density and optimum water content. These methods of measuring in-place density and water content can usually effect a more detailed control of a job than can be accomplished by direct methods alone because they can provide quicker determinations. However, no indirect method should ever be used without first checking and calibrating it with results obtained from direct methods, and periodic checks by direct methods should be made during construction. Indirect methods include the use of the nuclear moisture-density meter, the Proctor penetrometer (often referred to as the "Proctor needle"), the hand cone penetrometer, and in the hands of an experienced inspector even a shovel.

(a) The nuclear moisture-density method conducted in accordance with ASTM D 2922 (for density determination) and ASTM D 3017 (for water content determination) is the only indirect control method used for the Corps quality acceptance control. The method provides a relatively rapid means for determining both moisture content and density. Of the three methods presented in ASTM D 2922, Method B - Direct Transmission is the best suited for a compacted lift thickness exceeding approximately 4 inches. The nuclear moisture-density method is discussed in more detail in section B- 3, appendix B.

(b) Penetrometers, such as the Proctor and hand cone penetrometers, are useful under certain conditions for approximating density. However, both methods require careful calibration using soils of known density and water content and considerable operating experience. Even then, the results may be questionable because nonuniform water content (in fine-grained material) *or* a small piece of gravel can affect the penetration resistance. Penetrometers, therefore, are not recommended for general use in compaction control; however, they can be a very useful tool in supplementing the inspector's visual observations and providing a general guide for detecting areas of doubtful compac-

tion. The procedure using the Proctor penetrometer for determining the relation between wet density, penetration resistance, and water content is described in ASTM D 1558 and in section B-3, appendix B. The hand cone penetrometer procedure also is discussed in section B-3.

(c) Many inspectors in the past have had good success in estimating density by simply observing the resistance of the compacted soil to penetration by a spade. This method requires considerable experience and is useful only in detecting areas that might require further density tests.

(3) *Direct methods.* Direct field density determination consists of volume and weight measurements to determine the wet density of in-place backfill and water content measurements to determine in-place water contents and dry densities. The three methods used for the Corps quality acceptance density determination are: (a) the sand-cone method according to MIL-STD-621 (Method 106) and ASTM D 1556; (b) the rubber-balloon method according to ASTM D 2167; and for soft, fine-grained cohesive soils, the drive-cylinder method according to MIL-STD-621 (Method 102) and ASTM D 2937. In addition to the approved methods, a method sometimes employed to measure densities of coarse-grained cohesionless material consists of the large-scale, water-displacement method. The large-scale, water-displacement method is discussed in EM 1110-2-1911. The sand cone method is considered to be the most reliable method and is recommended as the proof or calibration test for calibrating other methods such as the nuclear density method. The direct field density methods are discussed in section B-3, appendix B.

e. Water content by microwave oven. The biggest problem associated with both field compaction tests and in-place density and water content control tests is the length of time required to determine water content. Conventional ovendrying methods require from 15 to 16 hours for most fine-grained cohesive soils. In some cases, such as confined zones, the contractor may have placed and compacted several layers of backfill over the layer for which density tests were made before quality acceptance test data are available. Even though the contractor places successive layers at his own risk, a rapid turn around between testing and test results could prevent costly-tear out and recompact procedures. Drying specimens in microwave ovens offers a practical means for rapid determination of water content for most backfill materials if properly conducted. Times required for drying in a microwave oven are primarily governed by the mass of water present in the specimen and the power-load output of the oven. Therefore, drying time must be calibrated with respect to water content and oven output. Also, it may not be possible to successfully dry certain soils containing gypsum or highly metallic soils such as iron ore, aluminum rich soils, and bauxite. Details of the microwave-oven method used for rapid determination of soil water content is given in section B-3, appendix B.

f. Frequency and *location of quality acceptance density tests.* Acceptance control testing should be more frequent at the start of backfill placement. After compaction effort requirements have been firmly established and inspection personnel have become familiar with materials behavior and acceptable compaction procedures, the amount of testing can be reduced. Many factors influence the frequency and location of tests. The frequency will be dependent on the type of material, adequacy of the compaction procedures, and how critical the backfill being compacted is in relation to the performance of the structure.

(1) A systematic testing program should be established at the beginning of the job. Acceptance control tests laid out in a predetermined manner are usually designated as routine control tests and are performed either at designated locations or at random representative locations, no matter how smoothly the compaction operations are being carried out. A routine acceptance control test should be conducted for at least every 200 cubic yards of compacted backfill material in critical areas where settlement of backfill may lead to structural distress and for at least every 500 cubic yards in open areas not adjacent to structures.

(2) In addition to routine acceptance control tests, tests should be made in the following areas: where the inspector has reason to doubt the adequacy of the compaction; where the contractor is concentrating fill operations over relatively small areas; where small compaction equipment is being used such as in confined areas; and where field instrumentation is installed, mainly around riser pipes.

g. Errors in field density measurements. Density and water content measurements determined by any of the methods discussed above are subject to three possible sources of errors. The three categories of possible error sources are human errors, errors associated with equipment and method, and errors attributed to material property behavior.

(1) Human error includes such factors as improper equipment readings and following improper test procedures. Human errors are not quantitative. However, errors of this type may be minimized by utilizing competent testing personnel familiar with testing procedures.

(2) There are two types of possible errors related to test equipment. One type of error relates to the sensitivity of the equipment with respect to its capability to accurately measure the true density or water content. Sensitivity errors are quantitative only in the sense that limiting ranges of possible error can be es-

tablished. An example of sensitivity error would be the nuclear density device that is capable of determining densities only to within 3 to 5 pounds per cubic foot of true density. The second type of error relates to constant deviations between measured and true density. Constant deviation errors can be corrected by calibrating test equipment against known densities.

(3) Material property errors are primarily limited to density determinations using either the sand-cone or the rubber-balloon method in sands. When a soil is physically sampled during the process of conducting an in-place density measurement using these two methods, a shearing action of the soil is unavoidable. Cohesionless soils are sensitive to volume change during shear, dense sands tend to expand and increase in volume, and loose sands tend to contract and decrease in volume. Errors of this nature cannot be quantified or detected in the field. However, such errors can be as high as 6 percent for sand using the rubber-balloon method for volume measurements.

h. Acceptance or rejection. The inspection personnel have the responsibility to accept or reject the backfill or any part thereof based on the quality acceptance control tests. On the surface, this task seems straightforward. If a segment of the backfill tested at several locations for acceptance passes or fails to pass minimum requirements by a wide margin, then it is generally safe to assume that the backfill within that segment either has or has not been adequately compacted and the acceptance or rejection of that segment can be made based on the test results. On the other hand, if the tests indicated insufficient compaction, the size of the affected area may be questionable; it is possible that the test(s) represents only a small area and the lift being tested may be sufficiently compacted elsewhere. In view of the possible errors associated with control tests, tests that indicate marginal passage or failure should be treated with caution. The borderline case requires a close look at several factors: how the result compares with all previous results on the job, how much compaction effort was used and did it differ from previous efforts, how does this particular material compare with previously compacted materials, the importance of the lift location in relation to the entire structure, and the importance of obtaining the correct density or water content from the designer's standpoint. When all factors have been considered, a decision is made as to which corrective measures are required. What makes such decisions so difficult is that they must be made immediately; time will not permit the problem to be pondered. Discussion with design engineers prior to beginning compaction operations may help in the evaluation of many of these factors.

(1) On jobs requiring large volumes of backfill, it may be advantageous to base the decision to accept or reject on statistical methods. Statistical methods require separate analysis for each backfill material type and compaction effort, complete random selection of test locations, and a large number of control tests as compared with the conventional decision method. In addition, statistical methods include water content control, which is not normally included in military specifications.

(2) The theory and details concerning the application of statistical methods for compaction control are well developed. Figure 7-1 shows a sequential inspection plan example of how the end results of a statistical analysis might be used for the purpose of acceptance or rejection. In this example, it was established by statistical analysis that adequate densities could probably be obtained with reasonable confidence by a given compaction effort for desired water contents ranging from 3 percentage points below to 1 percentage point above optimum. It was also established that a density corresponding to 95 percent of CE 55 maximum dry density was the minimum acceptable density based on required engineering performance of the backfill. The sequential inspection plan consists of examining, in sequence, single tests that are obtained at random from a segment of the backfill being considered for acceptance or rejection and, for each test, making one of three possible decisions: the segment is acceptable; the segment is unacceptable; and the evidence is not sufficient for either decision without too great a risk of error as indicated by the retest block in figure 7-1(a). The reject areas in figure 7-1 indicate conditions that cannot be corrected by additional rolling. The material must be replaced in thinner lifts and be within the desired water content range before adequate compaction can be achieved with the compaction equipment being used. If the retest decision is reached, an additional test is made at a second random location, and the same three decisions are reconsidered in light of this additional information. If the second test falls below the accept blocks, the segment of backfill representative of that test should be rejected; or if compaction procedures that have produced acceptable tests in the past have not been altered, then the compaction characteristics of that part of the backfill should be reevaluated.

(3) The primary advantage of statistical methods is that they offer a means of systematically evaluating acceptance or rejection decisions rather than leaving such decisions entirely to the judgment of the inspection personnel. However, if experienced and well trained inspection personnel are available, this approach may not be necessary.

i. Construction reports. A record should be maintained of construction operations. It is valuable in the event repairs or modifications of the structure are required at a later time. A record is necessary in the event claims are made either by the contractor or the

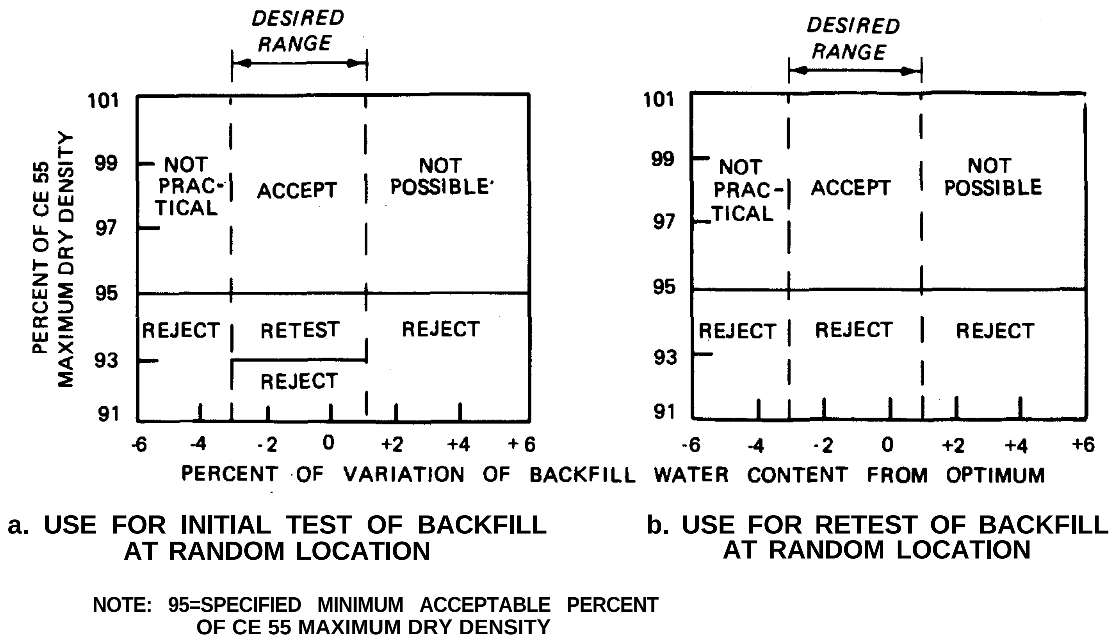


Figure 7-1. Acceptance Rejection Scheme for a Backfill Area.

Contracting Officer that work required or performed was not in accordance with the contract. Recorded data are also beneficial in improving knowledge and practices for future work. The basic documents of the construction record are the plans and specifications, modifications adopted that were considered to come within the terms of the contract, amendments to the contract such as extra work orders or orders for change, results of tests, and measurements of work performed. The amount of reporting required varies according to the importance and magnitude of the earthwork construction phase of the project and the degree of available engineering supervision. The forms to be used should be carefully planned in advance, and the inspection personnel should be apprised of the importance of their reports and the need for thorough reporting. Records should be made on every test performed in the laboratory and in the field. All information necessary to clearly define the locations at which field tests are made should be presented. In the daily reports, inspection personnel should include information concerning progress, adequacy of the work performed, and retesting of areas requiring additional work to meet specifications. These daily reports could be of vital importance in subsequent actions. It is good practice for the inspection personnel to keep a daily diary in which are recorded the work area, work accomplished, test results, weather conditions, pertinent conversations with the contractor, and instructions received and given.

APPENDIX A

REFERENCES

Government Publications

Department of Defense

Military Standards

MIL-STD-619	Unified Soil Classification System for Roads, Airfields, Embankments, and Foundations.
MIL-STD-621	Test Methods for Pavement Subgrade, Subbase, and Base Course Materials

Department of the Army, the Navy, and the Air Force

Technical Manuals

AFM 89-3, Chapter 2	Materials Testing
TM 5-818-1/AFM 88-3, Chap. 7	Soils and Geology: Procedures for Foundation Design of Buildings and Other Structures (Except Hydraulic Structures)
TM 5-818-2/AFM 88-6, Chap. 4	Pavement Design for Frost Condition
TM 5-818-5/NAVFAC P-418/ AFM 88-5, Chap. 6	Dewatering and Groundwater Control for Deep Excavations
TM 5-818-6	Grouting Methods and Equipment
TM 5-820-2/AFM 88-5, Chap. 2	Subsurface Drainage Facilities for Airfields
TM 5-820-4/AFM 88-5, Chap. 4	Drainage for Areas Other Than Airfields
NAVFAC DM-7	Soil Mechanics, Foundations, and Earth Structures

Department of the Army, Corps of Engineers

USACE Publications Depot, 809 South Pickett, Alexandria, VA 22304

EM 385-l-l	Safety and Health Requirements Manual
EM 1110-2-1906	Laboratory Soils Testing
Em 1110-2-1908	Instrumentation for Earth and Rockfill Dams
EM 1110-2-1911	Construction Control for Earth and Rockfill Dams
EM 1110-2-2502	Retaining Walls
EM 1110-2-2902	Conduits, Culverts, and Pipes
ER 1110-2-1806	Earthquake Design and Analysis for Corps of Engineers Dams

Department of Interior

Bureau of Reclamation, Manual, Second Edition	Earth Manual

Department of Transportation (DOT) 1920 L Street, N.W., Washington, DC 20036

Report No. FHWA-RD-78-141	Design and Construction of Compacted Shale Embankments, Vol 5. Technical Guidelines (December 1978)

Report No. FHWA-RD-79-51	Technical Guidelines for Expansive Soils in Highway Subgrades (June 1979)

Non-Government Publications

American Society for Testing and Materials; 1916 Race Street, Philadelphia, PA 19103

D 1556	Standard Test Method for Density of Soil in Place by the Sand-Cone Method
D 1557	Standard Test Methods for Moisture-Density Relations of Soils Using 10-lb (4.5 kg) Rammer and 18-in. (457-mm) Drop
D 1558	Standard Test Method for Moisture-Penetration Resistance Relations of Fine-Grained Soils
D 2049	Standard Test Method for Relative Density of Cohesionless Soils
D 2167	Standard Test Method for Density of Soil In Place by the Rubber-Balloon Method
D 2216	Standard Method of Laboratory Determination of Moisture Content
D 2922	Standard Test Method for Density of Soil and Soil-Aggregate In Place by the Nuclear Methods
D 2937	Standard Test Method for Density of Soil In Place by the Drive-Cylinder Method
D 3017	Standard Test Method for Moisture Content of Soil and Soil-Aggregate In Place by the Nuclear Methods
Special Technical Publication STP No. 293	Symposium on Nuclear Methods for Measuring Soil Density and Moisture (June 1960)
Special Technical Publication STP No. 479	Special Procedures for Testing Soil and Rock for Engineering Purposes (June 1970)
Special Technical Publication STP No. 599	Soil Specimen Preparation for Laboratory Testing (June 1976)

APPENDIX B

FUNDAMENTALS OF COMPACTION, FIELD COMPACTION TEST METHODS, AND FIELD MOISTURE-DENSITY TEST METHODS

Section B-1. FUNDAMENTALS OF COMPACTION

B-1. Factors influencing compaction. Soil compaction is the act of increasing the density (unit weight) of the soil by manipulation by pressing, ramming, or vibrating the soil particles into a closer state of contact. The most important factors in soil compaction are type of soil, water content, compaction effort, and lift thickness. It is the purpose of field inspection to ensure that the proper water content, lift thickness, and compaction effort are used for each soil type so that the desired degree of compaction is obtained. When the water content, lift thickness, or compaction effort being used does not produce the desired degree of compaction, changes may be necessary. The determination of the necessary changes of these factors to produce the desired degree of compaction requires knowledge of the principles governing the compaction of soils. Therefore, it is important that inspection personnel have a general understanding of the fundamentals of compaction.

a. General. It has been established through research and construction experience that there is a maximum density to which a given soil can be compacted using a particular compaction effect, For each soil and a given compaction effort, there is a unique water content, which is called the optimum water content, that produces the maximum density. The purpose of the lab oratory compaction test is to determine the variation in density of a given soil at different water contents when compacted at a particular effort or efforts. Normally, the soil to be used is compacted in the laboratory over a range of water contents using the impact-compaction procedures given in MIL-STD-621A and ASTM D 1557. The compaction effort used is selected on the basis of the requirements of the structure. In foundation or backfill design for most major structures, the CE 55 (also termed modified) compaction effort that produces approximately 56,000 foot-pounds per cubic foot of compacted soil should be used.

(1) For some cohesionless soils, a greater maximum density can be obtained using vibratory-type compaction procedures given in EM 1110-2-1906 and ASTM D 2049 than can be obtained using MIL-STD-621A or ASTM D 1557 impact-compaction procedure. Thus, there may be cases where the vibratory compaction method may be more appropriate in determining the maximum density. The compaction effort used for design purposes should be the basis for construction control.

(2) A compaction curve is developed in the impact-compaction test by plotting densities (dry unit weights) as ordinates and the corresponding water contents (as percent of dry soil weight) as abscissas. For most soils the curve produced is generally parabolic in form. Figure B-1 shows a compaction curve. The water content corresponding to the peak of the curve is the optimum water content. The dry unit weight of the soil at the optimum water content is the maximum dry density. The zero air voids curve represents the relation between water content and dry density for 100 percent saturation of the particular material tested. Thus, it shows the dry density for a given water content based on the condition that all the air is forced out of the voids by the compaction process.

b. Influence of soil type. Compaction characteristics vary considerably with the type of soil. Figure B-2 shows four compaction curves representing the water content-density relation for four general soil types for standard compaction. The maximum dry density for a uniform sand occurs at about zero water content, although density approaching maximum can be obtained when the sand is saturated. A very sharp peaked curve of dry density versus water content is usually obtained for a silt, and water content is critical to achieving maximum density. A small change in water content (as small as 0.5 percentage point) above or below optimum causes a significant decrease in the density (as much as 2 to 4 pounds per cubic foot) for a given compaction effort. The compaction curve for a lean clay is not as sharp as that for the silt, and water content control is not as critical. Optimum water contents for silts and lean clays generally range between 15 and 20 percent. The compaction curve for fat clays is rather flat and water content is not particularly critical to obtaining maximum density; a 2 to 3 percentage point change in water content from optimum for fat clays causes only a *small* decrease (1 pound per cubic foot *or* less) in density. The maximum dry density, as obtained in laboratory compaction tests using MIL-STD-621A and

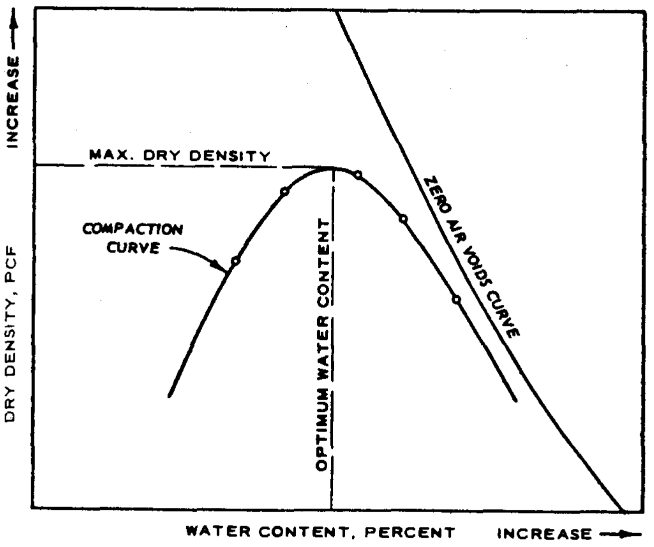


Figure B-1. Compaction curve.

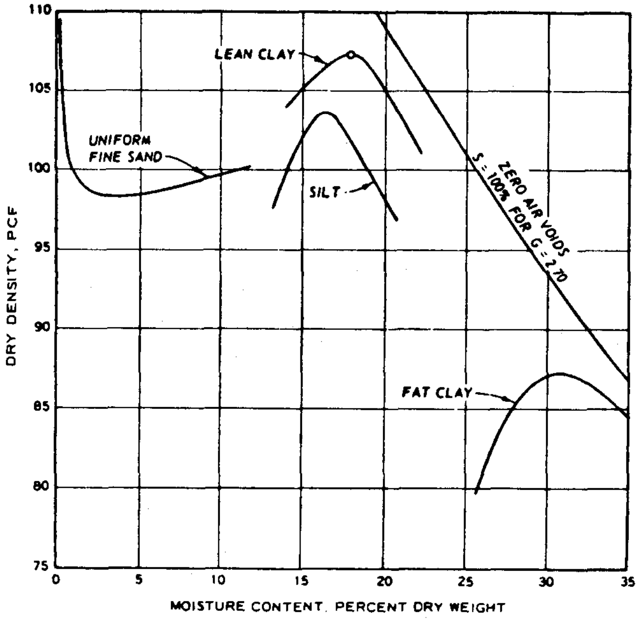


Figure B-2. Typical compaction test curves.

ASTM D 1557 or modified compaction effort, depends on the soil type and varies generally from about 125 to 140 pounds per cubic foot for well-graded, sand-gravel mixtures to about 90 to 115 pounds per cubic foot for fat clays. The optimum water content generally ranges from zero for the sand-gravel mixtures to about 30 percent for the fat clays.

c. Influence of water content. For a given fine-grained soil and a given compaction effort, the water content determines the state at which maximum dry density occurs. At low water contents when the soil is stiff and hard to compress, low, dry densities and high values of air content result. As the water content is increased, higher dry densities and lower air content values are obtained. Increased densities result with an increase in water content up to optimum water content. Beyond this point, the water in the voids becomes excessive, and pore pressures develop under the application of the compaction effort to resist a closer packing; lower dry densities are the result.

d. Influence of compaction effort. For most soils, increasing the energy applied (compaction effort) per unit volume of soil results in an increase in the maximum density (unit weight). This greater density occurs generally at a lower water content. This phenomenon is evident in both field and laboratory compactions. Thus, for each compaction effort, there is a unique optimum water content and maximum dry density for a given soil. Figure B-3 shows the effect of variation in compaction effort on the maximum dry density and optimum water content for a lean clay (CL). Where values of maximum dry density and optimum water content are specified, they should be referenced to the compaction effort used.

e. Influence of lift thickness. Compaction effort applied to a soil surface dissipates with depth. Therefore, it is important that the lift thickness to be compacted be commensurate with the type of soil and the compaction effort. With proper consideration and control over factors influencing compaction, most soils can be com-

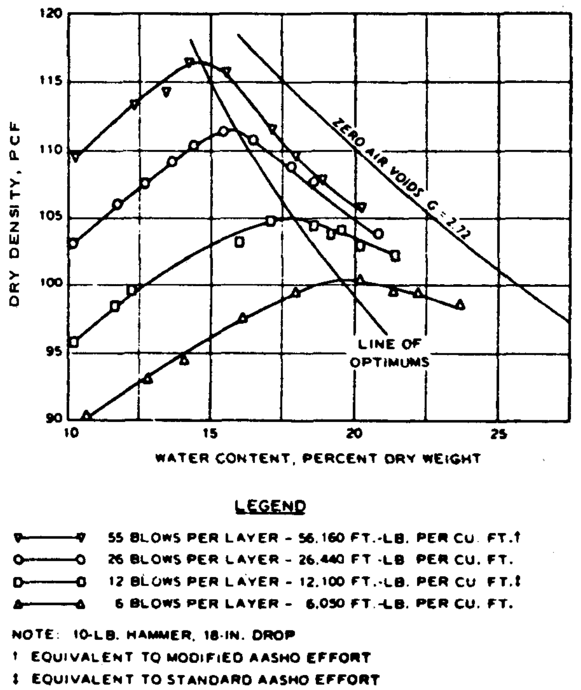


Figure B-3. Molding water content versus density-lean clay (laboratory impact compaction).

pacted to provide a stable backfill, with the exception of certain bouldery soils and soils containing significant amounts of soluble, soft, or organic materials.

B-2. Mechanics of compaction. The influence of the water content on compaction is markedly different on coarse-grained, cohesionless soils and fine-grained, cohesive soils. As a result, the mechanics or manipulation of soil grains in the two types of soil during the compaction process are different. The mechanics of compaction for the two soil types are discussed in subsequent paragraphs.

a. Compaction of coarse-grained soils. Compaction of coarse-grained soils that contain little or no fines and thus exhibit no plasticity (termed cohesionless soils) is achieved by causing the individual particles to move into a closer, more compact arrangement, with smaller particles filling in voids between larger particles. The compaction energy overcomes friction at contact points between particles as they move past one another into closer packing.

(1) A loose volume of coarse-grained soil, such as gravel or sand, contains spaces or "voids" between individual particles that are filled with air and/or water. The density that can be obtained in such a soil under a given amount of compaction effort depends on the gradation and shapes of the particles and on the water content. For a well-graded gravel or sand, the range of particle sizes is sufficient to allow a fairly compact arrangement of particles, with smaller particles filling in the voids between larger particles. For poorly graded soil, either of uniform gradation or skip-graded (lacking a specific range of particle sizes), the distribution of particle sizes limits the density that can be obtained. Segregation of similar size particles in a skip-graded material tends to occur and prevents the voids from being greatly reduced. In a uniform soil, point-to-point contact occurs at very low compaction effort and low density results; further increase in density can only be accomplished by crushing the grains. Therefore, a well-graded, coarse-grained material can generally be compacted to a greater density under a given compaction effort than a poorly graded, coarse-grained soil. The increase in maximum density with increase in compaction effort will be greater for a well-graded soil than that for a poorly graded soil.

(2) Rounded particle shapes facilitate movement and sliding of particles, while angular particle shapes restrict movement and sliding of grains in relation to one another. For either a well-graded, or a poorly graded, coarse-grained material, increase in angularily of grains requires a corresponding increase in compaction effort to obtain a given density. However, a higher density can usually be attained with angular soils because the particle shapes are more conducive to filling the voids.

(3) For coarse-grained soils containing only a small percentage (5 or less) of fine-grained particles, maximum density is more readily obtained when the soil is either dry or saturated. For water contents between these limits, the water in the soil forms menisci between the particle contacts, which tend to hold the soil particles together. This resistance to movement of particles into a more compact structure, termed apparent cohesion or "bulking," results in lower densities than those for either a dry or saturated cohesionless soil under the same compaction effort.

(4) It is to be noted that in the preceding paragraphs, the discussion has centered around the density in weight per unit volume of coarse-grained soils with different gradation characteristics. A more realistic parameter that is often used is the relative density of cohesionless coarse-grained soils. Relative density expresses the degree of compactness of a cohesionless soil with respect to the loosest and the densest conditions of the soil that can be attained by specified laboratory procedures. A soil in the loosest state would have a relative density of zero percent and in the densest state, a relative density of 100 percent. The dry unit weight of a cohesionless soil does not, by itself, reveal how loose or how dense the soil is due to the influence of particle shape and gradation on the density. Only when viewed against the possible range of variation, in terms of relative density, can the dry unit weight be related to the compaction effort used to place the soil in a backfill or indicate the volume-change tendency of the soil when subjected to foundation loads.

(5) Most coarse-grained soils can be compacted to a density such that detrimental additional consolidation will not take place under the prototype loading. This factor is the first important consideration. Another important consideration may be that the compacted soil be sufficiently pervious to provide good drainage. Proper consideration of these two basic factors will allow the use of most coarse-grained soils for backfill purposes.

b. Compaction of fine-grained soils. The mechanics by which fine-grained soils are compacted is quite complex because capillary pressures, hysteresis, pore air pressure, pore water pressure, permeability, surface phenomena, osmotic pressures, and the concepts of effective stress, shear strength, and compressibility are involved. Numerous theories have been developed in an attempt to explain the compaction mechanics. The current state-of-the-art theories involving effective stress give satisfactory explanations. The basic concepts of these theories are discussed below.

(1) Fine-grained soils are compacted in a partially saturated state; therefore, voids or pores contain both pore air and pore water between the soil particles. Ini-

tial compaction water contents below optimum result in initial high pore air pressures and pore water pressures, which reduce shear strength and allow soil particles to slide over one another displacing the pore air to form a more dense mass. This process continues as long as the trapped pore air pressure can escape but requires increasing amounts of compaction effort to achieve higher densities since the soil particles carry increasing amounts of the compaction energy. For a given compaction effort, enough water may eventually be added to the soil so that air channels become discontinuous, and the air is trapped. When the air voids become completely discontinuous, the air permeability of the soil drops to zero; no further densification is possible because at this condition transient pore air pressures can develop that resist the compaction effort. At zero permeability the soil has reached its so-called "optimum water content." Since zero permeability may also be established by closer packing of soil particles, it is evident that lower optimum water contents are possible at higher compaction efforts.

(2) The addition of water above optimum water content causes the voids to become completely filled with trapped pore air and pore water and thereby prevents the soil particles from moving into a more compact arrangement no matter what the compaction effort. Pore water pressure increases significantly with increasing water contents and causes increased reduction in shear strength. This fact is evident in the laboratory compaction mold when the compaction foot sinks deeper and deeper into the soil as water content increases past optimum. The same process occurs in the field when sheepsfoot rollers sink into the soil until the weight is carried by the drum or excessive rutting with rubber-tired rollers.

Section B-2. FIELD COMPACTION TEST METHODS

B-3. General. Laboratory test data obtained from laboratory-compacted specimens provide a basis for design, and it is assumed that the engineering characteristics that will be built into the field-compacted backfill will be approximately the same as those of the specimens. Experience has indicated that for most soils, laboratory densities, water contents, and strength characteristics can be satisfactorily reproduced in a field-compacted backfill.

B-4. Field compaction tests.

a. Compaction control tests. Compaction control of soils requires comparison of fill water content and dry density values obtained in field density tests with optimum water content and maximum dry density, or determination of relative density if more appropriate for the fill materials that are cohesionless. For fine-grained or coarse-grained soils with appreciable fines, field results are compared with results of CE 55 laboratory (modified effort) compaction tests performed according to procedures presented in MIL-STD-621A and ASTM D 1557. For free-draining cohesionless soils, relative density of the fill material is determined, if appropriate, using vibratory test procedures prescribed in EM 1110-2-1906 and ASTM D 2049.

b. Frequency compaction control tests. The performance of a standard laboratory compaction test on material from each field density test would give the most accurate relation of the in-place material to optimum water content and maximum density, but this test is not generally feasible to do because testing could not keep pace with the rate of fill placement. However, standard compaction tests should be performed during construction (1) when an insufficient number of the compaction curves were developed during the design phase, (2) when borrow material is obtained from a new source, and (3) when material similar to that being placed has not been tested previously. In any event, laboratory compaction tests should be performed periodically on each type of fill material (preferably 1 test for every 10 field density tests) to check the optimum water content and maximum dry density values being used for correlation with field density test results.

c. Quick field compaction tests. In addition to the standard compaction or relative density tests (para B-2a), at least four relatively quick compaction test methods can provide good approximations of maximum dry density comparable to the standard methods. The quick compaction methods include: one-point and two-point compaction methods; the Water and Power Resource Service (WPRS), formerly U.S. Bureau of Reclamation (USBR) rapid compaction control method; and for granular cohesionless material, compaction control by gradation. Since only the one-point and two-point methods are currently accepted by the Corps of Engineers for compaction control tests, only these two methods will be discussed in detail. The USBR and gradation methods are briefly summarized.

(1) *One-point compaction method.* In the one-point compaction method, material from the field density test is allowed to dry with thorough mixing to obtain a uniform water content on the dry side of estimated optimum, and then compacted using the same equipment and procedure used in the five-point standard compaction test. The water content and dry density of the compacted sample are then used to estimate its optimum water content and maximum dry density as illustrated in figure B-4. The line of optimums is

well defined in the figure, and the compaction curves are approximately parallel to each other; consequently, the one-point compaction method could be used with a relatively high degree of confidence. In figure B-5, however, the optimums do not define a line, but a broad band. Also, the compaction curves are not parallel to each other and in several instances cross on the dry side. To illustrate the error that could result from using the one-point method, consider the field density and water content shown by point B in figure B-5. Point B is close to three compaction curves. Consequently, the correct curve cannot be determined from the one point. The estimated maximum dry density and optimum water content could vary from about 92.8 pounds per cubic foot and 26 percent, respectively, to 95.0 pounds per cubic foot and 24 percent, respectively, depending on which curve was used. Therefore, the one-point method should be used only when the basic compaction curves define a relatively good line of optimums.

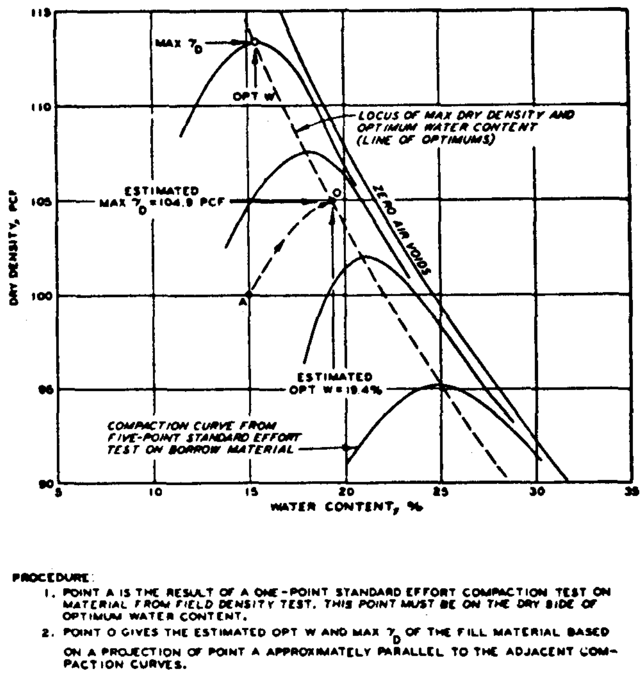


Figure B-4. Illustration of one-point compaction method.

(2) *Two-point compaction test results. In* the two-point test, one sample of material from the location of the field density test is compacted at the fill water content if thought to be at or on the dry side of optimum water content (otherwise, reduced by drying to this condition) using the same equipment and procedures used in the five-point compaction test. A second sample of material is allowed to dry back about 2 to 3 percentage points dry of the water content of the first sample, and then compacted in the same manner. After compaction, water contents of the two samples are determined by ovendrying or other more rapid means

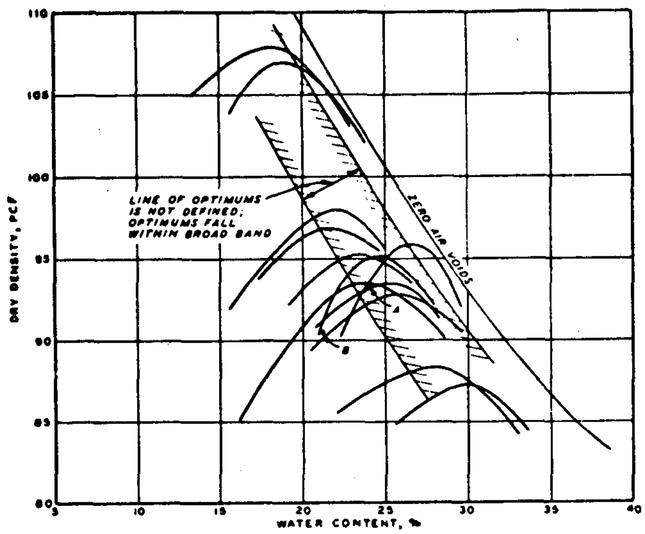


Figure B-5. Illustration of possible error using one- and two-point compaction methods.

(para B-8a), and dry densities are computed. The results are used to identify the appropriate compaction curve for the material test (fig. B-6). The data shown in figure B-6 warrant the use of the two-point compaction test since the five-point compaction curves are not parallel. Using point A only as in the one-point test method would result in appreciable error as the shape of the curve would not be defined. The estimated compaction curve can be more accurately defined by two compaction points as shown. Although the two-point method is more accurate than the one-point method, neither method would have acceptable accuracy when applied to the set of compaction curves shown in figure B-5.

(3) *Rapid one-point test for sands.* A rapid check test for compaction of uniform sands (SP to SM) with less than 10 percent fines (minus No. 200 sieve) is a modified one-point test. The ovendry sand is compacted in a 4-inch-diameter mold using CE 55 (modified) effort. Correlation with standard compaction tests is required to confirm the validity of test results for different sands used on each project.

(4) *USBR rapid compaction control method.* Details of this method are described in the USBR Earth Manual (app A), The test is applicable to fine-grained (100 percent minus No. 4 sieve) cohesive soils with liquid limits less than 50. The method, however, is applicable to soils containing oversize particles providing the proper corrections, as stated in EM 1110-2-1911, Appendix B, are applied. It is a faster method than the standard compaction test and is often more accurate than other methods. The method usually requires adding water to or drying back sampled fill material, and thorough mixing is needed to obtain uniform drying or

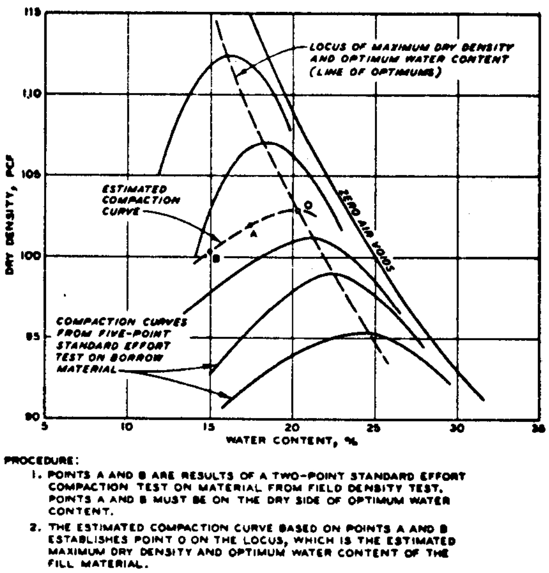


Figure B-6. Illustration of two-point compaction method

distribution of added water. Otherwise, the results may be erroneous, especially for highly plastic clays. In tough clays, it is likely to be inaccurate because of insufficient curing time for the specimens.

(5) *Grain-size gradation compaction control method.* This test method developed in 1938 is applicable to coarse, medium, and fine-grained sands. The method involves sieve analysis to establish grain-size gradation curves, whose shapes are then correlated with maximum dry density obtained from the standard five-point compaction tests or relative density tests. For a given compaction effort, the maximum dry density of cohesionless material (sand) is also a function of particle shape. Thus, the correlation between grain-size distribution and density would, by necessity, have to include consideration of particle shape. It is doubtful that this method would provide test results more rapidly than the one-point and two-point methods or the relative density method currently accepted by the Corps since samples must be dried for sieve analysis. Therefore, this method is not recommended for routine compaction control.

d. Possible errors. All tests involving mechanical devices and human judgment are subject to errors that could affect the results. In order to properly evaluate test results, the inspector must be familiar with the possible sources of such errors.

(1) *Five-point compaction tests.* The following errors can cause inaccurate results:

(a) Aggregations of air-dried soil not completely reduced to finer particles during processing.

(b) Water not thoroughly absorbed into dried material because of insufficient mixing and curing time.

(c) Material reused after compaction.

(d) Insufficient number of tests to define compaction curve accurately.

(e) Improper foundation for mold during compaction.

(f) Incorrect volume or weight of compaction mold.

(g) Incorrect rammer weight and height of fall.

(h) Excessive material extending into the extension collar at the end of compaction.

(i) Improper or insufficient distribution of blows over the soil surface.

(j) Tendency to press the head of the rammer against the specimen before letting the weight fall.

(k) Insufficient drying of sample for water content determination.

(2) *One-point and two-point compaction test.* The possible sources of errors for the one-point and two-point compaction test are essentially the same as those for the five-point method discussed in (1) above. In addition, appreciable inaccuracy in results may occur for both methods if attempts are made to extrapolate maximum density and optimum water contents from nonuniform families of compaction curves (fig. B-5).

B-5. Field compaction and test sections.

For most soils, laboratory densities, water contents, and strength characteristics can be satisfactorily reproduced in a field-compacted backfill. However, during the initial stage of construction frequent checks of density and water content should be made for comparison with design requirements and adjustments should be made in the field compaction procedure as necessary to ensure adequate compaction.

a. When a compacted backfill is constructed as foundation support for critical structures, or when other requirements, materials, and conditions are unusual, the specifications may provide for the construction of test sections. The test section is used to determine the best procedures for processing, placing, and compacting the materials that will produce compacted backfill having engineering properties compatible with design requirements. Therefore, construction of a test section may involve using different types and different weights of compaction equipment, using different lift thicknesses, using different amounts of compaction applications (different numbers of passes or coverages), processing materials differently with respect to water content control, and mixing to obtain improved gradation. A discussion on test sections for shale materials is presented in Appendix A of FHWA-RD-78-141 and illustrates a wide variation in test results, even for very carefully conducted field tests.

b. By exercising rigid control over the water content, processing, placement, and compaction procedures, by frequent density sampling, by keeping complete records of the procedures and tests, and then by studying and evaluating these records, a procedure to use on the job can be established. In addition to water content and density check tests, undisturbed samples should be obtained to determine that the shear and consolidation characteristics are consistent with design requirements. Once control for field conditions has been established, the backfill can proceed at a normal rate. The contractor should be required to adhere to the established processing, placement, and compaction procedures.

c. If provisions for construction of a test section are not contained in the specifications, the field engineers and inspection personnel should provide maximum guidance to the contractor to aid him in establishing adequate processing, placement, and compaction procedures. To meet this problem the contractor must be provided with suggested improvements of equipment type, if they have not been specified, and procedures during the initial stages of backfill operations. The establishment of the procedures and equipment type that will produce adequate compaction of the backfill material must be supported by a comprehensive program of control testing.

Section B-3. FIELD MOISTURE-DENSITY TEST METHODS

B-6. General. Field density measurements of the compacted backfill are essential to ensure that backfill meets the required design densities necessary for the proper functioning of the structure within that backfill. Although water content requirements are not generally specified in military specifications, the measurement and control of water content is important in obtaining required densities. The four density measurement test methods used for the Corps record and contract acceptance enforcement are listed below.

a. The sand-cone method as described in MIL-STD-621A (Method 106) and ASTM D 1556.

b. The rubber-balloon method as described in ASTM D 2167.

c. The nuclear moisture-density method as described in ASTM D 2922 (for density) and ASTM D 3017 (for water content).

d. The drive-cylinder method as described in MIL-STD-621A (Method 102) and ASTM D 2937 for soft, fine-grained cohesive soils. The water-displacement method described in EM 1110-2-1911, although not currently used for Corps contract enforcement, may be used for supplementary density testing for rocky materials. Rapid field methods of determining or approximating water content-density are also discussed in the following paragraphs.

B-7. Water content and density test methods. Field density can be determined by direct or indirect methods. In the direct methods, the weight of soil removed from a hole and the volume of the hole are determined and used to compute the density. In the indirect methods, a characteristic of the soil, such as radiation scattering or penetration resistance, is measured with an instrument such as a nuclear density meter or penetrometer, and then a previously determined relation between density and the characteristic measured is used to determine the density.

a. Direct methods. The sand-displacement method is considered to be the most reliable direct method and should be used as the standard test by which indirect test results are correlated with density. Other direct methods are the drive-cylinder method, rubber-balloon method, and water-displacement method.

(1) *Sand-cone method.* Procedures and equipment for the sand-cone method are described in MIL-STD-621A (Method 106) and ASTM D 1556. The procedure as described in the references involves preparation of the ground surface, measurement of an initial volume for the purpose of correcting for surface irregularities, and measurement of a second volume after a small hole is dug. The difference in the volumes is the volume of the hole. The sand used is a standard sand (Ottawa or other sands having rounded grains and a uniform gradation) that has been calibrated for weight versus volume occupied when falling from a standard, constant height. The weight of sand used is measured by weighing the sand density cylinder before and after each volume measurement, and the volume is determined from the weight versus volume calibration. The soil removed from the hole is weighed, the water content determined (MIL-STD-621A), and the dry weight computed. The wet density and dry density of the soil are computed by dividing the appropriate weights by the computed volume. The sand-cone method can be used to determine the in-place density of practically all soils except those containing large quantities of large gravel sizes.

(2) *Drive-cylinder method.* Procedures and equipment for the drive cylinder method are described in detail in MIL-STD-621A (Method 102) and ASTM D 2937. The procedure consists of driving a 3-inch-diameter by 3-inch-high sampling tube of known volume into the soil, excavating the sampling tube and soil, and trimming off the soil protruding from the ends of the tube. The weight and water content of the soil are measured and the dry weight is computed. The wet density and dry density of the soil are computed by dividing the appropriate weights by the computed volume. The drive-cylinder method is limited to moist, fine-grained cohesive soils.

(3) *Rubber-balloon method.* Procedures and equipment for the rubber-balloon method are described in ASTM D 2167. This method utilizes a rubber balloon attached to a glass or metal cylinder containing water and having a scale graduated in cubic feet. An annular device is seated on the prepared ground surface, and the balloon apparatus is placed and held down firmly on the ring. Then water is forced into the balloon under pressures of 2 to 3 pounds per square inch to obtain an initial volume measurement to correct for ground surface irregularities. The apparatus is removed, a small hole is dug, and the apparatus is replaced on the ring. Water is again pumped into the balloon and causes the balloon to conform to the boundary of the hole; then the volume is measured. This volume less the initial volume is the volume of the hole. The volumeter apparatus is simple and easy to operate, and the volume measurement can be made directly and in somewhat less time than that with the sand-cone volume apparatus. The results obtained are considered to be as accurate as those obtained from the sand-cone apparatus. Like the sand-cone method, the rubber-balloon method can be used to determine the in-place density of practically all soils except those containing large quantities of large gravel sizes.

(4) *Water-displacement method.* Where it is necessary to determine the in-place density for a large volume of soil, as in coarse-grained soils containing significant quantities of large gravel sizes, an approximate density can be obtained by excavating a large hole (several cubic feet) and determining the volume by lining the hole with thin plastic sheeting and measuring the quantity of water required to fill the hole. A relatively small sample representative of the material from the excavation is used for determining the water content. Using the wet and dry weights of the material excavated and the measured volume of the hole, the wet and dry densities of the soil can be determined. Although the procedure is not contained in a Military Standard, it is about the only means of determining an approximate density for soils with large sizes of gravel or rock.

b. Size and preparation of test hole. The size of the hole and the care used in preparing the test hole for the sand volume and balloon methods influence the accuracy of the volume measurement. The proper size of the hole is not well established; however, the larger the hole, the less significant small errors in measurement of volume become. The instructions in TM 5-824-2 indicate that a volume of at least 0.05 cubic foot should be used when testing materials with a maximum particle size of 1 inch and that larger volumes should be used for larger maximum particle sizes. ASTM D 1556 suggests certain relations between particle size and the test hole volume and weight of water content specimen. It also recommends increasing the size of the sample used for water content determination with increasing maximum particle size. The relations suggested by the American Society for Testing and Materials are shown in the following tabulation:

Maximum particle size, in.	Minimum test hole volume cu ft	Water content sample
0.187 (No. 4)	0.025	100
1/2	0.050	250
1	0.075	500
2	0.100	1,000

For significant quantities of larger particles the volumes above should be doubled. The accuracy of the test results is influenced by not only the care taken in preparing a test hole but also the degree of recovery of the excavated material. A hole with irregular surfaces will cause the volume measurement to be less accurate than a hole with smooth surfaces. Thus, the inside of the hole should be kept as free of pockets and sharp projections as possible. Digging a smooth test hole in cohesionless coarse-grained material is particularly difficult. In fine-grained soils without gravel particles, the hole may be bored with an auger, but hand tools will be required to smooth the walls and base of the hole and to recover loose material. For coarser-grained soils and soils containing a significant amount of gravel-size particles, hand tools will generally be required to excavate the hole to prevent disturbing the material in the walls and base of the test hole. Should it become necessary in digging a test hole in highly compacted material to loosen the material by using a chisel and hammer, care must be taken not to disturb the soil around the limits of the hole. All loose particles must be removed after the final depth has been reached, and all particles must be recovered. All soil should be placed in a waterproof container as the soil is taken from the hole. This measure will prevent loss of water before the soil can be weighed.

c. Indirect methods. The indirect methods include use of the nuclear moisture-density apparatus, Proctor penetrometer, and cone penetrometer. Both the Proctor penetrometer and cone penetrometer methods for determining the density require very careful calibration using soils of known density and water content, and considerable experience in operating the device; even so, the accuracy of these methods may be subject to question because of the great influence that nonuniformity of water content or a small piece of gravel can have on the penetration resistance. The Proctor penetrometer may also be used to approximate water content of fine-grained soils.

(1) *Nuclear moisture-density method.* Procedures and equipment for the nuclear moisture-density method are described in ASTM D 2922 (for density) and ASTM D 3017 (for water content). The three methods for determining in-place densities described in ASTM

D 2922 are Method A-Backscatter, Method B-Direct Transmission, and Method C-Air Gap. Of the three methods, Method B-Direct Transmission is recommended over Method A and Method C because it eliminates the effect of vertical density variations.

(a) Modern nuclear-moisture density equipment incorporates a radioactive source emitting neutrons and gamma rays and measuring elements (geiger tubes) or "scalers" into a single, self-contained unit. The determination of moisture by the nuclear method is dependent on the modifying of high energy or "fast" neutrons into low energy or "slow" neutrons (ASTM, STP No. 293). Any material containing hydrogen will moderate fast neutrons. Since hydrogen is present primarily in the molecules of free water, the degree of interaction between the fast neutrons and hydrogen atoms represents a measure of the water content of the soil, Density measurements are based on the scattering of gamma rays by the orbital electrons on the atoms comprising the soil. Since the scattering is a function of the electron density, which in turn is approximately proportional to the density of the soil, it is possible to correlate the backscatter of the gamma rays with the soil density.

(b) To obtain a water content or density measurement, the appropriate meter is set in place and the voltage setting is adjusted to the correct operating voltage. After the scaler is turned on, a short warmup period (not exceeding 1 minute) is allowed before the test count is started. Intimate contact at the interface between meter and soil is necessary for Method A-Backscatter because the scattering of the gamma rays for the density measurement is quite sensitive to *even* minute air gaps. The normal counting period is 1 minute, with one or two repeat counts taken as a check. Calibration curves for both moisture and density determinations, once the count rates have been established, are furnished by the manufacturers for each individual unit. In general, the calibration curve for moisture determination is more reliable than the curve for density determination. However, it is advisable to correlate both calibration curves on each type of soil with which the instrument is to be used. Such a correlation should be accomplished by using current standard methods for moisture and density determinations or by calibrating on blocks of material of known moisture and density. Examples of calibration for shale materials are given in Appendix A of FHWA-RD-78-141.

(c) For all nuclear-moisture density devices, separate standards are provided so that the count rate can be determined on each instrument at any time in the field. A standard count should be taken three or four times during a day's operation. Although adjustments can generally be made on the instruments so that the count will coincide with the standard count; even a slight adjustment is not usually justified. A more satisfactory procedure is to record the field measurement in terms of percent of this standard count rate, which should be within a reasonable percentage (± 5) of the given reference count. Use of the percent of standard count, rather than simply the counts per minute, is recommended for increased accuracy. Use of this procedure largely cancels out the effects of such variables as reduction in source strength, background count, and changes in sensitivity of the detector tubes.

(d) The calibration curve for the soil being tested is entered with the value of the density meter count rate (taking into consideration the variation from the standard count) to obtain the wet unit weight of the soil. Similarly, the moisture meter yields the weight of water per cubic foot of soil. The unit dry weight of the soil is simply the wet unit weight obtained by the density meter minus the weight of water obtained by the moisture meter. By dividing the water measurement by the dry density, the water content can be expressed in the more familiar terms of percentage of dry weight.

(e) Anyone working with nuclear meters must recognize that a possibility of exposure to radiation exists if the safety rules listed by the manufacturer are not followed. When proper procedures and safety rules are followed, the radiation hazard is negligible. For certain instruments, operating personnel must wear a body radiation film badge and carry a pocket dosimeter. These instruments must be ready weekly to ensure that the maximum permissible weekly dosage is less than 100 milliroentgen. Other safety rules deal with handling the devices and being aware of the built-in safety devices. The safety precautions mentioned above may vary or not be applicable for some of the newer devices being manufactured. Therefore, the manufacturer's literature should be carefully studied to determine appropriate safety requirements.

(f) It is possible, using nuclear-moisture density apparatus, for one inspector to conduct perhaps 30 water content and 30 density tests per 8-hour working day. The time required per test is only 20 or 25 percent of that required in direct sampling methods. A large number of tests with the nuclear meter correlated with a much smaller number of direct sampling determinations can be of great benefit in ensuring that adequate compaction of the backfill is being obtained. A simple statistical analysis of the data can be made, such as a plot of dry density versus number of tests (ASTM STP No. 293). The resulting bell-shaped curve is a very useful tool since each day's results can easily be added to the plot of previous test results. This procedure can provide an up-to-date picture of the fill densities being obtained and can show the effect of changes made in field compaction procedures.

(2) *Hand cone penetrometer.* The hand cone penetrometer offers a rapid means of checking density requirement of some compacted backfills. The process involves the correlation of penetration resistance with known in-place densities as determined by either the sand-cone or the rubber-balloon method.

(a) Cone penetration resistance is a measurement of soil bearing capacity. Since bearing capacity is dependent on shear strength and thus density, the hand cone penetrometer is an indirect measurement of density. Because shear strength is a function of any pore air and pore water pressures that may be generated by a shearing action of soils containing pore water, the method is applicable only to free-draining materials where pore pressures are dissipated as fast as they are generated. Penetration resistance can also be drastically influenced by the obstruction of gravel-size particles. Therefore, the method is applicable only to sands with 100 percent passing the U.S. Standard No. 4 sieve (4.76 mm) and no more than 15 percent passing the U.S. Standard No. 200 sieve (0.074 mm).

(b) A plot of hand-cone sounding resistance versus depth of sounding will result in an approximate linear relationship for homogenous materials of relatively constant density for depths of sounding ranging from approximately 2 inches to 20 inches depending on the geometry and size of the cone point and material type. Correlations may be made between known in-place densities and either the angle of inclination between sounding resistance and depth of penetration or the sounding resistance at a given depth. The range of known in-place density must be sufficient to establish a trend between sounding resistance and density. Correlations between density and sounding resistance at a given depth is the simplest correlation since the angle of inclination does not have to be computed. Figure B-7 shows a case example of a correlation between dry density and sounding resistance measured at 6 inches below the surface. Contract specification required a minimum acceptable dry density of 104.7 pounds per cubic foot (98 percent of the maximum dry density according to the compaction method described in ASTM D 1557). Figure B-7 also indicates that all soundings with resistances of 110 pounds or more corresponded to densities greater than 104.6 pounds per cubic foot. Therefore, no additional standard density checks are needed beyond the routine tests. When all soundings with resistance of 86 pounds and below correspond to densities below 104.6 pounds per cubic foot, it is evident that sufficient compaction has not been achieved and additional standard density checks are definitely needed for an acceptance or rejection decision. Sounding with resistances between 86 and 110 pounds may or may not need additional density checks depending on whether the inspector has reason to suspect adequate compaction has or has not been achieved.

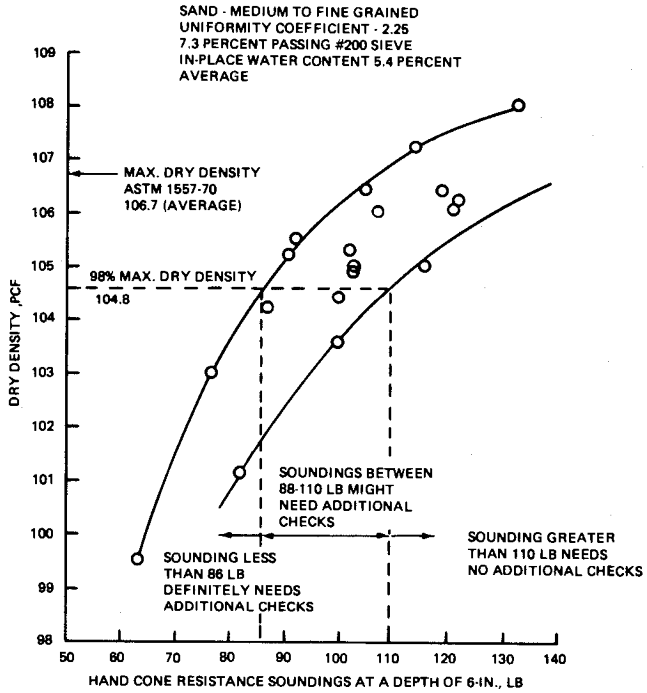


Figure B-7. Correlation between dry density and hand cone resistance at a depth of 6 inches below the surface.

(c) The correlation between sounding resistance and known in-place dry densities (fig. B-7) is made directly without knowing water content at each sounding location. Although sounding resistances are affected by water content for the dry, moist, and 1 to 2 percentage points above optimum state, the range of possible water content in the moist state does not significantly affect sounding resistance.

(d) The hand cone penetrometer is ideally suited for use in confined zones where sand is used as backfill and where rapid control aids are needed to determine if adequate compaction has been achieved. With a little practice, a hand-cone sounding can be -made in less than 1 minute.

d. Possible sources of errors. Since the decision to accept or reject a particular part of a backfill is primarily dependent upon the results of in-place density control tests, it is important for the inspector to be familiar with the possible sources of errors that might cause an inaccurate test result. Some of the more likely sources of errors for the sand-cone, rubber-balloon, and nuclear moisture-density methods are discussed below. All tests that are suspected to be in error must be repeated.

(1) *Sand-cone method.* The major sources of possible error are as follows:

(a) The sand-cone method relates the bulk density of a standard sand to the known weight of the

same sand occupying an in-place volume of sampled material. Changes in effective gradation between or within batches of sand may significantly affect the test results. This error can be minimized by frequent calibration of the sand's bulk density.

(b) Loose sand increases in density when subjected to vibrations. Care must be taken not to jar the sand container while calibrating bulk density in the laboratory or during in-place volume measurements in the field. A common error is to use the sand cone method for in-place volume measurements adjacent to the operation of heavy equipment. Heavy equipment can generate vibrations that densify the sand and result in erroneously high-volume measurements and low in-place densities.

(c) Appreciable time intervals between bulk density determination of the sand and its use in the field may result in change in the bulk density caused by a change in the moisture content of the sand.

(2) *Rubber-balloon method.* The major sources of possible error are as follows:

(a) New rubber-balloon volumeters should be calibrated against several known volumes of different sizes covering the volume range of in-place measurements.

(b) For stiff soils such as clay, it is possible to trap air between the sides of the sample hole and balloon. This error can be minimized by placing lengths of small-diameter string over the edge of the hole and down the inside wall slightly beyond the bottom center.

(c) The application of the 2- to 3-pounds-per-square-inch pressure to extend the balloon into existing irregularities in the hole will cause a noticeable upward force on the volumeter. Care must be taken to ensure that the volumeter remains in intimate contact with the base plate.

(d) The rubber balloon must be frequently checked for leaks.

(3) *Nuclear moisture-density method.* The major sources of possible error are as follows:

(a) The single consistent source of error is related to the accuracy of the system. The overall system accuracy in determining densities is statistical in nature and appears to vary with the equipment used, test conditions, materials tested, and operators. If proper procedures are followed, the standard deviations in terms of accuracy will vary on the order of 3 to 5 pounds per cubic foot for density tests and 0.5 to 1.0 pound of water per cubic foot of material for water content tests.

(b) Manufacturers furnish calibration curves for each piece of equipment. Due to the effects of differing chemical compositions, calibration curves may not be applicable to materials not represented in establishing the calibration curve. Apparent variations in calibration curves may also be induced by differences in the seating, background count, sample heterogeneity, and surface texture of the material being tested.

B-8. Rapid field water content control procedures. In many cases, particularly in confined zones, it is important to rapidly determine the dry density of a given part of the backfill in order to prevent the possibility of costly tear out and rebuild operations. The test procedures for determining dry densities using the sand-cone and rubber-balloon methods sometimes require extensive drying times (depend on material type up to 16 hours) to determine water content. Alternate techniques for rapidly determining water content are discussed below.

a. Microwave ovens. Microwave energy may be used to dry soil rapidly and thus enable quick determination of water content (ASTM STP No. 599). However, in drying soils with microwaves, the only control on the amount of energy absorbed by the soil is exposure time; consequently, if soils are left in the oven too long, severe overheating can occur. This overheating of the soil can cause bound water, a part of the soil structure, to be driven off and thus result in significant errors in water content measurements. In addition, continuous heating can result in excessive heat being generated; certain soils have been observed to fuse or explode and thereby create hazards to both equipment and personnel.

(1) Times required for drying in a microwave oven are primarily governed by the mass of water present and the power-load output of the oven, as expressed by

$$G_T = \frac{M_w[(0.2/w + 1)(100 - t_o) + 539](4.18896)}{P} \quad \text{(B-1)}$$

where

- T = time in the microwave oven, seconds
- M_w = mass of water present in the soil-water mixture, grams
- w = water content of the specimen
- t_o = initial temperature of the soil-water mass, degree Centigrade
- P = power output of the oven, watts

This governing equation indicates that in order to predict accurately the drying times required, an estimate of the specimen water content must be made and the oven power versus load relationship must be established by calibration.

(2) The limitation of having to estimate the initial water content of the specimen is not insurmountable. Test results indicate that slight overestimations of the actual water content, i.e., longer drying times, generally result in small differences between conventional oven and microwave oven water contents. Conversely, underestimations of water content result in more serious errors. If an accurate estimate of water content

cannot be made, experience has shown that close. visual observation often can be used to determine if soil overheating is occurring. An alternative approach is to incrementally dry a duplicate specimen until a constant weight is obtained, calculate the water content, and input this value into equation (B-1).

(3) The useful power output "P" is determined in the laboratory by subjecting a mass of distilled water to microwaves for a given time and then measuring the rise in temperature induced in the water. Power in watts is calculated from

$$P = \frac{M_w t}{T_c} 4.18896 \qquad \text{(B-2)}$$

where

M_w = mass of distilled water in the oven, grams

t = increase in temperature of the distilled water, degree Centigrade

T_c = time in the oven for calibration, seconds

A plot is then made of power output and oven load (mass of water in oven) in grams of water as shown in figure B-8.

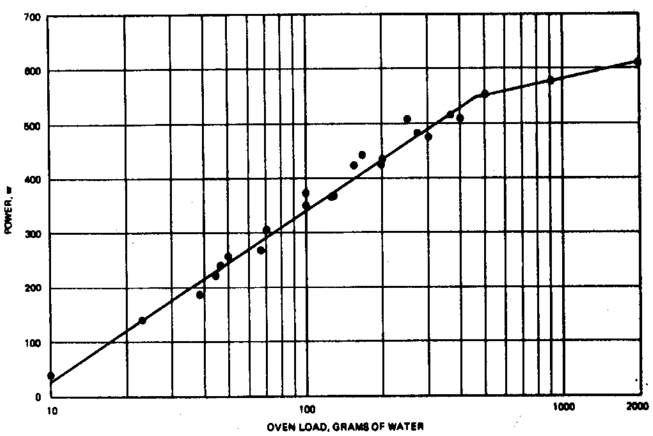


Figure B-8. Power Applied by the Oven to Dry Moist Soils.

(4) The water content estimate is used to calculate the mass of water in the specimen from

$$M_w = \frac{(W_{wet})(W)}{(1 + w)} \qquad \text{(B-3)}$$

where

M_w = mass of the water in the specimen, and equivalent to oven load in figure B-8, grams

W_{wet} = wet weight of the specimen, grams

By calculating M_w (oven load in fig. B-8) from equation (B-3) and finding a comparable value of power from a plot similar to figure B-8 for the particular oven used, the drying time may be calculated from equation (B-1).

(5) It may not be possible to successfully dry certain soils in the microwave oven. Gypsum may decompose and dehydrate under microwave excitation. Highly metallic soils (iron ore, aluminum rich soils, and bauxite) have a high affinity for microwave energy and overheat rapidly after all the free water has been vaporized. Hence, extreme care is required when drying these soils. For the same reason, metallic tare cans or aluminum plates are not permissible as specimen containers.

(6) Because microwaves are a type of radiation, normal safety precautions to avoid undue exposure should be observed.

b. Proctor penetrometer. The Proctor penetration resistance method in the hands of inspection personnel experienced in its use provides a rapid expedient check on whether the field water content is adequate for proper compaction. However, the method is suitable only for fine-grained soils because coarse sand or gravel may cause erroneously high resistance readings. The method consists of compacting by the procedure used for control of a representative sample of soil taken from the loose lift being placed. The compacted specimen is weighed, and the wet unit weight is determined. The penetration resistance of the compacted specimen in the mold is then measured with the soil penetrometer. The moisture content can then be estimated by comparing the penetration resistance of field compacted specimens with a relation previously established in the laboratory between wet unit weight, penetration resistance, and moisture content. The procedure requires about 10 minutes and is sufficiently accurate for most field purposes. The procedure to determine the relation between wet unit weight, penetration resistance, and moisture content is described in ASTM D 1558. The relation is generally developed in conjunction with the compaction test.

c. Other methods. Other methods for determining water content include drying by hot plate or open flame, drying by forced hot air and a rapid moisture test that uses calcium carbonate. In the hot plate method, a small tin pan and a hot plate, oil burner, or gas burner (something to furnish fast heat) are used. A sample of wet soil is weighed, dried by one of the above mentioned methods, and weighed again to determine how much water was in the sample. This method is fast, but care must be taken to ensure that the material is thoroughly dry. Also, if both organic matter and bound water are removed, higher water content determinations than those obtained by ovendrying sometimes result. In the forced hot air, a sample is placed in a commercially available apparatus containing an electric heater and blower. Hot air at 150 to 300 degrees Fahrenheit is blown over and around the sample for a preset time. A 110- or 230-volt source is required. Available sizes of apparatus can accommodate sample weights from 25 to 500 grams. Drying times are estimated to vary from 5 minutes for sand to as long as 30 minutes for fat clay. The rapid moisture test and limitations are described in STP 479.

APPENDIX C

BIBLIOGRAPHY

Broms, B., "Lateral Earth Pressures Due to Compaction of Cohesionless Soils". *Proceedings, Fourth Budapest Conference on Soil Mechanics and Foundation Engineering,* Budapest, Hungary (1971).

Burmister, D. M., "The Grading-Density Relations of Granular Materials". *Proceedings, American Society for Testing and Materials,* Volume 38, Part II, Philadelphia, Pennsylvania (1938).

Davis, F. J., "Quality Control of Earth Embankments". *International Conference on Soil Mechanics and Foundation Engineering,* Volume 1, Switzerland (1953).

de Mello, U. F. B., Sonto Silveira, E. B., and Silveira, A., "True Representation of the Quality of a Compacted Embankment". *First Pan-American Conference on Soil Mechanics and Foundations Engineering,* Volume II, Mexico (1960).

Hilf, J. W., "Compacting Earth Dams with Heavy Tamping Rollers". *Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers,* Volume 83, No. SM2, Paper 1205, Ann Arbor, Michigan (1957).

Ingold, T. S., "The Effects of Compaction on Retaining Walls". *Geotechnique,* Volume 29, No. 3. London (1979).

Ingold, T. S., "Retaining Wall Performance During Backfilling". *Journal of the Geotechnical Engineering Division, American Society of Civil Engineers,* Volume 105, GT5, Paper 14580, New York, New York (1979).

Li, C. Y., "Basic Concepts on the Compaction of Soil". *Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers,* Volume 82, SM1, Paper 862, Ann Arbor, Michigan (1956).

Joshi, R. C., Duncan, D. M. and Durbin, W. L., "Performance Record of Fly Ash as a Construction Material". *Proceedings, Fourth International Ash Utilization Symposium,* St. Louis, Missouri, 24-25 March 1976. John H. Faber, editor, Energy Research and Development Administration Morgantown, West Virginia (1976) (NTIS: MERC/SP-76/4).

Olson, R. E. "Effective Stress Theory of Soil Compaction". *Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers,* Volume 89, No. SM2, Paper 3457, Ann Arbor, Michigan (1963).

Plantema, G., "Influence of Density on Sounding Results in Dry, Moist, and Saturated Sands". *Proceedings of the Fourth International Conference on Soil Mechanics and Foundation Engineering,* Long Volume I (1957).

Proctor, R. S., "The Design and Construction of Rolled Earth Dams". *Engineering News-Record,* Volume III (1933).

Quigley, D. W. and Duncan, J. M., "Earth Pressures on Conduits and Retaining Walls". Report No. UCB/GT/78-06, University of California, Department of Civil Engineering (1978).

Turnbull, W. J. and Foster, C. R., "Stabilization of Materials by Compaction". *Journal of Soil Mechanics and Foundations Division, American Society of Civil Engineers,* Volume 82, No. SM2, Paper 934, Ann Arbor, Michigan (1956).

Winterkorn, H. F. and Fang, Hsai-Yang, *Foundation Engineering Handbook.* Van Nostrand Reinhold Company, New York, New York (1975).

The proponent agency of this publication is the Office of the Chief of Engineers, United States Army.
Users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) direct to HQDA (DAEN-ECE-G), WASH DC 20314.

By Order of the Secretaries of the Army and the Air Force:

E. C. MEYER
General, United States Army
Chief of Staff

Official:
ROBERT M. JOYCE
Major General, United States Army
The Adjutant General

CHARLES A. GABRIEL, *General, USAF*
Chief of Staff

Official:
JAMES L. WYATT, JR., *Colonel, USAF*
Director of Administration

DISTRIBUTION:
Army: To be distributed in accordance with DA Form 12-34B, TM 5-800 Series requirements for Engineering and Design for Real Property Facilities.
Air Force: F

*U.S. GOVERNMENT PRINTING OFFICE: 1983-605-040:190

UFC 3-220-10
1 February 2022
Change 1, 11 March 2025

UNIFIED FACILITIES CRITERIA (UFC)

SOIL MECHANICS
(DM 7.1)

This Page Intentionally Left Blank

UFC 3-220-10
1 February 2022
Change 1, 11 March 2025

UNIFIED FACILITIES CRITERIA (UFC)

SOIL MECHANICS (DM 7.1)

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS
NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)
AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	**Date**	**Location**
1	03/11/2025	Front Matter: Included disclaimer for use of commercial software. Added Introduction (Chapter) to comply with UFC Template. Table 3-1: Adjusted sample size requirements for consistency. Table 3-2: Corrected error in equation and improved equation resolution and or size. Table 4-2: Corrected error in equation and improved figure resolution and or size. Sections 4-6.1 and 5-1.1: Deleted reference to NAVFAC DM 7.3. Table 6-4: Revised subscript v in table headings. Equation 6-13: Corrected error in numerator. Figure 6-11: Replaced figure to fix nomenclature and variable definition. Figure 8-13: Replaced figure to correct exponent. Figure 8-42: Revised figure caption. Appendix B: One software package added.

This UFC supersedes UFC 3-220-10N, dated 8 JUNE 2005.

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site http://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

CHRISTINE T. ALTENDORF, PhD, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

R. DAVID CURFMAN, P.E., SES
Chief Engineer
Naval Facilities Engineering Command

NANCY J. BALKUS, P.E., SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MICHAEL McANDREW
Deputy Assistant Secretary of Defense
(Construction) Office of the Secretary of
Defense

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)
REVISION SUMMARY

Document: UFC 3-220-10, *Soil Mechanics*

Superseding: UFC 3-220-10N, *Soil Mechanics*

Description: "Soil Mechanics" or DM 7.1 (UFC 3-220-10N) has been a valuable legacy document in geotechnical engineering for 50 years. Revisions to the document occurred in 1982, 1986, and 2005; but for the most part; the document has remained substantially unchanged since the original publication in 1971. DM 7.1 has been on the bookshelf of many civil engineers, it has been used in many graduate and undergraduate soil mechanics classed attended by generations of geotechnical engineering students, and charts and correlations from the document have been cited in numerous textbooks and research papers. Currently, it can be found in electronic format at a variety of sites on the internet.

The lasting value of DM 7.1 is attributed to its success in distilling geotechnical engineering design procedures, particularly into graphical examples that are easy to follow and understand. The manual also contains correlations to estimate engineering properties of soil and rock that have become ubiquitous in engineering practice. Although the manual continues to be a part of everyday engineering, changes in the profession necessitate a substantial update of DM 7.1. The manual was initially written when the slide rule was the main calculation tool of engineers. Subsequent revisions predate the widespread use of personal computer software tools that are used by every practicing engineer. The manual also predates the global use of the internet as a means to gather pertinent information and to transfer data and documents. In addition, there have been many new methods of testing, exploration, and analysis that have been developed since the publication of the original manual.

This current revision was undertaken with an emphasis on retaining the elements that were responsible for the lasting value of DM 7.1. Graphical examples of engineering solutions, both old and new, are found throughout the chapters. A new chapter has been written that focuses on geotechnical engineering correlations. Details about computer solutions and numerical modeling tools have been added to the manual. Owing to the rapid changes that occur in geotechnical engineering software tools and internet addresses, the authors have tried to minimize the number of URLs and the names of specific software packages in the text. Appendix B contains a listing of software packages available at the time of publication (2021), along with vendor contact information, with the intention that this appendix can be updated periodically in the future. **1**\ The list is provided solely as a courtesy and has not been verified by the Tri-Services. The user is fully responsible for proper verification, validation, and applicability of the software. /**1**/

In accordance with MIL-STD-3007 and UFC 1-300-01, Criteria Format Standard, this UFC varies in format from traditional UFC format requirements. It was approved for variation in format as required in UFC 1-300-01.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

I-1 REISSUES AND CANCELS.

This UFC supersedes UFC 3-220-10N dated 8 June 2005.

I-2 PURPOSE AND SCOPE.

This UFC provides technical guidance on contemporary soil mechanics principles and the practice of geotechnical engineering used in planning, design, construction, evaluation and maintenance of Government facilities for the Department of Defense (DoD). Where other criteria, contractual, statutory or regulatory requirements are referenced, the more stringent requirement must be met.

I-3 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, as it pertains to soil mechanics and the practice of geotechnical engineering.

I-4 GENERAL BUILDING REQUIREMENTS.

Comply with UFC 1-200-01, *DoD Building Code*. UFC 1-200-01 provides applicability of model building codes and government unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, high performance and sustainability requirements, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

I-5 GLOSSARY.

APPENDIX C contains a list of symbols used in geotechnical engineering. APPENDIX D contains definitions of terms.

I-6 REFERENCES.

APPENDIX A contains a list of references used in this document.

This Page Intentionally Left Blank

CHAPTER 1 IDENTIFICATION AND CLASSIFICATION OF SOIL AND ROCK

1-1 INTRODUCTION.

1-1.1 Scope.

This chapter presents criteria for *soil* and *rock* identification and classification based on internationally accepted standards as well as information on their physical engineering properties. Common soils and rocks are discussed as well as special materials, such as expansive and collapsing soils, permafrost, limestone and related materials, coral and coral formations, quick clays, and other materials (i.e. man-made fills, chemically reactive and lateritic soils, calcareous sands, and submarine soils).

1-2 SOIL DEPOSITS.

1-2.1 Geologic Origin and Mode of Occurrence.

Soils are masses of solid particles along with the materials within the voids between the particles. The solid particles typically are a mixture of sediments or other accumulated, unconsolidated[1] material produced by the chemical and physical disintegration of rocks. Soils can contain organic materials. From a geologic standpoint, soils can be classified in terms of origin (e.g., transported, *pyroclastic*, *residual*, and *organic*), and mode of occurrence (e.g., *aeolian*, *alluvial*, *colluvial*, *glacial*, and *marine*). A geologic description can assist in correlating experiences between several sites, and in a general sense, can indicate the pattern of strata to be expected prior to making a field investigation (test borings, etc.).

Soils with similar origin and mode of occurrence are expected to have comparable, if not similar, engineering properties. For quantitative foundation analysis, a geological description is inadequate and a more specific classification and testing is required. A study of references on local geology should precede a major subsurface exploration program as this will help with planning the exploration and also with identifying possible challenges for the project. Also, information on known projects near the site should be obtained, if available, to give specific details about the soils and conditions that will likely be encountered. Table 1-1 describes the principal soil deposits grouped in terms of origin, and Table 1-2 describes the principal soil deposits by mode of occurrence.

[1] In this context, unconsolidated means that the particles have not lithified into rock. It does not imply a particular state of consolidation as described in Chapter 5.

Table 1-1 Principal Soil Deposits in Terms of Origin

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
Organic: Accumulation of highly organic material formed in place by the growth and subsequent decay of plant life	*Peats*: Somewhat fibrous aggregate of decayed and decaying vegetation matter having a dark color and odor of decay	Very compressible; entirely unsuitable for supporting building foundations
	Mucks: Peat deposits which have advanced in stage of decomposition to such extent that the botanical character is no longer evident	
Pyroclastic: Material ejected from volcanoes and transported by gravity, wind and air	*Ejecta*: Loose deposits of volcanic ash, lapilli, bombs, etc.	Typically, shard-like particles of *silt* size with larger volcanic debris; weathering and redeposition produce high plasticity, compressible *clay*; unusual and difficult foundation conditions
	Pumice: Highly porous volcanic rock that is frequently associated with lava flows and mud flows, or may be mixed with nonvolcanic sediments	
Residual: Material formed by disintegration of underlying parent rock or partially indurated material	Residual sands and fragments of gravel-sized material formed by dissolution and leaching of cementing material, leaving behind the more resistant particles, commonly quartz	Generally favorable foundation conditions
	Residual clays formed by the decomposition of silicate rocks, disintegration of shales, and solution of carbonates in limestone; with few exceptions, becomes more compact, rockier and less weathered with increasing depth; at intermediate stage may reflect composition, structure and stratification of parent rock	Variable properties requiring detailed investigation; deposits present favorable foundation conditions except in humid and tropical climates, where depth and rate of weathering are very great
	Transported soils: See Table 1-2	

Table 1-2 Principal Soil Deposits by Mode of Occurrence

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
Aeolian: Material transported and deposited by wind.	*Loess*: A calcareous unstratified deposit of silts or sandy or clayey silt traversed by a network of tubes formed by root fibers now decayed	Relatively uniform deposits characterized by ability to stand in vertical cuts; collapsible structure; deep weathering or saturation can modify characteristics
	Dune sands: Mounds, ridges, and hills of uniform fine sand characteristically exhibiting rounded grains	Very uniform grain size; may exist in relatively loose condition
Alluvial: Materials transported and deposited by running water.	*Floodplain:* Low-lying stream or river deposits that are subject to inundation by floodwaters	
	Point bar: Alternating deposits of arcuate ridges and swales (lows) formed on the inside or convex bank of mitigating river bends; ridge deposits consist primarily of silt and sand, swales are clay filled	Generally favorable foundation conditions; however, detailed investigations are necessary to locate discontinuities; flow slides may be a problem along riverbanks; soils are quite pervious
	Channel fill: Deposits laid down in abandoned meander loops isolated when rivers shorten their courses; composed primarily of clay; however, silty and sandy soils are found at the upstream and downstream ends	Fine-grained soils are usually compressible; portions may be very heterogeneous; silty soils generally present favorable foundation conditions
	Backswamp: The prolonged accumulation of floodwater sediments in flood basins bordering a river; materials are generally clays but tend to become siltier near riverbank	Relatively uniform in a horizontal direction; clays are usually subjected to seasonal volume changes
	Terrace: Relatively narrow, flat-surfaced, river-flanking remnants of floodplain deposits formed by entrenchment of rivers and associated processes	Usually drained and oxidized; generally favorable foundation conditions
	Estuarine: Mixed deposits of marine and alluvial origin laid down in widened channels at mouths of rivers and influenced by tide of body of water into which they are deposited	Generally fine grained and compressible; many local variations in soil conditions
	Lacustrine: Material deposited within lakes (other than those associated with glaciation) by waves, currents, and organo-chemical processes; deposits consist of unstratified organic clay or clay in central portions of the lake and typically grade to *stratified* silts and sands in peripheral zones	Usually very uniform in horizontal direction; fine-grained soils generally compressible
	Deltaic: Deposits formed at the mouths of rivers, which result in extension of the shoreline	Generally fine-grained and compressible; many local variations in soil condition
	Piedmont: Alluvial deposits at foot of hills or mountains; extensive plains or alluvial fans	Generally favorable foundation conditions

Table 1-2 (cont.) Principal Soil Deposits by Mode of Occurrence

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
Colluvial: Material transported and deposited by gravity	*Talus*: Deposits created by gradual accumulation of unsorted rock fragments and debris at base of cliffs	Previous movement indicates possible future difficulties; generally unstable foundation conditions
	Hillwash: Fine colluvium consisting of clayey sand, sand silt, or clay	
	Landslide deposits: Considerable masses of soil or rock that have slipped down, more or less as units, from their former position on steep slopes	
Glacial: Material transported and deposited by glaciers, or by meltwater from the glacier.	*Glacial till*: An accumulation of debris, deposited beneath, at the side (lateral moraines), or at the lower limit of a glacier (terminal moraine); material lowered to ground surface in an irregular sheet by a melting glacier is known as a ground moraine.	Consists of material from *boulder* and *gravel* to clay; deposits are unstratified; present generally favorable foundation conditions but rapid changes in conditions are common.
	Glacio-fluvial deposits: Coarse and fine-grained material deposited by streams of meltwater from glaciers; material deposited on ground surface beyond terminal edge of a glacier is known as an outwash plain; gravel ridges known as kames and eskers; depressions known as kettles can be filled with peat	Many local variations; generally present favorable foundation conditions
	Glacio-lacustrine deposits: Material deposited within lakes by meltwater from glaciers; consisting of clay in central portions of lake and alternate layers of silty clay or silt and clay (varved clay) in peripheral zones	Very uniform in the horizontal direction
Marine: Material transported and deposited by ocean waves and currents in shores and offshore areas.	*Shore deposits*: Deposits of sands and/or gravels formed by the transporting, destructive, and sorting action of waves on the shoreline	Relatively uniform and of moderate to high density
	Marine clays: Organic and inorganic deposits of fine-grained material	Generally, very uniform, compressible and usually very sensitive to remolding

1-3 SOIL VISUAL DESCRIPTION, IDENTIFICATION, AND CLASSIFICATION.

Standardized procedures for visual description, identification, and formal classification of a soil specimen are presented in this section. These procedures follow the corresponding ASTM standard available for this purpose. Visual description entails describing the characteristics of the soil that can be perceived with the senses (e.g. vision, touch, and smell). The identification of the soil refers to knowing the soil type without having to use specialized equipment to do so. The visual description and identification of soils are normally done in the field and the procedures are based on ASTM D2488. The classification of the soils involves using specialized equipment and tests to classify the soil using a standard classification system.

1-3.1 Definitions.

The definitions used in this chapter agree with the Unified Soil Classification system presented in ASTM D2487.

Boulders: Rock particles will not pass a 12-inch square opening.

Clay: Soil particles passing a No. 200 (75-µm) sieve that exhibit plasticity (putty-like properties) within a range of water contents, and considerable strength when air dried. For classification of clayey soils, refer to Section 1-3.3.

Coarse-grained soils: Soils that contain 50% or more particles retained on a No. 200 (75 µm) sieve.

Cobbles: Rock particles that pass through a 12-inch square opening sieve but are retained on a 3-inch square opening sieve.

Fine-grained soils: Soils that contain 50% or more particles passing a No. 200 (75 µm) sieve.

Gravel: Soil particles that pass through a 3-inch square opening sieve but are retained on a No. 4 (4.75 mm) sieve. Gravels can be divided into: (1) coarse gravels, gravel particles that are retained on a ¾-inch square opening sieve, and (2) fine gravels, gravel particles that pass through a ¾-inch square opening sieve.

Sand: Soil particles that pass through a No. 4 (4.75 mm) sieve and are retained on a No. 200 (75 µm) sieve. Sands can be divided into: (1) coarse sands, sand particles that are retained on a No. 10 (2.00 mm) sieve, (2) medium sands, sand particles that pass through a No. 10 (2.00 mm) sieve and are retained on a No. 40 (425 µm) sieve, and (3) fine sands, sand particles that pass through a No. 40 (425 µm) sieve.

Silt: Nonplastic or very slightly plastic soil particles passing a No. 200 (75-μm) sieve that exhibit little or no strength when air dried. For classification of silty soils, refer to Section 1-3.3.

1-3.2 Visual Description and Identification (ASTM D2488).

Visual description of soil samples is commonly performed in the field during the drilling process and consists of a visual description of the soil accompanied by an identification of the type of soil. This should be done by an engineer or a qualified person and should include as much information as possible regarding the observed conditions of the soil *in situ*. The visual description of the soil, along with the drilling logs, can provide very useful qualitative information to the engineer if done correctly. One of the most widely used standards for this purpose is ASTM D2488, which uses visual examination and simple manual tests to describe and identify soils.

1-3.2.1 Visual Description.

The descriptors for soils consist of properties and qualitative information of the soil that can be perceived with our senses. This information can be very valuable to the engineer. Below are some guidelines on what should be observed based on ASTM D2488.

1-3.2.1.1 Descriptors for All Soils.

Color: Use the color or colors that best describes the sample. Color is an important property that can help in identifying organic soils. Within a given locality, it may also be useful in identifying materials of similar geologic origin. Layers or patches of different colors should also be noted. The color described should be that of a moist sample. If the color represents a dry condition, this should be stated in the report. A Munsell color chart is a useful tool to help describing the color.

HCl reaction: Diluted hydrochloric acid (HCl) (one part of HCl to three parts of distilled water) can be used to identify the presence of calcium carbonate. The HCl reaction should be described as: (1) none, for no visible reaction, (2) weak, for some reaction with bubbles forming slowly, or (3) strong, for violent reaction with bubbles forming immediately.

Moisture condition: The moisture condition of the soil should be described as follows: (1) dry, for soils with absence of moisture, dusty, or dry to the touch, (2) moist, for damp soils with no visible water, or (3) wet, for soils with visible free water.

Odor: The odor of the soils should be described if the soil is organic or has an unusual odor.

Others: Additional comments like the presence of roots or root holes, difficulty in drilling the hole, caving of the trench or hole, or the presence of mica should be included. In addition, a local or commercial name, or a geologic interpretation of the soil could be added to help identifying the soil.

1-3.2.1.2 Descriptors for Fine-Grained Soils.

Consistency: The consistency of intact fine-grained soils should be described as: (1) very soft, if the thumb will penetrate soil more than 1 inch (25 mm); (2) soft, if the thumb will penetrate soil about 1 inch (25 mm); (3) firm, if the thumb will indent soil about 1⁄4 inch (6 mm); (4) hard, if the thumb will not indent soil but readily indented with thumbnail; or (5) very hard, if the thumbnail will not indent soil.

Structure: The structure for intact soils should be described using the following terms:

1) *Stratified*: Use for soils with layers of different material or color of at least ¼ inch in thickness. The layer thickness should be noted.
2) *Laminated*: Use for soils with layers of different material or color of less than ¼ inch in thickness. The layer thickness should be noted.
3) *Fissured*: Use for soils that break along predetermined planes with little resistance.
4) *Slickensided*: Apply to fissured soils that show polished, glossy, or sometimes striated fracture planes.
5) *Blocky*: Describes soils that can be broken down into small angular lumps which are hard to break down further.
6) *Lensed*: Use for soils with inclusions of small pockets of different soils scattered through the mass of the clay. The lens thickness should be noted.
7) *Homogenous*: Use for soils with the same color and appearance throughout.

1-3.2.1.3 Descriptors for Coarse-Grained Soils.

Angularity: Describe the angularity of coarse-grained soils as: (1) angular, if the particles have sharp edges and relatively plane sides with unpolished surfaces, (2) subangular, if the particles are angular but with rounded edges, (3) subrounded, if particles have nearly plane sides but well-rounded corners and edges, or (4) rounded, if particles have smoothly curved sides and no edges. Figure 1-1 shows examples of these four terms.

Cementation: Describe the cementation of intact coarse-grained soils as: (1) weak, if the soil crumbles or breaks with handling or little pressure, (2) moderate, if the soil crumbles or breaks with considerable finger pressure, or (3) strong, if the soil will not crumble or break with finger pressure.

Figure 1-1 Typical Angularity of Bulky Grains (after Sowers 1979)

Hardness: Describe the hardness of coarse-grained soils as hard if the particles do not crack, fracture, or crumble when struck by a hammer, or state what happens to the particles when hit by a hammer.

Maximum particle size: Describe the maximum particle size. For sands, describe it as coarse, medium, or fine. For gravels, the maximum particle size is the smallest sieve opening that the particle will pass. For cobbles and boulders, the maximum particle size is the maximum dimension of the largest particle.

Range of particle size: Describe the range of particle sizes within each component. For example, about 15% of coarse gravel and about 45% of fine to coarse sand.

Shape: Describe the shape as: (1) flat, for particles with width/thickness > 3, (2) elongated, for particles with length/width > 3, or (3) flat and elongated, for particles that meet both criteria.

1-3.2.2 Identification.

The identification method presented in this section follows ASTM D2488. The identification should be performed on a sample that excludes cobbles and boulders. These large particles should be manually removed from disturbed samples and ignored for intact samples. The percentage of cobbles and boulders from the total samples should be estimated by volume and noted. Estimate the percentage, by dry mass, of gravel, sand and fines. The percentages should be estimated to the closest 5% and all the percentages should add to 100%. If one type of soil is encountered but the amount is less than 5% the term trace should be used to indicate its presence. A component described as trace should not be included in the 100%.

1-3.2.2.1 Identification of Fine-Grained Soils.

The identification of fine-grained soils is based upon the results of the dry strength, dilatancy, toughness, and plasticity tests.

Dry strength test: This test should be performed using a 0.5-inch diameter ball of soil. The ball needs to be air-dried or dried by artificial means at a temperature not exceeding 140°F. After drying, the ball is crushed between the fingers and the strength is classified as:

1) None, if the dry specimen crumbles into powder with the mere pressure of handling,
2) Low, if the dry specimen crumbles into powder with some finger pressure,
3) Medium, if the dry specimen breaks into pieces or crumbles with considerable finger pressure,
4) High, if the dry specimen cannot be broken with finger pressure but will break into pieces between thumb and a hard surface, or
5) Very high, if the dry specimen cannot be broken between the thumb and a hard surface.

Dilatancy: This test is performed using a 0.5-inch diameter ball molded to a soft but not sticky consistency. The ball is smoothed in the palm of one hand using the blade of a knife or a small spatula. The hand is then shaken horizontally and vigorously struck against the other hand several times. The reaction of water appearing on the surface should be noted. The soil is then squeezed by closing the hand or pinched between the fingers and the reaction of water is noted. The dilatancy is classified as:

1) None, if no visible change in the specimen was observed,
2) Slow, if water appears slowly on the surface of the specimen during shaking and does not disappear or disappear slowly upon squeezing, or
3) Rapid, if water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing.

Toughness: This test is performed after the dilatancy test is completed and using the same specimen. The test specimen is rolled by hand on a smooth surface into a thread of about 1/8 inches in diameter. The sample is folded, mixed again, and rerolled until the threads break at a diameter of about 1/8 inches, which means the soil is near the plastic limit. The toughness of the soil is classified as:

1) Low, if only slight pressure is required to roll the thread near the plastic limit and the thread and the lump are weak and soft,
2) Medium, if medium pressure is required to roll the thread to near the plastic limit and the thread and the lump have medium stiffness, or
3) High, if considerable pressure is required to roll the thread to near the plastic limit and the thread and the lump have very high stiffness.

Plasticity: The plasticity of the soil is classified based on observations made during the toughness test as:

1) Nonplastic, if a 1/8-in-diameter thread cannot be rolled at any water content,
2) Low, if the thread can barely be rolled and the lump cannot be formed when drier than the plastic limit,

3) Medium, if the thread is easy to roll and not much time is required to reach the plastic limit, if it cannot be rolled after reaching the plastic limit, and the lump crumbles when drier than the plastic limit, or
4) High, if it takes considerable time rolling and kneading to reach the plastic limit, if the thread can be rerolled several times after reaching the plastic limit, and the lump can be formed without crumbling when drier than the plastic limit.

After these tests are performed, classify inorganic-fine-grained soils using the information in Table 1-2. If the soil contains enough organic matter, identify the soil as organic soil, OL/OH. Normally organic soils have a brown to black color and some organic odor. Normally organic soils will not have a high toughness or plasticity and the threads for the toughness test will be spongy.

Table 1-3 Classification of Fine-grained Soils

Soil Symbol	Dry Strength	Dilatancy	Toughness and Plasticity
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

For fine-grained soils with an estimated percentage of sand, gravel or both the term “with sand” or “with gravel” depending on which one is more predominant should be added to the group name. If the percentage of sand and gravel is the same, use the term “with sand.” For fine-grained soils with an estimated percentage of sand, gravel or both above 30%, the words “sandy” or “gravelly” should be added to the group name depending on which one is more predominant. If the percentage of sand and gravel is the same, use the word “sandy.”

1-3.2.2.2 Identification of Coarse-Grained Soils.

For coarse-grained soils, the identification is only based on visual observations. Classify the soil as gravel or sand depending on which soil type is more predominant. The soil is considered a clean gravel or a clean sand if the percentage of particles that pass the #200 (75 μm) sieve is less than 5%. If the soil has a wide range of particle sizes and considerable amount of the intermediate particle sizes, the soil is considered to be a well-graded gravel or sand (GW or SW, respectively). If not, the soil is considered a poorly-graded gravel or sand (GP or SP, respectively).

For soils with 10% fines, a dual classification should be used. The first set of symbols consist of the clean gravel or sand symbols (GW, GP, SW, or SP) followed by the gravel or sand with fines symbols (GC, GM, SC, or SM). The group name should consist of the name of the first set of symbols followed by the words “with clay” or “with silt” to identify the fines.

If the soil has 15% or more fine-grained particles, the soil shall be identified as clayey gravel (GC) or clayey sand (SC), if the fines are clay as determined in the previous section, or silty gravel (GM) or silty sand (SM) if the fines are silty.

For gravels or sands with an estimated 15% or more of other coarse-grained particles, the words “with gravel” or “with sand” should be added. If the sample contains cobbles, boulders, or both the words “with cobbles,” “with boulders,” or “with cobbles and boulders” should be added to the group name.

1-3.2.3 Examples.

Below are a few examples of visual descriptions and identifications (ASTM D2488):

1) Poorly-Graded Gravel with Sand (GW): About 80% medium to coarse, hard, angular gravel; about 20% fine to coarse, hard, subangular sand; trace of fines; maximum size, 70 mm, gray, moist; no reaction with HCl.
2) Silty Sand with Gravel (SM): About 65% predominantly medium to fine sand; about 20% silty fines with low plasticity, low dry strength, low dilatancy, and low toughness, about 15% fine, hard, rounded gravel, a few gravel-size particles fractured with hammer blow; maximum size, 1.5 inch (38 mm); weak reaction with HCl.
3) Organic Soil (OL/OH): About 100% fines with low plasticity, slow dilatancy, low dry strength, and low toughness; wet, black, organic odor; strong reaction with HCl.
4) Well-Graded Gravel with Clay, Sand, Cobbles and Boulders (GW-GC): About 70% medium to coarse, hard, rounded to subangular gravel; about 20% fine, hard, rounded to subangular sand; about 10% clay low plasticity fines; moist, dark grey; no reaction with HCl; original field sample had about 5% (by volume) hard, rounded cobbles and a trace of hard, rounded boulders, with a maximum dimension of 18 inches (450 mm).

1-3.3 Unified Soil Classification System (ASTM D2487).

The unified soil classification system (USCS) is the most common classification system used for soils in the engineering community. This section is based on the USCS as presented in ASTM D2487. This classification system consists of three major soil divisions: coarse-grained soils, fine-grained soils, and highly organic soils, which are further subdivided into 15 soil groups. To use this soil classification system the grain-size distribution (ASTM D6913) of the minus 3-inch (75-mm) material, and the liquid limit and plasticity index (ASTM D4318) of the minus No. 40 (425-μm) sieve material should be known. The various groups used in this classification system have been divided to correlate in a general way with the engineering behavior of soils.

The grain-size distribution is needed for soils with 10% or more coarse-grained particles and it can be estimated for soils with less than 10% coarse-grained particles. The liquid limit and plasticity index are required for soils with 15% or more fines and the plasticity can be estimated for soils with 5% to less than 15% fines as described in Section 1-3.2.2.1. For soils with less than 5% fines, the plasticity is not needed.

1-3.3.1 Classification of Fine-Grained Soils.

Using the liquid limit and plasticity index, classify inorganic soils as lean clay (CL), fat clay (CH), silt (ML), elastic silt (MH), or silty clay (CL-ML) using Figure 1-2. For dark soils with organic odor, two liquid limit tests should be performed on the soil. One test is performed before drying, and a second test is completed after oven drying the soil at 110 ± 5°C. The soil is considered an organic silt or clay if the liquid limit of the oven-dried material is less than 75% of that of the material before oven drying. Classify the organic soil as organic silt or clay OL or OH depending on where the liquid limit and plasticity index of the non-oven-dried material plot in Figure 1-2.

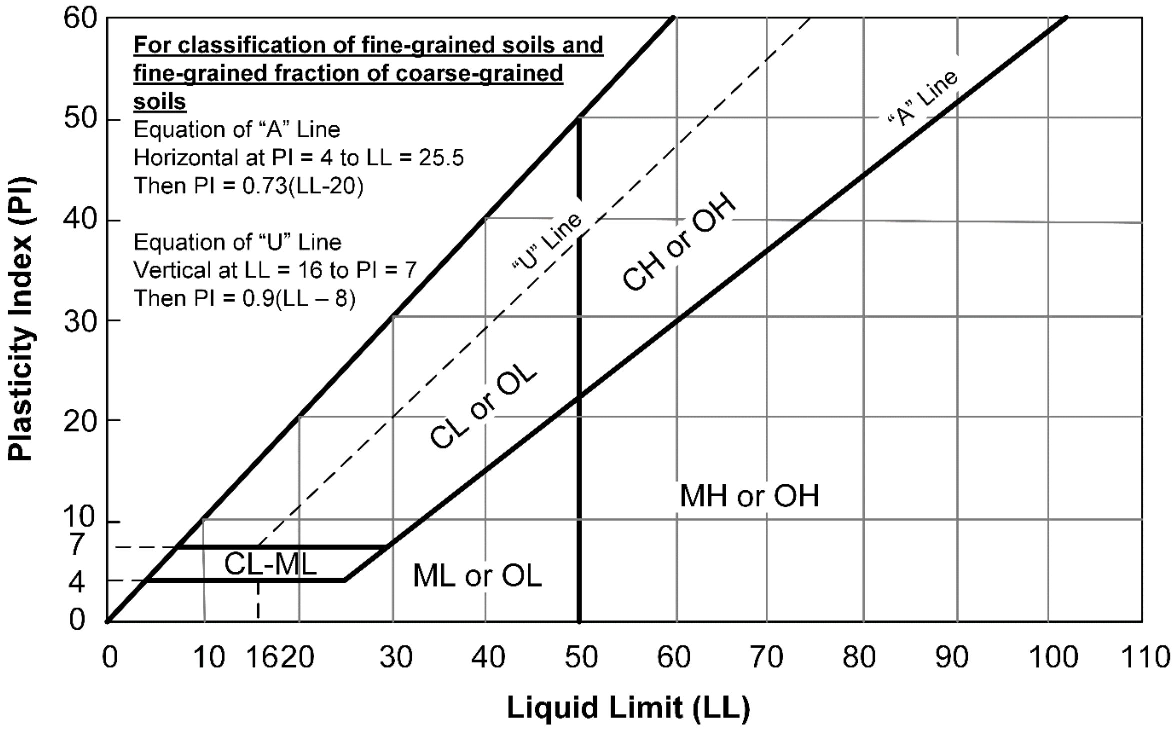


Figure 1-2 Plasticity Chart

If the fine-grained soil contains 30% or more retained in the No. 200 (75 μm) sieve the words "gravelly" or "sandy" should be added to the group name based on the type of particle that is predominant in the coarse-grained portion. For soils with equal percentage of sand and gravel, use “sandy.” If the coarse-grained portion is less than 30% but greater or equal than 15%, the words “with gravel” or “with sand” should be added to the group name depending whichever is predominant. For soils with equal percentage of sand and gravel, use “with sand.”

Some properties of fine-grained soils are usually related to the plasticity characteristics of the soil. Figure 1-3 describes how the liquid limit and plasticity index affect the compressibility, permeability, toughness at the plastic limit, and the dry strength of fine-grained soils.

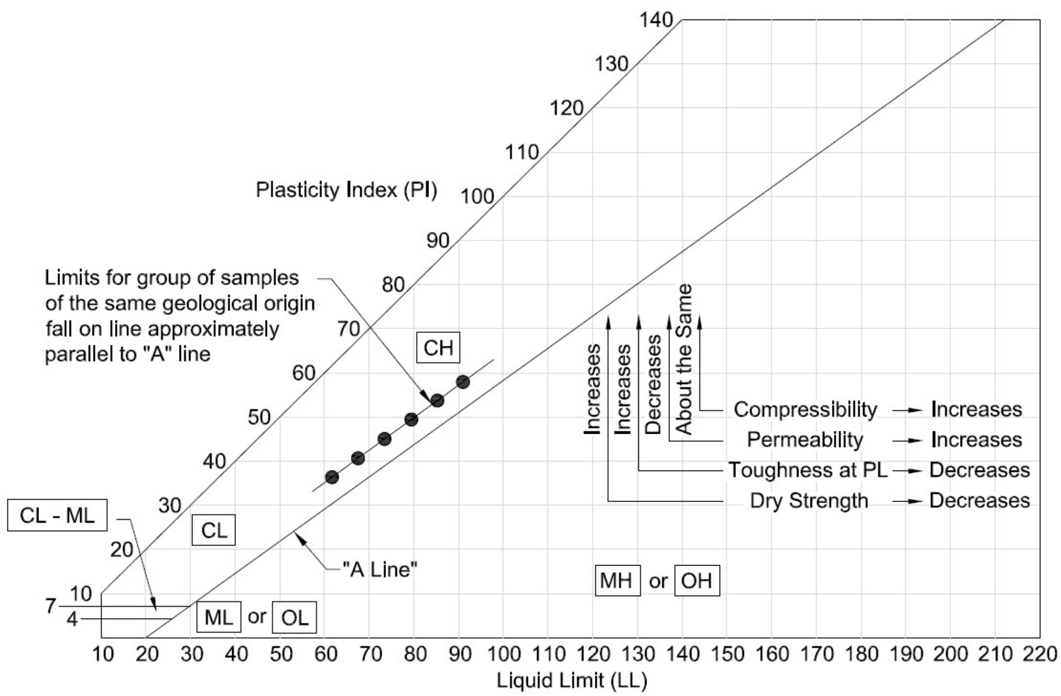


Figure 1-3 Soil Property Variation with Liquid Limit and Plasticity

1-3.3.2 Classification of Coarse-Grained Soils.

Coarse-grained soils that contain more than 50% of the coarse-grained fraction retained on the No. 4 (4.75-mm) sieve should be classified as gravel, and as sand otherwise. Using the information on the grain-size distribution curve, calculate the following to define whether the soil is well-graded or poorly-graded:

$$C_u = \frac{D_{60}}{D_{10}} \quad \textbf{(1-1)}$$

and

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} \quad \textbf{(1-2)}$$

where:
D_{60}, D_{30}, and D_{10} = particle-size diameters corresponding to 60%, 30%, and 10%, respectively, passing on the cumulative particle-size distribution curve,
C_u = coefficient of uniformity, and
C_c = coefficient of curvature.

Coarse-grained soils are classified as well-graded if C_u is greater than or equal to 4.0 for gravels or greater than 6.0 for sands, and C_c is at least 1.0 but not more than 3.0. Otherwise, the soil is poorly-graded.

Coarse-grained soils with less than 5% passing the No.200 (75-µm) sieve are considered *clean* and are classified as well-graded gravel (GW), well-graded sand (SW), poorly-graded gravel (GP), or poorly-graded sand (SP).

For coarse-grained soils with more than 12% fines, the classification of the fines needs to be determined using the plasticity chart presented in Figure 1-2. If insufficient fines are available to run plasticity tests, the classification of the fines shall be completed as described in Section 1-3.2.2.1. Classify the soil as silty gravel or sand (GM or SM, respectively) if the fines are silt or clayey gravel or sand (GC or SC, respectively) if the fines classify as clay. If the fines plot as silty clay (CL-ML) classify the soil as a silty, clayey gravel (GC-GM) or a silty, clayey sand (SC-SM).

Coarse-grained soils with a fine content between 5% and 12% require the use of a dual classification. The first group symbol corresponds to that for a gravel or sand having less than 5% fines (GW, GP, SW, or SP), and the second symbol correspond to a gravel or sand having more than 12% fines (GC, GM, SC, or SM). The group name is formed by the name of the first group symbol following the words “with clay” or “with silt” depending on the characteristics of the fines. If the fines plot as a silty clay, CL-ML, the second group symbol would be either GC or SC and the words “with silty clay” will be used in the name.

If the soil is mainly sand or gravel but contains 15% or more of the other coarse-grained constituent, the words “with gravel” or “with sand” shall be added to the group name. Soils with cobbles and boulders should have the words “with cobbles,” “with boulders,” or “with cobbles and boulders” added to the group name.

1-3.3.3 Examples.

Below are a few examples of visual descriptions and identifications accompanied by the proper USCS classification (ASTM D2487):

1) Well-Graded Gravel with Sand (GW): 71% fine to coarse, hard, angular gravel; 25% fine to coarse, hard, angular sand; 4% fines; C_c = 2.7, C_u = 12.4.
2) Silty Sand with Gravel (SM): 62% predominantly medium sand; 22% silty fines, LL = 32, PI = 6; 16% fine, hard, rounded gravel; no reaction with HCl.
3) Poorly-Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM): 75% medium to coarse, hard, rounded to subangular gravel; 19% fine to medium, hard, rounded to subangular sand; 6% silty (estimated) fines; moist, brown; no reaction with HCl; original field sample had 7% hard, subrounded cobbles and 2% hard, subrounded boulders with a maximum dimension of 18 inches.

1-3.4 Soil Classification for Highways (AASHTO).

The American Association of State Highway and Transportation Officials (AASHTO) developed their soil classification system, which is mainly used for highway design and construction purposes. This system classifies the soils in 12 divisions based on the grain-size distribution, the liquid limit, and the plasticity index, using only the soil particles that pass through a 3-inch sieve. This section is based on the classification system as detailed in ASTM D3282.

An important distinction between this classification system and the USCS is the threshold used between the different types of soils. Coarse-grained or granular materials are considered to be any soil that has 35% or less passing a No. 200 (75 µm) sieve. Gravel is any material passing a 3-inch sieve and retained on a No. 10 (2.00 mm) sieve. Coarse sand is considered any soil that passes a No. 10 (2.00 mm) sieve and is retained on a No. 40 (0.425 mm) sieve. Fine sand is any material passing a No. 40 (0.425 mm) sieve and retained on a No. 200 (75 µm) sieve. Silts and clays are anything passing a No. 200 (75 µm) sieve, silts being materials with plasticity indices of 10 or less and clays being materials with plasticity indices above 10.

Soils are classified using Table 1-5 below from left to right. Highly organic soils (peat or muck) may be classified in Group A-8. Classification of organic soils is based on visual inspection and is not dependent on the percentage passing the 75-µm (No. 200) sieve, liquid limit, or plasticity index. Organic material is composed primarily of partially decayed organic matter, generally has a fibrous texture, a dark brown or black color, and an odor of decay. These organic materials are unsuitable for use in embankments and subgrades. They are highly compressible and have low strength.

The classification obtained with the table above might be modified by adding a group-index value that will be shown in parenthesis after the group symbol. The group index is calculated using the empirical equation shown below:

$$GI = (F - 35)[0.2 + 0.005(LL - 40)] + [0.01(F - 15)(PI - 10)] \quad \textbf{(1-3)}$$

where:

GI = group index,
F = percentage passing a No. 200 (75 μm) sieve (only considering the particles passing a 3-inch sieve),
LL = liquid limit of the soil, and
PI = plasticity index of the soil.

The group index should be reported as zero if calculated to be negative, if the soil is nonplastic, and when the liquid limit cannot be determined. For soils in the A-2-6 and A-2-7 subgroups, the group index should be calculated using the second part of the equation only (the part that contains the PI).

1-3.5 Other Classification Systems.

Different regions in the United States and countries around the world have their own soil classification systems. Below is a list containing the name of the country or region in the United States and the reference to the standard used. This list is not intended to be exhaustive but to show some examples. For the countries who are member of the European Union, all the local standards are superseded by the ISO standards which have the same numbers as European Norms (EN). Each country is allowed to further refine the ISO/EN standards by adding appendices as long as the appendices do not contradict the main standard. Each local standard will have the same number as the ISO standard but will have the country designation at the beginning (e.g. BS for British standards). When working on different projects in different parts of the United States or the world the engineer should investigate the standards and norms that are used in that particular area.

Table 1-4 Other Soil Classification Systems

Country / Region of USA / Agency	Reference / Name
Australia	AS 1726
Canada	Canadian System of Soil Classification
International Organization for Standardization (ISO)	ISO 14688
Occupational Safety and Health Administration (OSHA)	1926 Subpart P App A
New Orleans	USACE New Orleans District Internal Document
USDA	USDA Soil Taxonomy

Table 1-5 AASHTO Soil Classification System

Instructions: Work from left to right checking each column. The classification is the first one that matches all the criteria in the column.

General Classification	Coarse-grained (granular) Materials (35% or less passing No. 200 sieve)							Fine-grained (Silt-Clay) Materials (more than 35% passing No. 200 sieve)					Highly Organic
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7[b]		A-8
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5	A-7-6	
Sieve analysis Percent passing:													
#10 (2 mm)	≤ 50												
#40 (0.4 mm)	≤ 30	≤ 50	≥ 51										
#200 (0.075 mm)	≤ 15	≤ 25	≤ 10	≤ 35	≤ 35	≤ 35	≤ 35	≥ 36	≥ 36	≥ 36	≥ 36	≥ 36	
Characteristics of fraction passing #40													
Liquid Limit				≤ 40	≥ 41	≤ 40	≥ 41	≤ 40	≥ 41	≤ 40	≥ 41	≥ 41	
Plasticity Index	≤ 6	≤ 6	NP[a]	≤ 10	≤ 10	≥ 11	≥ 11	≤ 10	≤ 10	≥ 11	≥ 11	≥ 11	
Usual types of significant constituent materials	Stone fragments; gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils			Peat or muck
General rating as subgrade	Excellent to good							Fair to poor					Unsuitable

Notes:

[a]NP indicates that the soil is "non-plastic." NP soils have $LL = PL$, $LL < PL$, or PL that cannot be determined.

[b]Use the following criteria to divide A-7: A-7-5 has $PI \leq (LL - 30)$ and A-7-6 has $PI > (LL - 30)$.

Group Index, GI

$$GI = (F-35)\left[0.2+0.005(LL-40)\right]+0.01(F-15)(PI-10)$$

Calculate the group index as:
where: F= %fines = P#200, LL = liquid limit, and PI = plasticity index.

If a negative value is calculated for GI, then report GI = 0.
Note: Use only the second term in the GI equation for A-2-6 and A-2-7 soils.

1-3.6 Common Soil and Rock Names.

In practice, some areas have specific names for different types of soils. Some of these names can be considered colloquialisms within the geotechnical engineering community. Below is a list with definitions of the most common soil names used in practice.

Adobe: Refers to sandy clays and silts of medium plasticity usually found in the semiarid regions of the southwestern United States. These soils were commonly used to make sun-dried bricks. The name is also applied to some high plasticity clays with high clay content and high swell and shrink potential usually found in the western part of the United States.

Baby poop: Refers to a very soft clay located just above limestone in karst. Frequently orange and formed by dissolution.

Back-packing: Refers to any material (commonly granular) that is used to fill the empty space between the lagging of a wall system and the rock surface.

Bank-run sand and gravel: Refers to the raw material excavated from a borrow pit, but not sorted or separated into specific grades.

Beachrock: See reefrock.

Bentonite: Refers to a high plasticity clay consisting of mostly montmorillonite, resulting from the weathering of volcanic ash mainly in the presence of water. It is normally hard when dry but swells considerably when wet. This clay is commonly used with water as drilling mud and as liner in landfills.

Black cotton soil: Refers to a black expansive soil commonly encountered in India. The name comes because this soil is common in areas where the main crop is cotton.

Blow sand: Term normally used for wind-driven or drifted sands.

Blue Marl: Name given to a bluish-green clay from the Miocene that can be found along the fall line from Richmond into Maryland. This soil is considered to be acidic, usually with a pH less than 4.0, which can affect water quality and prevent plant or aquatic life.

Bog: Refers to a wetland covered with peat with a high water table that accumulates dead plants, such as sphagnum. It is generally nutrient poor and acidic.

Boney ground: Ground containing significant amounts of large gravel, cobbles and boulders.

Boulder clay: Geological term used to designate clays formed from glacial drift that have not been subjected to the sorting action of water and therefore contains particles from boulders to clay sizes. Boulder clays are also called tills.

Breaker run: Crushed rock with large particles refers to large broken stone obtained as part of quarrying or mining activities.

Buckshot: Term applied to clays of the southern and southwestern United States that cracks into small, hard, relatively uniform-sized lumps on drying. The lumps are usually the size of buckshot and the soil is very sticky when wet.

Bull's liver: Name given to an inorganic silt or silty sand usually encountered in the New York City area. The name Bull's liver comes from its red color and jelly-like behavior when it is subjected to vibration.

Bull's Tallow or Bull Tallow clay: Refers to a tan or gray high plasticity clay typically found in relatively thin layers directly above partially weathered rock or rock in the Charlotte, NC area. This clay normally has high shrink and swelling potential.

Caliche: Refers to a sedimentary rock from arid and semiarid climate in which soil particles, such as gravel, sand, clay, and silt, are cemented and coated by carbonate (often calcium or magnesium carbonate). The level of cementation varies significantly within a deposit. The soil has light coloration often exhibits light colored concretions of various sizes depending on the level of development of the soil profile. The consistency of caliche varies from soft rock to firm soil.

Chip: Name given to crushed angular rock fragments smaller than a few centimeters.

Coffee grounds: Soil formed from freshwater marshes that has been dry for decades and has decomposed to the point that is black and inert with no plasticity. It is black and granular even when wet.

Colluvium: Loose soil deposited at the bottom of a slope.

Coquina: Soft, porous sedimentary rock, mainly limestone, composed largely of shells, coral, and fossils cemented together with particles averaging 0.079 inch (2 mm) or greater in size.

Desert varnish: Also called patina, rock varnish or rock rust. Consists of a thin, dark red to black mineral coating found on pebbles and rocks surfaces in arid regions.

Diatomaceous earth: Soft, siliceous sedimentary rock that usually crumbles into powder. When crumbled, the particles are silty and contain large amounts of diatoms, the siliceous skeletons of minute marine or freshwater organisms.

Dispersive clays: These clays contain a high percentage of dissolved sodium in the pore water. When these soils are exposed to water, the clay particles deflocculate (i.e., separate) making these soils very susceptible to erosion.

Fibric peat: Peat in which the original plant fibers are slightly decomposed and contain 67% or more of fibers.

Fill: Any man-made soil deposit. It can range from soils that are free of organic matter and that are carefully compacted to heterogeneous accumulations of rubbish and debris.

Fuller's earths: Soils having the ability to absorb fats or dyes. These soils have the capability to decolorize oil or other liquids without chemical treatment. They are usually high plasticity sedimentary clays.

Glacial till: See boulder clay.

Glassified sand: Term used to name the ground surface after a big forest fire.

Goonies: Name given to the cobbles found floating in a soil matrix.

Grove sand: See sugar sand.

Gumbo: Refers to a fine-grained, high plasticity clay of the Mississippi Valley according to Sowers (1979). It has a sticky, greasy feel and forms large shrinkage cracks on drying.

Gyp or gip soil: Refers to gypsum soil (or soil containing gypsum) or caliche soil.

Hardpan: Normally refers to a soil layers that has become hard as rock due to cementing minerals, does not become plastic when mixed with water and is relatively impervious. The name has also been applied to any hard or overconsolidated layer that is hard to excavate. Because of this ambiguity, Sower (1979) recommends that engineers should avoid this term because many lawsuits have centered about the meaning of it. The name implies a condition of the soil rather than a type of soil.

Humus: Refers to a brown or black material formed by the partial decomposition of vegetable or animal matter. It is the organic portion of soil.

Kaolin: Refers to a white or pink clay of low plasticity. It is composed largely of minerals of the kaolinite family.

Laterites: Refers to residual soils rich in iron formed in hot and humid climates (tropical regions). The cementing action of iron oxides and hydrated aluminum oxides makes dry laterites extremely hard. The high iron oxide content makes nearly all laterites to be rusty-red. These are usually developed after significant weathering of the parent rock.

Ledge: Name used for bedrock in Vermont, and sometimes in New Hampshire.

Loam: Refers to a low plasticity sandy silt or silty sand mixed with organic matter that is well suited to tilling. Mainly applies to the uppermost soil layer and should not be used to describe deep deposits of parent materials. Major soil type in the USDA system.

Marl: Refers to a calcium carbonate or lime-rich sedimentary rock. It is mainly composed of a mixture of sand, silt, or clay. Marls are often light to dark gray or greenish in color and sometimes contain colloidal organic matter.

Montmorillonite: A group of very fine clay minerals with extreme swelling and shrinking properties. Normally results from volcanic or hydrothermal activities. Bentonite is a form of montmorillonite.

Muskeg: Refers to peat found in North America. According to Sowers (1979) the bogs in which the peat forms are often termed muskegs.

Peat: Refers to a fibrous, partially decomposed and highly compressible organic soil. Peats are dark brown or black.

Pit-run sand and gravel: See bank run.

Pluff mud: Refers to an odoriferous and very soft mud usually encountered in South Carolina.

Recycled concrete aggregate (RCA): Recycled road or structural concrete. The concrete is usually processed and screened. The processing consists of crushing the concrete into smaller pieces. Any leftover steel is removed using a magnet. This type of material is very popular as a replacement for natural stone aggregates.

Recycled or reclaimed asphalt pavement (RAP): Term used to describe the removed asphalt layer. When properly processed, it consists of high-quality and well-graded aggregates coated by asphalt cement.

Recycled or reclaimed asphalt shingles (RAS): Recycled shingles that are used as aggregate for hot mix asphalt. Depending on the quality, this can reduce the cost of the new asphalt mix and the amount of fine aggregate used in the mix.

Recycled pavement material (RPM): Pulverized mixture of asphalt and base course material usually forming a broadly-graded material.

Reefrock: Cemented coralline deposits.

Riprap: Boulder-size material normally placed to strengthen structures against scour, wave action, and ice erosion.

Riverjack: Name usually given to alluvial cobbles and boulders.

Rock dirt combination (RDC): Local term used in the Harrisonburg, VA area to describe material from a quarry consisting of a mixture of overburden soil and rock.

Rock flour: Fine-grained soil with silt-sized particles formed by the grinding of bedrock by glaciers.

Shale: Refers to a fine-grained sedimentary rock made of silt and clay particles. This rock usually breaks along thin laminates and can slake when subjected to wet-dry cycles.

Shot rock: Refers to the material from a rock quarry that has not been sorted. It includes everything that can be picked up (from fine sand to small boulders) after a quarry blast. It is also a name given to riprap, although riprap is typically sorted and graded.

Slickensided clay: Name given to a clay that has experienced repeated or enough displacement along a fissure or a failure plane causing the surface to be smooth and shiny.

Stone: Gravel size-particles manufactured by crushing rock.

Sugar sand: Local name for a type of fine sandy soil found in New Jersey. In Kansas, the term refers to a type of granular calcite found in Ness and Hodgeman counties. In addition, the term may refer to a fine sand usually found in Florida that does not hold water or nutrients very well. It is normally windblown medium and/or fine sand, poorly-graded, nonplastic. It often contains nonplastic silt.

Till: See boulder clay.

Tire derived aggregate (TDA): Refers to a lightweight construction material obtained by shredding or chipping scrap tires. The particle size usually ranges from 0.5 inches to 12 inches. TDA has been used in a wide range of projects, including lightweight embankment fill, landslide repair or stabilization, landfills, retaining wall backfill, roads, vibration mitigation, among others.

Topsoil: Upper and outermost layer of soil that support plant life. Usually contains considerable organic matter.

Trap: Includes any dark-colored, fine-grained, non-granitic intrusive rock. The most common trap rock is basalt, but also includes peridotite, diabase, and gabbro.

Tuff: Refers to a soft porous rock made from consolidated volcanic ash.

Varved clays: Sedimentary deposits consisting of alternate thin layers of silt and clay. According to Sowers (1979), each pair of silt and clay layers is from 1/8 inch to 1/2 inch thick. These soils result from deposition in lakes during periods of alternately high and low water in the in flowing streams and are often formed in glacial lakes.

1-4 ROCK VISUAL DESCRIPTION, AND CLASSIFICATION.

1-4.1 Definitions.

Azimuth: Angle of a feature measured from North at 0° in a spherical coordinate system.

Bedding: Planes of dissimilar materials caused by deposition normally encountered in sedimentary rocks.

Dip: Angle that the surface of the rock forms with a horizontal plane.

Flow banding: Refers to the layering that is normally seen in rocks formed from magma.

Foliation: Refers to the laminated structure of the minerals in a rock created by the deformation.

Igneous rocks: Rocks formed from the cooling and solidification of magma.

Lamination: Sequence of fine layers in a small scale (usually less than one centimeter in thickness) normally observed in sedimentary rocks.

Metamorphic rocks: Rocks formed from the transformation by heat, pressure, or both of existing rocks. This transformation can alter the physical and chemical properties of the rock.

Rock: Natural solid mineral or aggregate of minerals which is normally classified by the way it was formed.

Rock mass: A large body containing rock in intact and weathered conditions accompanied by structural discontinuities like fault, joints, etc., which can be interbedded with soil material.

Sedimentary rocks: Rocks formed by the accumulation and cementation of smaller particles.

Strike: Is the line representing the intersection of the rock surface with a horizontal plane.

1-4.2 Visual Classification.

Rock samples and exposures can be visually classified by weathering, discontinuities, color and grain size, hardness, and geological origin.

1-4.2.1 Geological Name and Origin.

The first step in visually classifying a rock is to identify the type of rock (e.g., igneous, metamorphic, or sedimentary). Then, the geologic name and local name (if any) is identified based on characteristics, such as texture and mineralogy. Igneous rocks are normally classified by their mineralogical composition, texture, and color as can be seen in Table 1-6.

Metamorphic rocks are normally classified by their texture and structure, as can be seen in Table 1-7. Sedimentary rocks are normally classified by whether they are derived from clastic sediments or chemical precipitates/organisms, as can be seen in Table 1-8. Subordinate constituents in rock samples, such as seams or bands of other type of minerals, should also be identified (e.g., dolomitic limestone, calcareous sandstone, sandy limestone, mica schist).

Table 1-6 Simplified Rock Classification - Common Igneous Rocks

Color		Light		Intermediate	Dark	
Principal Mineral		Quartz and Feldspar Few other minerals	Feldspar	Feldspar and Hornblende	Augite and Feldspar	Augite, Hornblende, Olivine
Texture	Coarse, Irregular Crystalline	Pegmatite	Syenite Pegmatite	Diorite Pegmatite	Gabbro Pegmatite	
	Coarse and Medium Crystalline	Granite	Syenite	Diorite Dolerite	Gabbro Dolerite	Peridotite Dolerite
	Fine Crystalline	Aplite			Diabase	
	Aphanitic	Felsite			Basalt	
	Glassy	Volcanic Glass			Obsidian	
	Porous (Gas Openings)	Pumice		Scoria or vesicular basalt		
	Fragmental	Tuff (fine), Breccia (coarse), cinders (variable)				

Table 1-7 Simplified Rock Classification - Common Metamorphic Rocks

Texture	Structure		
	Foliated		Massive
Coarse Crystalline	Gneiss		Metaquartzite
Medium Crystalline	Schist	Sericite	Marble
		Mica	Quartzite
		Talc	Serpentine
		Chlorite	Soapstone
Fine to Microscopic	Phyllite		Hornfels
	Slate		Anthracite Coal

Table 1-8 Simplified Rock Classification – Common Sedimentary Rocks

Group	Grain Size	Composition		Name
Clastic	Mostly coarse grains	Rounded pebbles in medium-grained matrix		Conglomerate
		Angular coarse-grained fragments, often quite variable		Breccia
	More than 50% medium grains	Medium coarse grains	Less than 10% of other minerals	Siliceous sandstone
			Appreciable quantity of clay minerals	Argillaceous sandstone
			Appreciable quantity of calcite	Calcareous sandstone
			Over 25% feldspar	Arkose
			25%-50% feldspar and darker minerals	Graywacke
	More than 50% fine grains	Fine to very fine quartz grains with clay minerals		Siltstone (if laminated, Shale)
		Microscopic clay minerals	<10% other minerals	Shale
			Appreciable calcite	Calcareous Shale
			Appreciable carbon / carbonaceous material	Carbonaceous Shale
			Appreciable iron oxide cement	Ferruginous Shale
Organic	Variable	Calcite and fossils		Fossiliferous Limestone
	Medium to microscopic	Calcite and appreciable dolomite		Dolomite Limestone or Dolomite
	Variable	Carbonaceous material		Bituminous coal
Chemical	Microscopic	Calcite		Limestone
		Dolomite		Dolomite
		Quartz		Chert, Flint, etc.
		Iron compounds with Quartz		Iron Formation
		Halite		Rock Salt
		Gypsum		Rock Gypsum

1-4.2.2 Color and Grain Size.

Rock can be described with respect to basic colors on a rock color chart. The most common chart used for this purpose in the United States is the Munsell rock color chart which includes 115 color chips and works with both wet and dry specimens. Another commonly used system is the one published by the Geological Society of London (1977). This system is based on three descriptors as can be seen in Table 1-9.

Grain size for rock refers to the sizes of the small grains that comprise the rock. Because of the nature of some rocks, a 10X hand lens can be used, if necessary, to examine rock sample. Various grain-size criteria have been established, and no single criteria is standard or used most often. An example of grain-size descriptors for different types of rock are found in Table 1-10. Another criterion presented by FHWA (2017) is also included here in Table 1-11 which is similar to that presented by the Geological Society of London (1977).

Table 1-9 Rock Color Descriptors (Geological Society of London 1977)

1st Descriptor	2nd Descriptor	3rd Descriptor
Light Dark	Yellowish Buff Orangish Brownish Pinkish Purplish Orange Olive Greenish Greyish	White Yellow Buff Orange Brown Pink Red Blue Green Purple Olive Grey Black

Table 1-10 Grain-Size Descriptors for Rock

Igneous and Metamorphic		Sedimentary Rocks	
Description	**Grain Diameter**	**Description**	**Grain Diameter**
Coarse-grained	> 5 mm	Coarse-grained	> 2 mm
Medium-grained	1 to 5 mm	Medium-grained	0.06 to 2 mm
Fine-grained	< 1 mm	Fine-grained	0.002 to 0.06 mm
Aphantic	Too small to be perceived by eye	Very fine-grained	< 0.002 mm
Glassy	No grain form distinguishable		

Table 1-11 Criteria for Defining Rock Grain Size (after FHWA 2017)

Grain Size	Description	Criteria
< 0.003 in. (< 0.075 mm)	Very Fine-Grained	Cannot be distinguished by unaided eye. Few to no mineral grains are visible with a hand lens.
0.003 – 0.02 in. (0.075 – 0.425 mm)	Fine-Grained	Few crystal boundaries are visible; grains can be distinguished with difficulty by the unaided eye but can be somewhat distinguished by hand lens.
0.02 – 0.8 in. (0.425 – 2 mm)	Medium-Grained	Most crystal boundaries are visible; grains distinguishable by eye and with hand lens.
0.8 – 2 in. (2 – 4.75 mm)	Coarse-Grained	Crystal boundaries are visible; grains distinguishable with naked eye.
2 in. (> 4.75 mm)	Very Coarse-Grained	Crystal boundaries are clearly visible; grains are distinguishable with the naked eye.

1-4.2.3 Weathering.

Weathering is the mechanical or chemical deterioration of rock properties by the exposure to water, temperature changes, among other factors. Rock can be described as fresh, slightly weathered, etc. in accordance with Table 1-12 as indicated by the International Society of Rock Mechanics (ISRM). As the degree of weathering increases, usually the strength, stiffness, and quality of the rock decrease.

Table 1-12 Weathering Classification

Grade	Symbol	Weathering Grade[1]	Diagnostic Features
Fresh	F	I	No visible sign of decomposition or discoloration; rings under hammer impact
Slightly Weathered	WS	II	Slight discoloration inwards from open fractures, otherwise similar to F
Moderately Weathered	WM	III	Discoloration throughout; weaker minerals such as feldspar decomposed; strength somewhat less than fresh rock but cores cannot be broken by hand or scraped by knife; texture preserved
Highly Weathered	WH	IV	Most minerals somewhat decomposed; specimens can be broken by hand with effort or shaved with knife; core stones present in rock mass; texture becoming indistinct but fabric preserved
Completely Weathered	WC	V	Minerals decomposed to soil but fabric and structure preserved (saprolite); specimens easily crumbled or penetrated
Residual Soil	RS	V	Advanced state of decomposition resulting in plastic soils; rock fabric and structure completely destroyed; large volume change.

[1] After FHWA (2017).

1-4.2.4 Discontinuities.

The spacing of discontinuities in the rock can be described as close, wide, etc., in accordance with Table 1-13. The structural features of a rock mass can be described as thickly bedded or thinly bedded, in accordance with Table 1-13. Depending on project requirements, the form of joint should be identified as stepped, smooth, undulating, planar, etc. In addition, the dip (in degrees), surface condition (rough, smooth, slickensided), opening size (giving width), and filling (none, sand, clay, breccia, etc.) should also be recorded.

1-4.2.5 Hardness.

The hardness of rock can be estimated by field tests using a geologic hammer or knife and, in the laboratory, using the point load test in accordance with Table 1-14. The corresponding range of strength values for intact rock is also provided. A more recent grading system presented by the ISRM is presented in Table 1-15.

Table 1-13 Discontinuity Spacing

Type of Feature	Description	Spacing	Description for Joints, Faults, or Other Fractures
Macrostructural: Bedding, Foliation, or Flow Banding	Very thickly (bedded, foliated, or banded)	> 6 feet	Very widely (fractured or jointed)
	Thickly	2 to 6 feet	Widely
	Medium	8 to 24 inches	Medium
	Thinly	2.5 to 8 inches	Closely
	Very Thinly	0.75 to 2.5 inches	Very Closely
Microstructural: Lamination, Foliation, or Cleavage	Intensely (laminated, foliated, or cleavage)	0.25 to 0.75 inch	Extremely close
	Very Intensely	< 0.25 inch	

Table 1-14 Hardness Classification of Intact Rock (Hough 1969)

Class	Hardness	Field Test	Approximate compressive strength (kg/cm^2 or tsf)
I	Extremely hard	Many blows with geologic hammer required to break intact specimen	>2000
II	Very hard	Handheld specimen breaks with hammer end of pick under more than one blow	1000 - 2000
III	Hard	Cannot be scraped or peeled with knife, hand held specimen can be broken with a single moderate blow with pick	500 - 1000
IV	Soft	Can just be scraped or peeled with knife. Indentations of 1 mm to 3 mm show in specimen with moderate blow with pick	250 - 500
V	Very soft	Material crumbles under moderate blow with sharp end of pick and can be peeled with a knife, but is too hard to hand trim for triaxial test specimen	10 – 250

Table 1-15 Criteria and Descriptions for Relative Rock Strength (after FHWA 2017)

Grade	Description	Field Identification	Approximate Compressive Strength (kg/cm^2 or tsf)
R0	Extremely Weak Rock	Specimen can be indented by thumbnail	2.5 – 10.8
R1	Very Weak Rock	Specimen crumbles under sharp blow with point of geological hammer and can be peeled with a pocket knife	10.8 – 52.2
R2	Weak Rock	Shallow cuts or scrapes can be made in a specimen with a pocket knife; a firm blow with a geological hammer creates shallow indents	52.2 – 252
R3	Medium Strong Rock	Specimen cannot be scraped or cut with a pocket knife; specimen can be fractured with a single firm blow with a geological hammer point	252 – 522
R4	Strong Rock	Specimen requires more than one firm blow of the point of a geological hammer to fracture	522 – 1,044
R5	Very Strong Rock	Specimen requires many firm blows from the hammer end of a geological hammer to fracture	1,044 – 2,610
R6	Extremely Strong Rock	Specimen can only be chipped with firm blows from the hammer end of a geological hammer	> 2,610

1-4.3 Classification by Field and Laboratory Measurements.

1-4.3.1 Rock Quality Designation.

The Rock Quality Designation (RQD) is only for NX size core samples and is computed by summing the lengths of all pieces of core equal to or longer than 4 inches and dividing by the total length of the coring run. The resultant is multiplied by 100 to get RQD in percent. It is necessary to distinguish between natural fractures and those caused by the drilling or recovery operations. The fresh, irregular breaks should be ignored and the pieces counted as intact lengths. Depending on the engineering requirements of the project, breaks induced along highly anisotropic planes, such as foliation or bedding, may be counted as natural fractures. A qualitative relationship between RQD, velocity index, and rock mass quality is presented in Table 1-16. The velocity index is defined as the square of the ratio of the *in situ* to laboratory or intact compressional wave velocities.

Table 1-16 Engineering Classification for *In situ* Rock Quality (Merritt and Coon 1970)

RQD	Velocity Index	Rock Mass Quality
90-100	0.80-1.00	Excellent
75-90	0.60-0.80	Good
50-75	0.40-0.60	Fair
25-50	0.20-0.40	Poor
0-25	0.00-0.20	Very Poor

1-4.3.2 Classification by Strength.

The uniaxial compressive strength and modulus ratio can be used to classify rock using the results of ASTM D7012. The strength of intact sample can be used with Figure 1-4 to assign a classification as weak, strong, etc.

The point load strength can also be used to classify rock as indicated in Figure 1-4. Point load strength tests, described in ASTM D5731, are sometimes performed in the field for larger projects where rippability and rock strength are critical design factors. This simple field test can be performed on core samples and irregular rock specimens. The point load strength index, $I_{s(50)}$, is defined as:

$$I_{s(50)} = F \cdot \frac{P}{d^2} \quad \textbf{(1-4)}$$

$$F = \sqrt{\frac{D_e}{50}} \quad \textbf{(1-5)}$$

where:
F = size correction factor,
P = the applied force at failure,
d = the distance between the loaded points, and
D_e = equivalent core diameter.

This index is related to the direct tensile strength of the rock by a proportionality constant F depending on the size of sample. Useful relationships of point load tensile strength index to other parameters such as specific gravity, seismic velocity, elastic modulus, and compressive strength are readily available in the literature.

1-4.3.3 Classification by Durability.

Short-term weathering of rocks, particularly shales, and mudstones, can have a considerable effect on their engineering performance. The weatherability of these materials is extremely variable, and rocks that are likely to degrade on exposure should be further characterized by use of tests for durability under standard drying and wetting cycles. The slake durability test is a standardized procedure, described in ASTM D4644, used for this purpose. For example, if wetting and drying cycles reduces the grain size of shale, then rapid slaking and erosion in the field is probable when the rock is exposed. Another method used for this purpose is the jar slake test described by Santi (1998).

1-4.4 Rock Mass Classification Systems.

Various classification systems have been developed for classifying rock mass for engineering projects. Three of the main systems are described in this section. The reader is encouraged to check for the classification system used in the region of practice and that most applies to the project in question.

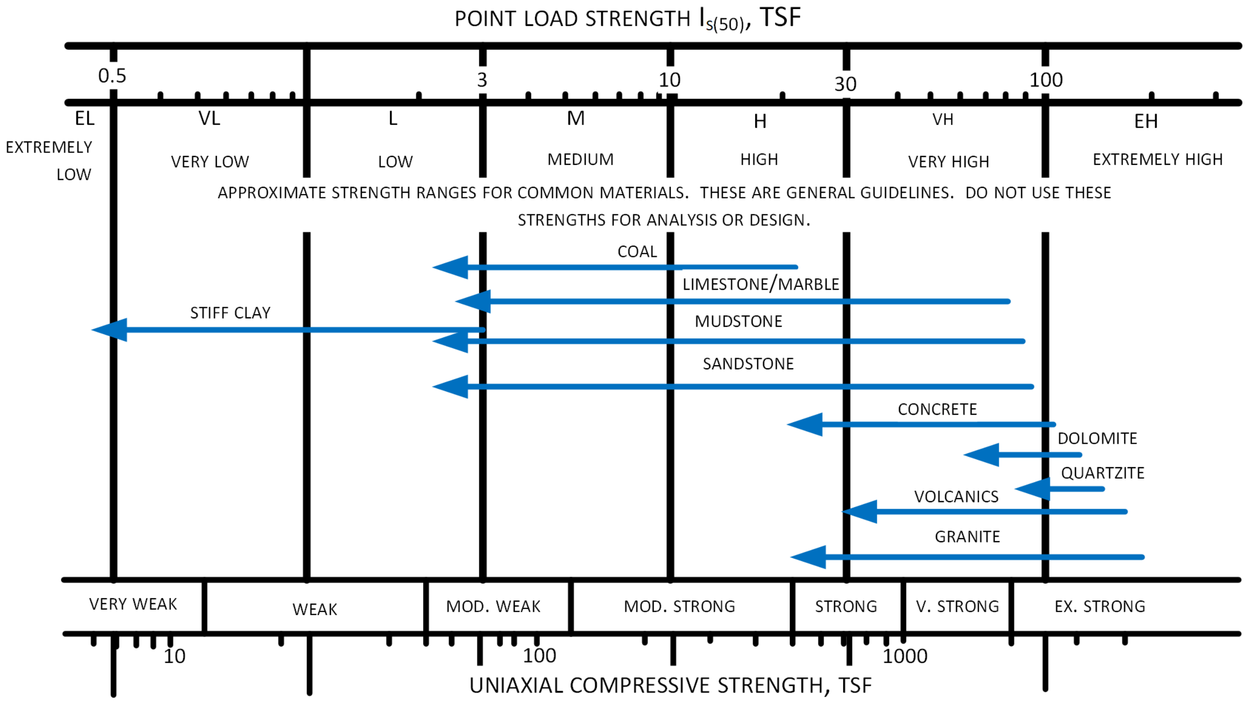


Figure 1-4 Rock Strength Characterization (after Broch and Franklin 1972)

The classification of the rock mass using some of these systems is useful to estimate physical and engineering properties using published values and charts. Also, some design methodologies rely on the classification of the rock mass.

1-4.4.1 *Q* System.

Barton et al. (1974) defines the value of *Q* in terms of *RQD*, the number of joint sets, the joint properties, and a stress reduction factor. Extensive tables are provided to guide the engineer in the selection of appropriate values. The roof pressure and support requirements for tunnels can be estimated from the value of *Q*, as well as some of the joint properties.

1-4.4.2 Rock Mass Rating System.

The rock mass rating system (*RMR*), also known as the Geomechanics classification, by Bieniawski (1973) classifies rock based on the uniaxial compressive strength, *RQD*, the spacing and properties of the joints, and groundwater conditions. While not solely intended for tunneling applications, the *RMR* can be related to stand-up time, unsupported active span length, and roof pressure.

1-4.4.3 Geological Strength Index.

The Geological Strength Index (*GSI*) has become a commonly used approach to describe rock mass quality in a qualitative manner (Marinos et al. 2007). Because it is closely linked to rock strength, *GSI* is most useful as a tool to help estimate rock properties for stability analysis. The *GSI* can be quantified as indicated in Figure 1-5; however, a range of values should always be used. Such values of *GSI* may be used as input for empirical equations for the shear strength of a rock mass.

The *GSI* is most useful for rock masses with many discontinuities that cannot be effectively modeled in direct fashion. According to Marinos et al. (2007), *GSI* should not be used for (1) rocks with clear discontinuities and well-defined dominant structure, (2) excavated faces in strong, hard rock with discontinuities spaced at similar dimensions to the tunnel or slope, or (3) low strength "young" rocks such as marls, claystones, siltstones, and weak sandstones. Marinos et al. (2007) developed a modified *GSI* system for heterogeneous rocks, such as layered shales and sandstones, as shown in Figure 1-6. The application of *GSI* to these rocks should account for their tendency to behave differently at depth compared to near the ground surface.

1-4.4.4 Other Classification Systems.

Some other classification systems have been proposed depending on the region, purpose, and needs. Some of these systems are summarized in Table 1-17.

Table 1-17 Other Rock Classification Systems

Rock Mass Classification System	**Main Uses**	**Reference**
Rock Structure Rating	Tunnel support and excavation and other ground support work in mining and construction	Skinner (1988)
Unified Rock Classification	Foundations, methods of excavation, slope stability, uses of earth materials, blasting characteristics of earth materials, and transmission of groundwater	Williamson and Kuhn (1988)
Rock Material Field Classification	Shallow excavation, particularly with regard to hydraulic erodibility in earth spillways, excavatability, construction quality of rock, fluid transmission, and rock-mass stability	NRCS (2002)
New Austrian Tunneling Method	Conventional (cyclical, such as drill and-blast) and continuous (tunnel-boring machine or TBM) tunneling; this is a tunneling procedure in which design is extended into the construction phase by continued monitoring of rock displacement; support requirements are revised to achieve stability	Lauffer (1997)
Coal Mine Roof Rating	bedded coal-measure rocks, in particular with regard to their structural competence as influenced by discontinuities in the rock mass	Molinda and Mark (1994)

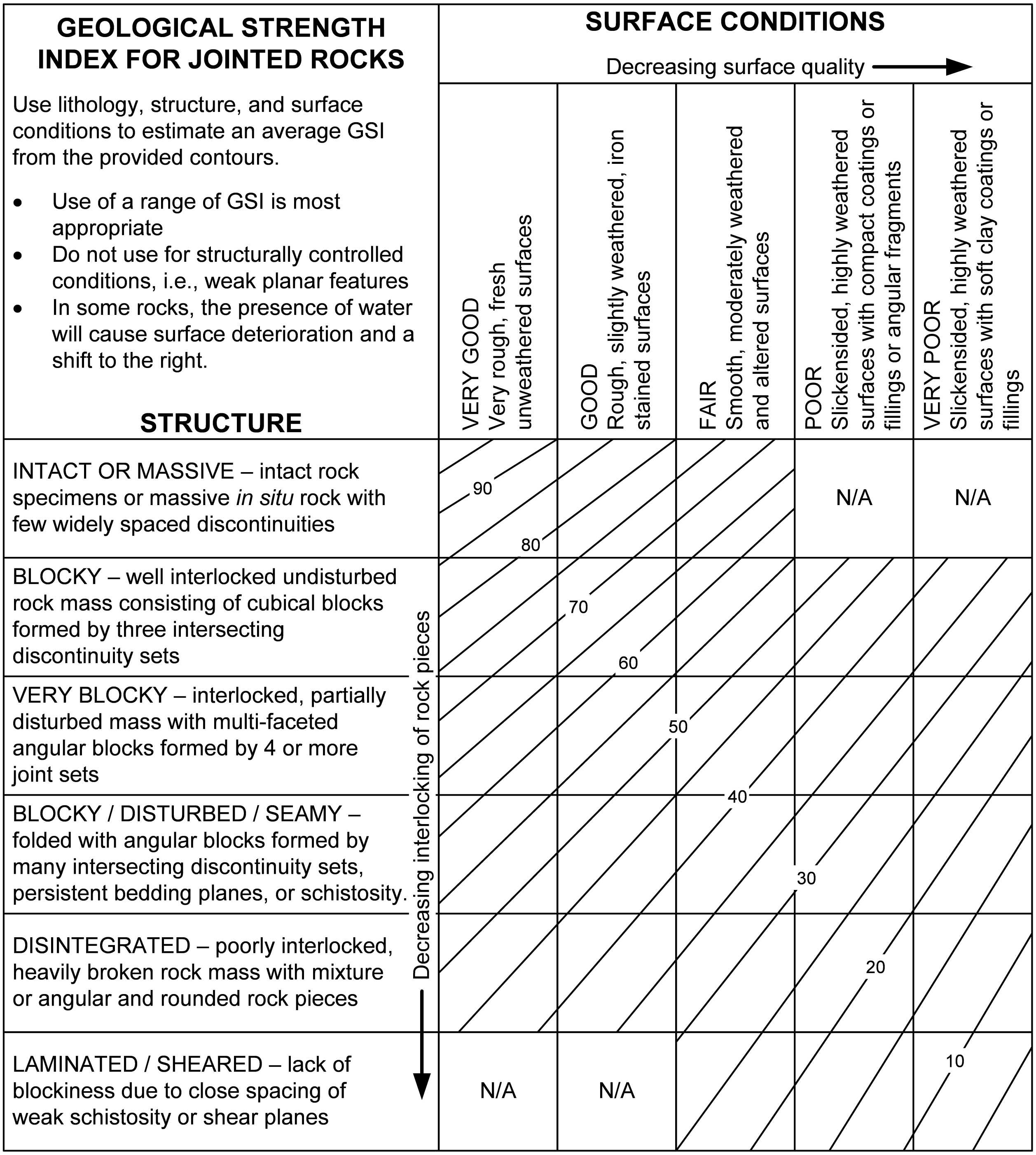
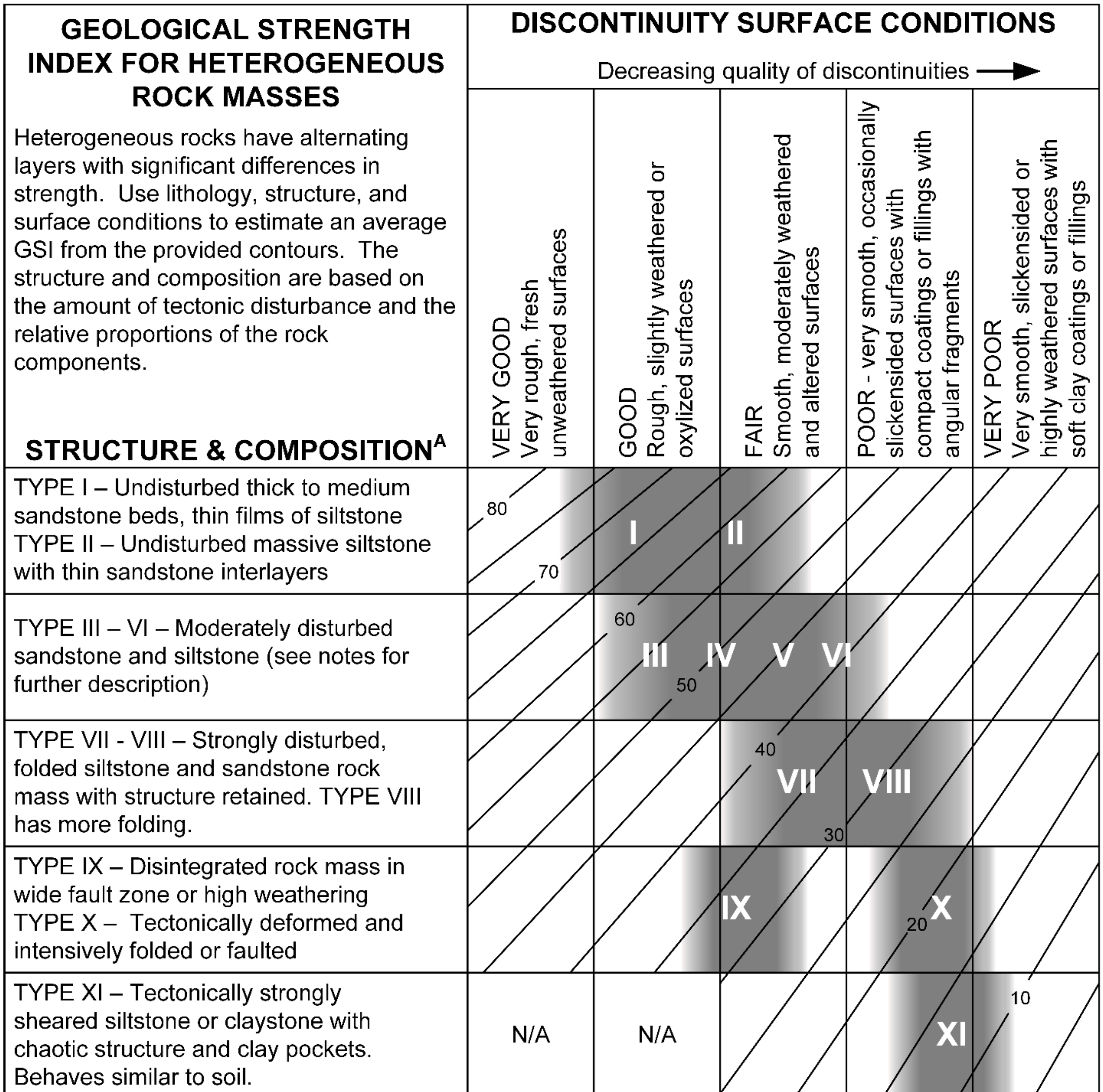


Figure 1-5 *GSI* Selection Chart for Jointed Rock (after Marinos et al. 2007)



NOTES:
[A] See Marinos et al. (2007) for more details on distinguishing Type I to XI rocks
TYPE III – Sandstone with this films or interlayers of siltstone
TYPE IV – Sandstone and siltstone in similar amounts
TYPE V – Siltstone with sandstone interlayers
TYPE VI – Siltstone with sparse sandstone interlayers

Figure 1-6 *GSI* Selection Chart for Heterogeneous Rock (after Marinos et al. 2007)

1-5 SPECIAL MATERIALS.

1-5.1 Expansive Soils.

1-5.1.1 Characteristics.

Expansive soils are distinguished by their potential for excessive volume increase upon access to moisture. The swelling potential and the magnitude of the swelling pressure are controlled by the clay minerals contained in the soil, the structure and fabric of the soil, overburden pressure, and other physical-chemical aspects of the soil (Holtz et al. 2011). These soils usually contain montmorillonite and vermiculite clay minerals. Expansive soils are characterized by a very high dry strength and high plasticity, are often shiny when cut with a knife, and are very weak when wet (Holtz et al. 2011). These soils usually form deep cracks during the dry season and expand closing the gaps creating a homogenous appearance during the wet season.

Even though expansive soils can be encountered at great depth, they are mainly a problem at shallow depths were the effect of variations in water content is greater (FHWA 2017). The zone affected by seasonal variation in water content is also called the *active zone* for expansive soils. This is very important when designing foundations, roads, etc.

According to Holtz et al. (2011) expansive soils can be found around the world. In the United States, the regions with the greatest occurrence of highly expansive soils are North and South Dakota, Montana, eastern Wyoming, eastern Colorado, the Four Corners Region, California, and east Texas. Figure 1-7 illustrates the distribution of expansive soils throughout the United States.

1-5.1.2 Identification and Classification.

Expansive soils can be identified in various ways, and their swelling potential can be nominally predicted. Expansive soils can sometimes be identified during visits to a project site by looking for cracks in nearby structures or desiccation cracks in the soil surface. Another method is identifying the clay minerals in the soil. If the soil has highly expansive clay minerals (e.g. montmorillonite), that is a good indication that the soil could be expansive. Some of the methods that can be used to identify clay minerals are x-ray diffraction, differential thermal analyses, cation exchange capacity, and electron microscopy.

Soil plasticity is often used to identify expansive soils. As the plasticity index or liquid limit of the soils increases, the potential for swelling upon contact with water also tend to increase. Dakshanamurthy and Raman (1973) presented the method shown in Table 1-18 to infer the swelling potential based on the liquid limit. The information presented in Table 1-19 and Figure 1-8 provides another method of assessing the potential for volume change of a given soil.

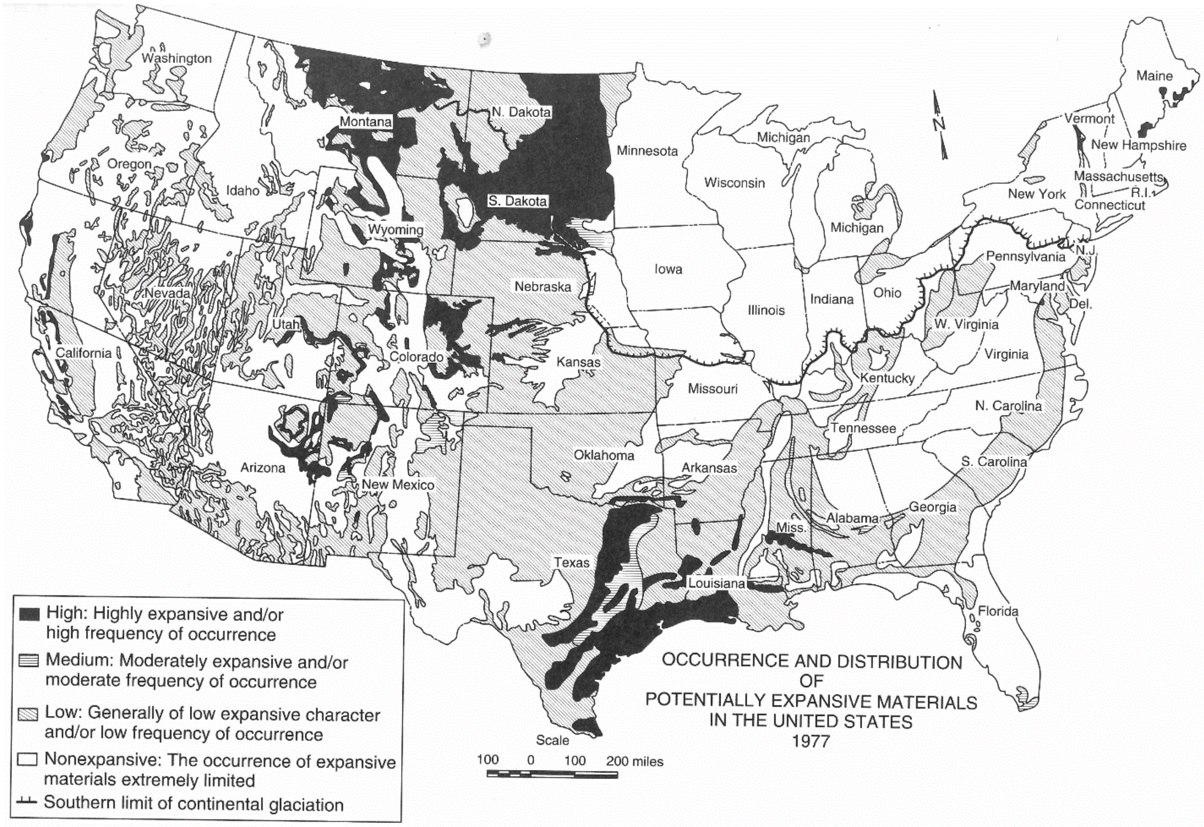


Figure 1-7 Expansive Soils in the United States (Nelson and Miller 1992)

Table 1-18 Swelling Potential (Dakshanamurthy and Raman 1973)

Liquid Limit	Classification
0 to 20	Non-Swelling
20 to 35	Low-Swelling
35 to 50	Medium-Swelling
50 to 70	High Swelling
70 to 90	Very High Swelling
> 90	Extra High Swelling

Table 1-19 Expansion Potential from Classification Test Data (Holtz et al. 2011)

Degree of Expansion	Probable Expansion as a Percent of Total Volume Change (Dry to Saturated Condition)[1]	Colloidal Content (% < 1μm)	Plasticity Index	Shrinkage Limit
Very high	>30	> 28	>35	<11
High	20-30	20-31	25-41	7-12
Medium	10-20	13-23	15-28	10-16
Low	<10	<15	<18	>15

[1]Under a surcharge of 1 psi.

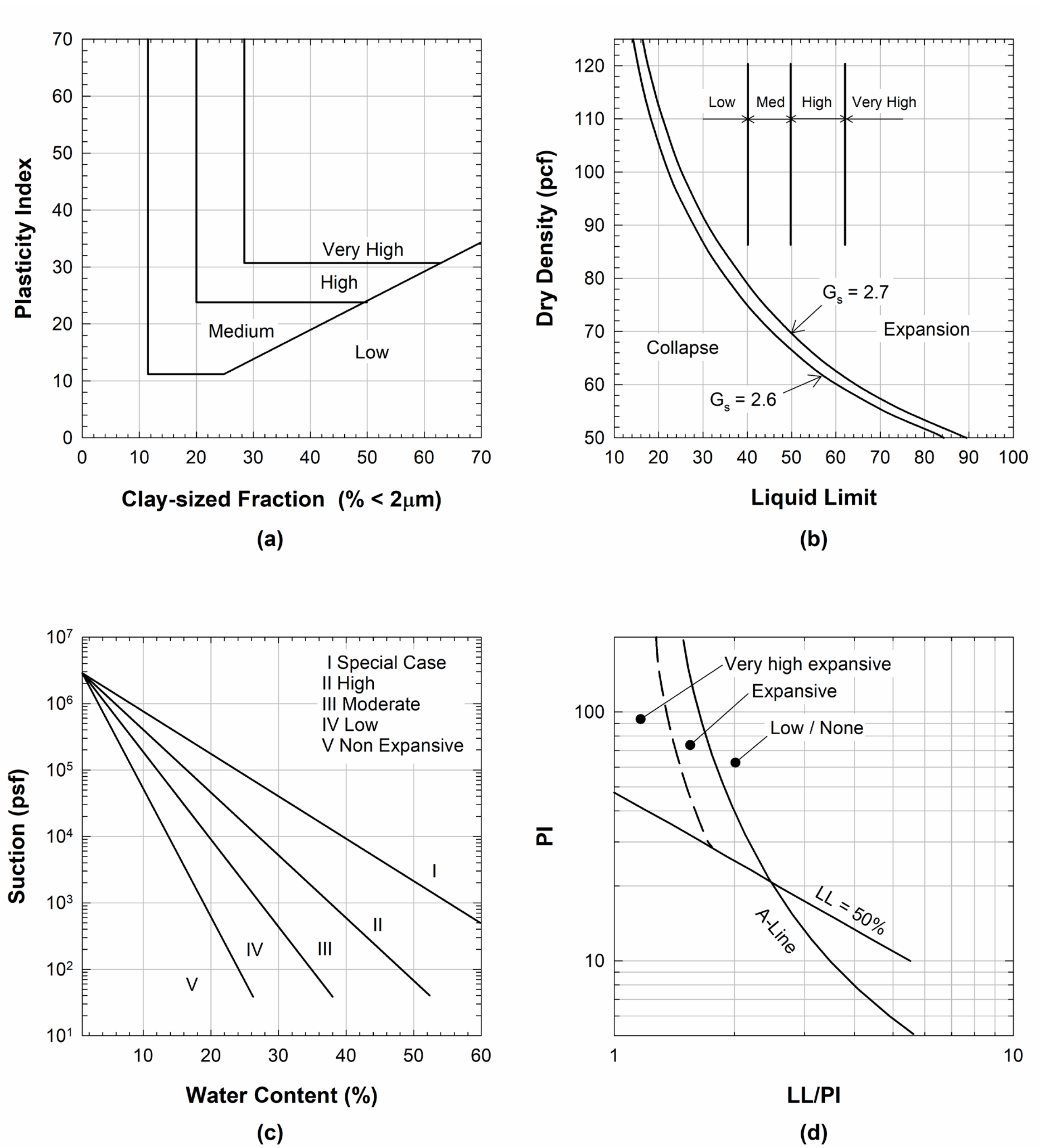


Figure 1-8 Soil Expansion Prediction (after Holtz et al. 2011)

The International Building Code 2018 (ICC 2018) considers a soil to be expansive if these four criteria are met:

1) Plasticity index equal or greater than 15 as determined using ASTM D4318,
2) More than 10% of soil particles passing a No. 200 (75 μm) sieve, as determined using ASTM D6913 or D1140,
3) More than 10% of soil particles are less than 5 μm in size, as determined using ASTM D7928, and
4) Expansion index is greater than 20, as determined using ASTM D4829 (described below).

If the soil shows compliance with Item 4, it is not necessary to show compliance with Items 1 through 3.

Two laboratory tests have standardized procedures to measure the swelling potential of soils. In the *Expansion Index test* (ASTM D4829), the soil is compacted in a rigid mold at a water content and unit weight that gives a degree of saturation of 50% ± 2%. A vertical confining pressure of 1 psi is applied to the specimen before the specimen is submerged in distilled water, and the deformation of the specimen is recorded for 24 hours or until the rate of deformation is below 0.0002 inch/hour, whichever occur first with a minimum recording time of 3 hours. This test is used to obtain the expansion index of the soil, defined as follows:

$$EI = \frac{\Delta H}{H_i} \times 1000 \tag{1-6}$$

where,
EI = expansion index,
ΔH = change in height during the test, and
H_i = initial height of the test specimen.

According to ASTM D4829, the expansion index can be used to estimate the swelling potential of soils as described in Table 1-20.

Table 1-20 Classification of Potential Expansion of Soils using EI (ASTM D4829)

Expansion Index, EI	Potential Expansion
0-20	Very low
21-50	Low
51-90	Medium
91-130	High
>130	Very High

The one-dimensional swell or collapse test (ASTM D4546) can also be used to measure expansion potential. This test method allows intact samples and samples compacted at different water contents and compactive effort to be tested. In addition, this test allows different loading conditions, wetting and drying schedules, and reading intervals to be used.

1-5.2 Collapsing Soils.

1-5.2.1 Characteristics.

Collapsing soils are distinguished by their potential to undergo large decrease in volume upon increase in moisture content without an increase in external loading. When dry, these soils are stable and able to support significant structural loads. Examples of soils exhibiting this behavior are loess, weakly cemented sands and silts where cementing agent is soluble (e.g., soluble gypsum, halite, etc.), and certain granite residual soils. A common feature of collapsible soils is loose bulky grains held together by capillary stresses. Collapsible soils are also characterized by loss of strength when wetted, low density, moisture sensitivity, and the presence of gypsum or anhydrite. Deposits of collapsible soils are usually associated with regions of moisture deficiency (arid or semi-arid regions). According to FHWA (2017), the following conditions are necessary for collapse to occur:

1) an open, and partially saturated and unstable fabric,
2) enough total stress to make the soil structure metastable,
3) existence of a bonding agent or negative pore pressures to create a metastable structure, and
4) addition of water to destroy the metastable structure.

The collapse of soils supporting structures can cause significant damage as a result of total and differential settlement. The magnitude of the collapse depends on factors, such as the soil composition, dry density, water content, confining stress, and the agent causing the metastable structure. For this reason, it is important to identify collapsible soils during the subsurface investigation so they can be remediated or considered in the design phase.

1-5.2.2 Identification and Classification.

One method to identify the potential of soils to collapse is presented by Holtz et al. (2011) using data from the USBR and is shown in Figure 1-9. From this figure, the potential for collapse increases with decreasing liquid limit and *in situ* dry density.

Ayadat and Hanna (2007b) presented a detailed study on the potential of collapse of soil. In this study, they investigated the effect of the uniformity coefficient, water content, and dry unit weight on the collapse potential. Figure 1-10 was presented as a method to assess the potential for a soil to be collapsible along with a detailed method to estimate the strain caused by collapsing for different soils. Ayadat and Hanna (2007a) also presented a method to assess the potential for a soil to be collapsible using the fall cone apparatus (Section 3-2.4.2.6).

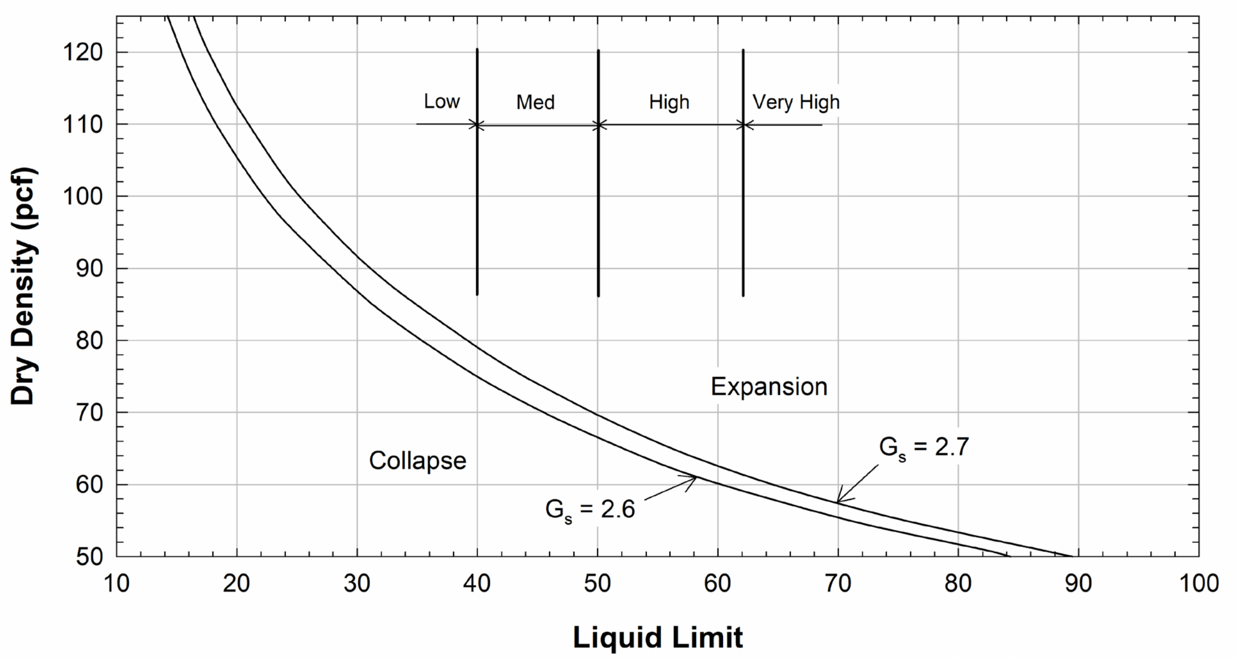


Figure 1-9 Collapsibility Based on *In situ* Dry Density and Liquid Limit (after Holtz et al. 2011)

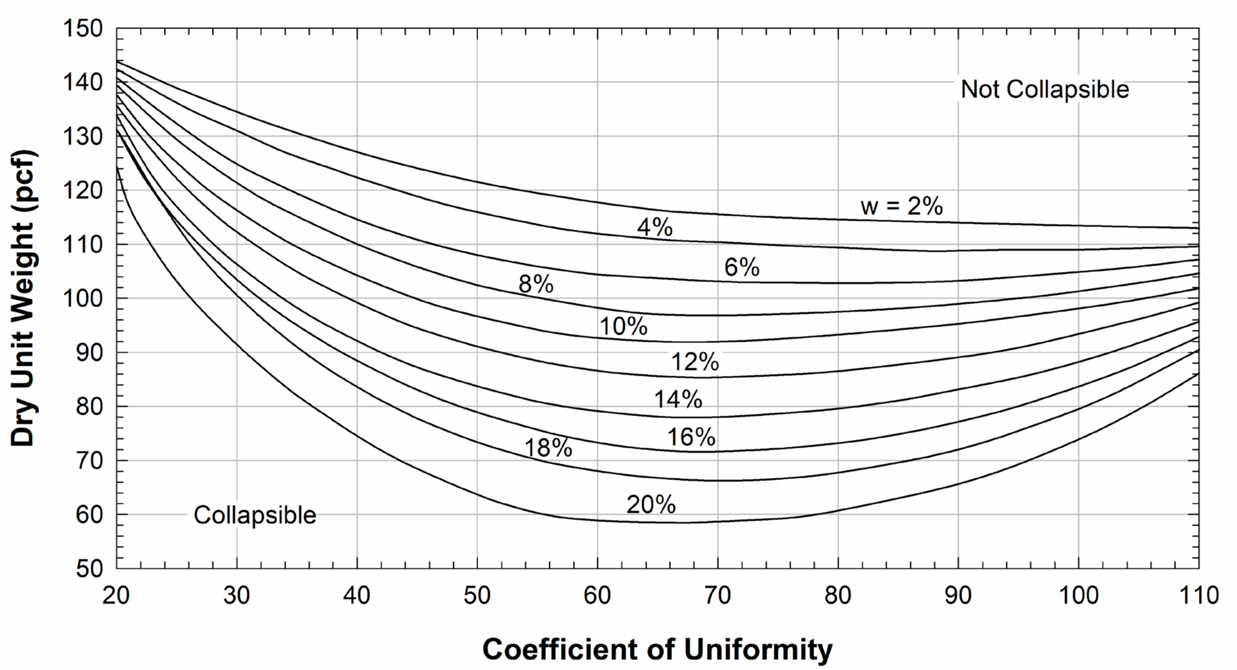


Figure 1-10 Design Charts for Predicting Collapse Behavior of Soils (after Ayadat and Hanna 2007b)

A method for quantifying the collapse potential of soils is presented in ASTM D4546. This test method allows intact samples and samples compacted at different water contents and compactive effort to be tested in a one-dimensional apparatus. In this test, the specimen is loaded to a desired normal stress using any loading sequence, water is added, and the vertical displacement is monitored.

1-5.3 Frost Susceptibility and Permafrost.

1-5.3.1 Characteristics.

In non-frost susceptible soil, a typical volume increase due to ground freezing is about 4%. This volume increase is caused by the increase in water volume as it freezes. In soils susceptible to frost, soil heave is much greater as water flows to colder zones forming ice lenses. The formation of ice lenses typically is not uniform, meaning that the increase in volume is not evenly distributed throughout a site and can cause distress to structures. During warmer weather, the soil and ice lenses will tend to thaw from the top down. Water can become trapped in the soil near the surface, leading to an increase in water content and softening of the soil. The associated loss of support can be even more detrimental to structures than the frost heave itself. This is specially a problem for pavement structures and structures supported on shallow foundations, as well as utilities, if not buried well below the depth of freezing.

Permafrost refers to a thick top later of soil that stays frozen throughout the year. Permafrost particularly occurs in the Northern Hemisphere, including Canada and Alaska. Construction in permafrost is very challenging and requires special considerations during design and construction.

1-5.3.2 Identification and Classification.

Problematic frost action requires both frost penetration into the ground and frost susceptible soils. According to Holtz et al. (2011), if the frost penetration during the worst part of the winter is less than about 0.30 m, frost heave should not be of concern to structures. The maximum depths of frost penetration in the United States are shown in Figure 1-11. These depths are for extremely cold winters without much snow cover. Snow cover, especially early in the winter, will decrease the frost depth significantly.

Silts are the most susceptible to frost heave, but most soils with some fines content have also some susceptibility to freezing. This includes soils classifying as SM, ML, GM, SC, GC, and CL. Holtz et al. (2011) presented the information shown in Table 1-21 summarizing a design classification system for frost susceptible soils. This system uses the soil classification system and the percent of soil finer than 0.02 mm ($8x10^{-4}$ inches) to assess the susceptibility to freezing.

Figure 1-11 Maximum Depths (in meters) of Frost Penetration in the Continental United States (NOAA 1978)

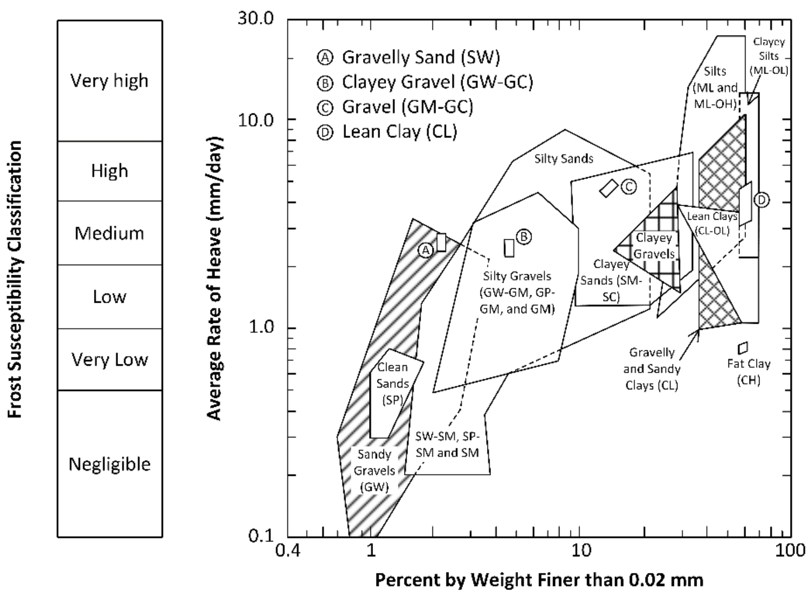


Figure 1-12 Rates of Heave in Laboratory Freezing Tests on Remolded Soils (U.S. Department of the Army 1984)

Table 1-21 U.S. Army Corps of Engineers Frost Design Soil Classification

Frost Group	Frost Susceptibility	Soil Type	Percent Finer than 0.02 mm	Typical USCS Classification
Not frost-susceptible (NFS)	Negligible to low	Gravels, crushed stone and rock	0-1.5	GW, GP
		Sands	0-3	SW, SP
Possibly frost-susceptible (PFS)	Possibly	Gravels, crushed stone and rock	1.5-3	GW, GP
		Sands	3-10	SW, SP
S1	Very low to medium	Gravelly soils	3-6	GW, GP, GW-GM, GP-GM
S2	Very low to medium	Sandy soils	3-6	SW, SP, SW-SM, SP-SM
F1	Very low to high	Gravelly soils	6-10	GM, GW-GM, GP-GM
F2	Medium to high	Gravelly soils	10-20	GM, GM-GC, GW-GM, GP-GM
		Sands	6-15	SM, SW-SM, SP-SM
F3	Medium to very high	Gravelly soils	>20	GM, GC
		Sands except very fine silty sands	>15	SM, SC
	Low	Clays, PI >12		CL, CH
F4	Low to very high	All silts		ML, MH
		Very fine silty sands	>15	SM
	Low to high	Clays, PI <12		CL, CL-ML
	Very low to very high	Varved clays and other fine-grained banded sediments		CL and ML; CL, ML, and SM; CL, CH, and ML; CL, CH, ML and SM.

Figure 1-12 relates the rate of frost heave to the percent of particles finer than 0.02 mm ($8x10^{-4}$ inches) based on USCS classification. This figure also includes the susceptibility classification for each type of soil. The information presented in this figure is based on laboratory testing by the U.S. Department of the Army (1984). According to Holtz et al. (2011), these rates are higher than those expected in the field, and soils with a laboratory rate of frost heave of up to 1 mm/day (0.04 inches/day) can be used under pavements, unless severe conditions are expected, but some frost heave should be expected.

1-5.4 Limestone and Related Materials.

1-5.4.1 Characteristics.

Limestone, dolomite, gypsum, and anhydrite are characterized by their solubility and thus the potential for the presence and/or development of cavities. Limestones are defined as those rocks composed of more than 50% carbonate minerals of which 50% or more consist of calcite and/or aragonite. Some near-shore carbonate sediments (also called limestone, marl, and chalk) could fit this description. Such sediments are noted for erratic degrees of induration, and thus variability in load supporting capacity and uncertainty in their long-term performance under sustained loads. The most significant limestone feature is its solubility. An extremely soluble limestone can contain many solution caves, channels, or other open, water, or clay-filled features. These features are often referred to as *karst* geology or topography.

Karst features that present important engineering challenges include vertical and horizontal fissures and joints, pinnacles, and sinkholes. Fissures and joints may contain very weak soil and also provide conduits for the flow of water, which are particularly problematic for water retaining structures. *Pinnacles* are spires or spines of rock left behind by the dissolution process and result in very uneven foundation support. *Sinkholes* are the result of soil erosion into karst voids or the sudden collapse of voids. Structures and pavements can be catastrophically damaged by sinkholes.

1-5.4.2 Identification and Classification.

The identification of karstic areas should start by desk studies and site visits to look for surface expressions of solution features. Sinkholes are the surface expression of rock dissolution and can be used to infer that karstic rocks are found in the area. Aerial photos, local geology maps, LIDAR data, etc. are also a useful source of information to identify features that are caused by karstic rocks. A map of the karst and potential karst areas in the United States presented by USGS (2014) is shown here in Figure 1-13.

A subsurface investigation program is very important in karstic areas to better characterize the possible caverns, sinkholes, pinnacles, etc. Drilling is a very powerful tool for this purpose and should be done more extensively in this type of terrain (FHWA 2017). Geophysical techniques, including shallow seismic refraction, resistivity, and gravimetry, are often found to be valuable supplements. The suggested methods by ASTM D6429 to estimate the depth to bedrock and the occurrence of sinkholes and voids is presented in Table 1-22.

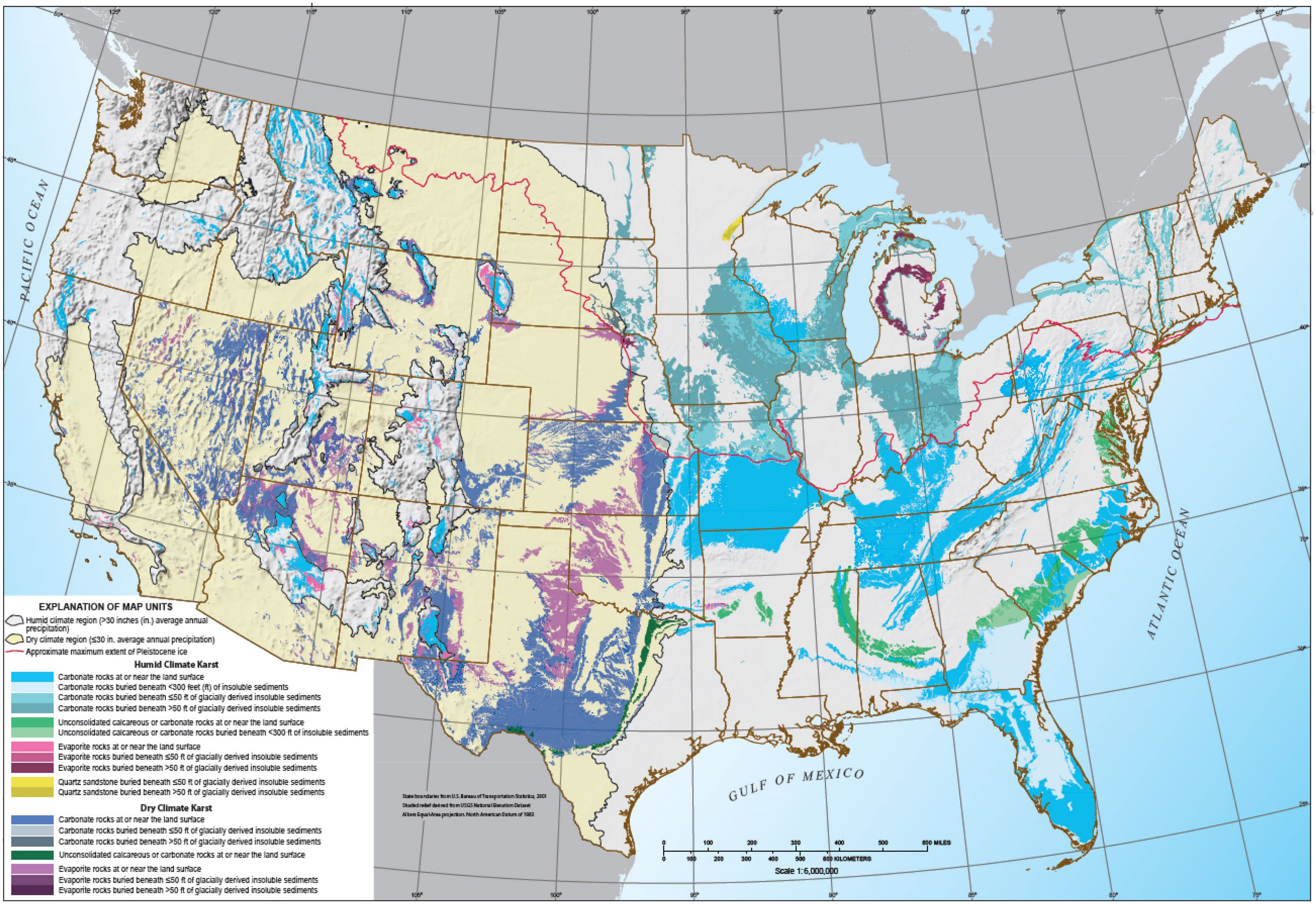


Figure 1-13 Karst and Potential Karst Areas in Soluble Rocks in the Contiguous United States (USGS 2014)

Table 1-22 Selection of Geophysical Method (after ASTM D6429)

Application or Method	Seismic		Electrical	Electromagnetic				
	Refraction or Reflection	MASW	DC Resistivity	Freq. Domain	Time Domain	Very Low Frequencies	Ground Penetrating Radar	Gravity
Depth to rock	A	A	B	B	B	B	A	B
Voids and sinkholes	B	A	B	B	B		A	A

Notes: "A" means preferred method and "B" alternate method based on the 2020 version of the standard.

1-5.5 Coral and Coral Formation.

1-5.5.1 Characteristics.

Living coral and coralline debris are generally found in tropical regions where the water temperature exceeds 20°C. Coral is a term commonly used for the group of animals which secrete an outer skeleton composed of calcium carbonate, and which generally grow in colonies. The term *coral reef* is often applied to large concentrations of such colonies which form extensive submerged tracts around tropical coasts and islands. In general, coralline soils deposited after the breakdown of the reef, typically by wave action, are thin (a few meters thick) and form a veneer upon cemented materials (limestones, sandstones, etc.).

Coralline deposits are generally poor foundation materials in their natural state because of their variability and susceptibility to solution by percolating waters, and their generally brittle nature. Coralline materials are often used for compacted fill for roads and light structures. Under loads, compaction occurs as the brittle carbonate grains fracture and consolidate. They can provide a firm support for mats or spread footings bearing light loads, but it is necessary to thoroughly compact the material before using it as a supporting surface. Heavy structures in coral areas are generally supported on pile foundations because of the erratic induration. Predrilling frequently is required.

Because of extreme variability in engineering properties of natural coral formations, it is not prudent to make preliminary engineering decisions on the basis of "typical properties." Unconfined compression strengths of intact specimens may range from 50 tsf to 300 tsf.

1-5.5.2 Identification and Classification.

Because the granular coralline and algal materials are derived from organisms which vary in size from microscopic shells to large coral heads several meters in diameter, the fragments are broadly graded and range in size from boulders to fine-grained muds. Similarly, the shape of these materials varies from sharp, irregular fragments to well-rounded particles. Coralline deposits are generally referred to as "biogenic materials" by geologists. When cemented, they may be termed "reefrock," or "beachrock," or other names which imply an origin through cementation of particles into a hard, coherent material.

1-5.6 Quick Clays.

1-5.6.1 Characteristics.

Quick clays are clays from marine origin that are characterized by their very high sensitivity or strength reduction upon disturbance. Quick clays are formed when the formation water containing salts is replaced with fresh water. Disturbance of these clays can be caused by construction activities or seismic ground shaking. In their undisturbed state, they are relatively strong. Following disturbance, they become very weak and possibly liquid. Because of their brittle nature, collapse occurs at relatively small strains. This type of clay is normally found in Norway, Canada, Sweden, Finland, Russia, the United States and other locations around the world. The Leda clay and Champlain Sea clay in Canada are examples of quick materials.

1-5.6.2 Identification and Classification.

Quick clays are readily recognized by measured sensitivities greater than about 15 and by the distinctive, strain-softening shape of their stress-strain curves from strength or compressibility tests. The sensitivity of clays is defined as the ratio of the undrained shear strength in the undisturbed state to that in the disturbed state. The *in situ* liquidity index of quick clays is typically above one, which means the water content is in excess of the liquid limit.

1-5.7 Other Materials and Considerations.

1-5.7.1 Man-made Fills.

Man-made fills can be divided into engineered fills and uncontrolled fills. Engineered fills are fills that were properly compacted to a specified density within a specified range of water contents. These fills are normally strong, have low compressibility, and are very favorable for building foundations. More detail on engineered fill can be found in NAVFAC DM 7.2 (NAVFAC 1982).

Uncontrolled fills are very problematic because these fills were placed under conditions that were not controlled and/or the materials that compose these fills were not controlled. These fills can be made from uncompacted soils and may contain deleterious building debris, old pavement, or concrete. Because of the variability of the materials and uncontrolled placement conditions, the engineering properties are very unpredictable and should be analyzed on a case-by-case basis.

1-5.7.2 Chemically Reactive Soils.

For foundation construction, the main concerns related to chemically reactive soils are usually are corrosion and gas generation. Corrosive soils can be problematic when dealing with foundations, especially steel foundation systems. Potential for corrosion must be considered in the design of foundations compared to the design life of the structure. Protection systems can be used to reduce the corrosion rate. For concrete foundations, increasing the cover thickness over the steel, the use of additive treated concrete, or a specialized cement for this purpose can help mitigate the effect of corrosion on the reinforcement.

Corrosion potential is determined in terms of pH, resistivity, stray current activity, groundwater position, chemical analysis, etc. Based on this information, a compatible foundation treatment, (e.g., sulfate resistant concrete, lacquers, creosote, cathodic protection, etc.) can be prescribed. According to AASHTO (2017), a soil is considered have high corrosion potential if: (1) the resistivity is less than 2,000 ohm-cm, (2) the pH less than 5.5, (3) pH between 5.5 and 8.5 for soils with high organic content, (4) the sulfate concentration is greater than 1,000 ppm, (5) is subjected to mine or industrial drainage, or (6) the chloride concentration is greater than 500 ppm.

The location of the water table also influences the corrosion rate. Decker et al. (2008) observed higher corrosion rate on steel piles in the section located above the water table in the fluctuation zone.

FHWA (2009) presents an extensive study on the corrosion potential of soils focused on MSE walls. Table 1-23 indicates regions in the United States with soils with high potential for corrosion.

Table 1-23 Corrosive Soil Environments (FHWA 2009)

Environment	Prevalence	Characteristics
Acid-Sulfate Soils	Appalachian Regions	Pyritic, pH < 4.5, SO_4 (1000 to 9000 ppm), Cl^- (200 to 600 ppm)
Sodic Soils	Western States	pH > 9, high in salts including SO_4 and Cl^-
Calcareous Soils	FL, TX, NM and Western States	High in carbonates, alkaline but pH<8.5, mildly corrosive
Organic Soils	FL (Everglades), GA, NC, MI, WI, MN	Contain organic material in excess of 1% facilitating microbial induced corrosion
Coastal Environments	Eastern, Southern and Western Seaboard States and Utah	Atmospheric salts and salt laden soils in marine environments
Road Deicing Salts	Northern States	Deicing liquid contain salts that can infiltrate into soils
Industrial Fills	Slag, cinders, fly ash, mine tailings	Either acidic or alkaline and may have high sulfate and chloride content

For gas concentration, organic matter content and field testing for gas are usually performed. If gas generation is expected, some form of venting system is designed. The potential presence of noxious or explosive gases should be considered during the construction excavations and tunneling.

1-5.7.3 Lateritic Soils.

Lateritic soils are found in tropical climates throughout the world. These soils are rich in iron and aluminum. Because of the high iron content, most of these soils have a rusty-red color. Extensive weathering of the parent rock normally develops these soils. These soils can be problematic because of their loss in strength with time, high void ratio and permeability, aggregate deterioration, and shrinkage cracks. These soils tend to have shear strength characteristics between those of sands and silts. They are prone to cause landslides, have highly variable moisture content, and provide erratic conditions for foundations.

1-5.7.4 Calcareous Sands.

Calcareous sands are composed mainly of the skeletal remains of marine organism having high carbonate content. These sands have significant intra-particle voids created by shells that have not broken yet and by the cavities in the corals. These sands are also characterized by having angular particles. The engineering properties of these sands vary over a wide range and are controlled by the cementation and the structure of the sand. More information on calcareous sands can be found in an ASTM Special Technical Publication on the topic (ASTM International 1981).

1-5.7.5 Submarine Soils.

Ocean environments contains the following main topographic features: (1) the continental margin including the continental shelf fringing the coast and the continental slope; (2) the continental rise; and (3) the abyssal plains with local seamounts and trenches (Randolph and Gourvenec 2011). The distribution of marine sediments along those geomorphological regions varies with thickest sediment deposits being mostly near continents and thinnest on recently formed mid-oceanic ridges. Continental margins contain almost 75% of marine sediments, while only representing 20% of the seabed area. The continental rise is also considered a depositional feature with sediment thickness reaching locally up to 1.6 km (Randolph and Gourvenec 2011).

Marine sediments are either terrigenous (i.e. transported from land to the ocean), or pelagic (i.e. settled through the water column). Coastal and nearshore zones are dominated by terrigenous sediments. Terrigenous sediments are often granular silicate minerals formed from erosion (lithogenous). Pelagic sediments are often finer and derived from insoluble remains of marine organisms. Poulos (1988) presented samples from abyssal plain and hill environments and found that most samples from abyssal plains and hills characterized as clayey silt to clay. Ocean sediment mapping also revealed that deep ocean floors are widely covered with calcareous ooze that classified as mostly silty clay (Poulos 1988).

Marine sediments that were deposited slowly and remained undisturbed from physical, chemical, benthic biogenic, and/or anthropogenic processes are commonly normally consolidated. Overconsolidated sediments can result from glaciation, recent sediment erosion, or submarine landslides. Underconsolidated marine sediments can follow from rapid sedimentation events and recent sediment dynamics, as well as from benthic biogenic processes, amongst others. More information on the stress states of marine sediments can be found in Randolph and Gourvenec (2011).

The following key differences between marine and terrestrial sediments can be listed:

- Environmental conditions cover a wider range of pressures (depending on water depth) and temperature and can affect the engineering behavior of marine sediments, particularly in deep ocean environments.
- Oceans feature saline water. Local salinity may affect the engineering behavior, particularly of clays.
- Hydrodynamic conditions (i.e., waves, tides, currents) vary on spatial and temporal scales, particularly in nearshore environments and on the continental shelf. Hydrodynamic forcing can exert stresses onto the seabed and change pore pressures. It also drives sediment dynamics, potentially leading to complex sediment dynamics including erosion, transport, and deposition, and resulting in geomorphodynamics including the formation, destruction, and migration of bedforms on scales of centimeters to hundreds of meters. These processes affect sediment composition, texture, and thus, engineering properties.

1-6 SUGGESTED READING.

Topic	Reference
Soil Classification	Holtz, R. D., Kovacs, W. D., and Sheehan, T. C. (2011). *An Introduction to Geotechnical Engineering*. Pearson.
	FHWA. (2017). *Geotechnical Engineering Circular No. 5 - Geotechnical Site Characterization*. U.S. Department of Transportation - Federal Highway Administration, Washington, DC.
Rock Description and Classification	Hoek, E. (2007). *Practical Rock Engineering*.
	ASTM. (1988). *Rock Classification Systems for Engineering Purposes - STP984*. ASTM International.
Expansive and Collapsing Soils	Holtz, R. D., Kovacs, W. D., and Sheehan, T. C. (2011). *An Introduction to Geotechnical Engineering*. Pearson.
	FHWA. (2017). *Geotechnical Engineering Circular No. 5 - Geotechnical Site Characterization*. U.S. Department of Transportation - Federal Highway Administration, Washington, DC.
Frost Susceptibility	U.S. Department of the Army. 1984. *Engineering and Design - Pavement Criteria for Seasonal Frost Conditions - Mobilization Construction - EM 1110-3-138*.
Limestone / Karst	FHWA. (2017). *Geotechnical Engineering Circular No. 5 - Geotechnical Site Characterization*. U.S. Department of Transportation - Federal Highway Administration, Washington, DC.
	Veress, M. (2020). “Karst Types and Their Karstification.” *Journal of Earth Science*, 31(3), 621–634.
	Waltham, A. C., and Fookes, P. G. (2003). “Engineering Classification of Karst Ground Conditions.” *Quarterly Journal of Engineering Geology and Hydrogeology*, 36, 101–118.
Lateritic Soils	Wesley, L. D. (2010). *Geotechnical Engineering in Residual Soils*. John Wiley & Sons, Ltd.
Submarine Soils	Randolph, M., and Gourvenec, S. (2011). *Offshore Geotechnical Engineering*. CRC Press.

1-7 NOTATION.

Symbol	Description
C_u	Coefficient of uniformity
C_c	Coefficient of curvature
d	Distance between the loaded points in rock point load test
D_e	Equivalent core diameter
D_{10}	Particle size diameter corresponding to 10% passing
D_{30}	Particle-size diameter corresponding to 30% passing
D_{60}	Particle-size diameter corresponding to 60% passing
EI	Expansion index

Symbol	Description
F	Percentage passing a No. 200 (75 μm) sieve (only considering the particles passing a 3-inch sieve)
F	Size correction factor for rock point load test
GI	Group index
GSI	Geological strength index
H_i	Initial height of the test specimen in the expansion index test
LL	Liquid limit of the soil
P	Applied force at failure
PI	Plasticity index of the soil
PL	Plastic limit of the soil
RMR	Rock mass rating
RQD	Rock quality designation
ΔH	Change in height during the expansion index test

CHAPTER 2 FIELD EXPLORATION, TESTING, AND INSTRUMENTATION

2-1 INTRODUCTION.

2-1.1 Scope.

This chapter contains information on exploration methods including use of geologic maps, air photos, and remote sensing; geophysical methods; test borings and test pits, and penetration resistance tests. Also presented is information on methods of drilling and sampling, obtaining groundwater measurements, measuring *in situ* properties of soil and rock, selecting field instrumentation and geotechnical performance monitoring equipment.

2-1.2 Planning for Field Investigations.

The initial phase of field investigations should commence with a thoughtful assessment of the data needs for the specific project, which will help define the objectives of the subsequent field investigation. Prior to mobilizing to the field, readily available information should be located that is relatively inexpensive and often invaluable. In cases where the new project is adjacent to an existing project (e.g., highway widening, lateral expansion of an existing levee, etc.), the initial research should focus on information and data that have previously been collected and/or compiled for the project. For a new project, the initial effort should include a detailed review of geological conditions at the site and within the region where the site is located. This should then be followed by a "desk top" study, utilizing sources of available data, including historical and current aerial photography, remote sensing imagery, and (whenever possible) a field reconnaissance. The collective information obtained from these activities should be used as a guide in planning the project-specific field exploration.

To the extent possible as dictated by project data needs, individual test borings should be supplemented by lower cost exploration techniques that include test pits, test probes, and geophysical surveys. This is particularly true for remote sites, sites exhibiting wide variability in subsurface conditions, projects occupying a large footprint, linear projects (e.g., roadways, pipelines, etc.), and projects in the offshore environment where mobilizations and test borings can be exceptionally expensive.

Project explorations generally have three distinct phases: (1) reconnaissance/feasibility exploration; (2) preliminary exploration; and (3) detailed/final exploration. These phases usually have different objectives. A fourth phase of exploration that involves additional sampling and/or *in situ* testing may be desired and/or required during or after construction to confirm conditions. Frequently (and most common for relatively small projects), these three phases are combined into a single exploration effort.

Reconnaissance includes a review of available topographic, geologic, and hydrogeologic information; aerial photographs; data from previous investigations and projects; and a site visit. Geophysical methods may prove to be helpful in many cases, particularly for large projects where subsurface conditions are variable and for linear projects (e.g., levees, highways, etc.). Reconnaissance/feasibility exploration frequently reveals difficulties which may be expected in later exploration phases and assists in determining the type, number and locations of borings required. Examples of information that can be obtained from field reconnaissance activities are presented in Table 2-1.

Table 2-1 Items that can be Evaluated During Field Reconnaissance (NCHRP 2018 and FHWA 2002)

Item	Things to Note	Comments
Access	Rank access using one of the following criteria: (1) easy, (2) accessible by four-wheel drive, (3) dozer and grading required, and (4) inaccessible.	Evaluating access helps determine the types of equipment that will be required.
Utilities	Existing overhead lines, marked gas lines, manholes, sewer outfalls, and power substations.	Utilities information helps select appropriate *in situ* testing, drilling, and sampling locations.
Surface soils	Presence of fill, debris, pollutants, slope instabilities, heave, subsidence, and scour	Evaluating surface soils can reveal evidence of abandoned landfills, historic landslides, contamination, subsidence, and flooding.
Shallow subsurface materials	Visual soil and rock classifications, loose cobbles, boulders, rock outcrops, rock joint patterns, faults, discontinuities, weathering, planes of weakness, talus, karst features	Subsurface materials can provide evidence for subsidence, landslide activity, unstable soil and rock, and stratigraphy.
Surface drainage	Swamps, ponds, lakes, streams, and rivers	Surface drainage information provides indications of the depth to groundwater level, hydraulic conductivity of the underlying materials, and potential for flooding.
Subsurface drainage	Major aquifers, water wells, and pumping from deep wells	Subsurface drainage information provides indication of groundwater level, natural springs, and potential artesian conditions.
Terrain	Rank terrain in terms of (1) level ground, (2) sloping, (3) hummocky, (4) rolling hills, and (5) mountainous.	Evaluating terrain helps with selecting appropriate exploration and construction equipment, assessing the need for slope stability investigations, and site access.
Past investigations	Existing test pits, boreholes, coreholes, and past blasting operations	Past investigations can provide information regarding stratigraphy, types of soil and rock, and groundwater levels.

Preliminary exploration may include borings and/or penetration soundings to identify specific features (e.g., top of rock, etc.) and/or to recover samples. The collected samples are generally used for index testing only. Penetration sounding test results are often used to help identify the location of strata or formations where detailed exploration activities will be advanced.

The detailed investigation phase typically includes subsurface borings, disturbed and intact sampling for laboratory testing, standard penetration resistances, cone penetration test soundings, and other *in situ* measurements. At critical sites it may also include test pits, piezometer installation and measurements, pumping tests, etc. Following completion of this phase and the associated testing, the site conditions and soil/rock properties should be sufficiently known to design the project.

Monitoring of the site or structure is recommended throughout the construction and the post-construction phases. Performance monitoring instrumentation (e.g., piezometers and/or settlement plates to assess consolidation during staged loading) may need to be installed. In some cases, further evaluation of foundation conditions may be required during the construction phase. This is particularly true when foundation conditions have the potential to vary widely across the project site (e.g., when using deep foundations for project sites underlain by karst).

2-2 PUBLISHED REFERENCE MATERIALS.

When starting an investigation, the first step is to identify sources of readily available and pertinent information. In general, this information comes from two sources: (1) previous investigations; and (2) published literature in the public domain.

2-2.1 Previous Investigations.

For studies in developed areas, subsurface conditions and selected foundation recommendations may be available from previous work for surrounding projects. Earlier site-specific data may be “dated” and while the underlying geology is unchanged, the site-specific information may have been superseded by recent activities. For example, industrialized waterfront areas near major cities may undergo cycles of expansion and reconstruction, causing subsurface conditions to change. Often old foundations and wharf structures remain buried in place. Records of former construction may contain information on borings, field tests, groundwater conditions, and potential or actual sources of construction difficulties. Note that explorations from state departments of transportation (DOT), the United States Geological Survey (USGS), and United States Environmental Protection Agency (USEPA) may be publicly available.

Review of data from previous work should receive the greatest attention of any phase in a reconnaissance investigation because it is likely very relevant. Additionally, this information generally comes at relatively little cost and allows the project team to quickly become familiar with the project location and noted problems related to geology and construction.

2-2.2 Published Geologic and Hydrogeologic Maps.

Data on the physical geology and topography of the United States (and foreign countries) are available in maps and reports by government agencies, universities, and professional societies. An example of documents and sources of available information is provided in Table 2-2. While providing excellent regional and general information, the information from these sources may not be entirely “site-specific.” However, this information often can be used to identify specific data gaps that need to be addressed during subsequent phases.

2-3 REMOTE SENSING DATA METHODS.

2-3.1 Sources.

Aerial photographs are a common type of remote sensing, including older printed images (scales from 1:12,000 to 1:80,000) and reasonably high-resolution digital images for most of the United States (scale of 1:1000 or better). Some regions possess a wealth of “historic” imagery that may extend before the current site was developed. Photos are useful for topographic and/or geologic mapping in addition to identifying drainage patterns, locations of existing structures, vegetation, access routes and site locations for planned explorations. Remote sensing also refers to non-photographic data gathering satellites, from which data, such as vegetation development, water sources, etc., are available. Table 2-3 summarizes sources and types of remote sensing data that have been historically (i.e., pre-2019) used by geotechnical engineers. The technologies identified in Table 2-3 generally require the purchase of images from the entities that generated the images.

Table 2-4 provides a summary of more recent remote sensing technologies. Data from some of these are free to the user and are often available on the internet. Data from remote sensing technology can be incorporated into developing augmented reality (AR) platforms, which provide an interactive experience where objects are projected into a perceived real-world environment. This requires computer-generated information presented in a geospatial environment through the use of special lenses and headsets.

2-3.2 Utilization.

Remote sensing represents a well-adopted resource by geotechnical engineers. The emergence of internet-based mapping tools coupled with the cross-section profiling capabilities using geographic information system (GIS) tools currently exceed the capabilities and functionality of earlier tools.

Table 2-2 Sources of Readily Available Subsurface Information (after NCHRP 2018, FHWA 2002, and FHWA 2016)

Types of Documents	Sources of Information	Type of Available Information	Comments
Topographic maps	USGS and state geological survey agencies	Site topography, physical features, and index map of site area	Maps can be used to evaluate access issues for field equipment and identify areas susceptible to slope instability.
Soil survey reports	National Resource Conservation Service, Web Soil Survey, and local soil conservation agencies	AASHTO and USCS classifications, moisture contents, Atterberg limits, organic contents, chemical properties (e.g., pH), permeability of soils, climate, stratigraphy, and groundwater level	Available information is for shallow depths (6 ft. or less) and is useful for identifying near-surface problematic soils (e.g., soils susceptible to swelling and shrinkage) or identifying potential borrow sources.
Geologic maps and reports, including sinkhole and karst maps	USGS and state geological survey agencies	Soil and rock formations (rock types, fracture, orientation and approximate age), groundwater flow patterns, and bedrock contours that provide approximate estimates of rock depths, and potential geologic hazards	These documents can be used to identify areas susceptible to sinkholes, landslides, subsidence, and other hazards.
Aerial photographs	Internet mapping sites, National Agriculture Imagery Program (NAIP), and aerial survey companies	Man-made structures, geologic and hydrogeologic information, current and past land use, borrow sources, and potential geologic and man-made hazards	Photographs can track site changes over time to identify potential problematic past land use activities or geologic events, including landslides.
Hydrological and well maps and well logs	USGS, state natural resources and soil survey agencies	Hydrogeological features (e.g., springs), groundwater hazards, stratigraphy, and groundwater depths	Well maps and logs can be useful to evaluate the need for construction dewatering and permanent groundwater control.
Utility maps	Utility companies and local government agencies	Locations of buried utilities	Very useful to identify locations for *in situ* testing, drilling, and sampling, useful to map equipment access routes
Flood insurance maps	FEMA, USACE, USGS, State and local government agencies	100- and 500-year floodplains, data for evaluating scour potential	This information can be used to ensure that the site isn't in the 100- and 500-year floodplains.
Sanborn fire insurance maps	Library of Congress, state and university libraries, and Sanborn Company	Environmental hazards and historical land use	Sanborn maps are available for urban areas.
Agencies: United States Geological Service (USGS), American Association of State Highway and Transportation Officials (AASHTO), Unified Soil Classification System (USCS) , Federal Emergency Management Agency (FEMA), United States Army Corps of Engineers (USACE)			

Table 2-3 Historic Remote Sensing Data Sources

Type	Description and General Use	Availability
Aerial photography	Available in 9-inch frames with overlap for stereoscopic viewing. Valuable because of high resolution and available scales could range from 1:12,000 (or larger) to 1:80,000.	USGS, NCIC, NCRS, USFS, BLM, TVA
	Satellite imagery with repetitive coverage every 18 days in four spectral bands: • BAND 4: emphasizes movement of sediment-laden water and delineates areas of shallow water and useful in differentiating lithology • BAND 6: emphasizes cultural features, such as metropolitan areas • BAND 7: emphasizes vegetation, the boundary between land and water, landforms and useful in structural interpretation of geology; • BAND 8: provides the best penetration of atmospheric haze, the best band for detecting faults, lineaments, mega-joint patterns or other structural features, and also emphasizes vegetation, the boundary between land and water, and landforms.	EROS
Skylab	High-quality photography of Earth's surface useful for regional planning, environmental studies, and geologic analyses. Images cover an area of 100 x 100 miles or 70 x 70 miles depending on the camera used. Images are from 1973-74 and do not provide full coverage.	EROS
NASA	Black and white, color, or false-color infrared aerial photography produced from NASA Earth Resources Aircraft Program with scales ranging from 1:120,000 to 1:60,000. Coverage not available for all areas. Useful for planning, environmental and site-oriented studies, and fault/lineament evaluation (color IR).	EROS
SLAR	Side-looking airborne radar (SLAR) is a valuable complement to photos for regional studies especially applicable in areas of persistent cloud cover. Scales range from 1:2,000,000 to 1:250,000. Best imagery for identifying regional faults/lineaments.	NCIC, Goodyear Aerospace Corporation and Motorola, Westinghouse Electric Corp.,
Thermal IR	Thermal infrared (IR) imagery can be useful where temperature contrasts are significant. Useful for special projects or as a complement to other remote sensing data Useful in fault detection in covered alluvial areas, geothermal exploration, location of seepage, location of near surface peat deposits, covered meander scars, and heat loss studies.	Obtained as needed by aerial survey firms. Images may be available from an HCMM.
Agencies: United States Geological Service (USGS), National Information Center (NCIC), National Resources Conservation Service (NCRS), U.S. Forest Service (USFS), U.S. Bureau of Land Management (BLM), Tennessee Valley Authority (TVA), Earth Resources Observation System (EROS), Heat Capacity Mapping Mission (HCMM) by National Space Science Data Center Goddard Space Flight Center		

For project sites where limited information is available, aerial images greatly aid in planning and layout of an appropriate boring program and currently be considered a minimal requirement for projects. For large engineering studies, including highway and airfield work, a three-dimensional (3D) visualization may be beneficial. Individual users can develop digital terrain model (DTM) files using data from UAVs data, and commercial companies can economically develop local 3D topography with the use of UAVs.

Table 2-4 Current Remote Sensing Data Sources

Type	Description and General Use	Availability
Aerial Photography	Recent and historical aerial maps (including approximate topography) for most of the United States. Generally, very good resolution at <1:1000 scale. Excellent to see regional and site-specific topography, roads, drainage features. In many areas, it is possible to get a relatively recent “street view” 3D image to depict observations from the ground surface.	Various internet map tools are available, with some databases updated quarterly. Most images are generally less than 3 years old.
LIDAR	Light Detection and Ranging (LIDAR) uses a pulsed laser light whose signal is reflected back to a sensor to record distance. The signal source is usually positioned on a moving vehicle and recovered data can be used to generate 3D images of terrain.	Usually provided by commercial vendors as a specialized commodity due to high equipment and processing costs.
SAR	Synthetic Aperture Radar (SAR) is an advanced form of SLAR that uses radio waves from a moving platform. Data can be used for high resolution 2D and 3D images, with the larger aperture (or larger antennae) providing higher resolution.	Provided by commercial vendors with specialized electronic equipment for data capture and processing, Images may be available to the general public at reasonable cost in the future.
UAV	Unmanned Aerial Vehicles (UAVs) or drones are increasingly useful for project aerial imagery. UAVs can carry digital and infrared cameras and other sensors. High resolution is possible. Overlapping passes allows for generation of 3D imagery and topography. Excellent resource for tracking construction progress.	Equipment is readily available at low cost for individual users. Commercial services are also widely available.

Interpretation of information from aerial photographs and other remote sensed data requires experience and skill. The interpretation process combined with other information from the published reference material often informs the interpretation of what features may be present at the project site. Spot checking in the field is an essential element in the interpretation of geologic features from aerial photographs. Aerial photographs are most helpful when assessing similarities and differences between areas. Use of these images in urbanized and develop areas is of limited quantitative subsurface informational value. As with any aerial image, whether photographic or remote data, vegetation and cloud cover can often obscure the underlying topography. Recently, computer enhancements of multi-spectral imagery have made LANDSAT data compatible with conventional aerial photography.

2-4 GEOPHYSICAL METHODS.

2-4.1 Utilization and Applications.

With increasing regularity, geophysical investigations are being used to estimate subsurface conditions because of improved interpretation techniques and the overall acceptance within the professional community of the geophysical characterization techniques. Table 2-5 provides a summary of the common geophysical testing techniques and the objectives/characterizations that are obtained from these techniques. Information regarding the selection of appropriate surface geophysical testing techniques is also presented in ASTM D6429.

Geophysical methods are best suited when investigating relatively large and/or linear sites, including dams, reservoirs, tunnels, highways, and large groups of structures. Techniques are available for both onshore and offshore exploration. Geophysics have been used to locate gravel deposits and sources of other construction materials, particularly for stratified materials where properties differ substantially from adjacent soil/rock. As shown in Table 2-5, many of the geophysical testing methods are helpful in identifying different subsurface strata and anomalies in the subsurface.

Table 2-5 Surface Geophysical Methods and Investigation Objectives (after NCHRP 2018, Fenning and Hasan 1995, USACE 1995a, Sirles 2006, FHWA 2006, and Anderson et al. 2008)

	Seismic		Electrical and Electromagnetic				Potential Field	
Information Obtained	Refraction and Reflection	Surface Wave	Resistivity	Electromagnetic	Ground-Penetrating Radar	Microgravity	Magnetometry	Self-Potential
Lithology and stratigraphy	✓	✓	✓	✓	✓			
Bedrock topography	✓	✓	✓	✓	✓	✓	✓	
Water table	✓		✓		✓			
Rippability of rock	✓							
Shear wave velocity profile		✓						
Fault detection	✓		✓	✓	✓	✓		
Void and cavity detection	✓	✓	✓	✓	✓	✓		
Subsurface fluid flow				✓				✓
Ferrous anomalies			✓		✓		✓	
Conductive anomalies			✓	✓	✓			✓
Corrosion potential			✓					

2-4.2 Advantages and Limitations.

In contrast to borings, geophysical surveys explore large areas rapidly and economically. Because they evaluate conditions over a large area, the results reflect average conditions in an area rather than a specific result that one would obtain from a series of vertically advanced borings. Geophysical testing can prove most advantageous in geologic conditions that display a strong contrast between adjacent strata (i.e., rock beneath soil, interface between hard and soft rock, water- or air-filled voids in soil or rock, etc.). Geophysical testing can often detect irregularities of bedrock surface and the interface between soil and rock strata, and may be particularly useful in karst topography.

Geophysical surveys can often distinguish boundaries between strata, but most methods can only indicate approximate soil properties. These “approximate” properties should be considered the average properties within the subsurface, as delineation of specific properties of specific strata are generally not possible.

Interpretation of geophysical testing results is often difficult and subjective to the experience of the operator or interpreter. In many cases, there are no definite criteria for the interpretation of geophysical testing techniques. Some techniques are highly specialized and almost all techniques require experienced operators and interpreters for each application. Spot checks of “interpreted” versus “actual” conditions are strongly recommended for each site using boring methods. Previously successful techniques and an experienced interpreter should be used.

Differences in degree of saturation, presence of mineral salts in groundwater, or similarities of strata that effect transmission of seismic waves may lead to vague or inaccurate conclusions. These limitations notwithstanding, geophysical testing is anticipated to see more widespread use and acceptance in the future. Further reference and extensive discussion are found in FHWA (2003) and NCHRP (2018).

2-5 SOIL AND ROCK EXPLORATION METHODS.

Soil borings are the most commonly used method for subsurface soil exploration in the field. They allow a vertical profile of soil to be established at a specific location and for the collection of samples at selected vertical intervals at specific locations. Rock drilling and coring techniques are more specialized than those used for soils and are used less frequently.

2-5.1 Drilling and Boring Methods.

Most geotechnical borings in soils have historically utilized either hollow-stem augers or rotary wash techniques, where numerous variations technologies are available. Recent advancements that are gaining popularity and acceptance include the use of direct-push and sonic boring techniques. Table 2-6 identifies the applicability of the several methods for advancing soil borings. Table 2-7 provides similar information for rock.

The drilling equipment used for geotechnical investigation is selected based on a combination of: (1) ground conditions encountered at the site (i.e., soft ground, steep terrain, over water, etc.) and (2) the type of drilling that is selected (i.e., auger, rotary, percussion, etc.). Table 2-8 provides a summary of various types of drilling equipment and their application. Figure 2-1 provides a schematic of the various drilling methods.

Table 2-6 Methods of Advancing an Exploration Hole in Soil (NCHRP 2018 and Day 1999)

Method	Procedure	Applications	Limitations / Remarks
Auger boring (ASTM D1452)	Dry hole drilled with hand or power auger; samples recovered from auger flights	Identify geologic units and water content above water table in soil and soft rock	Stratification destroyed; sample mixed with water below the water table.
Hollow-stem auger boring	Hole advanced by hollow-stem auger; soil sampled with auger in place	Typically used in soils that would require casing to maintain an open hole for sampling.	Sample limited by larger gravel; maintaining hydrostatic balance in hole below water table is difficult.
Wash-type boring	Light chopping and strong jetting of soil; cuttings removed by circulating fluid and discharged into settling tub	Soft to stiff cohesive materials and many granular soils.	Coarse material tends to settle to bottom of hole; Should not be used in boreholes above water table where intact samples are desired.
Becker hammer penetration test (BPT)	Hole advanced using double acting diesel hammer to drive a 168 mm double-walled casing into the ground.	Typically used in soils with gravel and cobbles; casing driven open-ended if sampling of materials is desired.	Skin friction of casing difficult to account for; repeatability of test unclear.
Bucket auger boring	Rotates and advances a 600- to 1200-mm diameter drilling bucket with cutting teeth; bucket retrieved and emptied on the ground.	Most soils above water table; can penetrate harder soils than above types; can penetrate soils with cobbles and boulders if equipped with a rock bucket.	Not applicable in running sands; used for obtaining large volumes of disturbed samples; used to provide access to enter a boring for observations.
Direct push	Static weight and percussion used to advance a 90- to 115-mm diameter casing;	Most cohesive and granular soils; near-continuous sample	Recovered samples are generally disturbed
Sonic drilling	High-frequency resonant vertical oscillations advance a 75- to 300-mm diameter core barrel; recovers a continuous 3.3-m long core; after sample is retrieved, overcore barrel advanced to bottom of core barrel by similar technique and process is repeated	Applicable in nearly all soils and much bedrock; returns continuous stratigraphy; applicable for conditions both above and below the water table; process does not require drilling fluids	Not cost effective in very dense and hard rock where coring is desired; recovered samples are disturbed

Table 2-7 Rock Core Drilling Methods (NCHRP 2018 and Day 1999)

Method	Procedure	Type of sample	Applications	Limitations / Remarks
Rotary coring of rock (ASTM D2113)	Outer tube with diamond (or tungsten carbide) bit rotated to cut annular hole in rock; core protected by stationary inner tube; cuttings flushed by drill fluid	Rock cylinder 22 to 100 mm wide and as long as 3 m, depending on rock soundness; standard size is 54 mm diameter.	Obtain continuous core in sound rock (percent of core recovered depends on fractures, rock variability, equipment, and driller skill)	Core loss in fractured or variable rock; blockage prevents drilling in badly fractured rock; dip of bedding and joint evident but not strike
Rotary coring of rock, wire line	Same as ASTM D2113, but core and stationary inner tube retrieved from outer core barrel by lifting device or "overshot" suspended on thin cable (wire line) through large-diameter drill rods and outer core barrel	Rock cylinder 28 to 85 mm wide and 1.5 to 3 m long	Better core recovery in fractured rock; much faster cycle of core recovery and efficiency in deep holes	Core loss in fractured or variable rock; blockage prevents drilling in badly fractured rock; dip of bedding and joint evident but not strike
Rotary coring of swelling clay, soft rock	Similar to rotary coring of rock; swelling core retained by third inner plastic liner	Soil cylinder 28.5 to 53.2 mm wide and 600 to 1500 mm long encased in plastic tube	Soils and soft rocks that swell or disintegrate rapidly in air (protected by plastic tube)	Small sample; equipment more complex than other soil sampling techniques
Sonic drilling	High-frequency resonant vertical oscillations advance a 75- to 300-mm diameter core barrel; recovers a continuous 3.3-m long core	Continuous core sample when overcore barrel is advanced	Applicable most bedrock; applicable for conditions both above and below the water table; process does not require drilling fluids	Not cost effective in hard rock where coring is desired; recovered rock cores may be disturbed in fractured rock, provides good recovery and continuous stratigraphy
Percussive Method	Impact drill used; cuttings removed by compressed air	Rock dust and chips	To locate rock, soft seams, or cavities in sound rock; advance through boulders	Drill may become plugged by wet soil

Table 2-8 Soil and Rock Investigation Equipment and Their Applications (NCHRP 2018 and Australian Drilling Industry Training Committee 2015)

Rig Type	Application
Truck-mounted drill rigs	Areas with easy access
All-terrain vehicles drill rigs	Sites with soft ground and rugged terrain
Track-mounted drill rigs	Sites with swampy and very soft ground
Skid drill rigs	Sites with steep terrain
Wireline drill rigs	Rock sampling
Hydraulic direct-push rigs	Fast, continuous sampling, cleaner (no spoils)
Sonic rigs	Continuous sampling of soil and rock
Barges – regular	Over water drilling for shallow water depths (10 ft. [3 m] or less)
Jack up platforms	Over water drilling for areas with deep water (up to 40 ft. [12 m])

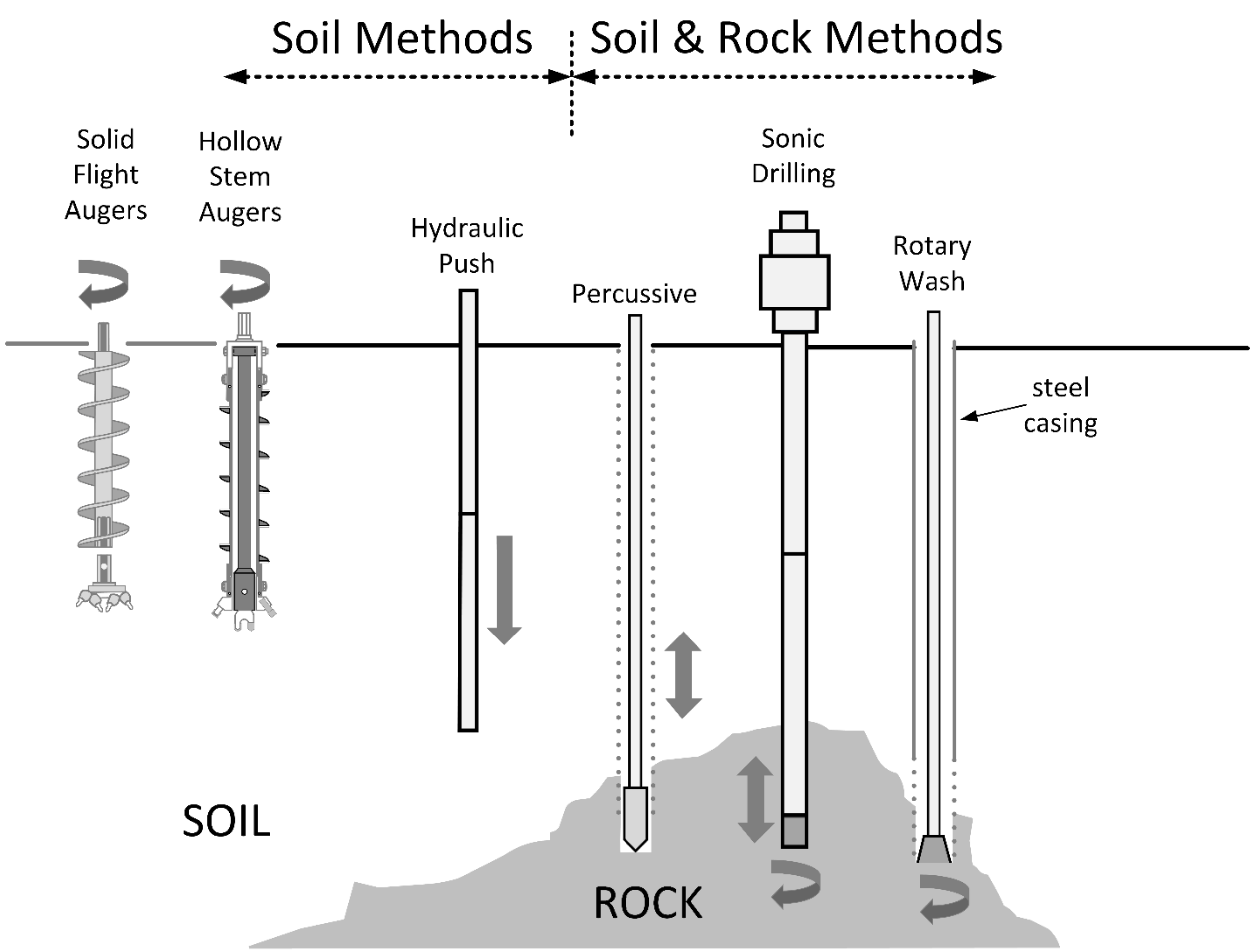


Figure 2-1 Schematic of Various Drilling Techniques for Soil and Rock (after NCHRP 2018 and Mayne 2012)

2-5.1.1 Boring Layout and Depth.

General guidance for preliminary and final boring layout (i.e., location and number of borings) and the depth of the borings is presented in Table 2-9 according to the type of structure and/or problem being investigated. Additional discussion of the spacing and number of borings is presented in FHWA (2002). In addition to structure type, boring layout and depth are strongly dependent on past experience in the region (or at the site) and the site/region geology. When a project is in an unfamiliar area, at least one boring should extend well below the zone necessary for apparent stability to verify that the site conditions are consistent with the anticipated geology and to assure no unusual or unanticipated condition exist at depth.

The site geology is an important factor in developing the boring layout and should influence the arrangement of borings so that geological sections may be viewed in the context of the final design. This requires review of geologic maps of the area and compilation of the information in a format that allows the geology, existing topography, current site plans, and boring locations to be presented at similar scales on the same figure/drawing.

In cases where detailed settlement, slope stability, or seepage analyses are required, the boring plan should include a minimum of two borings in each critical stratum to obtain intact samples (if applicable). For some site investigation programs this may mean that preliminary sample borings and/or cone penetration soundings may be needed to determine the most representative location and depth for intact sample borings.

Table 2-9 Selecting Number, Locations, and Depths of Investigation (after NCHRP 2018, FHWA 2002, FHWA 2016, NYDOT 2013, and SCDOT 2010)

Project	Minimum Number of Investigation Locations	Minimum Depth of Investigation[a]
Bridge - shallow foundations	• One location per pier if width of foundation is less than 100 ft. • Two locations per pier if width of foundation is greater than 100 ft. • Additional investigation locations should be included if uncertain or highly variable subsurface conditions are encountered.	• For $L \leq 2B$, use depth of $2B$ • For $2B \leq L \leq 5B$, use depth of $3B$ • For $L \geq 5B$, use depth of $4B$ • Extend below any soft compressible material into competent material • Extend 10 ft. into competent rock if encountered before the above are met.
Bridge - deep foundations	• One location per pier if width of foundation is less than 100 ft. • Two locations per pier if width of foundation is greater than 100 ft. • Additional investigation locations should be included if uncertain or highly variable subsurface conditions are encountered • At each shaft location for rock sockets	• In soil, extend below the anticipated tip or base elevation the greater of 20 ft. or 2x the maximum group dimension. • In rock, extend below anticipated tip or base elevation a minimum of 10 ft. or 3x shaft diameter for isolated piles/shafts or 2x maximum group dimension, whichever is greater.

[a] B = footing width and L = footing length

Table 2-9 (cont.) Selecting Number, Locations, and Depths of Investigation (after NCHRP 2018, FHWA 2002, FHWA 2016, NYDOT 2013, and SCDOT 2010)

Project	Minimum Number of Investigation Locations	Minimum Depth of Investigation[a]
Retaining structures	• A minimum of one location for each wall. If the wall is greater than 100 ft. long, spacing should be 100 to 200 ft. with locations alternating in front to behind the wall. • Anchored walls: Additional locations in the anchorage zone spaced at 100 to 200 ft. • Soil nail walls: Additional locations behind the wall at a distance of 1 to 1.5x the wall height; spacing should be at intervals of 100 to 200 ft	• Extend below bottom of the wall 2x the wall height or 10 ft. into hard rock. • Should extend below any soft compressible material into competent material.
Roadway - embankment foundations	• Along embankment centerline: spacing of 200 ft. in uncertain or highly variable conditions to 400 ft. in uniform conditions • At critical locations (maximum height or maximum depth of soft strata): a minimum of three locations along the transverse direction • Bridge approach embankment: a minimum of one location per abutment	• Depth of 2x the embankment height unless a hard stratum is encountered above this depth. • If soft strata are encountered extending to a depth greater than 2x embankment height, extend below the soft strata into competent material.
Roadway cuts	• Along centerline of cut: spacing of 200 ft. in uncertain or highly variable conditions to 400 ft. in uniform conditions • At critical locations (maximum cut depth or maximum depth of soft strata): a minimum of three locations along the transverse direction • For cut slopes in rock: perform geologic mapping along the length of the cut slope.	• Minimum depth of 15 ft. (4.5 m) below lowest cut elevation unless a hard stratum is encountered before the minimum depth is achieved. • If soft strata are encountered, extend investigation to a competent layer. • If base of cut extends below groundwater level, extend depth of investigation to determine the depth of the underlying pervious strata.
Pavements	• Spacing of 100 to 300 ft. depending on the subsurface conditions. Closer spacing for uncertain or highly variable conditions and longer spacing for uniform conditions.	• Minimum depth of 10 ft. from the proposed top of subgrade elevation.
Culverts and pipes	• One boring at each end of the culvert. • Additional borings between the end of culvert spaced at 100 to 300 ft. depending on the variability of the subsurface conditions • For culvert extensions: one boring every 50 to 100 ft. with a minimum of one boring	• Large culverts: same criteria as for bridge foundations • Small culverts: Minimum of 10 ft. below anticipated invert elevation
Poles, masts and towers	• One boring at each foundation location	• 30 ft. below the anticipated top of foundation in soil or 10 ft. of rock coring whichever is shallower.

[a] B = footing width and L = footing length

2-5.1.2 Abandoning or Sealing Boreholes.

Boreholes should be backfilled. Often, backfilling with the drill cuttings is sufficient. However, boreholes must be sealed with grout in cases where the borings are advanced below groundwater, in all cases where artesian pressures are encountered, and whenever environmental borings are advanced. Under these conditions, boreholes may be left temporarily unfilled to use for water-level observations after the initial field investigation drilling is completed. In boreholes for groundwater observations, the casings should be placed in tight contact with walls of boreholes or the annular space between the standpipe and borehole should be backfilled using the appropriately graded sand or gravel. Many agencies, such as the USACE and state DOTs have specific guidelines for sealing boreholes, and these are part of the project specifications. Additional discussion of details regarding groundwater investigation is presented in Section 2-8.

2-5.2 Test Pits and Test Trenches.

Test pits are commonly used to examine and sample soils *in situ* at relatively shallow depths. Test pits can be used to determine the depth to shallow groundwater, thickness of topsoil or surficial deposits, and/or to assess near surface conditions. Test pits are often used to determine sources of construction materials for earthwork projects, such as dams and embankments. Test pits range from shallow, hand-excavated pits or (more commonly) machine-advanced excavations.

Test trenches are essentially long test pits and are particularly useful for exploration in very heterogeneous deposits (e.g., rubble fills) where borings may be misleading, meaningless, or not feasible. Test trenches are used commonly for detection of fault traces in seismicity investigations and for investigating conditions near a slide plane in a landslide investigation. Safety precautions need to be recognized when working in and around test pits and trenches.

Table 2-10 provides guidance for the use and limitations of test pits and trenches. Hand-cut, block samples are frequently obtained from these explorations and may be necessary for sensitive soils, brittle and weathered rock, and soil formations exhibiting a honeycomb structure.

2-5.3 Other Exploratory Techniques.

Once a hole is advanced in either soil or rock, downhole tools can be placed in the open hole to make specific measurements or serve as carriers for geophysical testing instruments. Borehole cameras are commonly used for open holes in rock to assess stratigraphy, as well as strike and dip of the formation. Geotechnical performance monitoring instruments (i.e., slope inclinometers, water pressure transducers, borehole extensometers, etc.) can also be placed in the advanced borehole.

2-6 SAMPLING.

Recovery of representative samples of the subsurface soil and rock for testing is perhaps the most common goal of the techniques in Section 2-5. These samples are commonly referenced as *disturbed* or *undisturbed* depending on how well the recovered sample maintains the structure of the *in situ* material. Disturbance is initiated by the process of removing the soil/rock from the confined conditions in the subsurface. Thus, an "undisturbed" sample is actually a misnomer, as it (hopefully) represents a *minimally* (or *nominally*) *disturbed* sample. The term *intact sample* has largely replaced *undisturbed sample* in geotechnical engineering vernacular.

Table 2-10 Use and Limitations of Test Pits and Test Trenches (after NCHRP 2018)

Exploration Method	General Use	Capabilities	Limitations
Hand-excavated test pits and shafts	Bulk sampling, *in situ* testing, visual inspection	Provides data in inaccessible areas, less mechanical disturbance of surrounding ground.	Expensive, time-consuming, limited to depths above groundwater level.
Backhoe excavated test pits and trenches	Bulk sampling, block sampling, *in situ* testing, visual inspection, depth of bedrock and groundwater.	Fast and economical, generally less than 15-feet deep, can be up to 30-feet deep	Equipment access, generally limited to depths above groundwater level, limited intact sampling.
Drilled shafts	Pre-excavation for piles and shafts, landslide investigations, drainage wells.	Fast, more economical than hand excavated, min. 30-inches dia., max. 6-feet dia.	Equipment access, difficult to obtain intact samples, casing obscured visual inspection.
Dozer cuts	Bedrock characteristics, depth of bedrock and groundwater level, rippability, used in conjunction with backhoes for deeper excavations, used to level areas for other exploration equipment.	Relatively low cost, create exposures for geologic mapping.	Exploration limited to depth above groundwater level.
Trenches for fault investigations	Evaluation of presence and activity of faulting and sometimes landslide features.	Definitive location of faulting, subsurface observation up to 30 feet.	Costly, time-consuming, requires shoring, only useful where dateable materials are present, depth limited to zone above groundwater level. Specialized application.

Disturbed samples are primarily used for index tests that are performed for classification. A disturbed sample needs only to be representative of the soil composition and moisture because the soil structure is disturbed. Intact samples are obtained primarily for laboratory strength, compressibility, and permeability tests. The *in situ* structure and composition significantly influence the strength, compressibility and permeability (i.e., engineering) properties of the soil. Most of the discussion in this section focuses on sampling from terrestrial or shallow-water locations. Offshore samplers are specialized and are treated separately in Section 2-6.3.

The number and type of samples depend on the stratification of the subsurface, the type of material encountered, the quantity needed for testing, and the criticality of the application. For most projects, both disturbed and intact samples are obtained for testing.

2-6.1 Soil Sampling.

2-6.1.1 Disturbed Soil Samples.

In general, representative disturbed samples are obtained at vertical intervals of no less than 5 feet and at every change in strata. Continuous samples are occasionally required or justified. This may be the case when a relatively thin layer of critical material is anticipated. Table 2-11 lists common types of disturbed samples and samplers. Recommended procedures for obtaining disturbed samples are provided in ASTM D1586. The split barrel (a.k.a., split spoon) sampler, depicted in Figure 2-2, is the most commonly used sampler.

Table 2-11 Samplers to Collect Disturbed Soil Samples

Sampler (Method of Penetration)	Typical Dimensions	Soils that Give Best Results	Cause of Low Recovery	Remarks
Split Barrel (140-lb hammer driven)	2.0-inch outside diameter (OD), 1.375-inch inside diameter (ID)	All soils finer than gravel-size particles; gravels invalidate drive data; soil retainer may be used in coarse-grained soils	Gravel-sized particles and larger	Standard Penetration Test (SPT) performed using this hammer and sampler and hammer; samples are extremely disturbed
Continuous helical-flight auger (Rotation)	3- to 16-inch diameter; penetration to depths exceeding 50 ft.	Most soils above water table; will not penetrate hard soils or those containing cobbles or boulders	Hard soils, cobbles, boulders	Method of determining soil profile, bag samples can be obtained; log and sample depths must account for lag time between penetration of bit and arrival of sample at surface
Bucket auger (Rotation)	Up to 48-inch diameter common; with extensions, depth over 80 ft. are possible	Most soils above water table; can penetrate harder soils than above types, can penetrate cobbles and boulders with a rock bucket	Soil too hard to penetrate	Several bucket types available, including those with ripper teeth and chopping tools; progress is slow when extensions are used
Large Penetration Test (LPT) (Up to 300-lb hammer driven)	2- to 3-inch ID, 2.5- to 3.5-inch OD samplers, (e.g., Converse and California samplers)	Sandy to gravelly soils	Particles large than coarse gravel	Sample is intact but very disturbed; A resistance can be recorded during penetration, but is not equivalent to the SPT N value and is more variable due to no standard equipment and methods

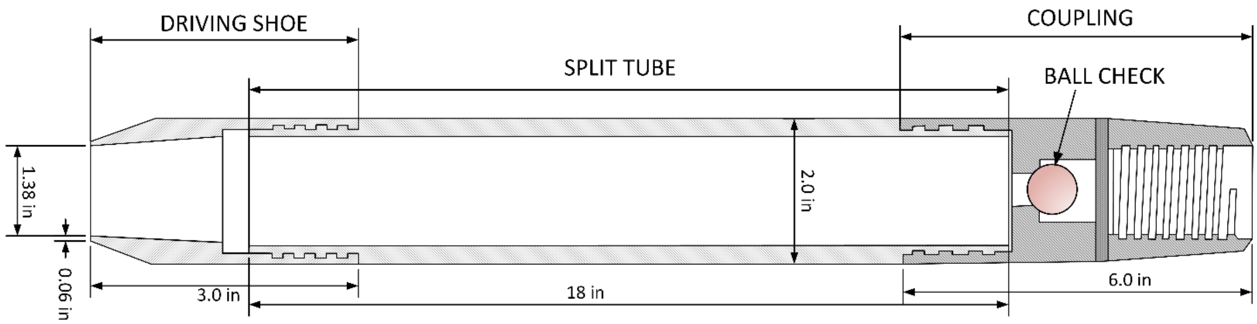


Figure 2-2 Cross Section of Split Barrel Sampler

2-6.1.2 Intact Soil Samples.

Intact (or “undisturbed”) samples are most commonly obtained using a thin-walled steel tube (Shelby tube) that is pushed at a relatively rapid and constant rate following procedures in accordance with ASTM D1587. Intact sampling and samplers should provide samples that comply with the following criteria: (1) show no visible distortion of strata, (2) include no visible openings or softened material, (3) exhibit a recovery ratio (i.e., sample length divided by distance of sample push) that exceeds 95 percent, (4) have an area ratio (i.e., area displaced by the sampler tube divided by the area of the sample) of less than 15 percent, and (5) have a clearance ratio (i.e., the difference between the diameter of inside of the tube and the diameter of the opening at the bottom of the tube divided by the diameter of the opening at the bottom of the tube) as small as possible but less than 3 percent. A schematic and photograph of a thin-walled Shelby tube that meets these criteria is presented in Figure 2-3.

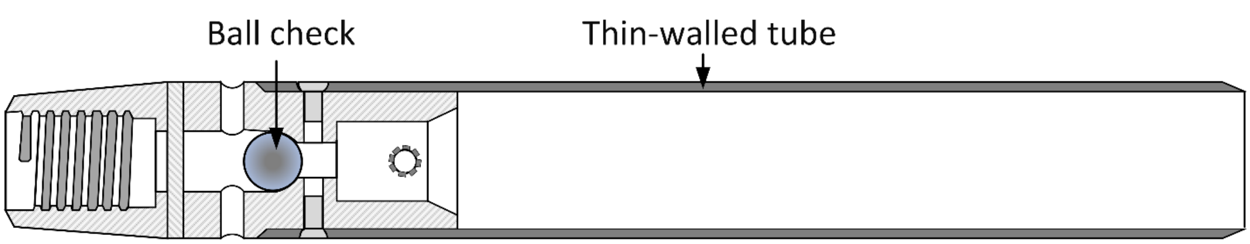


Figure 2-3 Cross Section of Shelby Tube Sampler with Ball-check Valve Head

In general, intact samples of clean sands and gravels cannot be obtained, even when using thin-walled samplers. For this reason, *in situ* testing methods are commonly used in these soils, and intact sampling focuses on silts, clays, and coarse-grained soils with a significant amount of silty and clayey fines. Because fine-grained soils can vary from very soft to very hard, different types of samplers have been developed to facilitate the recovery of intact samples. Table 2-12 summarizes common types of samplers used for intact soil samples.

Table 2-12 Samplers Used to Collect Intact Soil Samples

Sampler	Typical Dimensions	Method of Penetration
Shelby tube (ASTM D1587)	3.0-inch OD and 2.87-inch inside diameter (ID) most common; available from 2- to 5-inch OD; 30-inch sampler length standard	Pressing with relatively rapid, smooth stroke; can be carefully hammer driven but this will induce additional disturbance
Fixed or Stationary piston	3-inch OD most common; available from 2- to 5-inch OD; 30-inch sampler length standard	Pressing with continuous, steady stroke
Foil Sampler	Continuous samples with 2-inch ID; up to 65 ft. long	Pushed into the ground with steady stroke; Pauses occur to add segments to sampler
Hydraulic piston (Osterberg)	3-inch OD is most common; available from 2- to 4-inch OD; 36-inch length standard	Hydraulic or compressed air pressure
Denison	3.5- to 7-inch OD, producing samples 2.4 to 6.3 inches; 24-inch sampler length standard	Rotation and hydraulic pressure
Pitcher sampler	4-inch OD; uses 3-inch diameter Shelby tubes; sample length 24 inches	Same as Denison

Sampler	Soils that Give Best Results	Cause of Disturbance or Low Recovery	Remarks
Shelby tube (ASTM D1587)	Cohesive fine-grained or soft soils; gravelly / very stiff soils will crimp tube	Erratic sampling pressure, hammering, gravel particles, crimping of tube edge, improper soil types, pressing more than 80% of tube length	Simplest device for undisturbed samples; clean boring before sampler is lowered; little waste area in sampler; not suitable for hard, dense or gravelly soils
Fixed or Stationary piston	Soft to medium clays and fine silts; not for hard, dense, sandy, or gravelly soil	Erratic pressure during sampling, allowing piston rod to move during press, improper soil types for sampler	Piston at end of sampler prevents entry of fluid and contaminating material, requires heavy drill rig with hydraulic drill head; less disturbance than Shelby tube
Foil sampler	Soft sensitive clays, silts, and varved clays	Samplers should not be used in soils containing fragments or shells	Samples surrounded by thin strips of stainless steel, stored above cutter, to prevent contact of soil with tube
Hydraulic piston (Osterberg)	Silts and clays, some sandy soils	Inadequate clamping of drill rods, erratic pressure	Needs only standard drill rods; requires adequate hydraulic or air capacity to activate sampler; samples generally less disturbed compared with Shelby tube; not suitable for hard, dense, or gravelly soil
Denison	Stiff to hard clay, silt, and sands with some cementation, soft rock	Improper operation of sampler; poor drilling procedures	Inner tube face projects beyond outer tube, which rotates; amount of projection can be adjusted; generally good samples; not suitable for loose sands and soft clays
Pitcher sampler	Same as Denison	Same as Denison	Differs from Denison in that inner tube projection is spring controlled; often ineffective in cohesionless soils

For soft soils, a stationary (or fixed-piston) sampler (Figure 2-4) or hydraulic piston sampler is commonly deployed. For very soft soils and varved clays, a foil sampler may be deployed, although limited in use in the United States.

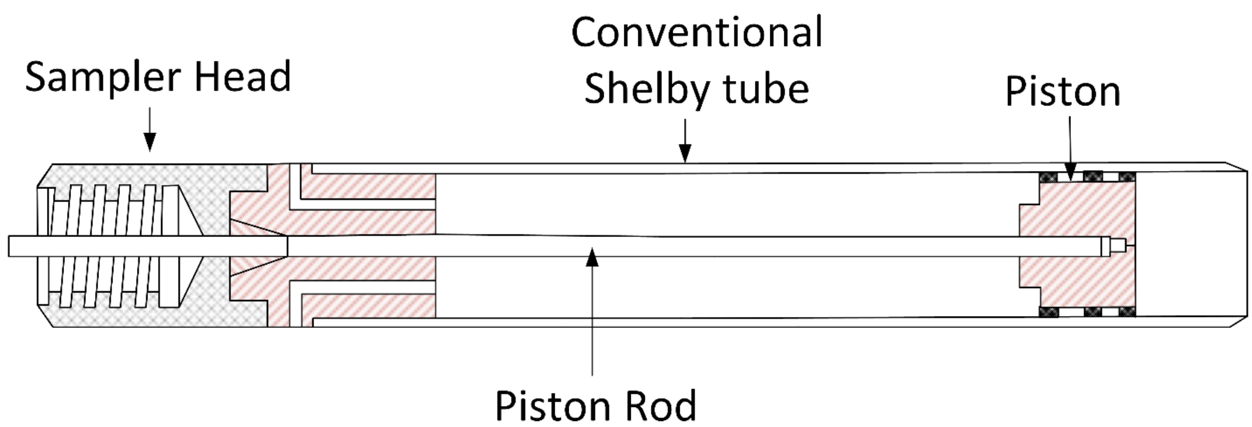


Figure 2-4 Cross Section of a Stationary or Fixed Piston Sampler

For stiff fine-grained soils, or for layers of soft and hard materials, special samplers have been developed that have the ability to "core" around the recovered stiff materials while capturing the softer materials in the same thin-walled tube. The Denison sampler and the Pitcher sampler are two types of common samples for these subsurface conditions.

2-6.1.3 Intact Samples from Test Pits and Test Trenches.

One of the advantages of test pits and test trenches is that hand-trimmed (i.e., block) samples may be obtained from the bottom or the sidewalls of the test pits and test trenches. These block samples are potentially the least disturbed of all types of samples. Unfortunately, the test pits and trenches are only feasible to a limited depth.

To obtain a block sample, a column of soil is trimmed the same size or slightly smaller than the container that will be used for transporting the sample. The container should be placed over the top of the sample and should provide as small an annular space as possible. This annular space ideally would be filled using wax. A tight fit in a stiff container that can be sealed provides the ideal conditions for retrieving and transporting block samples with least disturbance.

2-6.2 Rock Sampling.

Rock is sampled with core barrels that have either tungsten carbide or diamond core bits at the cutting face. Drill rods and core barrels come in a variety of standard sizes (see Table 2-13), depending on the size of the recovered rock core.

Table 2-13 Standard Size of Rock Casing, Drill Rods, Core Barrels, and Coreholes (after ASTM D2113)

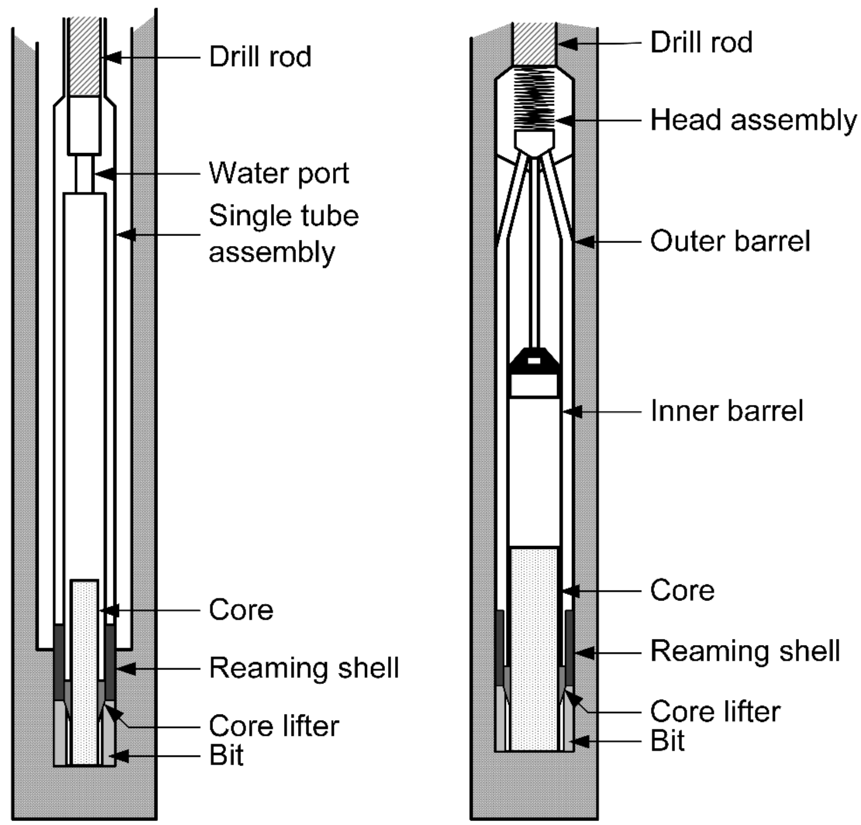
Casing, Core Barrel	Drill Rod	Casing OD (in.)	Casing Bit OD (in.)	Core Barrel Bit OD (in.)	Drill Rod OD (in.)	Approx. Diameter of Corehole (in.)	Approx. Diameter of Core (in.)
EX	E	1-13/16	1-7/8	1-7/16	1-5/16	1-1/2	7/8
AX	A	2-1/4	2-11/32	1-27/32	1-5/8	1-7/8	1-3/16
BX	B	2-7/8	2-31/32	2-5/16	1-29/32	2-3/8	1-5/8
NX	N	3-1/2	3-5/8	2-15/16	2-3/8	3	2-1/8

For hard and massive rock, relatively undisturbed rock samples may be obtained using just the core barrel to recover the sample. More commonly, a tube (or series of tubes) is used to contain the rock core and the tube is isolated from the core barrel to minimize disturbance. Inner tubes must be used for undisturbed rock sampling whenever the rock includes discontinuities. Table 2-14 lists summarizes techniques for recovery of relatively undisturbed samples of rock.

Table 2-14 Common Samplers for Rock Cores (after NCHRP 2018)

Diamond Core Barrels			
Dimensions		**Best Results in Soil or Rock Types**	**Methods of Penetration**
Standard sizes: 1-1/2” to 3” OD, 7/8” to 2-1/8” core. Barrel lengths 5 to 10 feet for exploration.		Hard rock. All barrels can be fitted with insert bits for coring soft rock or hard soil.	Rotary drilling using water or slurry
Details for tube sampling			
Type	**Causes of Disturbance or Low Recovery**	**Best Results in Soil or Rock Types**	**Remarks**
Single Tube	Fractured rock. Rock too soft.	Primarily for strong, sound and uniform rock.	Drill fluid must circulate around core – rock must not be subject to erosion. Single tube not often used for exploration.
Double Tube	Improper rotation or feed rate in fractured or soft rock.	Non-uniform, fractured, friable and soft rock.	Has inner barrel or swivel which does not rotate with outer tube. For soft, erodible rock. Best with bottom discharge bit.
Triple Tube	Same as Double Tube	Same as Double Tube.	Differs from Double Tube by having an inner split tube liner. Intensely fractured rock core best preserved in this barrel.

Double tube core barrels are the most commonly used in practice. Depending on the number of discontinuities in the rock, the recovered sample may be considered either disturbed or undisturbed. Schematics of single and double tube rock core samplers are provided in Figure 2-5(a) and (b), respectively.



(a) Single Tube (b) Double Tube

Figure 2-5 Rock Core Samplers (after NCHRP 2018)

The suitability of rock cores for structural property tests depends on the quality of individual recovered samples. If the properties of the intact rock are desired, then smaller diameter cores are recommended because large-diameter rock cores likely include more discontinuities than small-diameter rock cores.

The percentage of core recovery (i.e., recovered core length divided by the recorded core run) provides an indication of soundness and degree of weathering of rock. The Rock Quality Designation, *RQD,* (i.e., total length of recovered core pieces greater than 4 inches in length divided by the recorded core run) provide a better indication of the soundness and degree of rock weathering because it essentially disallows the consideration of the fractured and weathered rock intervals. The *RQD* is also a major factor in assessing the behavior of the *in situ* rock mass, as defined by the Rock Mass Rating (*RMR*) of the rock. The engineer and geologist should carefully examine rock core samples exhibiting low recovery and/or low *RQD* to assess the reasons for low recovery and the interpreted poor rock quality. Details regarding on rock classification and rock properties are presented in Chapter 1 and in NCHRP (2018).

Sampling of highly (or partially) weathered, fractured, or disintegrated rock is extremely difficult. These materials often occur near the interface between soil and rock and represent the transition between these two materials, especially in the case of residual soils. The best samples of these materials are obtained by experienced drillers using double- or triple-core barrel samplers.

2-6.3 Offshore Sampling.

In some cases, samples of soil and rock must be obtained from the bottom of rivers, lakes, or the ocean. For water depths less than about 60 feet, the conventional soil and rock boring equipment can be used on small jack-up platforms, small barges, or barrel floats. The challenge is that floating equipment requires suitable anchoring and is limited to fairly calm water, although tidal fluctuations can be easily accommodated. For deep water sites and/or extreme ocean settings, large dedicated drill ships, specialized equipment, and experience are required to obtain quality intact samples. Table 2-15 identifies some of the specialized equipment used for underwater sampling.

Numerous types of oceanographic samplers, both open-tube and piston types, are available for use when drilling from ships. Some of these depend upon free-fall penetration and are limited in the depth of exploration. Drilling and sampling from the ocean floor can be accomplished using specialized equipment deployed remotely from portable equipment that is deployed in underwater vessels or on underwater platforms operating on the ocean floor. The quality of samples obtained by most oceanographic samplers is not high because of their large length to diameter ratio and because air/gas in the dissolved state in the underwater environment comes out of solution when the sample is recovered at the ground surface. For detailed information on underwater sampling equipment, refer to ASTM STP 501 (ASTM 1972).

2-6.4 Field Logging and Boring Logs.

While monitoring drilling and sampling activities, an engineer, geologist, or experienced driller prepares a *field boring log* to document the findings and observations. This field logging is an important part of documenting the soil and rock conditions that exist at the project site. A typical field log includes all the relevant information for the boring that was completed, including a unique boring identification number, date of drilling, personnel on-site, boring advancement method (i.e., auger, rotary wash, direct push, sonic), depths where samples were obtained, type of samples (i.e., split-barrel and Shelby tube), hammer type, raw SPT N values, water level observations, and preliminary estimates of stratigraphy. If available, the global positioning system (GPS) coordinates should be included. The field log provides a unique designation of each recovered sample, whether disturbed or intact, as well as a field visual classification of the sample in accordance with ASTM D2488.

Table 2-15 Common Underwater Samplers (after NCHRP 2018)

Sampler	Size of Sample	Length of Sample	Water Depth Limitations	Method of Penetration	Remarks
Peterson Dredge	Grab	± 6-inch depth	To 200 ft. and more with additional weight	Clam shell jaw	Reliable grab sampler; intact samples may be obtained with jaws that precisely mate
Open Barrel Gravity Corer	2.5- to 6-inch diameter	Core barrels length from 6 to 30 ft	No limit on depth but required weight, amount of line or size of vessel may control	Spooled freely off the winch drum	
Pflueger Corer	About 1.5-inch diameter	Core barrels available in 12, 24 and 36 in. length	From 25 to 200 ft	Free fall from 10 to 20 ft. above bottom	Relatively light weight core for upper 1 to 3 ft. of bottom sediments; usually not suitable for strength tests
Piston Gravity Corer	Standard corer has 2.5-in. barrel	Standard barrel is 10 ft. Additional 10 ft. sections can be added	No depth limit except that available weight, amount of line, or size of vessel may control	Free fall from calibrated height above bottom such that piston does not penetrate sediments	Capable of obtaining samples suitable for strength tests with experienced crew; samples may be seriously disturbed
Vibratory Corer	Sample is 3.5-in. diameter	20 ft. standard, can be lengthened to 40 ft.	Minimum depth limited by draft of support vessel; maximum depth about 200 ft.	Pneumatic impacting vibratory hammer	Samples are disturbed because of vibration and large area ratio; not suitable for strength testing; Penetration resistance can be measured; obtains continuous samples in marine soils

The field log, the recovered samples, and lab/field testing results are used to produce the *final boring log*, which represents the official engineering record of the drilling and sampling efforts. The boring log provides the permanent, technical documentation of the materials encountered during drilling, sampling, and coring. The geotechnical engineer or geologist uses the results from the field and their training/experience to group samples/records together based on color, soil type, and SPT N values and identify layers or strata, which may be consistently found in the adjacent companion borings from the site. An example of the engineering boring log is shown as Figure 2-6. In the final engineering boring logs, soil types are categorized according to a user- or agency-specified soil classification system. The most common soil classification systems in the United States include the Unified Soil Classification System (USCS) (ASTM D2487 or D2488), the AASHTO system, and the United States Department of Agriculture (USDA) system.

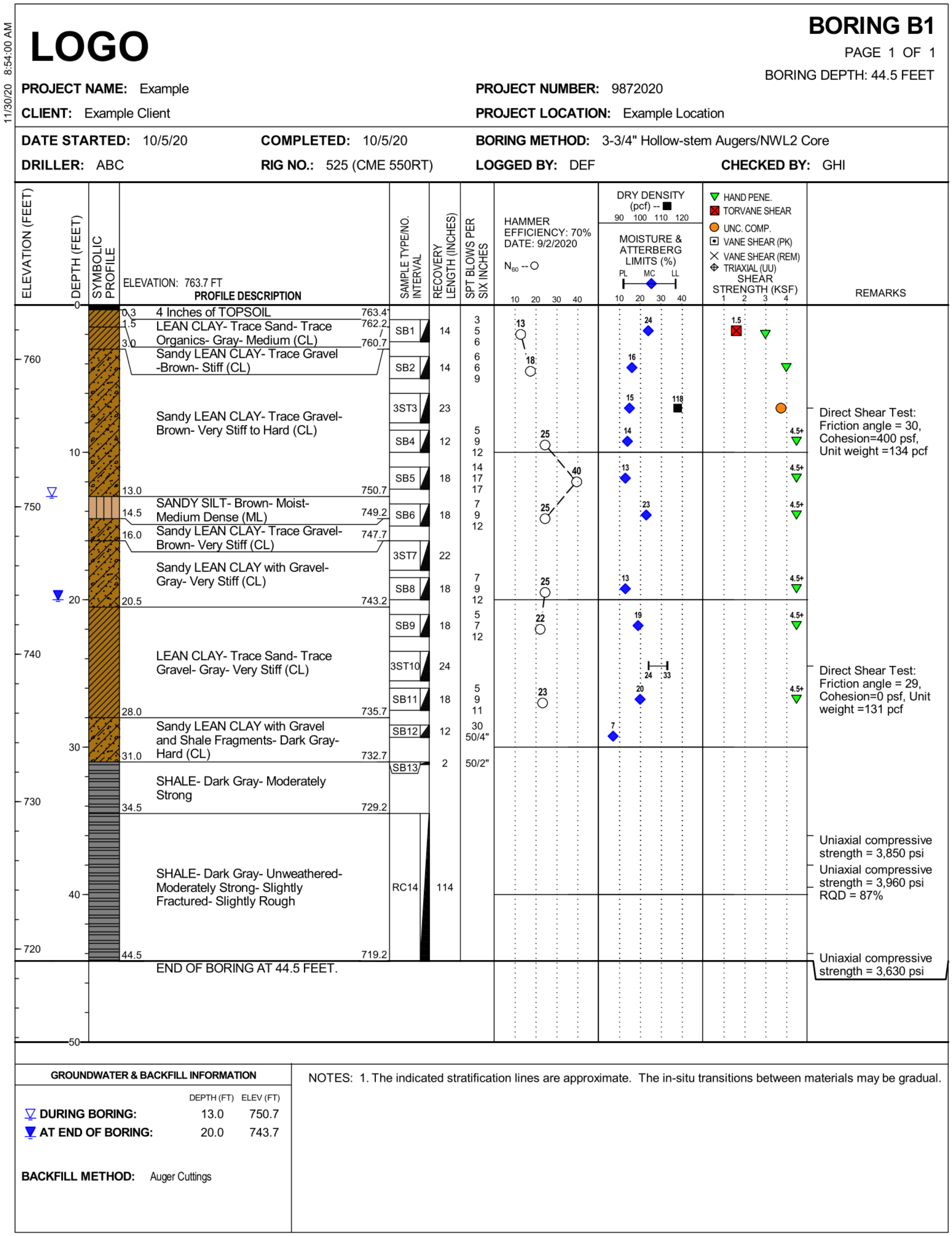


Figure 2-6 Example Geotechnical Boring Log

In addition to the soil classification, the boring log description should also include color, relative density (e.g., loose, dense, etc.) or consistency (e.g., soft, medium, hard, etc.), and the presence of organics, shells, peat and/or manmade materials. Identification of these additional features may impact engineering performance and may prove beneficial in subsequent construction/excavation phases of the project.

2-7 PENETRATION RESISTANCE TESTS.

Penetration resistance tests are the most common *in situ* testing techniques for characterizing subsurface conditions. The most common field penetration test remains the *Standard Penetration Test* (SPT), which measures resistance to the penetration of a standard, thick-walled drive sampler in an open borehole using a drop hammer. A more controlled and increasingly popular test is the *Cone Penetration Test* (CPT), which utilizes a standard cone-shaped instrument that is pushed at a standard constant rate from the ground surface. Another common test is the *flat plate dilatometer* (DMT). This device utilizes a robust steel blade that is pushed into the ground at a constant rate and then periodically stopped to allow the controlled measured inflation of a flexible steel membrane. In many parts of the United States, particularly when stiff soils and//or granular soils are encounters, a *dynamic cone penetration* (DCP) test is performed by driving a standard sized cone into the ground using a drop hammer. This section provides information regarding these four penetration tests. Section 2-9 will address other common *in situ* testing methods.

2-7.1 Standard Penetration Test (SPT).

The SPT was originally developed in the 1900s and proceeds by driving a thick-walled, split-barrel (a.k.a., “split spoon”) sampler into the ground using incremental blows from a drop hammer. The sampler is driven a total of 18 inches into the ground. The number of blows required to drive the sampler the 12-inch vertical interval between 6 and 18 inches is referred to as an N value or the *blow count*. The procedure is presented in ASTM D1586, and a schematic of the SPT is presented in Figure 2-7.

The SPT provides a disturbed sample of the tested material and generates useful data that can be used to correlate to many engineering properties. Many factors can affect the SPT results, and there are several vastly superior *in situ* testing methods. Nevertheless, the test is still almost universally referenced and often required in the United States. One reason for this is the large amount of historical (i.e., legacy) data available. Numerous correlations have been published (see Chapter 8) and their use along with SPT represents the Standard of Practice in many parts of the country.

2-7.1.1 Corrections to Field Blow Counts.

As an improvement on older donut and safety hammers, most current SPT programs use an automatic hammer that does not rely on an operator-dependent cathead and rope to establish the drop height of the hammer. Modern automatic deliver consistent energy to the sampler, which should be measured periodically. The field-recorded N values may be adjusted to reflect the energy of the specific hammer. The adjustments are intended to correct the N value to the 60 percent hammer efficiency that is assumed for the older equipment and historic correlations. The energy corrected value (N_{60}) can also be normalized to an equivalent value at a vertical stress of one atmosphere. The "overburden corrected" or "normalized" blow count is labeled $(N_1)_{60}$ or $N_{1,60}$. Several correlations to normalized blow count are presented in Chapter 8 and in McGregor and Duncan (1998).

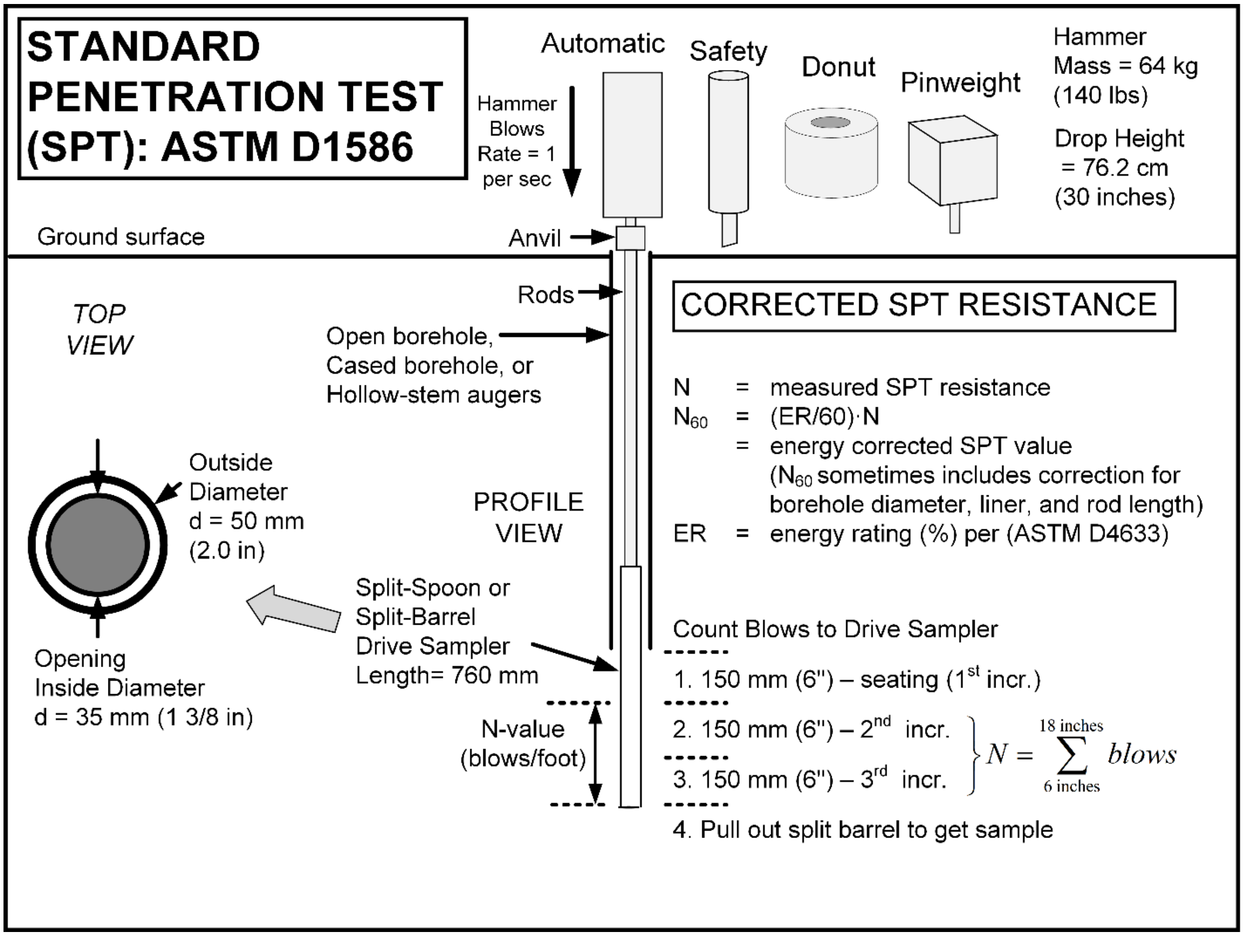


Figure 2-7 Standard Penetration Test (after NCHRP 2018 and Mayne 2012)

2-7.1.2 Advantages and Limitations.

The biggest advantage to the SPT is its near-universal acceptance and use in the United States. As a result, there is a large data set that can be used for correlation.

However, SPT blow counts are affected by many operational procedures, the presence of gravel, and by cementation between the particle grains. In clays, the blow count does not reflect the influence of fractures or slickensides. Table 2-16 presents a summary of the many operational factors that are known to influence the N value measured in the field.

Table 2-16 Factors Affecting the Standard Penetration Test and SPT results (after Kulhawy and Mayne 1990)

Cause	**Effects**	**Influence on SPT N Value**
Sampler driven above bottom of casing	Sampler driven in disturbed, artificially densified soil	Increases greatly
Inadequate cleaning of base of borehole	Test not performed in original *in situ* soil; soil may become trapped in sampler and may be compressed as sampler is driven, recovery reduced	Increases
Careless measure of drop	Hammer energy varies (generally variations cluster on low side)	Increases
Hammer strikes drill rod collar eccentrically	Hammer energy reduced	Increases
Lack of hammer free fall because of ungreased sheaves, new stiff rope on weight, more than two turns on cathead, incomplete release of rope each drop	Hammer energy reduced	Increases
Coarse gravel or cobbles in soil	Sampler becomes clogged or impeded	Increases
Use of bent drill rods	Inhibited transfer of energy of sampler	Increases
Hammer weight inaccurate	Hammer energy varies (driller supplies weight; variations of 5 – 7% common)	Increases or decreases
Careless blow count	Inaccurate results	Increases or decreases
Use of non-standard sampler	Correlations with standard sampler invalid	Increases or decreases
Failure to maintain adequate head of water in borehole	Bottom of borehole may become quick	Decreases

2-7.2 Cone Penetrometer Tests (CPT).

The CPT involves hydraulically pushing an instrumented steel probe at a constant rate to obtain a continuous record of the penetration resistance of the cone tip and the frictional resistance of the soil. The CPT does not produce a borehole, samples, or drill cuttings. The original test involved a mechanically operated cone, referenced as a “Dutch” cone (DPT). The original equipment has been superseded, modified, and improved to allow electronic measurements.

Most modern instruments also include a piezometer near the tip. When equipped with the proper sensors and instruments, the routine performance of the CPT also allows the measurement of temperature, vertical alignment, electrical resistivity, acoustic emissions, and shear wave velocity.

Testing is currently conducted in accordance with ASTM D5778. The test can be conducted without the use of a pore pressure measurement and is referenced simply as the CPT. Alternatively (and commonly) the test is performed using a device to measure pore pressures behind the tip of the probe while pushing. This is referred to as the *piezocone test* (CPTu). Recent advances have allowed the ability to measure the propagation of shear waves using a seismic piezocone, which is referred to as a *seismic CPT* (SCPTu).

2-7.2.1 Equipment and Testing Procedure.

The cone penetration test requires continuous hydraulic advancement of the probe and the simultaneous recording of multiple electronic instruments. Specific equipment and procedures necessary for performing a CPT are summarized as follows:

- Cone Penetrometer: A standard cone penetrometer is a 1.4-inch (35.7-mm) diameter cylindrical probe with a 60° apex at the tip, which results in a projected tip area of 1.55 in^2 (10 cm^2) and a 23.3 in^2 (150 cm^2) instrumented sleeve surface area. Other sizes (both smaller and larger) are available. The size of a cone is typically identified by the projected tip area (i.e., 10-cm^2 cone or a 15-cm^2 cone). A variety of tip load capacities (i.e., 2-ton, 15-ton, etc.) are available.
- Drill Rig/CPT Truck and Cone Rods: A hydraulic actuator is attached to a truck or drill rig that can provide sufficient reaction mass to advance the penetrometer at a constant rate of 2 cm/second. This reaction can be provided using a conventional drilling rig, but dedicated CPT trucks typically weighing 20 to 25 tons have become the standard.
- Water Pressure Transducer: Valuable information can be provided by measuring the pore water pressure behind the cone tip during penetration. For a CPTu, the water pressures are monitored using a transducer and porous filter element.
- Geophone: For the SCPTu, a geophone is located along the drill string at a distance of approximately 20 inches (500 mm) above the cone tip. The geophone detects shear waves generated at the ground surface at specific vertical intervals. During advancement of the seismic cone, a shear wave is generated at the ground surface. An average shear wave velocity of the soils between the ground surface and the geophone can be calculated.

An example record from a CPT sounding is shown in Figure 2-8. This shows a schematic of the CPT probe and the near-continuous vertical profile of cone tip resistance (q_t), sleeve friction (f_s), and pore pressure at the u_2 position (behind the tip).

2-7.2.2 Soil Classification with CPT.

Regardless of the specific type of cone penetration test probe (i.e., CPT CPTu, SCPTu), the testing concept has gained near universal acceptance and interest. As shown in

Figure 2-8, a near-continuous vertical profile of the stratigraphic variations is obtained. A variety of engineering parameters can be estimated from CPT results. Many correlations of CPT data to strength, compressibility, modulus, hydraulic conductivity, and other properties are available, some of which are provided in Chapter 8.

The CPT is able to estimate the soil type of the deposit penetrated. A common method for doing this is shown in Figure 2-9, which relates soil behavior type (SBT) to specific CPT results. This type of correlation is extremely useful for site characterization and subsurface stratigraphy. Other soil type correlations are available.

2-7.2.3 Advantages and Limitations.

The CPT provides numerous advantages, due to its popularity in engineering practice and proliferation of useful correlations to other engineering parameters. The test can be performed quickly. The speed of operation allows considerable data to be obtained in a short period of time, resulting in a continuous record of soil conditions. It is particularly helpful in assessing variability in subsurface conditions across a site.

The major limitation of all cone penetration tests is that discrete samples are not recovered for physical observation and companion testing. The cone can be difficult to advance in dense or stiff to hard soils, and if the operator is not experienced, the probe can be damaged (or destroyed) when encountering these materials. The specialized equipment and the reliance on electronic instrumentation usually requires the services of a specialty vendor to perform the tests.

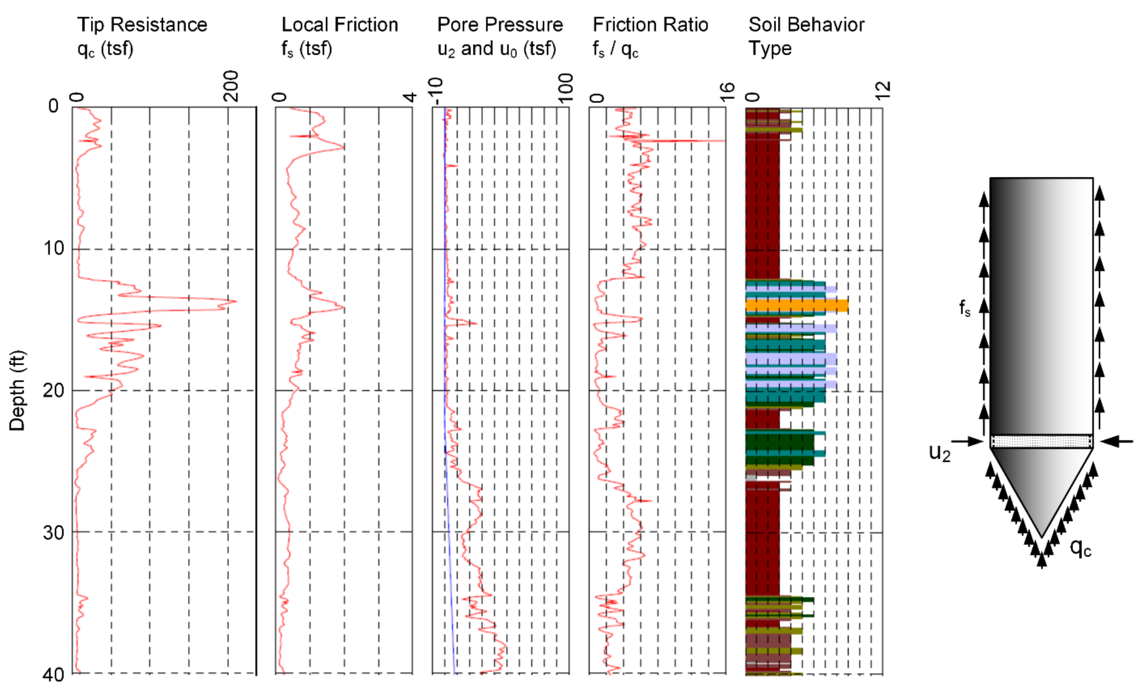


Figure 2-8 CPT - Example Test Record and Equipment

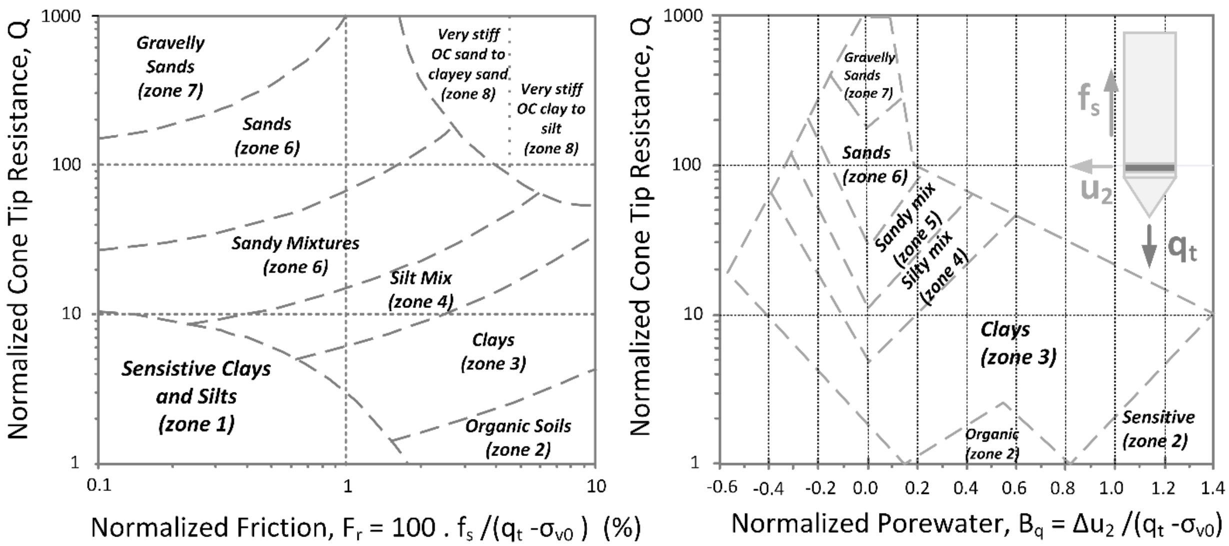


Figure 2-9 Nine Zone (Normalized) Soil Behavioral Chart for CPT (after Robertson 2009 and NCHRP 2018)

2-7.3 Flat Plate Dilatometer.

The flat plate dilatometer test (DMT) was developed in Italy and introduced to the United States practice in the 1980s (Marchetti et al. 2006). It has been widely adopted worldwide and the testing procedures have been standardized in ASTM D6635. The test involves pushing a relatively long and thin flat plate into the ground, generally in 9- to 12-inch vertical increments and then inflating a flexible steel diaphragm while making two or three specific measurements (i.e., A, B, and C). The A reading is the pressure required to lift off the membrane from the face of the blade. The B reading is the pressure required to move the center of the membrane a distance of 0.04 inch (1.1 mm) into the soil. The C reading is an optional reading that can be taken by deflating the membrane until the center of the membrane again contacts the face of the blade. Many practitioners perform the DMT using the same specialized equipment for performing a CPT. In most cases, the test is run without an excavated borehole, so no samples or drill cuttings are produced. However, in some cases, the DMT is lowered into a sampled borehole, advanced approximately 12 inches past the base of the borehole and then inflated as described above. A schematic representation of the test is presented in Figure 2-10.

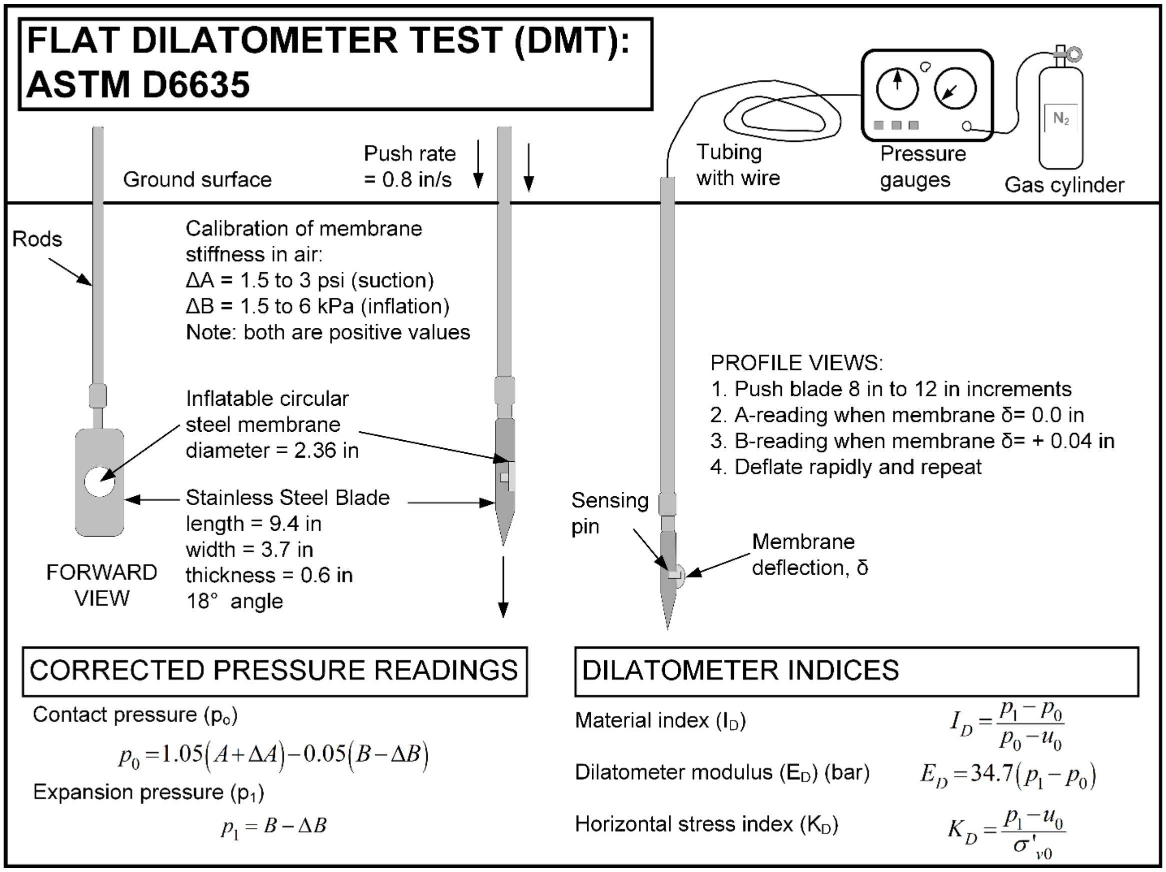


Figure 2-10 Flat Plate Dilatometer Test Schematic (after NCHRP 2018 and Mayne 2012)

2-7.3.1 Equipment, Procedure, and Results.

A photograph of the flat plate dilatometer is presented in Figure 2-11(a), and the control unit used to perform the test (i.e., control inflation and deflation of the membrane) is shown in Figure 2-11(b). The dilatometer blade is nominally 3.75-inches (95-mm) wide, 0.60-inches (15-mm) thick, and 7.5-inches (190-mm) tall with a 30° apex angle at the tip. A 2.4-inch (60-mm) diameter stainless steel membrane is used. The membrane is typically 0.008-inches (0.20-mm) thick and requires careful calibration. The control unit uses bottled gas (nitrogen) supply. A CPT rig is often used to push the dilatometer at a rate of about 0.4 to 1.2 inches/second (1 to 3 cm/s). The vertical thrust is typically monitored and recorded during the test.

(a) Flat plate dilatometer (b) Control unit

Figure 2-11 Flat Plate Dilatometer and Control Unit (Marchetti et al. 2006)

The DMT method and calculations are summarized in Figure 2-10. For more details about the test procedure, refer to NCHRP (2018). The reduced DMT test results produces three values, p_0, p_1, and u_0, from which the following DMT index values are directly calculated for each test depth:

- Material Index, $I_D = (p_1 - p_0) / (p_0 - u_0)$, which is used to identify soil type;
- Dilatometer Modulus, $E_D = 34.7 \times (p_1 - p_0)$ in units of atmospheres, which is a measure of soil stiffness; and
- Horizontal Stress Index, $K_D = (p_1 - p_0) / \sigma'_{v0}$, which is used to assess stress history.

These three indices are typically plotted with respect to test depth to develop a near-continuous vertical profile. Similar to the techniques used for the CPT, these directly calculated values are used to estimate important engineering parameters, including strength, compressibility, modulus, lateral earth pressure) by semi-empirical correlations. A summary of correlations to the DMT results is presented Chapter 8.

2-7.3.2 Advantages and Limitations.

The DMT provides multiple advantages. The test can be performed relatively quickly using a variety of insertion equipment. The probe itself is relatively simple to maintain and training is not particularly onerous. It provides some information regarding horizontal stress and stiffness, which the SPT and CPT are unable to provide.

A major limitation of the dilatometer is that the thin blade and particularly, the diaphragm, can be easily damaged when penetrating soil with particles the size of coarse sand or larger. The diaphragm can be replaced, but the break-in and calibration procedures must be performed, and that can often be difficult to do in the field. The specialized equipment needs to be maintained and properly cleaned between tests, as erratic electric signaling has been experienced when humid conditions exist beneath the membrane. Caution should be used when using dilatometer correlations directly for engineering design parameters.

2-7.4 Dynamic Cone Penetrometer.

Like the CPT, the dynamic cone penetrometer (DCP) has seen a historical evolution. In the United States, the device was developed in the late 1950s in the southeastern United States, primarily to confirm near-surface conditions for spread footings and as a potential surrogate for the SPT. This original, heavier DCP correlate closely with the SPT blow count but was not formally standardized. The United States Army Corps of Engineers (USACE) developed a lightweight DCP that correlates to SPT N values and California Bearing Ratio, CBR (Webster et al. 1992). This lightweight device has seen more widespread use and is standardized in ASTM D6951.

2-7.4.1 Equipment, Procedure, and Results.

A schematic of the lightweight DCP equipment and details of the cone tip are presented in Figure 2-12. A drop hammer (either 17.4 or 10.1 pounds) strikes the anvil to drive in the cone tip. The upper and lower shaft guide the hammer and transmit the driving force to the cone tip. The 60° apex angle cone is at the bottom of the lower shaft. Both fixed and disposable cone tips are available. An extraction jack may be needed to remove the cone and shaft.

The DCP is normally conduct by two people. After seating the cone tip about 1.0 inch, the cone is advanced incrementally by successive drops of the hammer, while holding the device vertical. After each hammer blow, the penetration of the cone is measured and recorded to the nearest 0.1 inch. The test is terminated when a target depth is achieved, when the full length of the lower shaft is embedded, or when the total penetration is less than 0.1 inch/blow for 10 successive hammer blows. The extraction jack is then used to retrieve the embedded shaft/cone.

From the recorded test results, the DCP Penetration Index (DPI) is calculated, and tabulated versus depth. A plot can be developed of the *incremental* values of DPI versus the *cumulative* penetration depth, providing an indication of relative stiffness/strength versus depth. Correlations to DCP are found in Chapter 8.[2]

---

[2] DCP is often used to represent the DCP Index in equations. This convention is followed in Chapter 8.

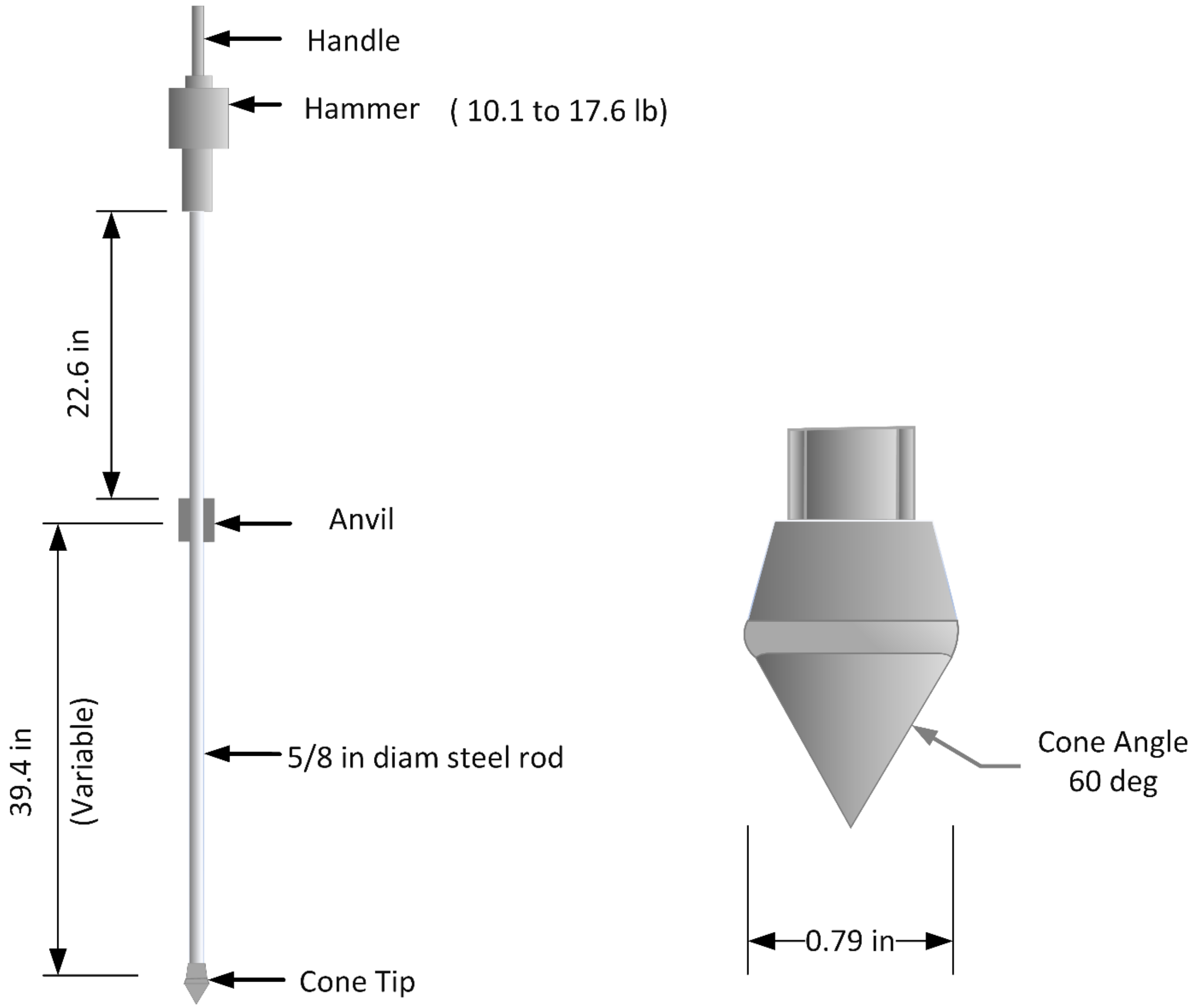


Figure 2-12 Schematic of Dynamic Cone Penetrometer (DCP) Equipment (after Webster et al. 1992)

2-7.4.2 Advantages and Limitations.

The DCP is a simple, low-cost, easy-to-use tool, which is ideal for quick or very low-cost results, or when site access is limited. The results of the DCP can be used as compaction acceptance criteria. It can easily assess stratigraphy, particularly in the delineation of soft and hard layers. The equipment is easy to maintain. Perhaps the biggest advantage is that local and regional correlations can be easily developed and updated as needed.

A significant limitation of the test is the shallow depth of penetration. Verticality of the shafts when driving is critical, and operator experience is valuable. Because a donut-style drop hammer is used, the operator (and helper) need to be avoid “pinch points” between the hammer and anvil.

2-8 GROUNDWATER MEASUREMENTS.

Because of its importance in geotechnical analysis, location of the groundwater table is a key element of a subsurface investigation. During drilling, depths are typically recorded at which the water is first encountered in the borehole and at which the water level stabilizes after drilling. The latter is often recorded after the borehole remains open for approximately 24 hours. In some soils, the sidewalls will collapse unless they are confined or supported (e.g., sands beneath the water table). In these cases, perforated pipe may be used as a temporary casing to protect against borehole collapse while allowing water to flow through the perforations. Knowledge of the seasonal groundwater fluctuation is important, and long-term measurements can be made by converting borings to piezometers, which can vary from open wells to electronic transducers.

Knowledge of the local groundwater regime is required to correctly interpret groundwater measurements, especially those from piezometers. Groundwater can occur at different elevations in the subsurface. It may be *perched* in isolated zones, or it may be confined between different low-permeability strata. In addition, groundwater flow can affect the interpretation of water levels. Where gradients are low and the groundwater table is relatively horizontal, groundwater depths can be directly inferred from piezometer measurements. However, where large gradients are present, the water pressure measured at a point in the ground cannot be directly used to calculate the vertical depth of water above that point. Knowledge of the seepage conditions is required (see Chapter 7-6) to make this determination. Finally, a distinction must be made between steady state and transient conditions. Steady state conditions can be effectively monitored using all types of piezometers. However, under transient conditions (e.g., rapid drawdown in dams, consolidation or swell in fine-grained soils), pore pressures may be changing significantly with time and require instrumentation with a fast response time, such as diaphragm type transducers.

2-8.1 Types of Standpipe Piezometer.

Groundwater level monitoring involves direct measurement of water levels within open well, open standpipe piezometer, or porous element piezometers. The common types of standpipe piezometer for monitoring groundwater levels are depicted in Figure 2-13 and summarized in Table 2-17. The type of standpipe that is selected depends on preferences, regulations (if applicable), and the type of subsurface soils in which the groundwater level will be measured.

The three basic components of a standpipe piezometer include: (1) the tip or well screen; (2) the standpipe itself; and (3) the standpipe seal. These can be installed by hand at shallow depths, but in most cases are installed using a drill rig after the completion of a boring in the soil or rock.

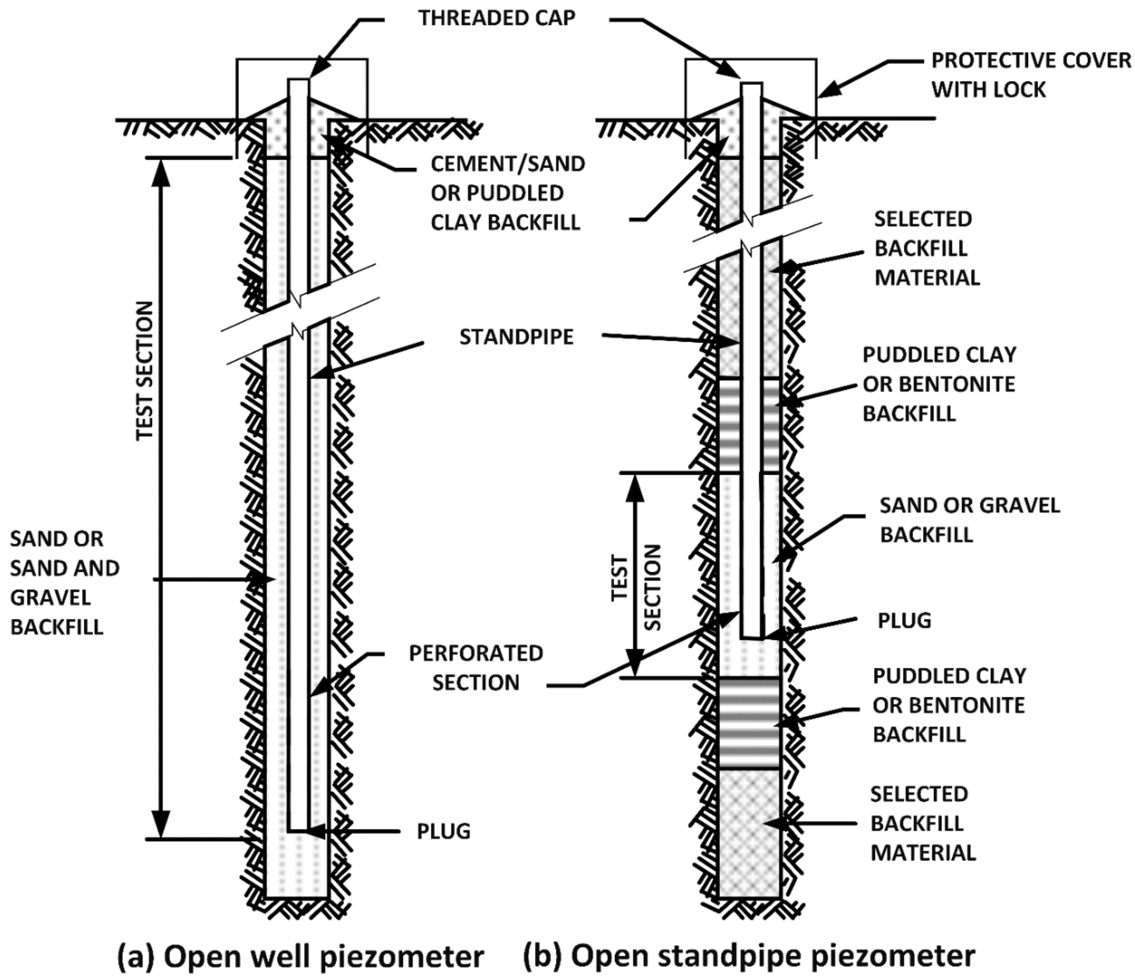


Figure 2-13 Open Piezometers

2-8.1.1 Open Well Piezometer.

A common groundwater monitoring technique is to install a *standpipe*, or water tight pipe, within an open boring as shown in Figure 2-13(a). The standpipe has a perforated tip or screen that allows water to enter are usually small-diameter (e.g., less than 2 inches) PVC plastic pipe but may be larger for environmental sampling applications. In an open well, the annular space between the pipe and borehole wall is filled with filter sand or gravel almost to the ground surface. At the ground surface, a seal of cement grout, bentonite slurry, or other low permeability material is placed above the filter sand to isolate the well from surface water flow. Open wells are often called groundwater monitoring wells and are commonly used for environmental applications when samples of the groundwater are required.

Table 2-17 Types of Standpipe Piezometers

Piezometer Type	Advantages	Disadvantages
Open well piezometer	Simple and reliable; long experience record; good for coarse-grained soils; large diameter may be required/needed for environmental monitoring and groundwater sampling	Slow response time, particularly in fine grained soils; unable to monitor distinct stratum exhibiting different groundwater levels; freezing potential in winter
Open standpipe piezometer	Simple and reliable; long experience record; able to monitor distinct stratum exhibiting different groundwater levels; good for coarse-grained soils	Slow response time in low permeability soils
Porous element piezometer (hydraulic)	Rapid response time; good for soils exhibiting medium permeability; good for applications impacted by electrical interference	Humid air entering tubing may impact readings; time consuming to make measurements.
Porous element piezometer (electronic)	Rapid response; high sensitivity; suitable for automatic readout	Relatively expensive; temperature and barometric pressure correction may be required; zero drift errors can arise

Because an open well has a full-length screen or a full depth filter zone, it is best suited for measuring water levels in relatively homogeneous deposits with high permeability. When multiple strata are crossed, the groundwater level corresponds the stratum with the highest total head. A significant advantage of an open well piezometer is that it can be cleaned and “developed” by flushing water from the standpipe into the formation, which is critical for open well piezometers used for environmental applications.

2-8.1.2 Open Standpipe Piezometer.

An *open standpipe piezometer* is similar to an open well, except that the screen extends only across a specific stratum of interest. Seals are installed above and below this zone to only allow water to enter from the stratum of interest. An open standpipe piezometer is shown in Figure 2-13(b). Outside of the screened test section, select backfill materials are used but not necessarily filter sand. A seal is typically placed around the open standpipe at the ground surface.

Multiple open standpipe piezometers can be installed to measurement groundwater levels in multiple strata within a single borehole through careful installation of multiple seals. This approach is sometimes referred to as a nested piezometer. The vertical location (i.e., depth, thickness, and elevation) of each seal must be accurately measured and recorded on the well log.

A major disadvantage of open well and open standpipe piezometers is the long equalization time that may be required for water to flow from the formation and fill the piezometer. Until the groundwater level stabilizes in this manner, the readings are inaccurate. To reduce the equalization time, the diameter of the standpipe can be reduced to less than 0.5 inches, which decreases the volume of water needed.

2-8.1.3 Porous Element Piezometers.

The primary disadvantage of open well and open standpipe piezometers is the potentially long equalization time for the groundwater level to stabilize since the riser pipe must fill with a considerable volume of water from the formation. Porous element or hydraulic piezometers have a ceramic or porous metal tip attached to a small-diameter riser pipe (i.e., standpipe). Modern versions use a porous element with pore sizes of <50 microns, so that the tip can be used in direct contact with fine-grained soils. One of the primary advantages of the porous element piezometer is the relatively short equalization time periods in fine-grained soils exhibiting low permeability. However, water must still flow from the formation through the porous element and into the standpipe to obtain accurate groundwater level measurements.

2-8.2 Multiple or Nested Installations.

Several standpipe piezometers may be installed in a single boring with an impervious seal separating the different measuring zones. These are called *nested* piezometers. This concept represents a cost advantage, as it reduces the number of borings (but increases the difficulties/challenges of installing seals and specific elevations) and the number of “obstacles” during for the contractor during construction. However, if measurements are needed in zones with 10 feet or less of vertical separation, piezometers should be installed in separate borings.

2-8.3 Measurement of Groundwater Levels.

Groundwater levels/elevations can be obtained by either direct or indirect methods. The direct method includes: (1) surveying the elevation of the top of the riser pipe and/or the ground surface; (2) measuring or calculating the “stick-up” of the riser pipe above the ground surface; and (3) measuring the distance depth from the top of the riser pipe to the water surface inside the open pipe or the standpipe. The elevation of the groundwater can then be easily calculated. There are several methods to measure the distance from the water surface to the top of the riser pipe; including a plumb bob, cloth or metal surveyors' tapes coated with chalk, or commercially available electrical indicators. Using these direct measurements, the water level can be established generally within a tolerance of about 0.5 inch.

An indirect, but more accurate, method for measuring the depth of water in an open well uses an electrical transducer capable of measuring water pressure. The transducer is attached to a hoisting cable and an electrical cable. Markings on the electrical cable are used to measure the length of the cable in the open pipe. Commercially, these portable systems are called *water level indicators*. The transducer is lowered to a depth typically near the bottom of the open hole such that the transducer is submerged. The electrical cable is attached at the surface to a readout unit that measures the pressure due to water column above the tip of the transducer. From the unit weight of water (i.e., 62.4 pcf or 9.81 kN/m^3), the depth of water above the tip of the transducer is calculated, which combined with the length of cable in the open pipe can be used to calculate the groundwater level in the pipe. This type of transducer can be connected to a data collection unit and groundwater levels can be automatically collected over time. This capability is often quite efficient and is, in fact, a requirement when groundwater pumping tests are performed and the time-dependent groundwater elevation as a function of pumping rate is necessary for subsequent calculations of *in situ* permeability of a formation (see Section 2-9.2). The indirect method can also be used with pore pressure transducers that are grouted or sealed directly in boreholes without a standpipe. More information on the transducers used with this type of piezometer is provided in Section 2-10.4.

While being simple in concept, the techniques for measuring groundwater levels have some inherent limitations. First, standpipe piezometers require access to the top of the vertical riser pipe, which usually extends above the ground surface and may be easily damaged during construction. If the riser is extended vertically during construction (e.g., installed in a constructed embankment), the extension activities must be carefully coordinated with the earthwork contractor. Manual or direct measurement of water levels is time consuming and may adversely impact construction. The largest source of error for standpipe piezometers is the lag time required for the piezometer to respond to changing groundwater levels because water must flow from the formation into the piezometer. For this reason, groundwater piezometers are intended to measure hydrostatic groundwater levels and are inappropriate for time-dependent pore pressures. Other sources of error that impact piezometer readings include the possibility of direct introduction of precipitation into the riser pipe due to a missing or vandalized cap, infiltration of surface water into the borehole, and the formation of gas bubbles within the pipe. Indirect groundwater measurements by porous element piezometers without a standpipe or pore pressure transducers can alleviate many of these limitations.

2-8.4 Detection of Combustible Gases

Gas bubbles in groundwater can influence the measurement of groundwater levels. Gas can exist in subsurface soils and pose other hazards. Specifically, methane (CH_4) and other combustible gases may be present in subsurface soils and rock, particularly in sites near municipal solid waste (MSW) landfills, or at sites near or over peat bogs, marshes, and swamp deposits. Methane is a dominating combustible gas in the subsurface because it is one of the primary by-products of the anaerobic decomposition of organic material. The other dominant gas is carbon dioxide (CO_2). Commercially available portable instruments, referenced as landfill gas analyzers, are used to detect the presence and concentration of combustible methane gas in landfill gas wells and monitoring probes. These instruments sample the air/gas from the confined space in wells and borings above the water table. The instrument generally detector indicates the concentration of gases in the collected gas sample. The critical concentration limits for methane is between 5 and 17 percent by volume. A concentration of less than 5 percent methane is considered too “lean” to burn or ignite and is referenced as the lower explosive limit (LEL). A concentration of more than 17 percent methane is considered too “rich” to ignite and cause a flash fire (i.e., explosion) and is referenced as the upper explosive limit (UEL). If methane concentrations are measured within the 5 to 17 percent range, all possibilities of spark generation (e.g., pile driving, grinding, welding, smoking) should be eliminated and a venting system should be considered, to provide worker protection.

2-9 MEASUREMENT OF SOIL AND ROCK PROPERTIES *IN SITU.*

Field sampling and laboratory testing can sometimes be complemented or replaced by *in situ* testing, which refers to measurements conducted on soil and rock “in place.” As a general rule, an *in situ* testing program can be performed faster and in many cases at a lower cost than most laboratory testing programs. As a result, this alternative has seen growing popularity since the 1980s. The SPT, CPT, DMT, and DCP are four of the most popular *in situ* testing methods, which are often correlated to engineering parameters. This section discusses other *in situ* tests that measure strength, stiffness/modulus, and permeability of existing soils, as well as the as compacted properties of earthwork. Methods for *in situ* testing of rock are also discussed.

Although not universally adopted, many practitioners find that the pocket penetrometer and the field torvane provide useful correlations to the shear strength as measured in the laboratory. These tests may be performed on the soil exposed at the bottom of a recovered Shelby tube sample. Practitioners who use these tests often correlate the results to results from laboratory strength tests, to increase the value of the field test. Although these tests are often used in practice, the results are very inexact and should not be used for design.

2-9.1 Strength and Deformation Properties of Soil.

The pressuremeter test, vane shear test, and the plate load test are the most commonly used *in situ* testing methods for assessing strength and stiffness of soils. A summary and comparison of these tests is presented in Table 2-18. Where ASTM standards are available, they have been included in the table.

Table 2-18 *In situ* Testing Methods Used in Soil for Strength and Deformation (after FHWA 2002)

Method and ASTM No.	Procedure	Applicable Soil Types	Applicable Soil Properties	Limitations / Remarks
Pre-bored Pressuremeter (PMT) ASTM D4719	Borehole drilled and the bottom is carefully prepared. The pressure required to expand the cylindrical membrane to a certain volumetric or radial strain is recorded	Clays, silts, and peat; marginal response in some sands and gravels	E, G, m_v, s_u	Preparation of the borehole most important step to obtain good results; good test for calculation of lateral deformation characteristics
Full Displacement Pressuremeter (PMT)	Cylindrical probe with a pressuremeter attached behind a conical tip is hydraulically pushed through the soil and paused at select intervals for testing. The pressure required to expand the cylindrical membrane to a certain volume or radial strain is recorded	Clays, silts, and peat	E, G, m_v, s_u	Disturbance during advancement of the probe will lead to stiffer initial modulus and mask liftoff pressure $\left(p_0\right)$; good test for calculation of lateral deformation characteristics
Vane Shear Test (VST) ASTM D2573	Four- blade vane is pushed into the bottom of a borehole. The vane is slowly rotated until the maximum torque required for rotation is recorded. The vane is rapidly rotated for 10 turns, and the residual torque is recorded.	Clays, some silts and peats if undrained conditions can be assumed. Not for use in granular soils	s_u, S_t, σ'_p	Disturbance may occur in soft sensitive clays, reducing measured shear strength; partial drainage may occur in fissured clays and silty materials, leading to errors in calculated strength; rod friction needs to be accounted for in calculation of strength; vane diameter and torque wrench capacity need to be properly sized for adequate measurements in various clay deposits
Plate Load Test (PLT) ASTM D1196	A circular, rigid steel plate is hydraulically pushed into the soil and the relationship between bearing stress and vertical settlement is recorded	All soils and rock, particularly helpful in unbounded base aggregate for pavements	q_{ult}, k_s	Limited depth of influence; short-term test will not capture consolidation impacts; not typically used as part of geotechnical site investigation

Note: E = elastic modulus; G = shear modulus; m_v = coefficient of volume compressibility; s_u = undrained shear strength; S_t = sensitivity; σ'_p = preconsolidation stress, q_{ult} = ultimate bearing capacity; k_s = modulus of subgrade reaction

2-9.1.1 Pressuremeter Test.

The pressuremeter test (PMT) was first developed in about 1955. In the PMT, a membrane is inflated from a cylindrical probe against the sidewalls of an open borehole. The radial expansion is measured, and this response is used to calculate specific strength and deformation properties of the subsurface soils. PMT can be performed in a wide range of materials, including sands, residual soil, tills, and soft rock, that are usually difficult to sample. The “traditional” is called the “pre-bored” or “Menard” pressuremeter. Other types include the self-boring pressuremeter (SBPMT) that includes its own cutting shoe and does not require an existing borehole and the full-displacement or cone pressuremeter (CPMT) that is pushed into the ground, usually behind a piezocone. A schematic of the PMT equipment and test is shown in Figure 2-14.

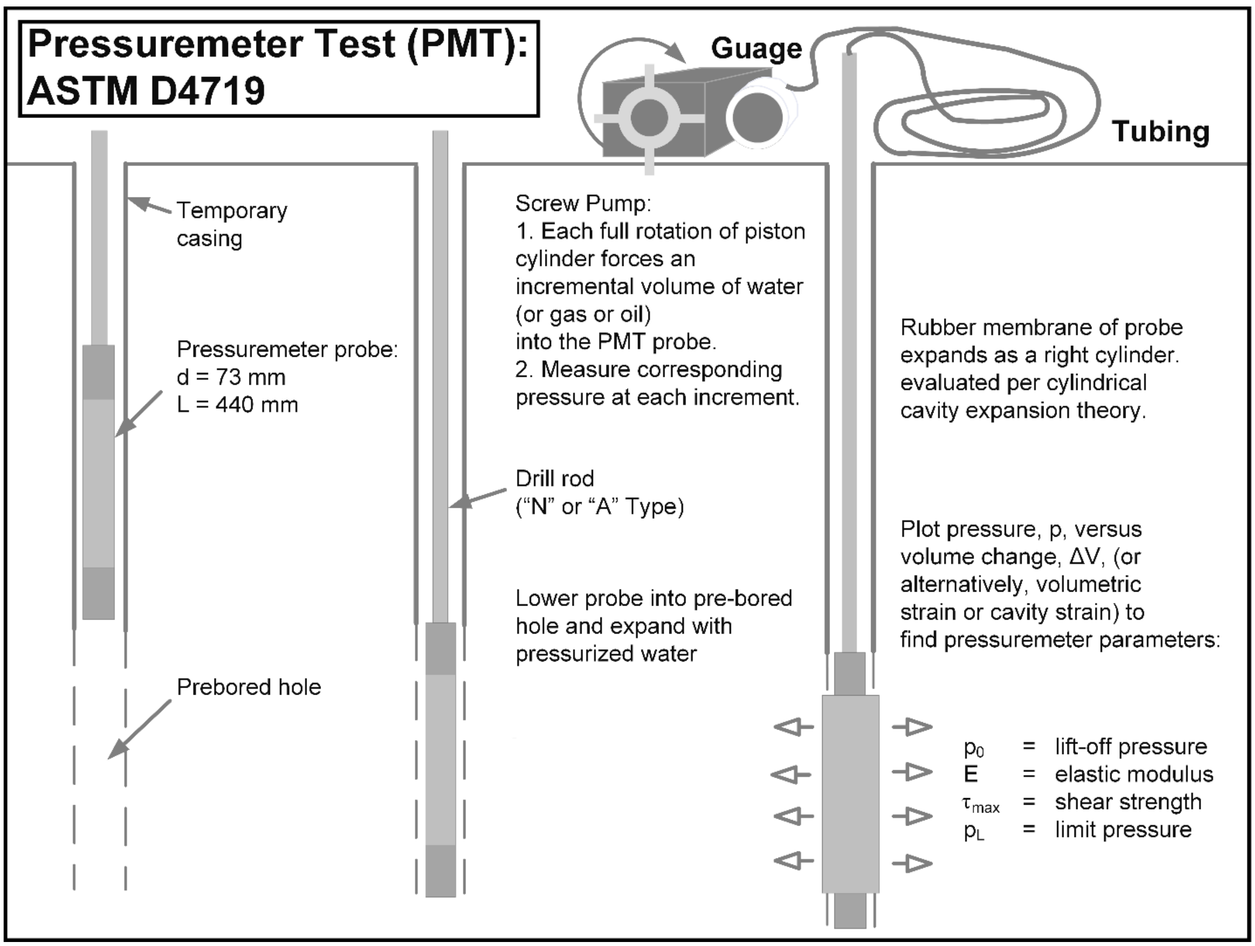


Figure 2-14 Schematic of Pressuremeter Test (after NCHR 2018 and Mayne 2012)

As shown in Figure 2-14, the equipment needed to perform a PMT includes of an expandable cylindrical probe, rubber membrane, outer slotted sleeve, pressure lines, and control unit. The PMT procedures are defined in ASTM D4719 and can be consulted for further details on the test method. The inner membrane is hydraulically expanded to obtain an expansion pressure versus volume curve. During loading, disturbed soil in the borehole wall first compresses, followed by a pseudo-elastic response and then plastic yielding. After plastic yielding is induced, a creep test is performed by holding pressure constant until the lateral expansion falls below a threshold. The PMT concludes with an unload-reload cycle to better define the elastic properties.

Typical PMT pressure vs. volume change results are shown in Figure 2-15 along with definitions of the characteristic pressures. For comparison, a typical SBPMT test result is presented in Figure 2-16.

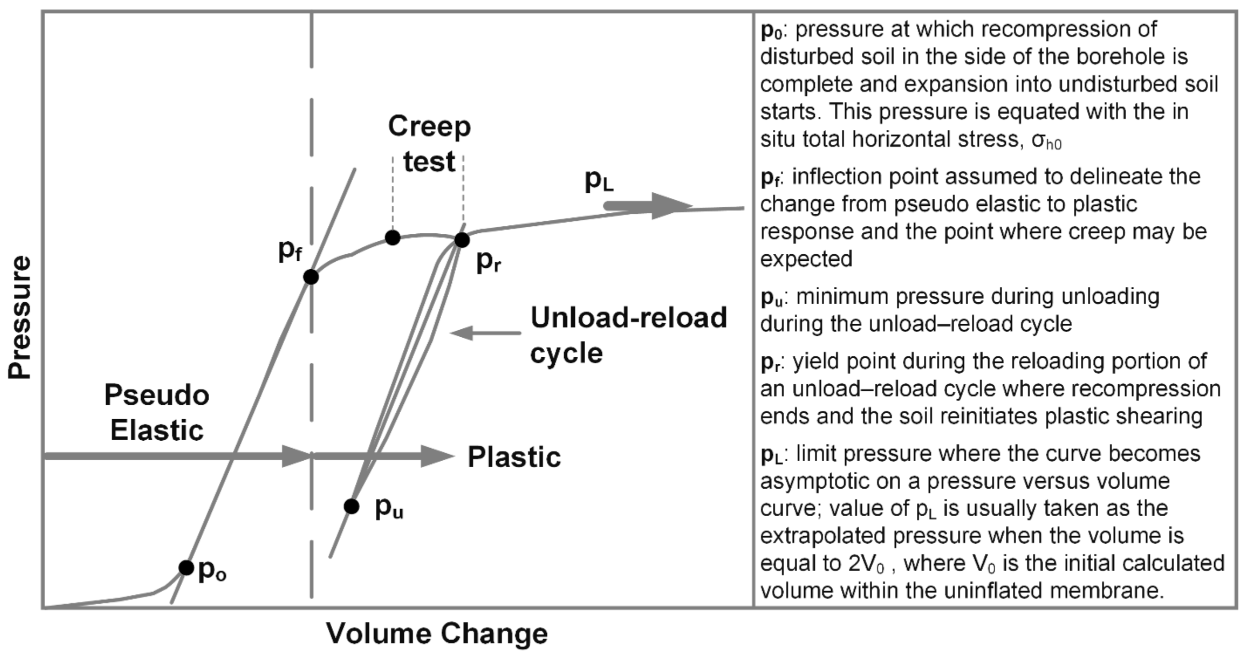


Figure 2-15 Typical Result and Characteristic Pressures from Pressuremeter Test (after FHWA 2002)

2-9.1.1.1 Test Interpretation.

Pressuremeter tests have been used to estimate the coefficient of lateral earth pressure at rest (K_0), the soil stiffness; and undrained shear strength (s_u).

- Coefficient of Lateral Earth Pressure at Rest (K_0): Upon initial inflation, the membrane will expand to contact the borehole sidewalls. In the PMT, p_0 is related to the *in situ* total horizontal stress, which combined with the vertical stress allows K_0 to be calculated. Due to unloading effects and disturbance during drilling the borehole, the accuracy of this calculation is questionable. To accurately assess the *in situ* lateral stress and K_0, a self-boring pressuremeter should be considered. Point A in Figure 2-16 is a relatively accurate representation of the total horizontal stress in the ground.

- Stiffness: The elastic stiffness of the soil can be estimated by the slope of the unload-reload pressuremeter curve where the response is assumed to be nearly elastic. One technique calculates the pressuremeter modulus (E_p), while another uses cavity expansion theory to calculate shear modulus, G (Gibson and Anderson 1961, Windle and Wroth 1977).
- Undrained Shear Strength (s_u): Methods exist to estimate the undrained shear strength from pressuremeter results, but the resulting values are less reliable than those from other *in situ* tests, such as the cone penetration test or the vane shear test.

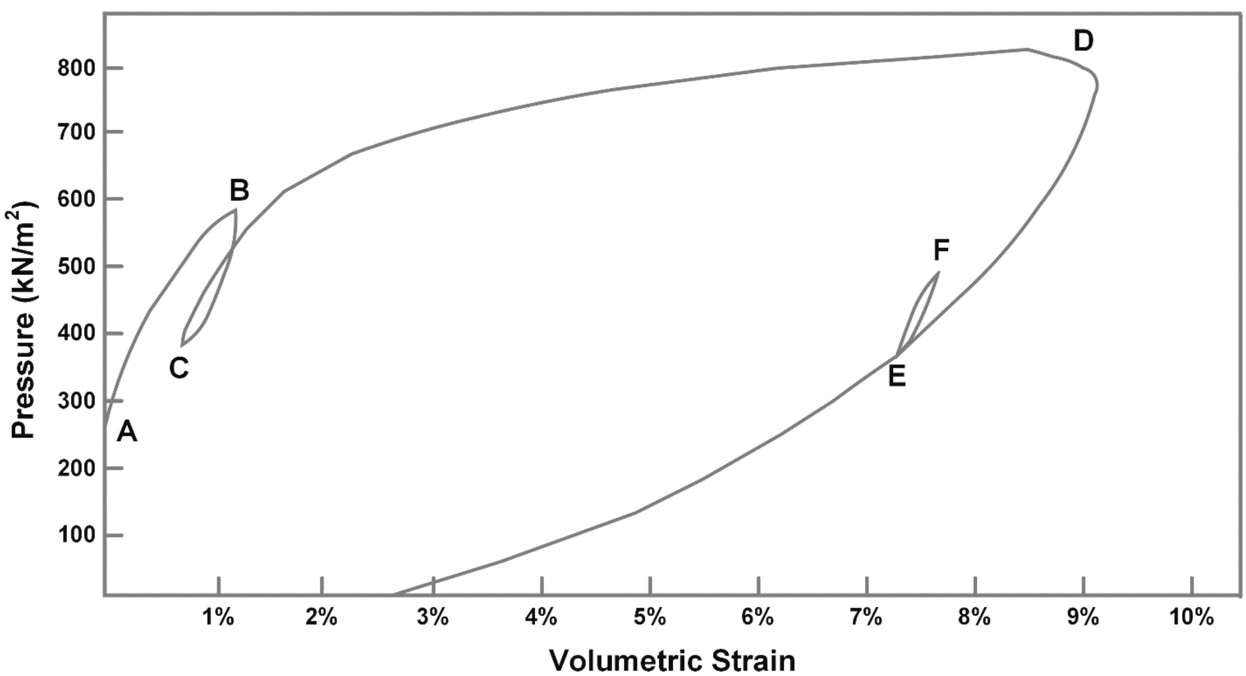


Figure 2-16 Example Result from Self-boring Pressuremeter Test in Clay (after Windle and Wroth 1977)

2-9.1.1.2 Limitations.

Pressuremeter testing is sensitive to test procedures. In very soft soils and in sands, it may be difficult to maintain borehole stability before the probe is inserted. In these cases, a self-boring pressuremeter may be necessary. Irregularities in the wall of the borehole wall also affects test results, and the self-boring pressuremeter eliminates some of this disadvantage. The SBPMT usually requires a specialist familiar with the test and the instrument. Pressuremeter test interpretation has a theoretical basis and, therefore, either drained or undrained conditions need to be maintained. The pressuremeter is relatively long (i.e., generally greater than 2 feet in length) and results reflect an averaging of the soils over this length. For this reason, the PMT in best used in relatively homogenous deposits, and it not expected to provide reliable parameters in stratified soil. Pressuremeter equipment has many moving parts and requires maintenance and careful handling.

2-9.1.2 Vane Shear Test.

The vane shear test (VST) is a popular and reliable *in situ* test that has been in use since the 1940s. The VST involves the use of a simple four-sided blade (i.e., vane) that is pushed into the ground and then rotated to evaluate the undrained shear strength and sensitivity of soft to stiff clays and silts. The use of the VST should be limited to soils in which slow (i.e., ~6° / min) rotation of the vane represents undrained shearing. A schematic of the VST equipment and operation is presented in Figure 2-17. At failure, the vane will cut a "cylinder" of soil equivalent to the outside dimensions of the vane and the torque will reduce. The vane is often rotated 10 more revolutions, and the residual torque is measured.

The undrained shear strength ($s_{u,fv}$), the remolded undrained shear strength ($s_{ur,fv}$), and the sensitivity ($S_{t,fv}$), can be obtained from the VST. During rotation, the maximum net torque (T_{max}) is measured and the undrained shear strength for a "standard" rectangular vane with an H/D ratio of 2 is as follows:

$$s_{u,fv} = \frac{6T_{max}}{7\pi D^3} \qquad \textbf{(2-1)}$$

where:
D = diameter of the vane.

To measure the remolded undrained shear strength, the torque reading (T_{res}) is taken during rotation of the vane following five to ten rapid turns of the vane. The remolded strength is calculated by replacing T_{max} with T_{res} in Equation 2-1. With knowledge of the peak and remolded values for undrained shear strength, the sensitivity of the soil from vane shear tests can be calculated by:

$$S_{t,fv} = \frac{s_{u,fv}}{s_{ur,fv}} \qquad \textbf{(2-2)}$$

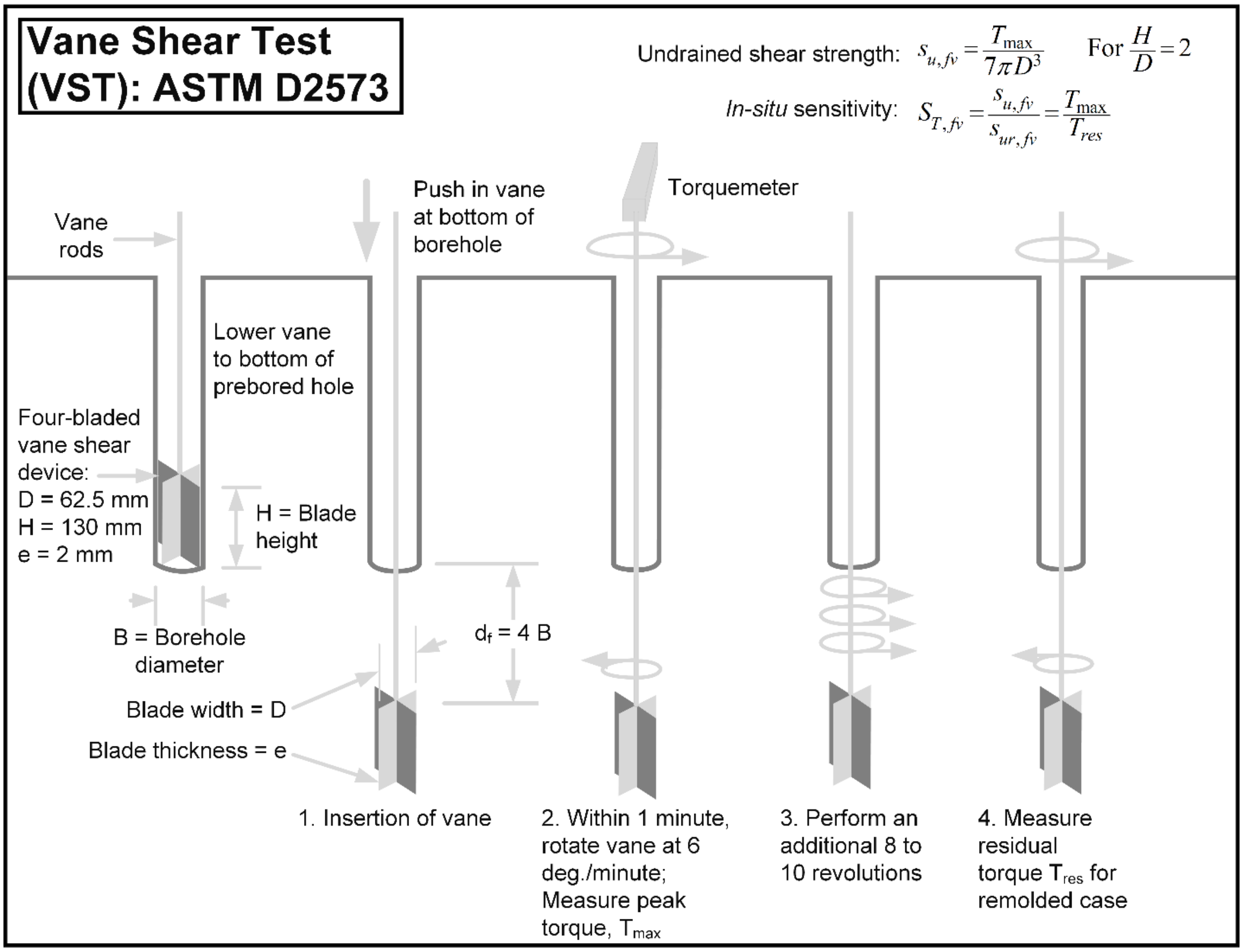


Figure 2-17 Schematic of Vane Shear Test (after Mayne 2012)

The undrained shear strength from the VST overpredicts the shear strength mobilized in failures of embankments, shallow footings, and slopes constructed on soft clay. In order to account for this, $s_{u,fv}$ should be adjusted by a correction factor (μ_R), which is a function of the PI of the soil tested. Three different vane correction methods are given in the ASTM specification. The corrected shear strength can be calculated by:

$$s_{u,field} = s_{u,fv} \times \mu_R \qquad \textbf{(2-3)}$$

where:
μ_R = vane correction factor.

The VST has proven to be a very reliable and repeatable *in situ* test and enjoys widespread popularity due to cost and efficiency. It is perhaps the best device to measure the *in situ* strength of soft to medium clays (s_u < 2000 psf). The biggest limitation of the VST is the types of soil where it can be used. The VST cannot accurately assess the strength of fissured clays, clays with significant amounts of sand or gravel, and soils with relatively thin laminations. The data for the VST is reduced based on the assumption of undrained conditions. Therefore, soils that might allow partial drainage during shear are problematic.

2-9.2 Hydraulic Conductivity of Soil.

Hydraulic conductivity is the most variable of all the material properties commonly measured and used in geotechnical analysis, with the range extending to more than ten orders of magnitude. Accurate measurement of hydraulic conductivity is very sensitive to the type of soil, the disturbance of the soil, site stratigraphy, and the variability of the soil deposit across the site. Laboratory testing of the hydraulic conductivity of soil, even on samples of minimally disturbed recovered samples, may not reflect the hydraulic conductivity of the natural deposit because the lab sample is quite small and certainly not representative of a geologically placed and weathered material. If the soils at the site are relatively uniform and can be sampled with minimal disturbance (i.e., uniform clay soils), laboratory testing may be sufficient and adequate. However, for deposits of coarse-grained materials, intact sample are nearly impossible to obtain, and *in situ* hydraulic conductivity tests are commonly used. In particular, *in situ* tests are important for uniform coarse-grained deposits. Correlations based on grain-size distribution are also very common for coarse-grained deposits (see Chapter 8).

The following five physical characteristics influence the performance and applicability of *in situ* hydraulic conductivity tests: (1) water level position, (2) type of soil or rock, (3) depth of the test zone, (4) hydraulic conductivity of the test zone, and (5) heterogeneity and anisotropy of the test zone.

The difficulties inherent with *in situ* hydraulic conductivity testing require that great care be taken to minimize sources of error and to correctly interpret and compensate for deviations from ideal test conditions. Many of these difficulties can be overcome by planning tests to isolate specific zones of material assumed to be uniform.

In situ hydraulic conductivity tests are most commonly used in geotechnical engineering investigations for dams, hydraulic barriers, geo-environmental projects, and project with a strong hydrogeologic component. For strictly geotechnical applications, steady-state testing is much more common than transient state testing. In addition, saturated hydraulic conductivity testing is more common than *in situ* testing for unsaturated conditions. A brief summary of the four most common types of *in situ* hydraulic conductivity tests is presented in Table 2-19.

A considerable amount of skill is necessary to correctly measured the hydraulic conductivity of soil *in situ*. Specialty firms will likely provide more accurate and prompt results compare with the personnel used for routine drilling and sampling. Specialty firms are staffed by geotechnical and hydrogeologists who routinely conduct *in situ* permeability tests.

Table 2-19 Summary of *In situ* Test Procedures for Measuring Hydraulic Conductivity of Soil Deposits

Type of Test	Description	Advantages and Disadvantages
Constant Head Test	Water is added to an open-ended pipe (cased borehole) at a constant rate. Water level in hole maintained at a constant level.	Can be performed in saturated and partially saturated soils. Difficult to perform on soils with a very high or very low k. Only a small zone of soil is tested (if unscreened).
Variable Head Rising Head and Falling Head Tests (ASTM D4044)	An interval of a borehole is screened. A "slug" of water removed from or added to the borehole. Elevation of the water level recorded over time.	Construction and development of the well is more difficult than constant head test. Data reduction can be complex.
Pressure Tests	Borehole section isolated by or sealed off with "packers." Elevated pressure can be applied to achieve increased flow.	Best for deep explorations. Can be conducted above or below the water table. Can be used to measure the hydraulic conductivity of fractured rock.
Pumping Tests	Install pumped well and observations wells radially from the pumped well. Record the amount of water pumped and the elevation of water in the wells is over time. Use analytical or numerical analysis to determine the hydraulic parameters of the soil deposit.	More expensive than other methods. Hard to justify increased cost for common geotechnical projects. Provides addition information regarding aquifer transmissivity and storativity. Tests a larger volume of soil than other methods. Long testing times.

2-9.3 Engineered Fill and Earthworks.

The *as-compacted* moisture/water content and unit weight (often referred to as density) of compacted soils is a significant component of geotechnical practice involving constructed engineered fill or earthworks (e.g., dams, embankments, etc.). For purposes of this discussion, the terms moisture content and unit weight will be used. Geotechnical engineers have long recognized that many of the desired engineering properties of both fine- and coarse-grained compacted materials depend on the compaction moisture content and/or unit weight. The compaction water content is much more important for fine-grained as opposed to coarse-grained soils. This section focuses on the use and limitations of the numerous techniques used in practice for these important measurements.

It should be noted that compactors are current available that can measure the stiffness of soils "on-the-fly" during compaction (McGuire et al. 2009). These special compactors are becoming very popular in earthwork construction, and their use has supplanted many of the older methods of compaction quality control incorporated into earthwork specifications.

2-9.3.1 Measurement of As-Compacted Soil Unit Weight.

Four general strategies can be used to assess the as-compacted unit weight of soils: (1) displacement methods; (2) drive-cylinder methods; and (3) nuclear gauge methods; and (4) non-nuclear gauge methods. All of these methods use measurements from the ground surface to assess the near-surface characteristics of the soil. This section provides a discussion of each of these strategies and methods.

2-9.3.1.1 Displacement Methods.

Of the displacement methods, the sand displacement and water balloon displacement techniques are the most widely used because of their simplicity, applicability to a wide range of material types, and their historical performance and record of accuracy. In both cases, a known weight of soil is excavated from the ground. Either sand or water of a known unit weight is used to measure the volume of the excavated hole. The results are more accurate when a large volume is measured. Displacement methods measure the total unit weight of the soil. The water content of the excavated soil must be determined to calculate the dry unit weight.

The sand displacement method, usually referenced as the “sand cone” method, is the most frequently used displacement test to assess *in situ* dry unit weight. A schematic of the sand cone apparatus is shown in Figure 2-18. Originally standardized in 1958 (ASTM D1556), the sand cone method remains the recognized reference test for all other methods used to assess *in situ* soil unit weight. Consistent results strongly depend on operator experience and care in performing the test.

The water balloon displacement test (ASTM D2167) uses the same principle as the sand cone. The excavated hole in the soil is lined with a balloon (i.e., watertight, thin membrane), which is filled with pressurized water from a volume-calibrated container as shown in Figure 2-19. The water balloon method should not be used in soils that contain significant amounts of gravel that can potentially puncture the balloon. The water balloon method generally provides consistent and accurate results when performed correctly, although not as consistent as the sand cone (Berney et al. 2013).

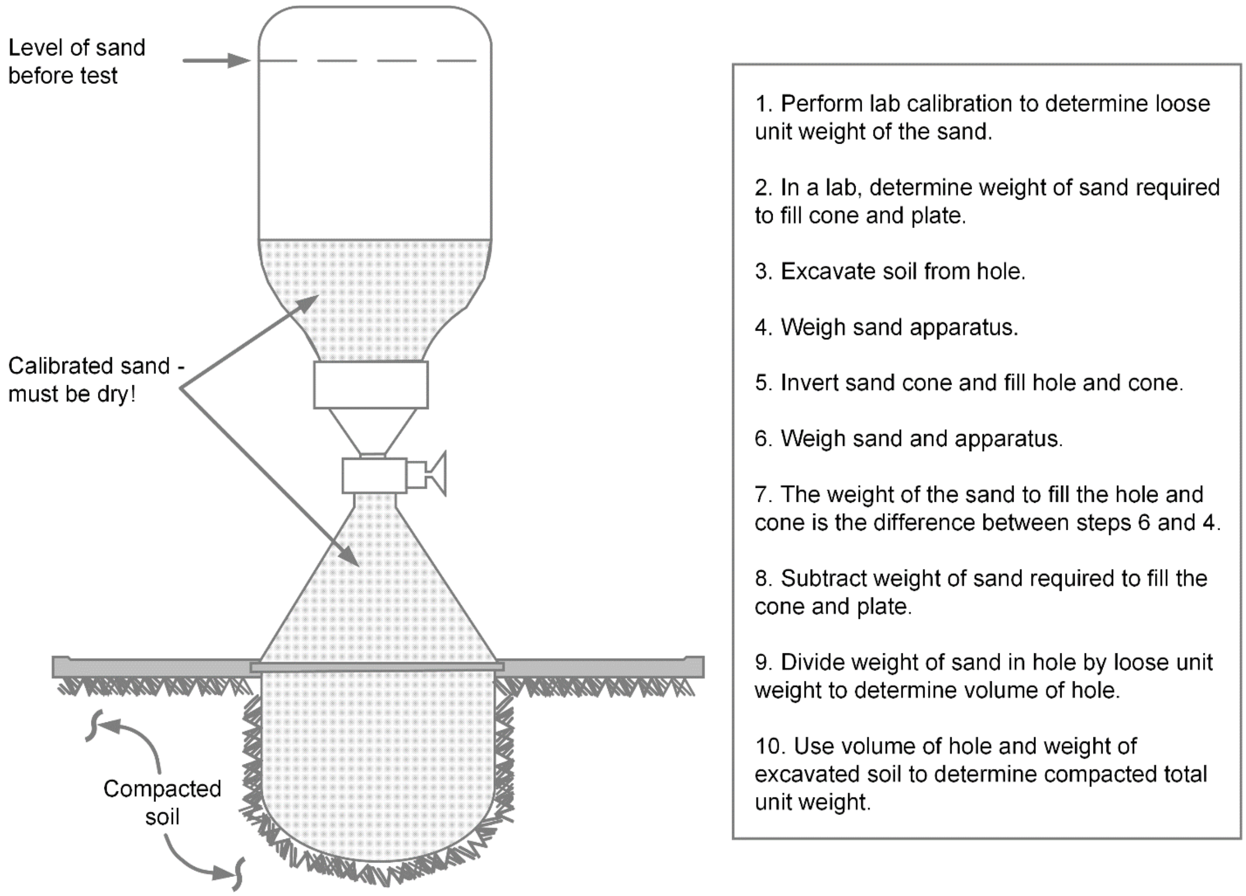


Figure 2-18 Schematic of Equipment and Process to Perform a Sand Cone Test (after Dunn 2017)

2-9.3.1.2 Drive-Cylinder Method.

The drive cylinder method (ASTM D2937) is a convenient and rapid technique to obtain the as-compacted total unit weight of soil. A slide hammer is used to drive a relatively short thin-walled tube (e.g., shortened Shelby tube) into the ground to obtain a sample. After the cylinder is driven, the soil-filled cylinder is carefully dug out of the ground, and the top and bottom of the sample is trimmed flush with the ends of the tube. The inside volume of the tube is the volume of the sample. A conventional drive cylinder is shown in Figure 2-20. This method can be used as long as the soil will remain in the cylinder, most notably fine-grained soils containing little or no gravel and moist, fine sands that exhibit apparent cohesion. The method cannot be used in soils that contain gravel, as the cylinder can be easily damaged. The drive cylinder measures the total unit weight, and the water content must be determined by drying the soil sample.

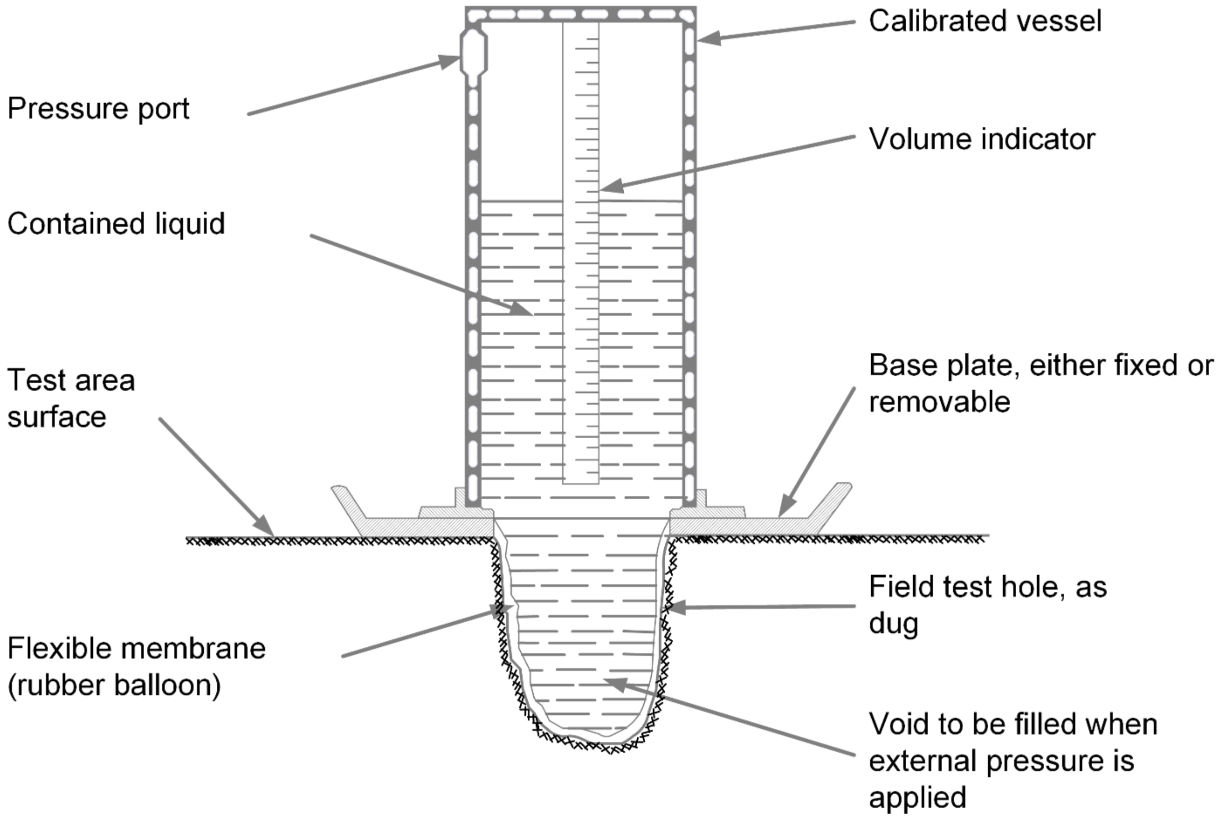


Figure 2-19 Schematic of Equipment to Perform Water Balloon Test (after Dunn 2017)

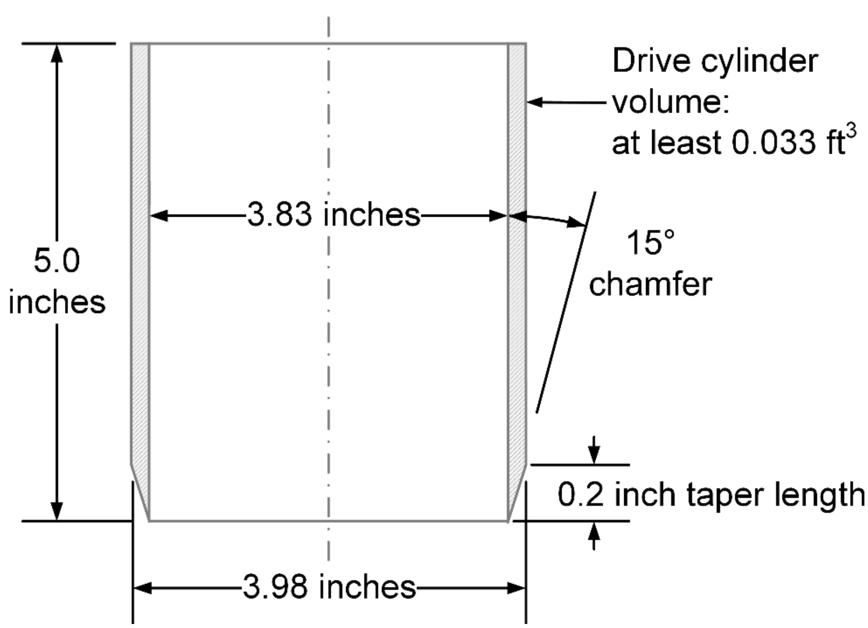


Figure 2-20 Schematic of Drive Cylinder (after ASTM D2937)

2-9.3.1.3 Nuclear Gauge Method.

The use of nuclear technology to assess soil unit weight and moisture content commenced in the early 1950s (Burgers and Yoder 1962). As shown in Figure 2-21, the nuclear source (usually Cesium-231) is housed near the tip of a rod that is inserted in a prepared hole at the test location. A low-power nuclear source is used to emit gamma rays through the soil to detectors in the gauge, and the detection rate is correlated to total unit weight of the soil. When not in use for testing, the nuclear source is protected inside of the shielded gauge. Procedures for using a nuclear gauge to measure unit weight and water content can be found in ASTM D6938. Proper, regular calibration of nuclear gauges is essential to obtain consistent and accurate results.

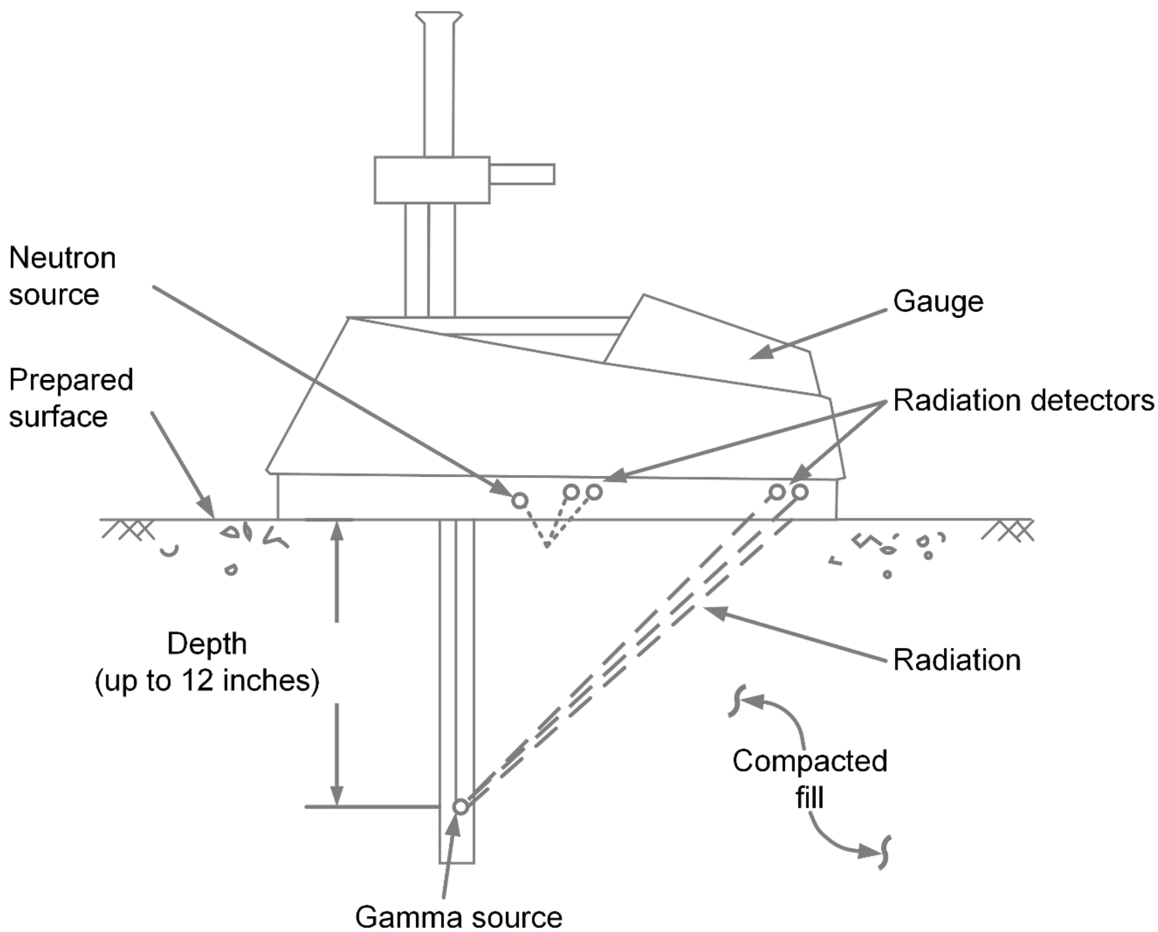


Figure 2-21 Schematic of Nuclear Gauge in Direct Transmission Mode (after NRC 1996)

Guidelines for the safe operation and licensing are provided by the Nuclear Regulatory Commission (NRC) in NUREG/BR-0133, *Working Safely with Nuclear Gauges* (NRC 1996). Technicians working with nuclear gauges should be trained in the safe operation and handling of the gauge. They also need to wear a dosimeter that is periodically tested to confirm no unexpected exposure, although the risks are relatively minor due to the low energy emitted and the safety precautions built into the gauge.

2-9.3.1.4 Non-nuclear Gauge Methods.

Because of the NRC requirements regarding licensing and transportation of nuclear gauges, several agencies (including the U.S. military) have been researching reliable alternatives to the nuclear gauge. Interestingly, these groups are also assessing direct measurement of the *in situ* strength and/or stiffness to replace the traditional density-moisture content specification for compacted soil. Table 2-20 provides a summary of various techniques and their performance compared to the “traditional” nuclear gauge based on field assessments by Berney et al. (2013, 2016). These devices are commercially available and operate using different principles.

Table 2-20 Comparison of Non-nuclear Technologies for Assessing Soil Density (Berney et al. 2013, 2016)

Non-nuclear Device	Measuring Technology	Field Performance
Moisture-Density Indicator (M-DI)	Electromagnetic pulses and time domain reflectometry used to determine total unit weight and moisture content	Requires third-party software, difficult installation without causing disturbance
Electrical Density Gauge (EDG)	High radio frequency waves measure the soil’s dielectric constant, capacitance, impedance, total unit weight, and moisture content are calculated	Highest precision, but average accuracy, requires extensive calibration to site-specific soil to establish accuracy
Soil Density Gauge (SDG)	Electrical impedance spectroscopy (EIS) used for non-contact measurement of total unit weight and moisture content	Accurate but imprecise measurement of density, requires calibration with site specific soil, (i.e., grain size and Atterberg limits)
License-exempt soil density gauge	Low level nuclear source (Cesium-127) used to measure total unit weight, exempt from NRC licensing because of source size	High correlation to results from traditional nuclear gauge
Lightweight Falling Deflectometer (LFD); Dynamic Cone Penetrometer (DCP); Impact Soil Tester (IST), Surface Stiffness (SS)	Various methods used to assess soil stiffness and/or strength, results can be correlated to unit weight and moisture content	None of the devices directly provide unit weight or moisture content, poor correlation to unit weight and moisture content.

2-9.3.2 Measurement of As-Compacted Soil Moisture Content.

The standard method to measure moisture content is the laboratory oven and is the appropriate basis of comparison for all other methods. Unfortunately, drying in the oven requires a 24-hour time period at a temperature of 110°C ± 5°C (ASTM D2216), which is too slow for quality control of engineered fill. At least ten alternative methods have been developed for *in situ* moisture content evaluation. These methods can be classified either as: (1) gravimetric, in which the soil is actually heated and dried; or (2) indirect, in which the moisture content is correlated to another parameter, as the soil is not physically dried.

Gravimetric methods for field measurement of moisture content are compared to ASTM D2216 in Table 2-21. In all four cases, the soil is physically dried to obtain total mass and dry mass measurements from which moisture content is calculated.

Table 2-21 Gravimetric Testing Methods for Moisture Content (after Berney et al. 2013)

Technique (Standard)	Summary	Comments
Laboratory Oven (ASTM D2216)	Sample dried in conventional oven at temperature of 110°C for 24 hours	Standard by which all other methods are compared, requires long testing time period (about 24 hours)
Standard (700-Watt) Microwave (ASTM D4643)	Sample heated and weighed repeatedly in 1-minute intervals until dry weight is constant	Results sensitive to specific microwave and type of soil, use of 1-minute cycles minimizes chance of overheating, requires electricity, relatively rapid testing time (≈ minutes)
Field Microwave (low power) (ASTM D4643)	Sample heated and weighed repeatedly in 1-minute intervals until dry weight is constant, more heating cycles are required compared to standard microwave	Same as standard microwave
Direct Heating (ASTM D4959)	Sample heated in a container exposed to direct flame from a field stove, heating and cooling cycles are used until specimen achieves constant weight	Heating time periods will vary depending on size of test specimen
Moisture Analyzer (N/A)	Sample dried under halogen lights or infrared heating elements on a dedicated laboratory-scale, internal controls periodically weigh specimen and terminate test automatically	Not traditionally used in geotechnical applications due to small size of test specimen (i.e., <50 gm)

A number of indirect methods have been developed to assess moisture content without physically drying the soil. As summarized in Table 2-22, these methods use a surrogate for temperature (i.e., gas pressure, dielectric constant changes, electrical impedance, etc.). Moisture content has a benchmark test that can and should be used - the laboratory oven. Each method has specific advantages and disadvantages, which can be expressed in statistical terms of bias, accuracy, and precision. Table 2-23 summarizes of comparison of the techniques (Berney et al. 2012, 2013).

Table 2-22 Indirect Testing Methods to Assess As-compacted Moisture Content (after Berney et al. 2012)

Technique (Standard)	Summary	Comments
Nuclear Density Gauge (NDG) (ASTM D6938)	A neutron source is used to determine hydrogen ion concentration by “backscatter” method, hydrogen is assumed to be in form of water in soil, measures upper 4 inches	Most common method used in compaction quality control, results can be affected by chemical composition of the soil, results biased by the soil closest to the surface.
Electrical Density Gauge (EDG) (ASTM D7698)	High-frequency radio waves are used to measure the dielectric constant of soil, which is correlated to moisture content	Very dependent on type of soil and requires calibration of the equipment to the site-specific soil, calculates average moisture content in a relatively large block of soil
Soil Density Gauge (SDG) (N/A)	Non-contact test uses electrical impedance spectroscopy (EIS) to assess dielectric constant of the soil	Similar to EDG because both measure dielectric constant, results in average estimate of moisture content, affected by near-surface moisture conditions.
Gas Pressure Moisture Tester (a.k.a., Speedy) (ASTM D4944)	A calcium carbide reagent reacts with water to produce acetylene gas within a sealed pressure vessel, gas pressure is proportional to the moisture content	Uses a small sample size that must be carefully selected, the acetylene gas by-product must be carefully vented, reagent must be kept dry, rapid test results
Electromagnetic Gauge (N/A)	An electromagnetic probe is used to measure the dielectric constant by “fringing field capacitance”	May be part of a license-exempt soil density gauge, similar comments to EDG

Table 2-23 Bias, Accuracy, and Precision of Test Methods for the As-Compacted Measurement of Moisture Content (after Berney et al. 2012, 2013)

Method	Bias (Slope)	Accuracy (R^2)	Precision (Standard deviation)
Lab Oven	1.00	0.995	0.087
Standard Microwave	1.11	0.973	0.109
Field Microwave	0.924	0.976	0.145
Direct Heating	1.027	0.964	0.159
Moisture Analyzer	0.731	0.915	0.044
Nuclear Density Gauge	0.922	0.970	0.091
Electrical Density Gauge	1.01	0.866	0.253
Soil Density Gauge	0.979	0.936	0.175
Gas Pressure Tester	1.405	0.867	0.056
Electromagnetic Probe	1.096	0.857	~0.10 (similar to NDG)
Explanation (for comparison of field and oven measurements of moisture content)	Slope of trend: slope > 1 indicates over-prediction, slope < 1 indicates under-prediction	Measure of scatter about trend, R^2=1 for results with no scatter	Scatter about the average value, standard deviation approaches 0 for more precise results

2-9.4 Rock Properties.

Strength and stiffness tests on rock core tend to reflect the characteristics of the “intact” rock, while the engineering performance of rock in the field is governed by the rock discontinuities (Deere and Deere 1988; Bieniawski 1989). Therefore, *in situ* tests that include rock discontinuities and assess their impact are useful. The following tests are discussed in this section: plate load, flat jack, rock dilatometer, rock borehole shear, field direct shear, and rock joint hydraulic conductivity. Because of the specialized nature of this testing and the cost of the equipment, many of these *in situ* testing methods for rock are subcontracted to a specialty contractor.

2-9.4.1 Strength and Stiffness Tests on Rock Masses.

Plate load testing (ASTM D4394, D4395) on rock is an *in situ* test method for that evaluates the rock mass stiffness (Goodman 1989, George et al. 1999). The test can also assess the strength of medium to low strength rock. The results from rock plate load tests are presented in terms of stress vs. displacement (Figure 2-22). Tests often include a series of loading and unloading cycles to help isolate the influence of fractures and discontinuities. Generally, the results are analyzed using solutions based on elastic theory to calculate an equivalent modulus, E' (Hoek 2007, Goodman 1989).

The plate bearing test requires a large reaction system to apply the required force. As an alternative, the flat jack concept uses a relatively thin (i.e., ~0.25 inches thick), flat, hydraulic jack that is inserted into a slot in the rock, thus allowing the rock to provide its own reaction. The flat jack test (ASTM D4729) is performed to assess the *in situ* state of stress in the rock and the rock mass stiffness.

For a geotechnical engineer who is familiar with *in situ* soil testing, a rock dilatometer is a misnomer, because it is actually a high-capacity pressuremeter (see Section 2-9.1.1). Operating procedures for a rock dilatometer are generally similar to those identified in ASTM D4719. The rock dilatometer test involves placing a long, cylindrical probe into a rock corehole and inflating a membrane on the probe. The membrane is expanded laterally while measuring the radial deformation. The results are used to evaluate rock mass stiffness.

The rock dilatometer may not be able to sufficiently stress the rock without rupturing the membrane. The *borehole jack*, commonly called a *Goodman jack*, overcomes this problem using small internal hydraulic jacks to induce lateral force across opposing curved steel platens that each stress a 90°sector of the borehole wall over a length of 8 inches. Equipment description and operating procedures are presented in ASTM D4971. The borehole jack can be used in boreholes core with NX-size coring equipment. The hydraulic system used for the borehole jack can generate up to 10,000 psi, so it can be used on virtually any rock. The borehole jack is a common *in situ* rock test that does not require extensive experience to perform and obtain reliable results.

The interpretation of the results presents some unique challenges, but also provides some insight regarding the *in situ* response of rock.

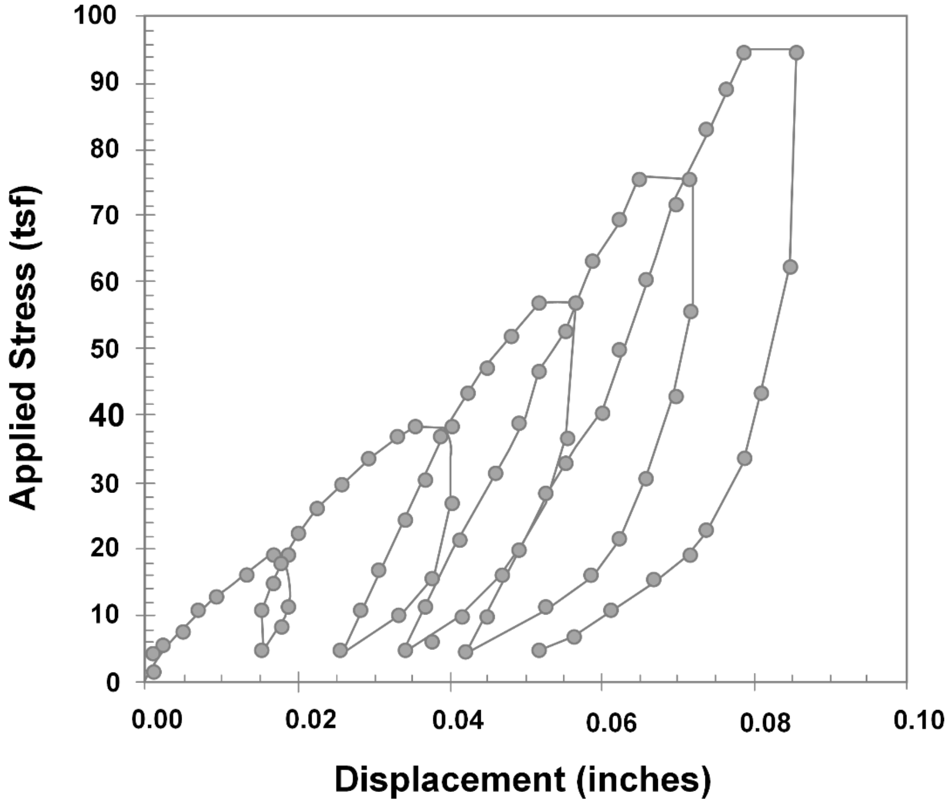


Figure 2-22 Example Plate Load Test Result on Intact Limestone (after NCHRP 2017)

The *rock borehole shear test* is an alternative *in situ* borehole method for relatively weak rock or rock that is easily disturbed upon drilling and coring (e.g., weathered rock, fractured rock, shale, etc.). This test is a modification of the Iowa borehole shear test originally developed for soil (Yang et al. 2006). The rock borehole shear test measures the shear strength of rock. While there is no recognized testing standard, guidelines for the rock borehole shear test are presented in Lutenegger and Hallberg (1981). The device is lowered down the hole to the desired test elevation. Hydraulic pressure is applied to shear plates to obtain the desired normal stress, and a tether is pulled to create a shear force on the plates. The normal stress and shear stress are recorded. The calculated shear stress values for each of three or four normal stresses provide the data points to construct a strength envelope.

2-9.4.2 Direct Shear Tests on Rock Discontinuities.

Rock mass behavior governs the engineering performance, as dictated by discontinuities, which can vary from clean fractures with a certain surface roughness caused by asperities to weathered rock joints to clay-filled fractures. Many field applications load those discontinuities in shear (e.g., rock slopes, tunnel side walls and crown). Undisturbed, representative samples of discontinuities can be difficult to obtain.

Direct shear testing of rock discontinuities has been developed similar to direct shear testing for soils. The test equipment is highly specialized and quite large. Large-scale *in situ* direct shear tests on rock are performed on exposed from natural rock outcrops, in tunnels, or in excavations. In almost all cases, the test is performed to evaluate the strength of the discontinuity.

A description and discussion of the use of large-scale direct shear testing of rock by USACE is presented in Zeigler (1972). Standardized testing procedures are presented in ASTM D4554. A confining ring is place around the *in situ* rock specimen such that the discontinuity is parallel to the ring. The specimen is encased in the ring using plaster of Paris or hydrostone. Normal and shear loads are applied perpendicular and parallel to the discontinuity, and displacements are measured.

While the performance of large-scale *in situ* direct shear tests on rock discontinuities can be daunting and difficult, the interpretation is similar to the conventional direct shear test performed on soil specimens. Pairs of normal and shear stress are plotted to define the failure envelope and shear strength parameters. In rock and along rock discontinuities, it is possible to measure the peak and residual strength of the discontinuities (Goodman 1970).

2-9.4.3 Hydraulic Conductivity of Rock Discontinuities.

Water flows through rocks occurs mostly in open voids, fractures, joints, and other discontinuities, which contribute to the “primary” porosity of the rock. Water flow in this regime may be turbulent instead of laminar and may not be governed by Darcy’s law, making quantification of water flow in rock discontinuities challenging. In the 1930s, the *lugeon* was introduced to quantify water flow in jointed rock (Houlsby 1976). A lugeon is defined as the flow of one liter of water per meter per minute under a pressure of 10 bars (145 psi) in a constant head double packer test as shown in Figure 2-23. For this situation, a lugeon is approximately 1×10^{-5} cm/s for laminar flow conditions.

To assess the flow regime for water in rock joints, the five-step test method summarized in Figure 2-23 was developed. Based on the five-step test results, the rock is characterized as being in one of five groups (Houlsby 1976).

- Group A – Laminar Flow: Lugeon values relatively constant through all five steps
- Group B – Turbulent: Lowest lugeon occurs at highest pressure
- Group C – Dilation: Highest lugeon occurs at highest pressure
- Group D – Wash-out: Lugeon increases as test progresses
- Group E – Void Filing: Lugeon decreases as test progresses

These characterizations are commonly used to select the appropriate grouting strategy for hydraulic barriers in jointed rock. The interpretation of the lugeon test and physical characterization of the jointed rock is shown in Table 2-24.

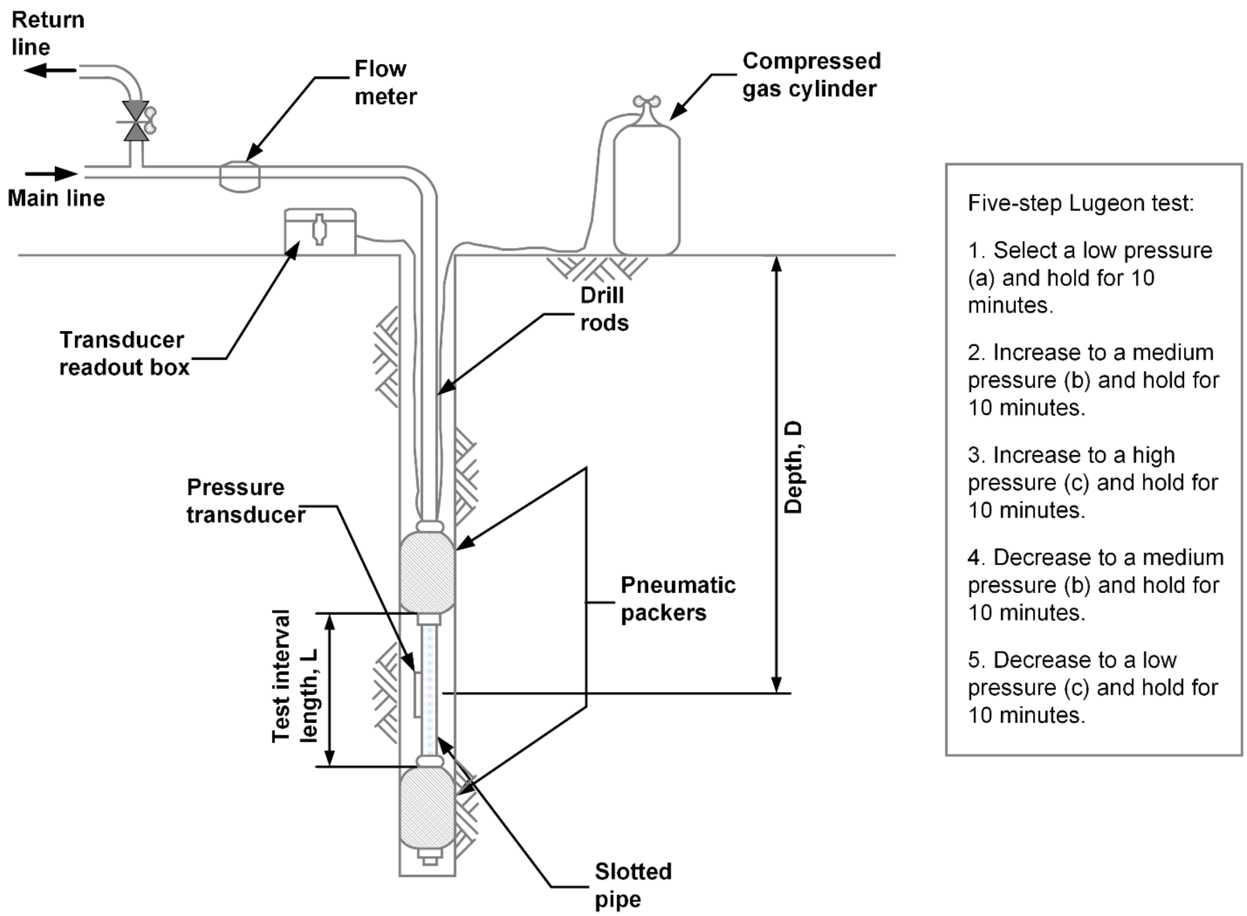


Figure 2-23 Double Packer Set-up to Conduct Five-step Lugeon test (after Clayton et al. 1995)

Table 2-24 Interpretation of Lugeon Test Results (after Tunbridge 2017)

Lugeon Range	Classification	Approx. Hydraulic Conductivity (cm/s)	Condition of Rock Mass Discontinuities	Report Precision (lugeons)
<1	Very Low	$< 1 \times 10^{-5}$	Very Tight	<1
1-5	Low	1×10^{-5} - 6×10^{-5}	Tight	±0
5-15	Moderate	6×10^{-5} - 2×10^{-4}	Few partly open	±1
15-50	Medium	2×10^{-4} - 6×10^{-4}	Some open	±5
50-100	High	6×10^{-4} - 1×10^{-3}	Many open	±10
>100	Very High	$> 1 \times 10^{-3}$	Open closely spaced or voids	>100

2-10 FIELD INSTRUMENTATION AND MONITORING.

Monitoring the performance of geotechnical structures is a vital consideration for individual projects and has helped guide the evolution of the practice (Peck 1969). Monitoring field performance starts with an assessment of what “performance” is anticipated. Once this is established, instruments may need to be installed before, during, and/or after construction or after a failure as part of the forensic investigation to understand the failure mechanisms. Finally, certain instruments may be integral components of early warning systems for sensitive structures. This section summarizes the types of geotechnical instrumentation and their operations to help guide the geotechnical engineer in selecting the most appropriate instrument for a given project. In-depth details regarding geotechnical instrumentation can be found in USACE (1987, 1995b), Bartholomew et al. (1987, 1987a), FHWA (1988) and most notably Dunnicliff (1993). The rapid evolution of the various measurement technologies and the recognition of the importance of performance monitoring will undoubtedly result in further expansion and utility of geotechnical instrumentation over the coming years.

2-10.1 Operating Concepts for Geotechnical Monitoring Instruments.

Making a measurement of engineering performance involves using some type of instrument or transducer for obtaining the measurement. The major types of instruments are summarized in Table 2-25. The transducers introduced in this table are incorporated into instruments that are used to make specific measurements. These measurements may include: (1) deformations (e.g., horizontal movement of a landslide, vertical settlement, tilt of retaining wall), (2) pore pressures in soil (e.g., excess pore pressure due to consolidation or static water levels in wells), (3) earth pressures (e.g., pressures acting on earth retaining structures), (4) loads (e.g., strut loads in braced excavations, anchor loads on tiebacks, vertical loads for plate load tests), (5) temperature (e.g., frost penetration, thermal-induced stress/deformation), and (6) vibration (e.g., geophysical testing, blast monitoring, seismic activity).

Regardless of the type, selection of monitoring instruments must consider the instrument range, accuracy, and precision as well as the required calibration procedures. Geotechnical instruments have a specific measurement range, which must encompass the values anticipated in the field application. Instruments also have a precision, which refers to the smallest recordable unit that can be measured. For example, a 1,000 lb. capacity load cell that records to the nearest 0.1 lb. has a precision of 0.01% of its full range or *full scale*. The accuracy of an instrument refers to the ability to obtain a correct and repeatable measurement of the desire quantity. Instruments with a large range are not always sufficiently accurate at values near the lower end of the range. Many instruments require calibration to convert the measured property into the desired engineering property. While typically provided by the manufacturer, the calibration should be confirmed and repeated on a regular basis.

Table 2-25 Types of Geotechnical Monitoring Instruments

Instrument Type	Examples	Advantages	Disadvantages
Mechanical	Plumb bob, tape measure, micrometer	Low cost, simple and direct measurement, readings in engineering units, external power not required	Continuous readings are not possible, manual recording
Pneumatic – use air pressure	Piezometers, earth pressure cells	Relatively rugged, and portable electrical supply not required, not impacted by electrical signals, relatively good for long-term measurements	Difficulty of reading systems, time-consuming manual effort
Hydraulic – use water or hydraulic fluid	Piezometers, earth pressure cells	Similar to pneumatic but with higher pressures available	Similar to pneumatic
Electrical – sensing element bonded to surface expected to strain	Bonded strain gauge, piezoelectrics, vibrating wire devices	Very stable and reliable, can be automated and remotely accessed, low voltage and portable power supplies are available	Higher cost, require a controlled power supply, signal processing is required to obtain data in engineering units
Micro-electro-mechanical (MEMS)	Tiltmeter, piezometer, load cell	Combine microscopic mechanical parts with electric signals, can be automated	Require a controlled power supply, signal processing is required to obtain data in engineering units
Fiber optics – measurements of strain along an embedded or bonded fiber	Strain gauge (distributed or discrete), temperature	Can measure strain along the entire length of a structure, sensor cost is low, potential for automation and dynamic analysis	Requires external power, relatively high cost for readout and signal processing, data interpretation is required

2-10.2 Linear Deformation Measurements.

There are many applications where deformation monitoring is either imperative or, at least beneficial (see Section 2-10.9 below). The deformation could involve vertical movement from consolidation adjacent to a deep excavation, horizontal and rotational movements from a landslide, or outward tilt of a retaining wall. Methods for determining linear deformation are summarized in Table 2-26 and can range from simple to relatively complex.

Table 2-26 Methods of Determining Linear Deformation

Instrument Type	Operation	Comments
Human eyes	Observe conditions within the subsurface and effects on structures	Readily available at no cost, helps develop observational method, often overlooked
Crack pins and tape measure	Measure cracking by distance between pins on either side of a crack in soil or rock	Simple solution, can be automated using electrical displacement sensors
Grid crack gauges	Used to monitor cracks in structures, two-piece plastic gauge attached to structure on opposite sides of crack	Simple solution, requires manual readings
Displacement gauge – e.g., dial gauge or LVDT (Figure 2-24)	Use to measure displacement over relatively short time or in a protected environment	Very accurate, electrical instruments can be automated, sensitive to environmental disturbance, more expensive
Field survey	Use conventional surveying to locate position and elevation of points	Requires a common benchmark, survey must be “closed,” precision should be established by completion of two surveys, including equipment tear-down, on the same day
Automated total station (AMTS)	Use an AMTS set up in a secure location to take measurements of targets at selected time interval	Excellent for construction-induced movements, more repeatable than conventional survey, near real-time readings, can be included in online monitoring sites
Surface settlement plates or platforms (Figure 2-25)	Plate with riser pipe is installed on or within the ground and surveyed over time to track settlement, riser extensions can be used for deep fills	Good long-term measurement technique, accurate and relatively inexpensive, riser pipes must be protected during construction, benchmark must be outside of area impacted by construction
Liquid level settlement gauge (Figure 2-25)	Similar to surface settlement plate with a pressure transducer and without risers, changes in pressure from an external reservoir are converted to settlement	Higher initial cost than surface settlement plates, construction is much easier without risers, potential for leakage, reservoir and tubing must be protected from freezing
Liquid level settlement profiler (Figure 2-26)	Install a flexible pipe below the embankment, pull transducer and water line through the pipe, measure pressure at intervals, calculate settlement from pressure	Can use a water filled pipe and a standalone pressure transducer, provides distributed measurement of settlement, time intensive manual measurements
Borehole extensometer (Figure 2-27)	Measures relative position of two or more points along the axis of a borehole, anchor the rod at the base or point of measurement	Requires a borehole, can monitor movements at multiple points

Simple methods for deformation monitoring should not be overlooked. Peck (1972) notes that the human eye is too often overlooked and “can detect most of what we need to know about subsurface construction.” Measurements by crack pins and tape measure can be used to monitor observed cracks in soils adjacent to slopes or cracks in rock. If conditions warrant, distances can be continuously monitored using a displacement transducer as shown in Figure 2-24. When considering instruments for monitoring observed cracks in the walls of buildings, a mechanical grid crack gauge can be monitored to show magnitude and direction of movement over time. This gauge is simply attached across the crack using epoxy or pins though the mounting holes.

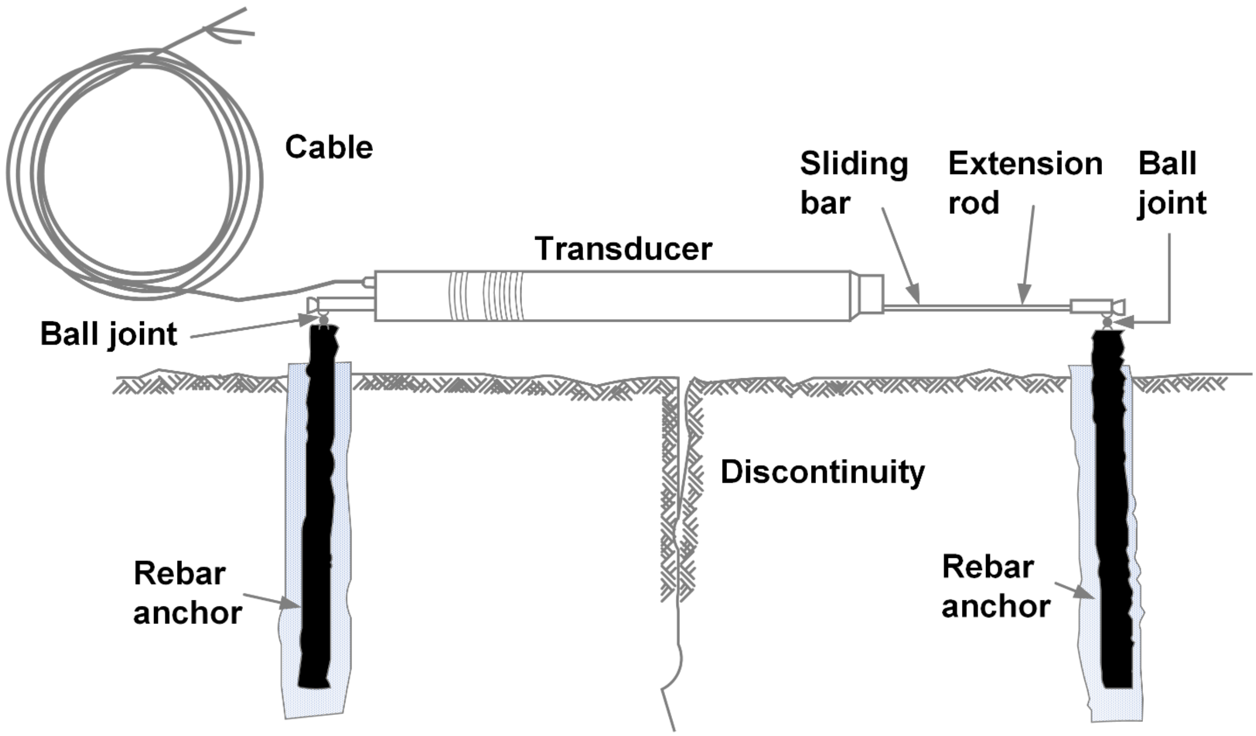


Figure 2-24 Electrical Crack Gauge and Reference Pins (after Dunnicliff 1993)

Where needed, more precise deformation measurements can be made using transducers. When monitoring deformations over relatively short time periods or when the instrument is protected, a simple dial gauge may be used. For automated readings, an electrical transducer (i.e., linear variable displacement transformer (LVDT), direct current LVDT, or linear potentiometer) provides a precise and potentially highly accurate alternative.

Conventional field survey equipment can be used to monitor deformations of several points over large distances and often over long time periods, based on a common benchmark. Such surveys must be “closed” by shooting the benchmark before and after the survey. Automated total stations (AMTS) can provide accurate near real-time monitoring for multiple points and are especially useful for monitoring construction-induced movements. The accuracy of the AMTS is inversely proportional to the distance from instrument to prism (or object), but can be used at distances greater than 1,000 feet. As with any surveying option, it is always desired to include a benchmark point during each reading cycle. The AMTS uses a laser for finding and monitoring the target so it can be used day or night.

The magnitude and time-rate of consolidation *settlements* during construction are often used to direct certain construction activities (i.e., fill placement rate). Monitoring long-term settlement is often desired. Surface settlement plates (often referred to as platforms) are monitored using conventional surveying instruments and provide an accurate and relatively inexpensive technique. The settlement plate is placed on the original ground surface before fill placement commences. A figure showing a typical set-up is provided in Figure 2-25a. It is necessary to protect the pipe from being damaged or tilted during construction by either vehicle impact or differential fill placement around the riser pipe. As with all survey measurements, a non-moving benchmark is to be shot during each cycle of readings. More advanced systems use liquid pressure to measure change in height below a fixed reservoir (Figure 2-25b) or probes to measure the profile of settlement in a buried tube (Figure 2-26).

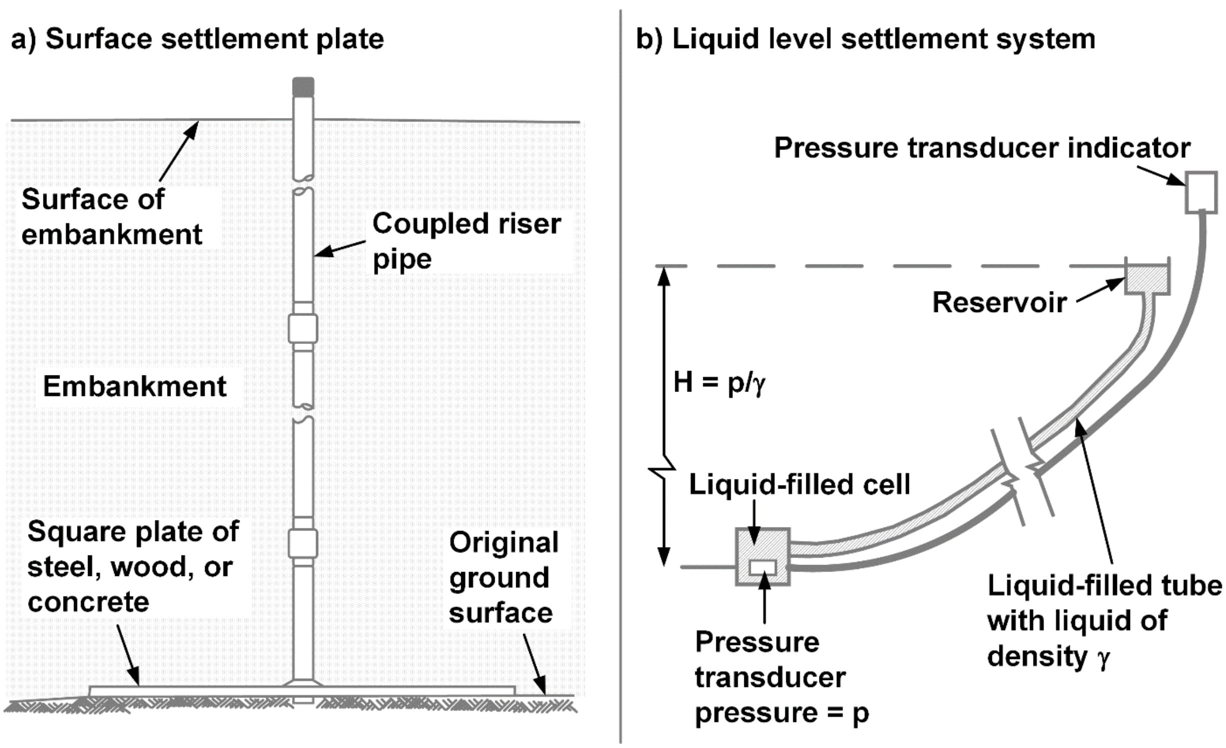


Figure 2-25 Surface Settlement (a) Plate or (b) Platform (after Dunnicliff 1993)

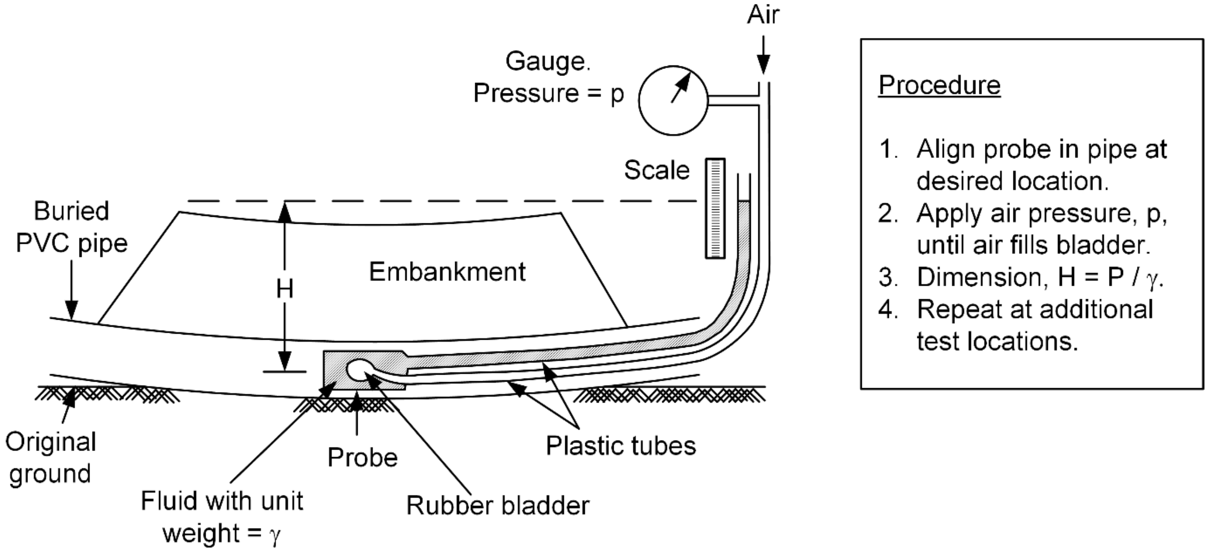


Figure 2-26 Liquid Level System to Continuously Profile Settlements (after Dunnicliff 1993)

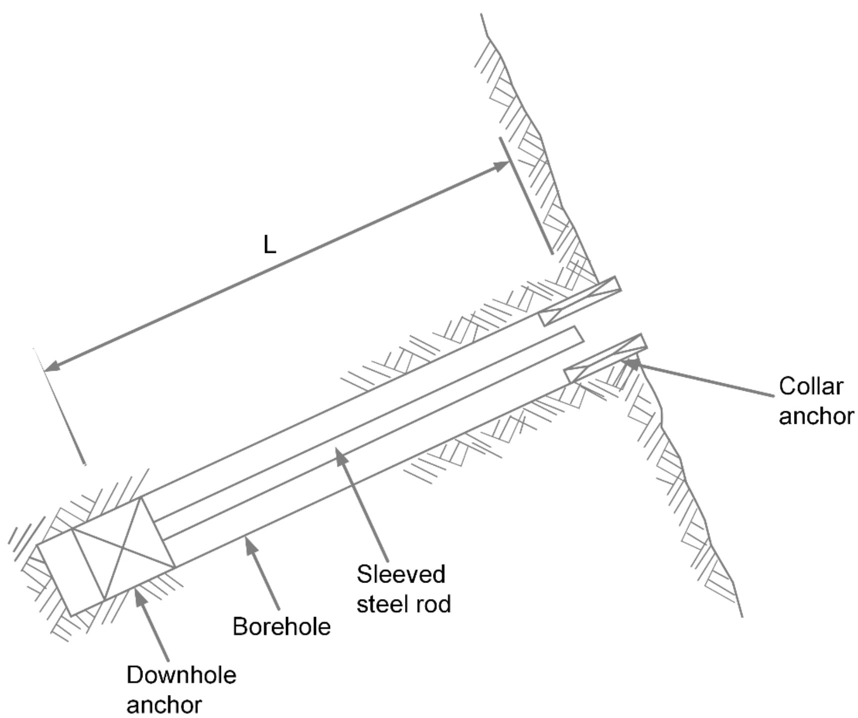


Figure 2-27 Borehole Extensometer (after Dunnicliff 1993)

2-10.3 Angular Displacement Measurements.

Angular displacement measurements are used to measure relative displacements of slopes or tilting of structures, such as retaining walls. These instruments can be used to determine the location of planes of sliding and to give warnings when structures become out-of-vertical. Types of angular displacement instruments are summarized in Table 2-27.

Table 2-27 Angular Displacement Instruments

Instrument Type	Operation	Comments
Tiltmeter	Uses accelerometer to determine inclination with respect to vertical, typical operating range of a few degrees, affixed to a structure or used as integral part of inclinometers	MEMS tiltmeters may have range up to 40 arc minutes and precision of 1 arc second
Slope inclinometer (Figure 2-28)	Special grooving casing grouted into a borehole, inclinometer probe with biaxial accelerometer is pulled through the casing, measures inclination of casing at regular intervals, integration of tilt provides deformed shape of casing	Frequently used to assess movement for landslides, can be used for vertical structures and deep excavations, initial baseline reading obtained after grout is set, casing should extend into a stable stratum, two passes through the casing are required for quality data, time-consuming manual process, bias correction must be completed in data processing, excessive deformation prevents ongoing use of casing
In-place inclinometer (Figure 2-28)	Same principle as conventional inclinometer except that the instrument has multiple segments with multiple accelerometers, the instrument remains at same location within casing	Can be automated, less time-consuming, much higher equipment cost compared to conventional inclinometer, MEMS accelerometers can be used that are cheaper and do not require special casing

2-10.4 Pore Pressure and Water Pressure Measurements.

Transducers that are capable of measuring transient water pressures are commonly relied upon for pore pressure measurements. These transducers are often generically referenced as *piezometers*. This is in contrast to the use of the term *standpipe piezometer* in Section 2-8 to describe a specific type of well. As described above, the same basic technology can be used for measuring both static and transient water pressures, and the transducer types include pneumatic, hydraulic, electrical, and MEMS devices. Operation and application of these piezometers are summarized in Table 2-28. All of these methods measure positive water pressures in saturated soil.

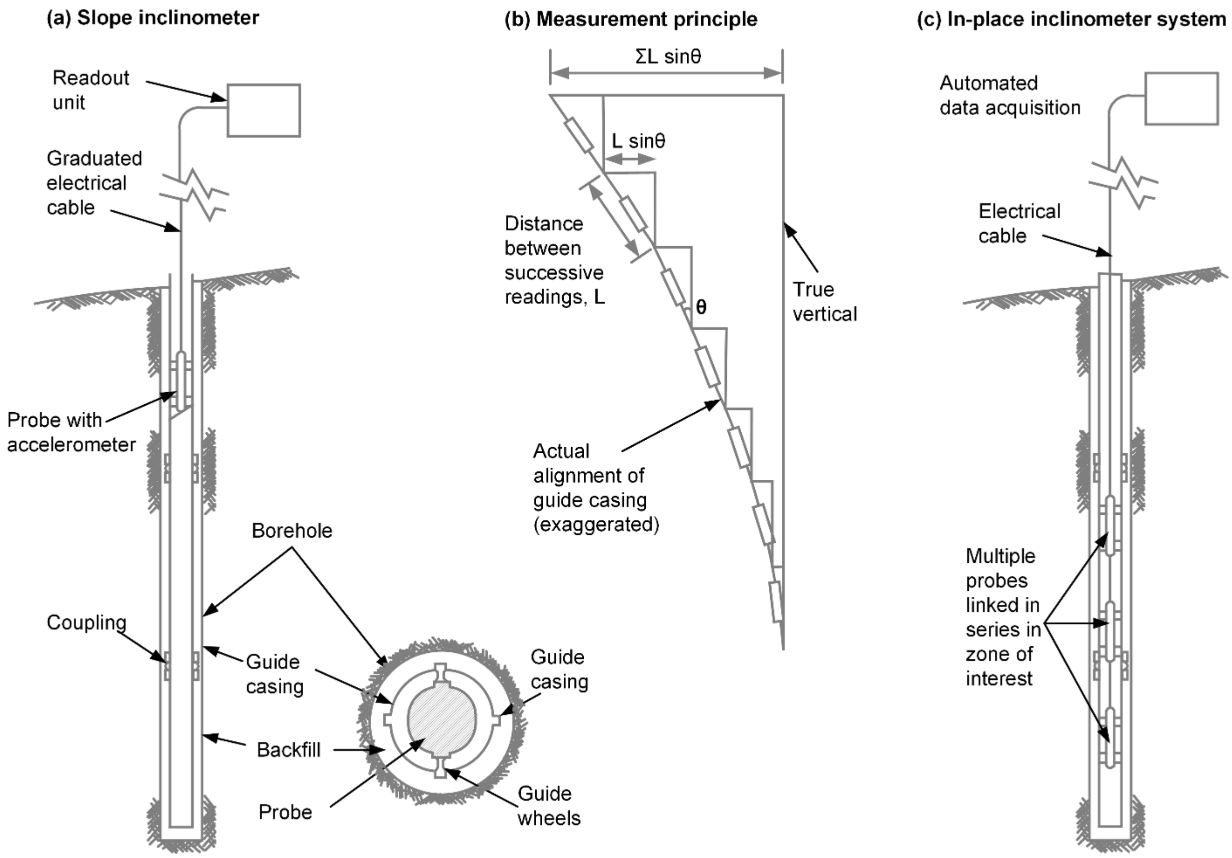


Figure 2-28 Slope Inclinometers – (a) Manual System, (b) Measurement Principle, and (c) In-Place Inclinometer System (after Dunnicliff 1993)

Hydrodynamic lag time or simply *lag time* refers to the time required for an instrument to respond to a change in pressure. Figure 2-31 plots the estimated lag time (in terms of time for 90% response) for various types of wells and piezometers compared to the hydraulic conductivity of the soil. Note the short lag time for diaphragm transducers and the extended time lag for open piezometer wells. As indicated by the figure, open wells cannot effectively measure hydrodynamic water pressures for transient flow situations.

Table 2-28 Piezometer Types

Piezometer Type	Operation	Comments
Pneumatic	Device pushed or grouted in-place at location of interest, air pressure is used to measure water pressure on opposite side of a diaphragm	Good choice for long-term monitoring, can be flushed and cycled to increase confidence, power source not required, insensitive to stray electrical signals, time-consuming manual readings
Hydraulic, a.k.a., twin-tube (Figure 2-29)	Similar operation to pneumatic except water pressure is used instead of air, pressure lines are filled with deaired fluid, pressure is measured with mechanical or electrical gauges	Period flushing is required for long-term monitoring
Electrical and MEMS (Figure 2-30)	Strain gauge, piezoelectric, or vibrating wire transducer attached to a diaphragm to measure pressure, transducer output is proportional to pressure, use high-air-entry saturated filters to accurately measure changes in pore pressure during transient conditions	Very common, can be automated and remotely monitored, very little water flow required to move the diaphragm resulting in rapid response to transient conditions (i.e., short lag time), requires power source (can be low voltage), MEMS sensors experience electrical drift in the signal, can recalibrate MEMS if sensor is accessible

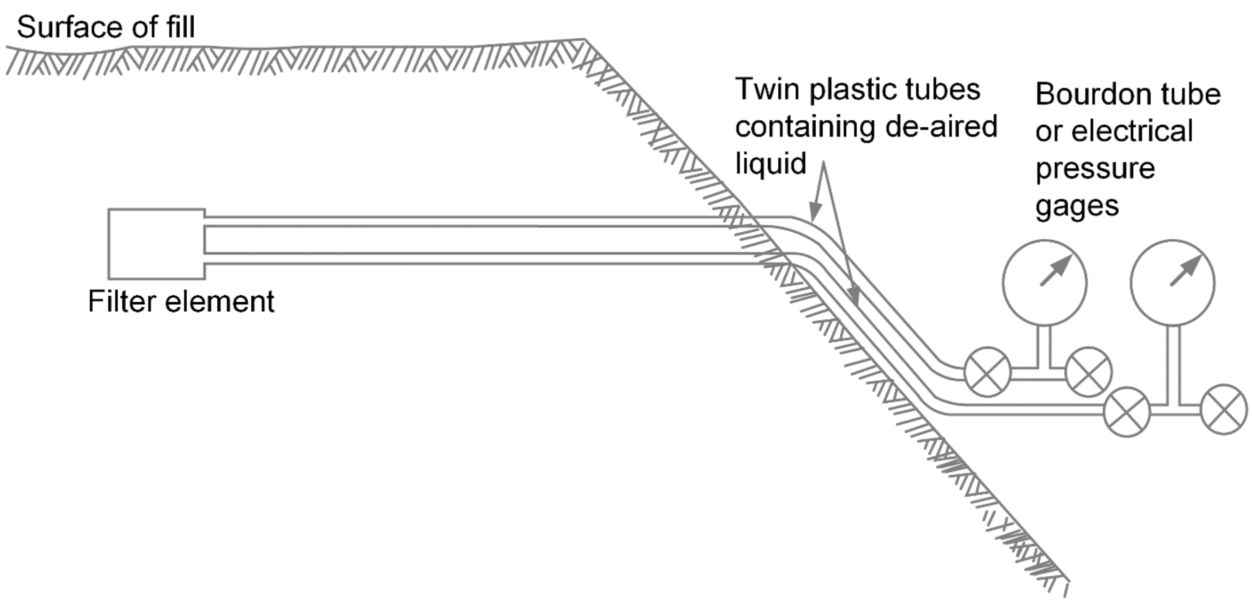


Figure 2-29 Dual-tube Hydraulic Piezometer in Embankment Dam (after Dunnicliff 1993)

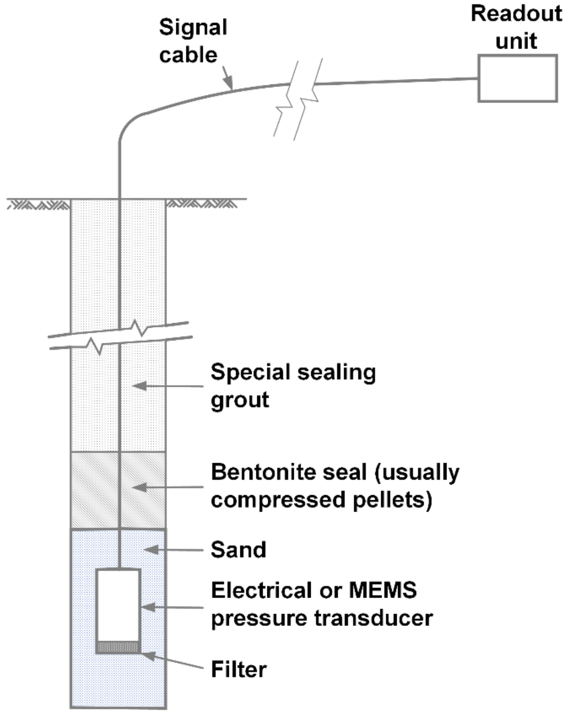


Figure 2-30 Example of Electrical Diaphragm Piezometer Transducer (after Dunnicliff 1993)

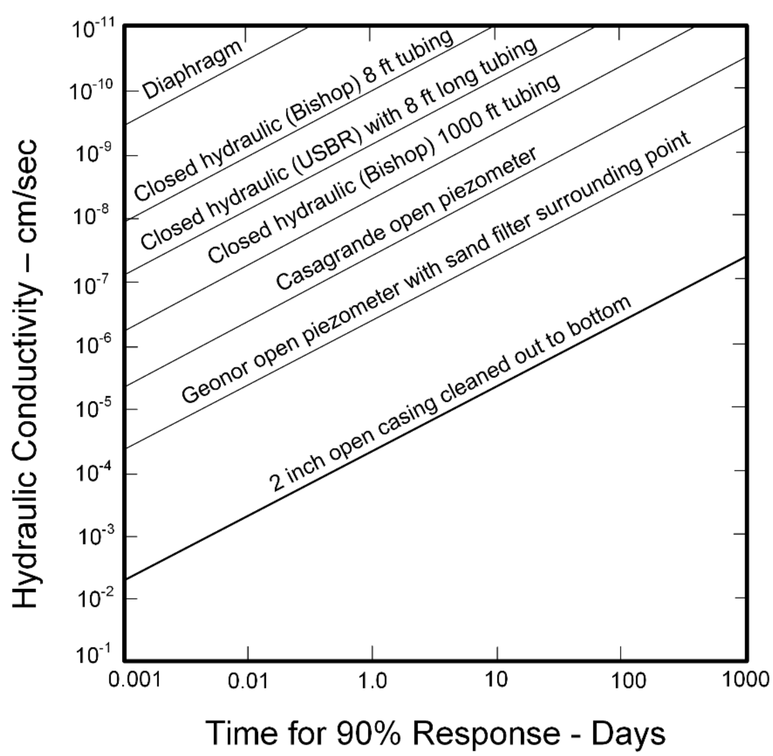


Figure 2-31 Estimated Hydrodynamic Lag Time for Various Piezometers and Wells (after Dunnicliff 1993)

2-10.5 Earth Pressure Measurements.

Although uncommon, measurement of the actual vertical and/or horizontal stress in the ground is sometimes desired. The concept for making these measurements is easy, while the interpretation of the results can be challenging. An earth pressure cell (a.k.a., total stress cell) measures stress by deformations of a thin diaphragm or transfer of pressure to a hydraulic cell. Deformations of the diaphragm-type cell can be measured by a strain gauge, vibrating wire transducer, or MEMS gauge. Earth pressure cells make an internal measurement compared with most of other transducers that monitor soil response externally. The presence of the cell alters the stresses in the soil due to differences between the stiffness of the cell and the soil. Good summaries of the influence of installation and type of earth pressure cells can be found in Filz and Brandon (1994) and Sehn (1990). As an alternative to earth pressure cells, tactile pressure sensors are thin, flexible polymer sheets with many embedded strain sensors that allow stress to be measured (Paikowsky et al. 2006).

From experience, earth pressure cells should be relatively large (i.e., 9 to 12 inches) in diameter and thin, resulting in a ratio of thickness to diameter of less than 1:10. The cell must be in intimate contact with the soil and is generally surrounded (i.e., bedded) using fine sand to minimize potential for stress concentrations from large particles in the soil.

2-10.6 Load Measurements.

Many applications in geotechnical projects require the measurement of load. A summary of the common load measuring instruments is provided in Table 2-29.

2-10.7 Temperature Measurements.

As described in Dunnicliff (1993), temperature measurements in geotechnical engineering are typically obtained for one of three specific reasons. The appropriate instrument for the specific application should be selected and used accordingly.

- Direct Measurement: Temperature measurements may be required for projects, such as depth of frost penetration, soil temperature beneath industrial furnaces, temperatures of thermal piles. Thermocouples and resistance temperature devices (RTDs) are the most common devices for these applications.
- Measurement of Temperatures that Induce Loads: Temperature changes cause thermal expansion and contraction of materials. The loads in structural members (e.g., struts for excavation support, tunnel support systems) will be impacted when subjected to temperature fluctuations. Again, thermocouple or RTDs are commonly used for these applications.
- Measurement of Temperatures that Influence Transducer Performance: Transducer temperatures can also have significant impacts on the response of geotechnical instruments themselves. For example, in closed hydraulic systems,

temperature can change the viscosity of the fluid and can cause expansion and/or contraction of the fluid and the hoses. These changes will influence the interpreted response unless appropriate corrections are made. Instrument manufacturers will report the necessary corrections. Monitoring temperature changes for transducers requires accurate measurement of small temperature changes. The thermistors used for this purpose are usually built directly into the transducer by the manufacturer.

Table 2-29 Instruments for Measuring Load

Instrument Type	Operation	Comments
Hydraulic Load Cell	Load is applied to a sealed hydraulic chamber, increase in pressure is measured and converted to load	Passive system that responds to load by internal pressure increase, relatively robust, capable of measuring loads >500 tons with about 0.1% accuracy, no external power required for cell with mechanical pressure transducer
Calibrated Hydraulic Jack	An external pressure transducer to measures pressure induced by a hydraulic jack, pressure over a known area is converted to load	Same advantages and capacities as hydraulic load cells, Osterberg Cell (O Cell) is an example used for load testing of drilled shafts
Electric Load Cell	Load applied to metal gauge, bonded strain gauges or vibrating wire transducers measure strain, which is converted to load via calibration	Commonly used in laboratory and field applications, wide range of capacities and physical sizes, can be custom made, robust and reliable, require external power supply, signal conditioning and data processing required to determine load
Embedded and surface-mounted strain gauges	Strain gauge attached to surface of metal structural members, stresses in structure are determined from strain and can be converted to load via section size	Can be bonded strain gauges attached to surface of structure or pre-attached (sister bars) gauges welded to the structural member or reinforcing cage, gauges must be correctly located to measure the desired strain and typically are installed in sets, must be protected during construction and operation

2-10.8 Vibration Measurements.

In some specialty cases, the measurement of vibrations may be a component of a performance monitoring program. Both steady state vibrations and transient vibrations may be of interest.

- Steady State Vibrations: Oscillating machinery that can induce vibratory loads to the foundation and foundation soils. These vibrations may induce cracks concrete floors, walls, masonry, or finishes. Vibration transducers use accelerometers (often MEMS based) to assess the magnitude and frequency of the vibration. These transducers may be included in portable handheld meters that are effective at capturing the induced vibrations from the machinery. Modern smartphones use MEMS accelerometers and can be used to assess vibrations.

- Transient Vibrations: Transient vibrations may be induced by construction activity, such as equipment traffic, pile driving, dynamic compaction, or blasting; machinery; or seismic activity. Transient vibration monitoring is an integral part of many of the geophysical tests discussed in Section 2-4. Transient vibrations are captured by accelerometers and require high sampling rates in order to capture vibrations that may occur over a few seconds. Of particular interest for the transient vibrations are the magnitude, duration, and frequency content.

Capturing and storing vibration data for detailed analysis usually requires dedicated hardware, specifically portable (or permanent) seismographs. This equipment may include geophones to measure ground velocity or accelerometers to measure ground acceleration. The equipment usually has a user-defined threshold limit for the device to trigger its recording and the ability to capture data a few seconds before the triggering event. A brief discussion of the equipment to measure and capture ground vibrations is presents in NCHRP (2018). There are engineering firms that specialize in measuring transient vibrations.

2-10.9 Field Applications for Instrumentation.

Every instrument used to monitor geotechnical projects should be selected to answer a particular performance question. This approach opposes the tendency to adopt a philosophy of "*if you can monitor it, you should monitor it,*" which is not recommended. Table 2-30 provides example performance questions that might be appropriate for various project types. Significant forethought should be given before an instrumentation plan is developed and the program should be organized around addressing specific questions. Additional discussion on these topics is provided in Dunnicliff (1993) and NCHRP (2018).

Table 2-30 Example Questions for Instrumentation Decisions

Project Category	Example Project Types	Potential Questions
Braced or Anchored Excavations	• Deep excavations in urban areas and/or near historical structures • Excavation support system that uses high strength anchors	• What is the lateral extent and magnitude of ground surface deformations? • Would an instrumented test anchor load test benefit the final design?
Embankments on Soft Ground	• Strength gain and staged construction are part of the design • Significant settlement or long-term movements are anticipated	• What rate of strength gain is required to not impact the construction schedule? • What is the confidence of predicted long-term settlement?
Embankment Dams	• Excavation for rehabilitation is anticipated near the downstream toe • Cutoff structure is part of the rehabilitation	• During rehabilitation, how much movement is anticipated at specific locations? • What measurements can be made to increase confidence of cutoff performance?
Excavated and Natural Slopes	• Existing slopes that have to be steepened • Seepage appears to be impacting slope stability	• What is the anticipated movement or impact of slope steepening? • What is the confidence that the design accurately accounts for groundwater levels?
Underground Construction	• Tunnel will be advanced below groundwater • Fractured rock conditions are anticipated • Seams of weak materials are anticipated	• What is the confidence in the ability to control water? • What is the confidence of the variation in rock structure along alignment?
Driven Piles	• Deep foundation system new to the area is being considered • Driven piles in urban environments	• What is the confidence of pile driving acceptance criteria? • What is level of vibration for structures in close proximity?
Drilled Shafts	• Larger loads than had previously been used in area are included in the design • Drilled shaft will be located below groundwater	• What is the confidence in lateral load capacity and location of bending moments? • What is the impact of excavation below the groundwater table?
Earth Retaining Structures	• Earth retaining structures not previously been used in area • Wall height exceeds heights previously constructed in the region	• What is the estimated settlement of the wall? • What is the estimated tilt of the wall? • What is the confidence in anchors loads and long-term creep?
Dewatering	• Dewatering in urban areas • Dewatering is considered on the critical path of construction	• Will the drawdown be uniform? • What is the confidence in pumping rate and drawdown?
Grouting	• Uncertainty regarding grout take • Grouting in fractured rock and karst • Grouting is initiated to minimize potential for settlement of critical structures	• What is the confidence in predicted grout take? • Will post-construction verification provide useful verification data?
Ground Improvement	• Techniques have previously been untried in region • Ground improvement is implemented to strengthen or stiffen the existing soil	• What is the confidence in long-term performance? • What is the confidence in ability to predict settlement and strength gain?
Liability Control	• Litigation is anticipated • Client may be implicated based on conditions encountered in the field during a forensic investigation	• How closely do original design assumptions match as-constructed conditions? • Will additional monitoring benefit the client? What type?

2-11 SUGGESTED READING.

Topic	Reference
Subsurface Exploration	NCHRP. (2018). *Manual on Subsurface Investigations. National Cooperative Highway Research Program. Publication No. CRP Project 21-20.* Transportation Research Board, National Academies of Science Engineering, and Medicine, Washington, DC.
Cone Penetration Test	Cone Penetration Testing (CPT) Design Manual for State Geotechnical Engineers. Report No. 2018-32, Minnesota Department of Transportation, St. Paul, MN, 2018.
In situ Measurements	*Geotechnical Site Characterization. Geotechnical Engineering Circular No. 5. Publication No. NHI-16-072.*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2016.
Groundwater Measurements	*Ground Water Manual*, Water Resources Technical Publication, United States Department of the Interior, Bureau of Reclamation, Washington, D.C., 1995.
Field Instrumentation	*Geotechnical Instrumentation for Monitoring Field Performance.* by J. Dunnicliff, John Wiley & Sons, New York, NY, 1993.

2-12 NOTATION.

Symbol	**Description**
D	Diameter of the vane - VST
E_D	Dilatometer modulus - DMT
E_p	Pressuremeter modulus - PMT
E'	Equivalent modulus
f_s	Sleeve friction - CPT
G	Shear modulus
I_D	Material index
K_D	Horizontal stress index - DMT
K_0	Coefficient of lateral earth pressure at rest
k_s	Modulus of subgrade reaction
q_t	Normalized tip resistance - CPT
q_u	Tip resistance - CPT
RQD	Rock Quality Designation
$S_{t,fv}$	Sensitivity in undrained shear strength from vane shear test
s_u	Undrained shear strength
$s_{u,fv}$	Undrained shear strength from vane shear test

Symbol	Description
$s_{ur,fv}$	Remolded undrained shear strength from vane shear test
T_{max}	Maximum net torque for vane shear test
T_{res}	Residual torque for vane shear test
V_0	Initial calculated volume within the uninflated membrane in PMT
μ_R	Vane correction factor
p_f	Inflection point assumed to delineate the change from pseudo elastic to plastic response and the point where creep may be expected in PMT
p_0	Pressure at which recompression of disturbed soil in the side of the borehole is complete and expansion into undisturbed soil starts in PMT, also referred to as liftoff pressure
p_r	Yield point during the reloading portion of a PMT unload–reload cycle where recompression ends and the soil reinitiates plastic shearing
p_t	Limit pressure in PMT where the curve becomes asymptotic on a pressure versus volume curve
p_u	Minimum pressure during unloading during the PMT unload–reload cycle
σ_{h0}	Total horizontal stress

CHAPTER 3 LABORATORY TESTING

3-1 INTRODUCTION.

3-1.1 Scope.

This chapter discusses the common laboratory tests that are used in geotechnical engineering practice. The chapter has been written assuming that the reader will not personally be conducting the tests, but will be engaging a commercial laboratory to do the tests. The discussion considers the types of test that can be conducted for different engineering parameters and important factors influencing the values obtained.

3-1.2 Evolution of Laboratory Test Procedures.

Geotechnical laboratory testing began in the early part of the last century. The test apparatuses and procedures were developed by a variety of organizations. Certain index tests used in geotechnical engineering were originally used in soil science and agronomy. Many of the compression and strength tests were initially developed by universities in the United States and Europe. An important early study published in 1946 was “The Use of the Triaxial Test in Engineering Practice” which was the summary report for a 10-year study sponsored by the Corps of Engineers. In this study, Professors Arthur Casagrande of Harvard, Don Taylor of MIT, and P. Rutledge of Northwestern, developed the major categories for triaxial testing of soils which are still used today.

During the next 40 years, testing procedures and specifications were developed by organizations involved in constructing dams and highways. The U.S. Bureau of Reclamation first published the *Earth Manual* in 1951, and newer editions were released in subsequent years. The U.S. Army Corps of Engineers developed EM 1110-2-1906 *Laboratory Soils Testing*, which provided procedures for conducting and presenting the results of a variety of geotechnical tests. AASHTO has published over thirty editions of *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, which contains many geotechnical tests. In addition, some state departments of transportation have developed their own test specifications. The testing procedures for all of these organizations have coalesced to procedures standardized by ASTM International.

ASTM was initially named the American Society of Testing Materials in 1902, and the first specifications focused on tests related to the railway industry. The organization has expanded to manage the specifications for testing a variety of engineering materials and consumer products. ASTM has been very active in developing standards for soil and rock testing, and these standards have been widely adopted in U.S. and international engineering practice. Committee D18 oversees the standards for soil and rock testing, and dozens of subcommittees covering a wide array of special areas in laboratory testing. The name of the organization was changed to ASTM International to reflect that the test standards are used internationally as opposed just in the United States. ASTM International provides standards for hundreds of soil and rock tests and these standards have been adopted by most of the organizations that once produced their own standards.

ASTM standards for soil and rock testing usually begin with a “C” or “D” followed by a three or four digit number. In geotechnical engineering practice, engineers often refer to specific tests by the ASTM number as opposed to the test name itself. As an example, engineers will often say “ASTM D698” as opposed to “standard Proctor compaction test.” The letter and test number are also followed by a dash and a two digit number reflecting the year that the standard was adopted or last reviewed. For example, ASTM D698-12 indicates that the standard was last approved in 2012. In this manual, the date portion of the ASTM standard is omitted since these will change during the useful life of the manual.

ASTM standards are not static. Each standard is reviewed every five years. During review, the standard may be reapproved, modified, or withdrawn. Individuals who are actively engaged in soil and rock testing need to ensure that tests are conducted to the most recent approved version of the standard.

3-1.3 Laboratory Certification.

The specifications and guidelines for laboratory tests are often quite complex. It takes a considerable investment of time and money for a laboratory to competently conduct many geotechnical tests and obtain reliable and repeatable results. It is often difficult for an engineer to know the competency of a laboratory to conduct high quality tests without conducting an assessment of the laboratory’s past performance. Two organizations conduct routine assessments of a laboratory’s ability to conduct standardized tests to a minimum level of competency.

The Materials Testing Center (MTC) of the U.S. Army Corps of Engineers inspects laboratories and validates their ability to conduct tests that follow ASTM standards. They see if the laboratory has a quality manual, certified technicians, functional equipment, and calibration procedures. Their inspection is done for specific tests, and they maintain an online register of validated labs and the tests that they are able to perform.

AASHTO also has a laboratory accreditation program. They perform on-site assessments of a laboratory’s prowess in conducting tests to AASHTO and ASTM standards. The laboratory must demonstrate the specific tests on the apparatuses where they will be performed. They also review the laboratory’s quality management program, technician training, and calibration procedures. AASHTO maintains a register of accredited labs online.

When planning to engage a private testing firm to conduct tests for a project, it is prudent to examine the validation or accreditation of the proposed laboratory for the specific tests that will be conducted. Even though a laboratory has been validated, it is still necessary to carefully review the test results to ensure that the tests were conducted properly and that the test results are reasonable.

3-2 LABORATORY TESTS ON SOILS.

There are hundreds of ASTM standardized tests used in geotechnical engineering. A small subset of those, perhaps 40 tests, are routinely used in geotechnical practice. It the following discussion, the tests will be categorized as: (1) index tests, (2) strength tests, (3) compression tests, (4) dynamic tests, and (5) permeability tests.

3-2.1 Sample Selection.

Soil samples normally can be categorized as *disturbed* or “undisturbed.” As explained in Chapter 2, disturbed samples can be obtained by drive samplers, cuttings generated by an auger, materials excavated in test pits, etc. “Undisturbed” or *intact* samples are those obtained from thin-walled samplers or excavated block samples.

Remolded samples are a form of disturbed sample, and this term is normally reserved for fine-grained soils. Clays can be remolded by mixing them with a spatula or other stirring device at a high water content. A remolded sample has lost the structure of the parent material. A *reconstituted* sample is also a form of disturbed sample, and that term is normally reserved for coarse-grained soils. *Compacted* samples, which can be formed from either fine-trained or coarse-grained soils, can also be considered disturbed samples.

The amount of material needed to conduct a given test can vary greatly. Over 100 pounds of soil may be required for compaction tests (ASTM D698 or ASTM D1557), and only a few ounces of soil may be needed for ring shear tests (ASTM D6467). The individual ASTM test procedures often state the amount of material needed for a test series. Table 3-1 provides a summary of the amount of material needed for common soil tests.

As a general rule, fine-grained soils should not be allowed to dry out prior to testing unless the test procedures specifically require drying the sample. In particular, oven drying of a fine-grained soil can cause irreversible changes in mechanical properties. Correct methods of sample storage for soils is provided in ASTM D3213 (Standard Practices for Handling, Storing, and Preparing Soft Intact Marine Soil) and ASTM D4220 (Standard Practices for Preserving and Transporting Soil Samples).

Table 3-1 Amount of Soil Needed for Common ASTM Tests \1\

ASTM #	Description	Sample Size[A]	Comments
D698	Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))	23 kg (Methods A and B) 45 kg (Method C)	16 kg dry (Methods A and B), 29 kg dry (Method C). If the sample has material larger than the No. 4 sieve (Methods A and B) or greater than ¾" (Method C), much more material may be needed.
D854	Specific Gravity of Soil Solids by Water Pycnometer	100 g dry	The test can be conducted with less material if the small (250 ml) pycnometer is used.
D1140	Determining the Amount of Material Finer than 75 µm (No. 200) Sieve in Soils by Washing	200 g	This value is for a sample where 100% passes the No. 4 sieve. Considerably more material is needed for accurate results of coarser soils.
D1557	Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))	23 kg (Methods A and B) 45 kg (Method C)	16 kg dry (Methods A and B), 29 kg dry (Method C). If the sample has material larger than the No. 4 sieve (Methods A and B) or greater than ¾" (Method C), much more material may be needed.
D2166	Unconfined Compressive Strength of Cohesive Soil	250 - 300 g	Around 150 g for test specimen and 50-70 g for trimmings
D2216	Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass	Depends on particle size: 20 g – 5 kg (Method A)	For maximum particle size: 75 mm: 5 kg required 37.5 mm: 1 kg 19 mm: 250 g 9.5 mm: 50 g 4.75 mm: 20 g 2 mm: 20 g
D2435	One-Dimensional Consolidation Properties of Soils Using Incremental Loading	300 g	Assuming 2.5-in. diameter sample with height 1 in. Also including weight of trimmings.
D2487	Classification of Soils for Engineering Purposes (Unified Soil Classification System)	Exact mass not provided in ASTM	
D2488	Description and Identification of Soils (Visual-Manual Procedures)	Depends on particle size: 110 g – 60 kg	For maximum particle size: 75 mm: 60 kg required 38.1 mm: 8 kg 19 mm: 1 kg 9.5 mm: 220 g 4.75 mm: 110 g
D2850	for Unconsolidated Undrained Triaxial Compression Test on Cohesive Soils	250 - 300 g	150 g -170 g for specimen loaded into cell for test and 50-70 g for trimmings. Minimum diameter is 1.3 in. and H/D ratio is 2 to 2.5. Considering a sample with 1.4-in. diameter and 3-in. height.

[A] Moist sample size unless indicated otherwise

/**1**/

Table 3-1 (cont.) Amount of Soil Needed for Common ASTM Tests

ASTM #	Description	Sample Size[A]	Comments
D3080	Direct Shear Test of Soils Under Consolidated Drained Conditions	250 – 300 g	Minimum specimen diameter for circular specimens, or width for square specimens, is 2 in. and minimum thickness 0.5 in. Considering 2.5-in. diameter and 1-in. height.
D3967	Splitting Tensile Strength of Intact Rock Core Specimens	200 g each (10 specimens required of this mass)	Circular specimen with D = 54 mm (2 in.) t/D = 0.2 to 0.75. Considering D = 54 mm, thickness = 27 mm, G_s = 2.7, approximate weight for each sample is 167 g. 10 specimens required.
D3999	Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus	200 g	Cylindrical specimens with a minimum diameter of 36 mm [1.4 in.]. The height-to-diameter ratio shall be between 2 and 2.5. Considering D = 1.4 in. and H = 3 in.
D4015	Modulus and Damping of Soils by Fixed-Base Resonant Column Devices	650 - 700 g	D = 7.1 cm, L = 14.2 cm. Average mass required is 609 g.
D4186	One- Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled- Strain Loading	300 g	Around 150 g for specimen loaded into cell for test and 50-70 g for trimmings
D4253	Maximum Index Density and Unit Weight of Soils Using a Vibratory Table	11 - 34 kg	Mass of specimen depends on Maximum particle size: 3 in: 34 kg required 1.5 in: 34 kg 0.75 in. or less: 11 kg
D4254	Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density	11 - 34 kg	Mass of specimen depends on Maximum particle size: 75 mm: 34 kg required 38.1 mm: 34 kg 19 mm: 11 kg 9.5 mm or less: 11 kg
D4318	Liquid Limit, Plastic Limit, and Plasticity Index of Soils	150 - 200 g	Sample should be passing No 40 sieve.
D4427	Classification of Peat Samples by Laboratory Testing	Representative samples of the peat should be used.	The size and type of sample needed is dependent on the tests to be performed and the coarseness and moisture content of the peat.
D4546	One-Dimensional Swell or Collapse of Soils	250 - 300 g	Considering 2.5-in. diameter and 1-in. height
D4643	Determination of Water Content of Soil and Rock by Microwave Oven Heating	100 - 1000 g	Percentage retained not more than 10 % of sieve: No 10: 100 – 200 g required No 4: 300 – 500 g required ¾ in: 500 -1000 g Rock/gravel samples: 500 g
D4648	Laboratory Miniature Vane Shear Test for Saturated Fine- Grained Clayey Soil	200 - 250 g	For vane of diameter 0.5 in. and height 1 in., Minimum Sample required has diameter 2 in. and height 2 in.
D4767	Consolidated Undrained Triaxial Compression Test for Cohesive Soils	200 – 250 g	Considering 1.4-in. diameter samples with height around 3 in. Including weight of trimmings.

[A] Moist sample size unless indicated otherwise

Table 3-1 (cont.) Amount of Soil Needed for Common ASTM Tests

ASTM #	Description	Sample Size[A]	Comments
D4829	Expansion Index of Soils	1 kg (dry)	Sample is first air dried or oven dried.
D5084	Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter	200 g	Considering 2-in. diameter and 2-in. height. Minimum height and diameter are 1 in.
D5311	Load Controlled Cyclic Triaxial Strength of Soil	750 - 800 g	Cylindrical specimens with min Diameter of 2 in. and ratio H/D = 2-2.5.
D5607	Performing Laboratory Direct Shear Strength Tests of Rock Specimens Under Constant Normal Force	Exact mass not provided in ASTM	The height of each specimen shall be greater than the thickness of the shear (test) zone and sufficient to embed the specimen in the holding rings. Specimens may have any shape such that the cross-sectional areas can be determined.
D5731	Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications	700 - 800 g each	Preferred diameter/width of 50 mm (2 in). Average Length = 4 to 5 in. 10 samples required
D6467	Torsional Ring Shear Test to Determine Drained Residual Shear Strength of Cohesive Soils	100 g	Soil passing through No. 40 sieve. Including soil for water content. Around 40-45 g needed for test specimen.
D6528	Consolidated Undrained Direct Simple Shear Testing of Fine Grain Soils	400 – 450 g	Considering 30 mm height and 78 cm^2 cross sectional area.
D6913	Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis	50 g – 70 kg (depends on particle size)	For maximum particle size (99% passing): 0.425 mm: 50 g required 2 mm: 50 g 4.75 mm: 75 g 9.5 mm: 165 g 19 mm: 1.3 kg 25.4 mm: 3 kg 38.1 mm: 10 kg 50.8 mm: 25 kg 76.2 mm: 70 kg
D7181	Consolidated Drained Triaxial Compression Test for Soils	250 – 300 g	Cylindrical sample, including trimmings
D7263	Laboratory Determination of Density (Unit Weight) of Soil Specimens	500 - 600 g	Considering 2.8-in. specimens on all sides.
D7928	Particle- Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis	50 g (dry)	Passing No. 10 sieve and retained on No. 200 sieve

[A] Moist sample size unless indicated otherwise

Tests conducted to determine important strength or compressibility parameters for *in situ* soil conditions require high-quality intact or undisturbed samples. It has become common practice to X-ray soil samples while still in the tube (prior to extrusion) to select the best portions for test assignments. ASTM D4452 (Standard Practice for X-Ray Radiography of Soil Samples) provides guidance for X-raying soil samples.

3-2.2 Index Property Tests.

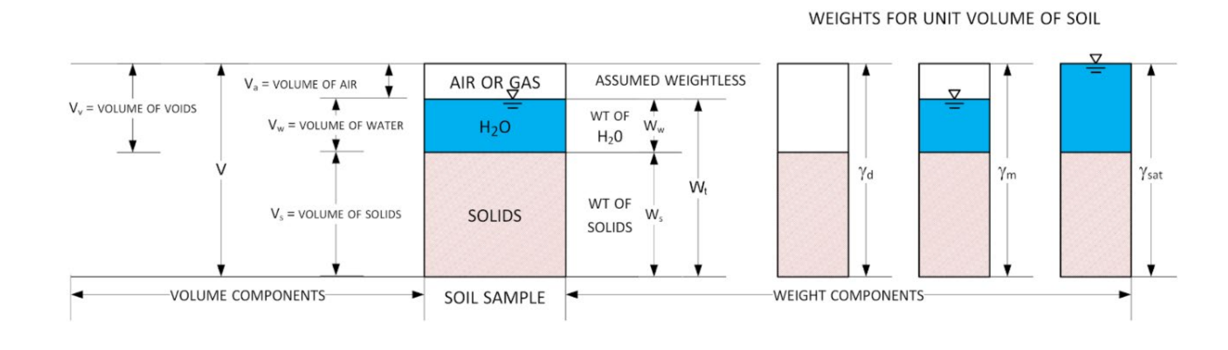
Index properties are used to classify soils and to group soils in major strata. In general, soils with similar index properties behave similarly, so index properties are often used in empirical correlations. Index property tests are normally much more inexpensive than other types of tests, so they are conducted in greater numbers than the more complex tests. Index property tests can be conducted on both disturbed and intact samples. However, it is prudent to save intact samples for tests that specifically require them, and to use disturbed samples for index property tests. One of the simplest and least expensive index property tests is ASTM D2216 (Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass). This test requires a relatively small sample, and it is good practice to conduct this test on every disturbed sample that is taken, particularly of fine-grained soils. Important engineering information can be gleaned from plots of water content versus depth.

Other index tests are essential to obtain the parameters required for soil classification. As discussed in Chapter 1, the most common classification scheme used in U.S. geotechnical engineering practice is ASTM D2487 (Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)). In order to correctly classify fine-grained and coarse-grained soils, ASTM D4318 (Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils) and ASTM D6913 (Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis) must be conducted. Determination of the Atterberg limits for fine-grained soils (ASTM D4318) is especially important because they are used in many of the correlations developed for strength and compressibility properties. The parameters from the gradation curve (ASTM D6913) are frequently used in correlations with fluid flow properties of granular soils.

Index tests provide the information necessary to calculate the phase relationship parameters used to characterize various aspects of densities and saturation conditions of soils. The phase relationship parameters are import parts of almost all soil tests. A summary of the phase relationship calculations for soils and rock is given in Table 3-2.

Some index tests are required for specific purposes. As an example, the specific gravity of soils (ASTM D854 - Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer) is necessary to calculate the void ratio and porosity of a soil or rock. It is also needed as part of a hydrometer test (ASTM D7928 Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis) in the data reduction procedure.

Table 3-2 Summary of Phase Relationship Calculations \1\



	Property	Saturated: W_s, W_w, G_s are known	Unsaturated: W_s, W_w, G_s, V are known	Supplementary Formulae Relating Measured and Computed Parameters			
Volume Components	V_s = Volume of solids	$\frac{W_s}{G_s \cdot \gamma_w}$		$V-(V_a+V_w)$	$V \cdot (1-n)$	$\frac{V}{1+e}$	$\frac{V_v}{e}$
	V_w = Volume of water	$\frac{W_w}{\gamma_w}$		$V_v - V_a$	$S \cdot V_v$	$\frac{S \cdot V_a}{1+e}$	$S \cdot V_s \cdot e$
	V_a = Volume of air	zero	$V-(V_s+V_w)$	$V_v - V_w$	$(1-S) \cdot V_v$	$\frac{(1-S) \cdot V_a}{1+e}$	
	V_v = Volume of voids	$\frac{W_w}{\gamma_w}$	$V - \frac{W_s}{G_s \cdot \gamma_w}$	$V - V_s$	$\frac{V_s \cdot n}{1-n}$	$\frac{V \cdot e}{1+e}$	$V_s \cdot e$
	V = Total volume	$V_s + V_w$	Measured	$V_s + V_w + V_a$	$\frac{V_s}{1-n}$	$V_s \cdot (1+e)$	$\frac{V_v \cdot (1+e)}{e}$
	n = porosity	$\frac{V_v}{V}$		$1 - \frac{V_s}{V}$	$1 - \frac{W_s}{G_s \cdot V \cdot \gamma_w}$	$\frac{e}{1+e}$	
	e = Void ratio	$\frac{V_v}{V_s}$		$\frac{V}{V_s} - 1$	$\frac{G_s \cdot V \cdot \gamma_w}{W_s} - 1$	$\frac{G_s \cdot w}{S}$	$\frac{n}{1-n}$
Weights for Specific Sample	W_s = Weight of solids	Measured		$\frac{W_t}{1+w}$	$G_s \cdot V \cdot \gamma_w \cdot (1+n)$	$\frac{W_w \cdot G_s}{S \cdot e}$	
	W_w = Weight of water	Measured		$w \cdot W_s$	$S \cdot \gamma_w \cdot V_v$	$\frac{e \cdot W_s \cdot S}{G_s}$	
	W_t = Total weight	$W_s + W_w$		$W_s \cdot (1+w)$			
Weights for Sample of Unit Volume	γ_d = Dry unit weight	$\frac{W_s}{V_s + V_w}$	$\frac{W_s}{V}$	$\frac{W_t}{V \cdot (1+w)}$	$\frac{G_s \cdot \gamma_w}{1+e}$	$\frac{G_s \cdot \gamma_w}{1 + \frac{w \cdot G_s}{S}}$	
	γ_t = Total (wet) unit weight	$\frac{W_s + W_w}{V_s + V_w}$	$\frac{W_s + W_w}{V}$	$\frac{W_t}{V}$	$\frac{(G_s + S \cdot e) \cdot \gamma_w}{1+e}$	$\frac{(1+w) \cdot \gamma_w}{\frac{w}{S} + \frac{1}{G_s}}$	
	γ_{sat} = Sat. unit weight	$\frac{W_s + W_w}{V_s + V_w}$	$\frac{W_s + V_v \cdot \gamma_w}{V}$	$\frac{W_s}{V} + \left(\frac{e}{1+e}\right) \cdot \gamma_w$	$\frac{(G_s + e) \cdot \gamma_w}{1+e}$	$\frac{(1+w) \cdot \gamma_w}{w + \frac{1}{G_s}}$	
	γ_b = Buoyant unit weight or submerged unit weight	$\gamma_{sat} - \gamma_w$		$\frac{W_s}{V} - \left(\frac{1}{1+e}\right) \cdot \gamma_w$	$\left(\frac{G_s + e}{1+e} - 1\right) \cdot \gamma_w$	$\left(\frac{1 - \frac{1}{G_s}}{w + \frac{1}{G_s}}\right) \cdot \gamma_w$	
Combined Relations	w = water content	$\frac{W_w}{W_s}$		$\frac{W_t}{W_s} - 1$	$\frac{S \cdot e}{G_s}$	$S \cdot \left(\frac{\gamma_w}{\gamma_d} - \frac{1}{G_s}\right)$	
	S = Degree of saturation	1.00	$\frac{V_w}{V_v}$	$\frac{W_w}{V_v \cdot \gamma_w}$	$\frac{G_s \cdot w}{e}$	$\frac{w}{\frac{\gamma_w}{\gamma_d} - \frac{1}{G_s}}$	
	G_s = Specific gravity	$\frac{W_s}{V_s \cdot \gamma_w}$		$\frac{S \cdot e}{w}$			

/**1**/ Some commercial laboratories may include the cost of conducting certain index tests within the cost of the more elaborate strength and compressibility tests. For example, a laboratory may include a specific gravity test (ASTM D854) automatically as part of a consolidation test (ASTM D2435 Standard Test Methods for One-Dimensional Consolidation Properties of Soil Using Incremental Loading). The water content test (ASTM D2216) is normally automatically performed in many other tests. There is a separate test to measure the unit weight of soils (ASTM D7263 – Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens), but determination of the unit weight is a by-product of most of the strength and compressibility tests on intact soil specimens.

Table 3-3 includes a list of the common ASTM index tests that are available and the associated parameters that are determined.

Table 3-3 Index Property Tests and Engineering Parameters Obtained

ASTM #	Description	Parameters	Comments
D698	Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))	$\gamma_{d\text{-}max}$, w_{opt}	Sometimes it is useful to conduct compaction tests at an effort less than D698. This can be done by using 15 to 20 tamps per lift.
D854	Specific Gravity of Soil Solids by Water Pycnometer	G_s	Required when void ratios are to be calculated or when hydrometer tests are performed.
D1140	Determining the Amount of Material Finer than 75 µm (No. 200) Sieve in Soils by Washing	% Fines	Useful when classifying a soil in lieu of conducting a complete gradation.
D1557	Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))	w_{opt}	The normal maximum mold diameter is 6 inches. If larger molds are to be used, calculations are necessary to guarantee the correct compactive effort.
D2216	Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass	$w\%$	Note that lower oven temperatures are used for organics. Oven drying can cause irreversible changes in the mechanical behavior of clay soils. Specimens which have been oven dried should not be used for other tests.
D2487	Classification of Soils for Engineering Purposes (Unified Soil Classification System)	Classification Symbol	Classification of peat (Pt) is in D4427
D2488	Description and Identification of Soils (Visual-Manual Procedures)	Classification Symbol Description	Visual classification is used on boring logs and most laboratory test reports.
D4221	Dispersive Characteristics of Clay Soil by Double Hydrometer	% Dispersion	Important when examining erosion potential of fine-grained soils for use in levees and dams.
D4253	Maximum Index Density and Unit Weight of Soils Using a Vibratory Table	e_{min}	A vibratory compactor standard for maximum density may be available. Concerns exist on proper calibration of the vibratory table.
D4254	Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density	$\gamma_{d\text{-}min}$	

Table 3-3 (cont.) Index Property Tests and Engineering Parameters Obtained

ASTM #	Description	Parameters	Comments
D4318	Liquid Limit, Plastic Limit, and Plasticity Index of Soils	PL LL PI	In international practice, the fall-cone device is often used for LL and sometimes PL.
D4427	Classification of Peat Samples by Laboratory Testing	Ash content Fiber content Acidity	
D4643	Determination of Water Content of Soil and Rock by Microwave Oven Heating	$w\%$	This normally is used for field compaction control tests. D2216 is normally used in standard laboratory practice.
D4647	Identification and Classification of Dispersive Clay Soils by the Pinhole Test	Dispersive classification	Important when examining erosion potential of fine-grained soils for use in levees and dams.
D4972	pH of Soils	pH	Important when examining the compatibility of steel and other engineering materials in contact with soil.
D6572	Determining Dispersive Characteristics of Clayey Soils by the Crumb Test	Dispersive classification	Important when examining erosion potential of fine-grained soils for use in levees and dams.
D6913	Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis	C_u, C_c, D_{xx}	
D7263	Laboratory Determination of Density (Unit Weight) of Soil Specimens	γ_d, γ_t, $w\%$	
D7928	Particle- Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis	% > 2µm	

3-2.3 Compaction Tests.

Two types of compaction tests are available for determining the compaction characteristics of soils. For soils having greater than 15% fines, impact compaction tests are the most appropriate. Impact compaction tests provide a compaction curve for the soil, and the maximum dry density (γ_{d-max}) and optimum water content (w_{opt}) can be determined from the curve. The as-compacted density of the soil can be characterized by relative compaction (RC). Relative compaction is defined as:

$$RC = \frac{\gamma_d}{\gamma_{d-\max}} \cdot 100\% \qquad \textbf{(3-1)}$$

where:
γ_d = dry density of the soil to be characterized, and
γ_{d-max} = maximum dry density from the compaction curve for a particular effort.

For soils having less than 15% fines, the density of a soil can be characterized by *relative density* (D_r). Relative density is defined as:

$$D_r = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \cdot 100\% = \frac{\gamma_{d-\max}}{\gamma_d}\left[\frac{\gamma_d - \gamma_{d-\max}}{\gamma_{d-\max} - \gamma_{d-\min}}\right] \cdot 100\% \quad \textbf{(3-2)}$$

where:
e = void ratio of soil to be characterized,
e_{max} = maximum index void ratio,
e_{min} = minimum index void ratio,
γ_d = dry density of soil to be characterized (corresponding to e),
γ_{d-max} = maximum index dry density (corresponding to e_{min}), and
γ_{d-min} = minimum index dry density (corresponding to e_{max}).

Soils in their loosest states have a relative density equal to 0% and soils in their densest state have a relative density equal to 100%. For these soils, tests must be conducted to determine the maximum and minimum index void ratios and index densities. These tests are not “compaction tests” in the strictest sense of the term, but are index values corresponding to the loosest and densest states of the soil. The maximum dry density used in relative density calculations is not necessarily the same as that obtained in ASTM D1557 that is described below.

3-2.3.1 Impact Compaction Tests.

ASTM D698 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3)) and ASTM D1557 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3)). These tests differ by the amount of effort that is applied to compact the soil. The ASTM standards provide test procedures for compaction molds having diameters of 4 inches and 6 inches. Following the specifications, both of these impact compaction tests should be limited to soils having no more than 30% retained on the 3/4-inch sieve, although corrections exist for materials having as much as 70% retained on the 3/4-inch sieve. However, if impact compaction test results are required for larger grain-size materials, the mold diameters and hammer weights should be scaled up to keep the compactive effort the same.

3-2.3.2 Index Density Determination.

For soils having less than 15% fines, there are specific tests that can be conducted to determine the maximum and minimum index densities so that the soil can be characterized in terms of relative density. ASTM D4254 (Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density) provides three methods to determine e_{max} and γ_{d-min} depending on the grain size of the soil tested. Methods are available for soils have a maximum grain size of 3 inches or less. ASTM D4253 (Test Methods for Maximum Index Density and Unit Weight of Soil

Using a Vibratory Table) is used to determine e_{min} and $\gamma_{d\text{-}max}$.[3] The apparatus used to perform this test is expensive and many commercial laboratories are not able to perform this test.

3-2.4 Strength Tests.

There are a variety of strength tests that have ASTM specifications for both drained (effective stress) strength parameters and undrained (total stress) strength parameters. The most common drained shear strength parameters are the effective stress cohesion (c') and the effective stress friction angle (ϕ'). Total stress shear strength parameters are s_u (undrained shear strength for a $\phi = 0$ envelope) for saturated soils, and total stress cohesion (c) and total stress friction angle (ϕ) for partially saturated soils.

The shear strength parameters listed above are for linear failure envelopes. It also is possible to determine parameters for non-linear failure envelopes for many of the strength tests.

Shear strength parameters are often needed for undisturbed or intact specimens, compacted specimens, remolded specimens, and reconstituted specimens. The different strength tests will be assessed based on their ability to accommodate these different types of test specimens. Table 3-4 lists the ASTM strength tests and the parameters obtained.

3-2.4.1 Drained or Effective Stress Strength Tests.

There are four recommended tests listed in the ASTM specifications for measuring drained or effective stress strength parameters: (1) Direct Shear Test, (2) Consolidated Drained Triaxial Test, (3) Consolidated Undrained Triaxial Test, and (4) Ring Shear Test.

3-2.4.1.1 Direct Shear Test (ASTM D3080).

The direct shear test (ASTM D3080 – Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions) is one of the oldest and most common strength tests. Figure 3-1 shows the basic elements of a direct shear tests and the data collected. In U.S. engineering practice, the most common specimen cross-sections are 2 inch × 2 inch and 4 inch × 4 inch square specimens and 2.5-inch diameter circular specimens. A few commercial laboratories have direct shear apparatuses that can accommodate 12 inch × 12 inch specimens. The 2.5-inch diameter cylindrical shear box is very popular since intact specimens can be easily trimmed from the common 3-inch diameter Shelby tubes. It is also easier to compact test specimens in a cylindrical

[3] Some engineers use the dry density obtained from ASTM D4253 for calculating relative compaction for a soil deposit in the same manner as done using the maximum dry density from impact compaction tests.

specimen container than a square specimen container. The direct shear apparatus can use intact, compacted, or remolded test specimens.

The direct shear test is most often used for clay soils and for some sandy soils. ASTM D3080 requires that the maximum grain size of the test specimen be no greater than 1/10 of the shear box width and no greater than 1/6 of the specimen height. Based on the common sizes of the shear box, it is not appropriate to test materials larger than medium sands.

Table 3-4 Laboratory Strength Tests with ASTM Standards

ASTM #	Description	Parameters	Comments
D2166	Unconfined Compressive Strength of Cohesive Soil	q_u	Best used as an index test as opposed to obtaining shear strength for design.
D2573	Field Vane Shear Test in Saturated Fine-Grained Soils	s_u, S_t strength anisotropy	Perhaps the best all-around tests for undrained strengths of soft, saturated clays.
D2850	Unconsolidated Undrained Triaxial Compression Test on Cohesive Soils	c-ϕ, s_u	Best results are obtained when all samples come from the same depth, which can be obtained using 5-in. diameter sampling tubes.
D3080	Direct Shear Test of Soils Under Consolidated Drained Conditions	c'-ϕ'	Good test for measuring fully softened shear strength.
D3967	Splitting Tensile Strength of Intact Rock Core Specimens	σ_t	Indirect measurement of tensile strength.
D4648	Laboratory Miniature Vane Shear Test for Saturated Fine- Grained Clayey Soil	s_u, S_t strength anisotropy	Very good test for soft clay samples that are not trimmable for UU triaxial tests.
D4767	Consolidated Undrained Triaxial Compression Test for Cohesive Soils	c'-ϕ' s_u for σ'_{3con}	Good for effective stress strength parameters of sands and clays. Use caution when using total stress strength parameters for stability analyses.
D5607	Laboratory Direct Shear Strength Tests of Rock Specimens Under Constant Normal Force	c'-ϕ' joint roughness coefficient	
D5731	Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications	I_s, $I_{s(50)}$	Used for rock classification and other applications.
D6467	Torsional Ring Shear Test to Determine Drained Residual Shear Strength of Cohesive Soils	ϕ'_r	Best test for residual shear strength for clays. Staged tests can save a lot of time. Very small test specimen.
D6528	Consolidated Undrained Direct Simple Shear Testing of Fine Grain Soils	s_u, G	The undrained strength measured is a conservative approximation of the maximum shear stress at failure.
D7181	Consolidated Drained Triaxial Compression Test for Soils	c'-ϕ'	Tests on CL and CH clays may take a very long time to complete. D3080 may be a better choice.

Direct shear tests are relatively easy to conduct. A consolidation stress is first applied to the test specimen. After all excess pore water pressures are dissipated, the sample is sheared at a constant displacement rate very slowly to ensure drained conditions are maintained. Direct shear tests do not produce stress-strain results, but rather stress-displacement results. Moduli cannot be determined from direct shear tests.

Since the failure plane in a direct shear test is constrained to the horizontal plane, then the shear strength parameters measured might be lower than those measured in other tests that have an inclined shear plane for soils that exhibit horizontal layering (Duncan et al. 2014). Soils that are deposited in water; such as lacustrine, alluvial, and marine soils; may exhibit this *inherent anisotropy* whereby the shear strength is a function of the orientation of the failure plane. This issue of the failure plane orientation is insignificant for remolded and compacted soils. Direct shear tests also may suffer from progressive failure, whereby the shear strength is not fully mobilized on the entire failure plane at the same instant. This can also result in lower peak shear strength parameters for materials that exhibit brittle stress-displacement curves, such as heavily overconsolidated clay.

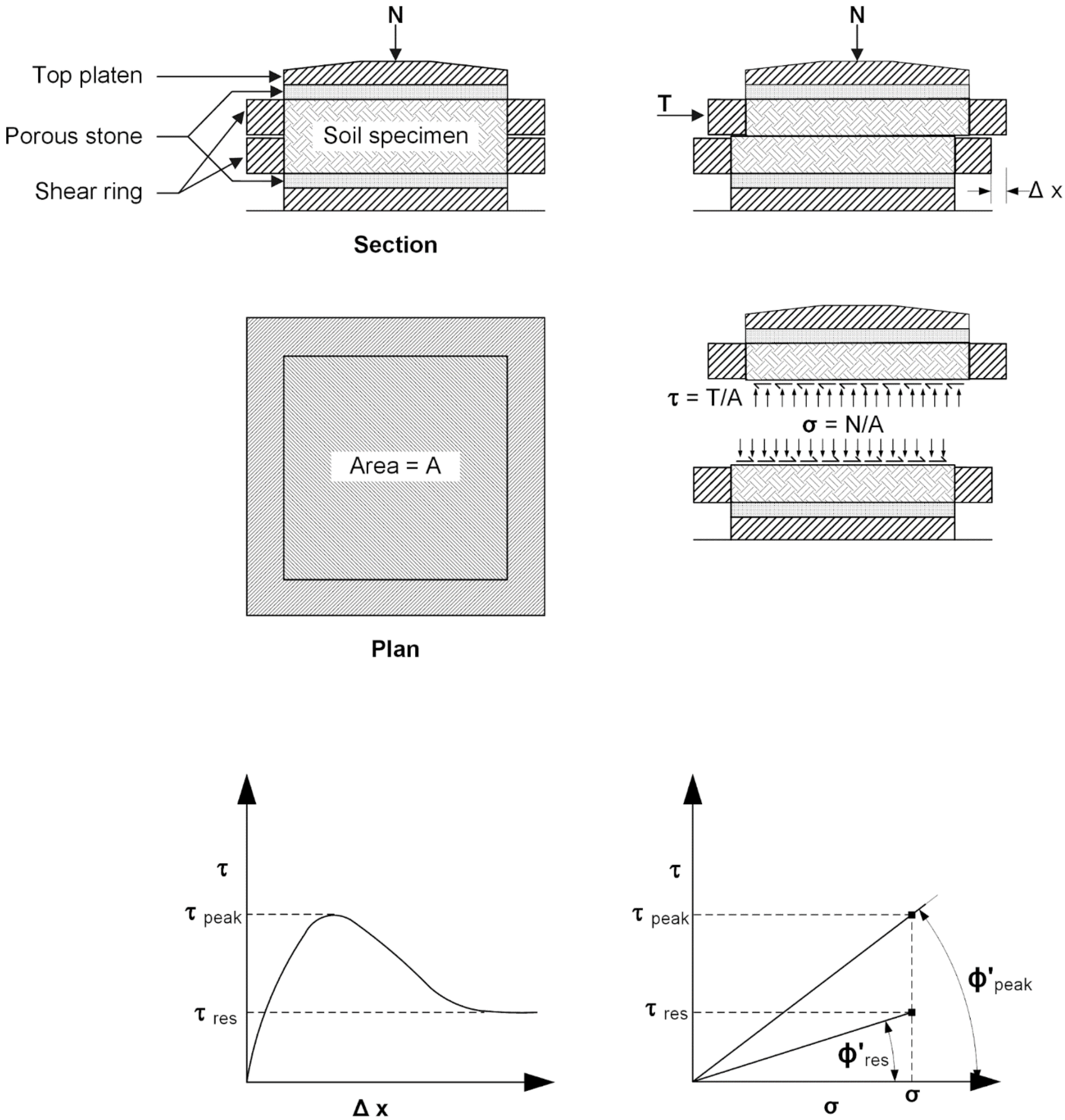


Figure 3-1 Basic Elements for a Consolidated Drained Direct Shear Test Along with Example Data Collected for One Test Specimen

Direct shear tests are especially well-suited for testing remolded clays. It is easy to form test specimens in the shear box and the device allows the application of small consolidation stresses. It is the best test available for measuring the *fully softened shear strength*, which is the peak shear strength of remolded, normally consolidated clays.

3-2.4.1.2 Consolidated Drained (CD) Triaxial Test (ASTM D7181).

The consolidated drained (CD) triaxial test (ASTM D7181 – Standard Test Method for Consolidated Drained Triaxial Testing of Soil) is one of the oldest types of triaxial test. The procedure was defined in the Army Corps of Engineers 1930s study. This type of triaxial tests was also called an *S* triaxial, with S denoting slow, since this test has the slowest shear phase of the major categories of triaxial tests.

Common specimen sizes in U.S. practice are 1.4-inch diameter for fine-grained soils and 2.8-inch diameter for sandy soils or for test specimens directly extruded from Shelby tubes without trimming[4]. Many laboratories can test 2-inch diameter and 4-inch diameter specimens as well. The larger 6-inch diameter and 12-inch diameter apparatuses are rarer in commercial laboratories. ASTM D7181 requires that the maximum grain size of the soil tested should be 1/6 of the test specimen diameter, so the diameter of the test specimen should be selected based on the grain-size distribution of the soil.

Figure 3-2 shows the basic elements of a manual CD triaxial test. The test specimen is consolidated by applying a cell pressure. Most tests specimens are consolidated to isotropic stress conditions, but anisotropic consolidation is also possible. The sample is back-pressure saturated by using an elevated pore pressure (back pressure), and the final consolidation stress is the cell pressure minus the back pressure. The sample is sheared very slowly, so that excess pore pressures are not developed, by increasing the vertical stress at a constant displacement rate. The volume change of the test specimen is measured by recording the level of the burette as the load is applied. These tests require considerable skill to perform correctly.

CD triaxial tests are more applicable to sandy soils because a high permeability allows the test specimen to be sheared in a reasonable time. If clayey soils are tested, the sample must be sheared very slowly, and the test may take weeks to months to complete. Some laboratories will not agree to conduct these tests on clay soils.

Triaxial tests can be used to test intact, compacted, and remolded test specimens. There is some difficulty in testing very soft remolded test specimens since the soil needs to have sufficient strength to allow trimming and mounting in the triaxial cell. Remolded soils often need to be consolidated outside of the triaxial cell to allow a strength gain prior to trimming. This procedure can limit the consolidation stress that can be applied to the test specimen if normally consolidated conditions are desired.

[4] Although ASTM D7181 allows directly extruded samples to be tested, it is better practice to trim samples to a smaller diameter to reduce the disturbance caused by sampling.

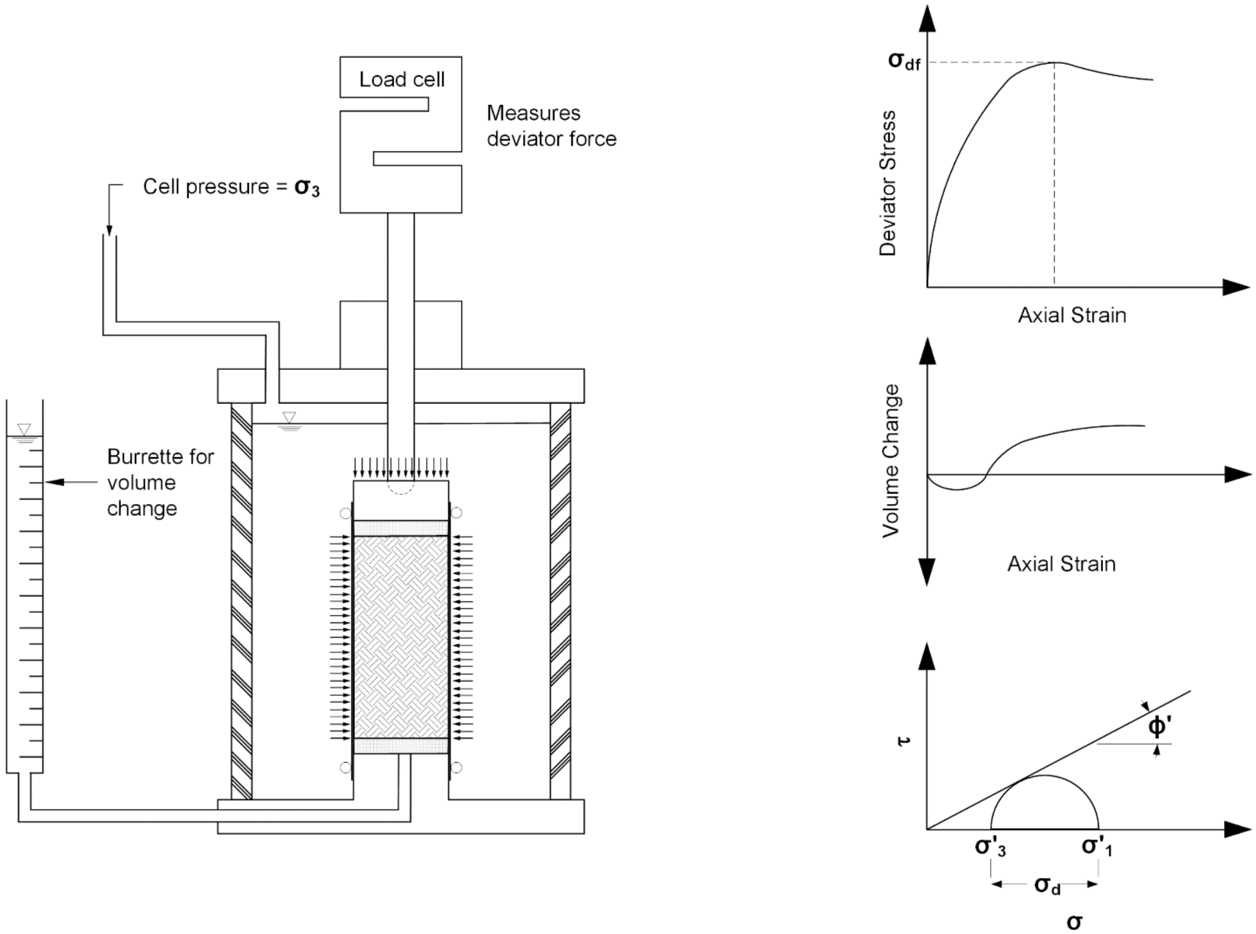


Figure 3-2 Basic Elements of a Consolidated Drained Triaxial Test Along with Example Data Collected for One Test Specimen

3-2.4.1.3 Consolidated Undrained (CU) Triaxial Test (ASTM D4767).

The consolidated undrained (CU) triaxial test (ASTM D4767 – Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soil) is another of the three major types of triaxial tests defined by the U.S. Army Corps of Engineers' 1946 study. This test was also called an *R* test if pore pressures are not measured and an $\overline{R}$ if pore pressures are measured.[5] The R test has become obsolete and it is difficult to justify a case where this test should be conducted. Figure 3-3 shows the basic elements of a CU triaxial test and example data.

5 It is not clear why the letter R is used for this test. It may be that the other tests are referred to Q and S tests, and R is the letter in the alphabet that falls between these. In the past, engineers would refer to the QRS triaxial test types.

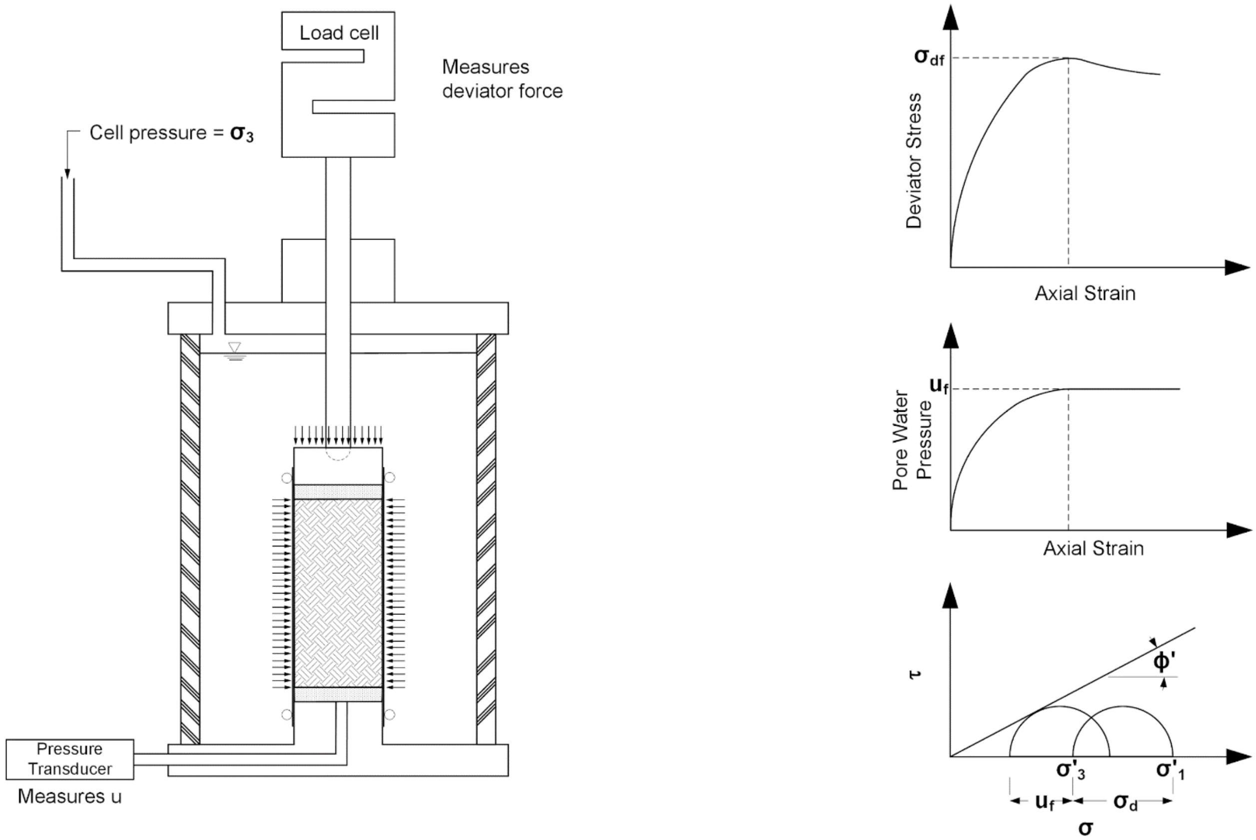


Figure 3-3 Basic Elements of a Consolidated Undrained Triaxial Test Along with Example Data Collected for One Test Specimen

The CU triaxial test is very similar to the CD triaxial test, and most of the information provided for the CD test is also true for the CU test. The test procedures are identical until it is time to shear the test specimen. In the CD test, the drainage valve is open during shear, and in the CU test, the drainage valve is closed during shear. Volume change is measured during a CD test, and pore pressure is measured during a CU test. In a CD test, the strain rate ($\dot{\varepsilon}$) is very slow because the pore pressured generated during shear must *dissipate* throughout the test specimen. In the CU tests, the strain rate is considerably greater since the goal is to allow *equalization* of pore pressures as opposed to dissipation. In other words, CU test specimens can be sheared much faster that CD tests test specimens, and this is a big advantage in clay soils.

Pore pressures are measured during shear during CU triaxial tests, and this allows the effective stresses in the sample to be determined. Since effective stress values are available, drained or effective stress strength parameters (c' and ϕ') can be determined. However, there is an important difference in the volume change of the test specimen in CU and CD tests and this can influence the shear strength parameters determined. In the CD test, volume change is allowed, and the void ratio of the test specimen can change during shear. In the CU test, there is not volume change during shear, so the test specimen has the same void ratio at failure as it did prior to shear (after consolidation). The void ratios of CU and CD test specimens can be different at failure, even though they may have started at the same consolidation pressure and void ratio, and this may cause differences in the effective stress shear strength parameters. In engineering practice, this difference is usually neglected, and results from CU and CD tests are often used interchangeably.

3-2.4.1.4 Ring Shear Test (ASTM D6467).

The ring shear test (ASTM D6467 – Standard Test Method for Torsional Ring Shear Test to Determine Drained Residual Shear Strength of Soil) is similar to a direct shear test in that it is a consolidated drained test with shearing occurring on a horizontal plane. A ring shear test should be only used to determine the *residual shear strength*, which is the shear strength of a soil at very high strains or displacements. Residual shear strength is used in geotechnical designs for situations where a failure has already occurred and considerable movement has taken place.

The ring shear apparatus uses an annular test specimen. The specimen size used the most in the U.S. has an inside diameter of 2.8 inches, and outside diameter of 4 inches, and a thickness of 0.2 inches. The basic elements of a ring shear tests are shown in Figure 3-4. The specimen tested is markedly smaller than the other strength tests discussed. The specimen volume is equivalent to about 4 teaspoons. Only remolded clay samples are tested in common ring shear apparatuses, and these are placed in the apparatus in the form of a paste.

The ring shear apparatus allows *staged* tests to be conducted[6]. A single test specimen can be reconsolidated and sheared multiple times. The normal test procedure is to place a specimen in the apparatus and consolidate it to the lowest vertical stress. The specimen is then sheared until the residual strength is achieved. Next, a higher consolidation pressure is applied, and the sample is sheared again. Normally, three different normal stresses can be used for one test specimens.

It is possible to measure residual shear strength properties using a direct shear apparatus if the direction of shear is reversed so that enough shear displacement can be accumulated to obtain residual conditions. Although this test is reported in geotechnical literature, there is not an ASTM procedure for conducting repeated direct shear tests. The ring shear tests is a better test for measuring the residual friction angle since the direction of shear does not need to be reversed during the test, and the area of the shear surface remains constant.

[6] Although some older testing manuals provide instructions for conducting staged CU and CD triaxial tests, the results of these tests are very unreliable. These types of tests should not be specified and the data from these tests should not be used.

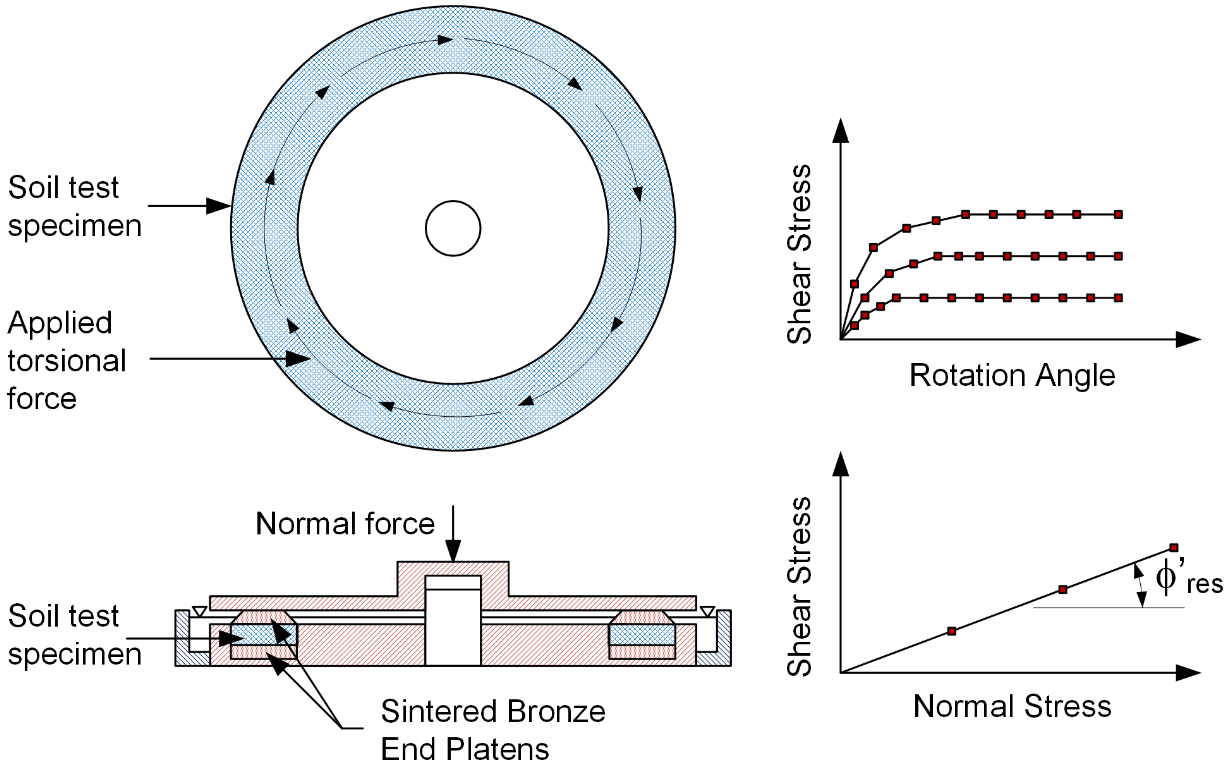


Figure 3-4 Basic Elements of a Ring Shear Test Along with Sample Data

3-2.4.2 Undrained or Total Stress Strength Tests.

There are five laboratory tests with ASTM standards for measuring the undrained shear strength of soils. Since undrained strengths are normally used for fine-grained soils, owing to their low permeability, these tests mainly address clayey and silty soils. The value of undrained shear strength can vary considerably from test to test. The two fundamental undrained strength envelopes that are used for fine-grained soils are shown in Figure 3-5.

For saturated soils undergoing undrained loading, the shear strength *is not* a function of the normal stress on the failure plane, thus $\phi = 0$. For partially saturated soils undergoing undrained loading, the shear strength *is* a function of the normal stress on the failure plane, thus $\phi > 0$. The envelope for the partially saturated soil usually deviates from a straight line, but a linear interpretation over the appropriate range of normal stress if often used in engineering analysis.[7]

[7] A saturated soil is often called a "$\phi = 0$ soil" and a partially saturated soil is called a "c-ϕ soil" by geotechnical engineers.

The undrained strength of a soil can depend on many different factors. Primary factors include the major effective consolidation stress prior to undrained loading and the overconsolidation ratio (OCR). There are many secondary factors, including the orientation of the failure plane, the rate of loading, the amount of sample disturbance, the system of stresses imposed by the field loading condition or the laboratory test, etc. For the envelopes shown in the figure, only one of the ASTM tests (D2850) provides multiple points to define the envelopes. The other ASTM tests only provide one point to define the shear strength envelope.

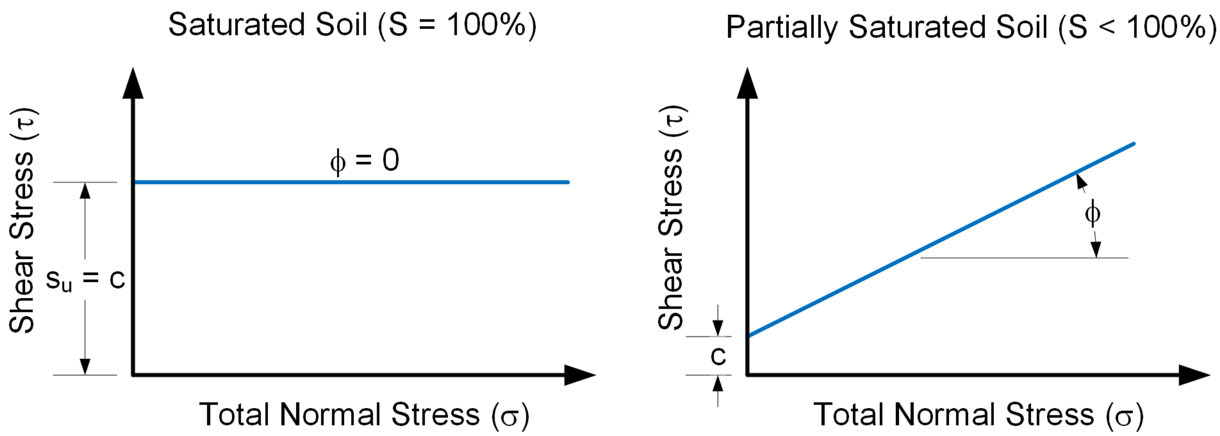


Figure 3-5 Undrained Shear Strength Envelopes for Saturated and Partially Saturated Soils

For layers of saturated fine-grained soils, the goal of an undrained strength testing program is often to determine the variation of undrained strength with depth, such as shown in Figure 3-6. For these cases, enough *in situ* or laboratory tests should be conducted so that the undrained shear strength values, shown as the squares, are determined in order that the variation with strength with depth can be estimated, shown as the dashed line.

3-2.4.2.1 Unconfined Compression Test (ASTM D2116).

Unconfined compression tests, UCTs, (ASTM D2166) are one of the oldest and simplest strength tests. The quality and care in conducting the test can vary greatly from specimens being tested using portable load frames in the field to testing the specimen in a membrane in a temperature-controlled laboratory. The basic premise of the test is that if the soil is saturated, the undrained shear strength (s_u) should be the same if the soil is tested with zero confining pressure (σ_3) as it would be with an elevated confining pressure. This assumption might be valid for high quality test specimens carefully tested, but actual test results can deviate from this assumption considerably. In general, UCTs provide lower strengths than would be determined from higher quality tests.

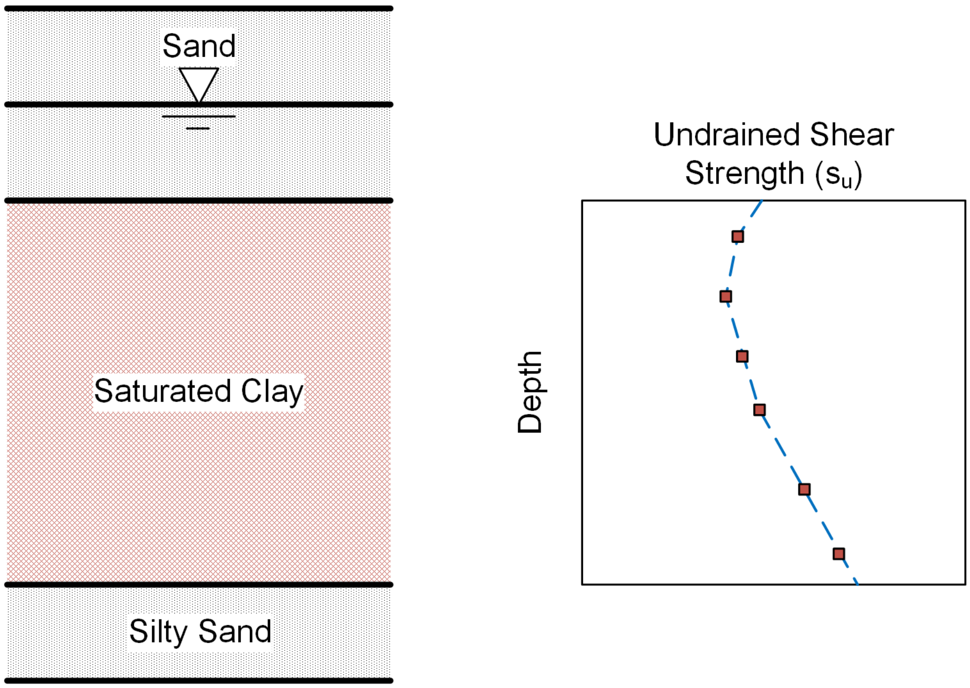


Figure 3-6 Example Distribution of Undrained Strength Versus Depth Relationship for a Hypothetical Saturated Clay

In practice, UCTs are also conducted on partially saturated soils. These tests are difficult to correctly interpret since the results would represent one shear strength value on a c-ϕ envelope, and one point cannot define the envelope. Shortcomings of the UCT have been recognized for over 70 years, and this test should be considered as an index test as opposed to a viable method to measure reliable shear strengths.

3-2.4.2.2 Unconsolidated Undrained (UU) Triaxial Test (ASTM D2850).

The unconsolidated undrained triaxial test (ASTM 2850 – Standard Test Method for Unconsolidated-Undrained Triaxial Compression Tests on Cohesive Soil) has been the most popular test for measuring undrained shear strength in U.S. geotechnical engineering practice. The basic procedure for this test was outlined in the Corps of Engineers Triaxial Test report in 1946. This test is often called a Q triaxial, with Q standing for “quick” since this is the fastest triaxial test. The test specimen is sheared at a strain rate of 1% axial strain per minute, so the shearing phase of the test only lasts about 20 minutes.[8]

UU tests on saturated fine-grained soils are normally conducted using three test specimens to define an envelope. All three test specimens should come from the same

[8] ASTM D2850 suggests using a strain rate of 0.3% for brittle soils, but most laboratories use 1% per minute for all soils.

depth, with all three having the same *in situ* consolidation pressure and *OCR*. All three specimens should have the same shear strength, which would verify the $\phi = 0$ failure envelope. UU tests on saturated soil should always be interpreted with a $\phi = 0$ failure envelope, regardless of any slope implied by the tests.

A schematic of the basic test apparatus is shown in Figure 3-7. The sample is sealed in thin rubber membranes, but there are not any porous stones or drainage lines. Special triaxial cells are commercially available just for UU tests. UU tests are most often conducted on 1.4-inch and 2.0-inch diameter trimmed specimens or 2.8-inch directly extruded specimens.

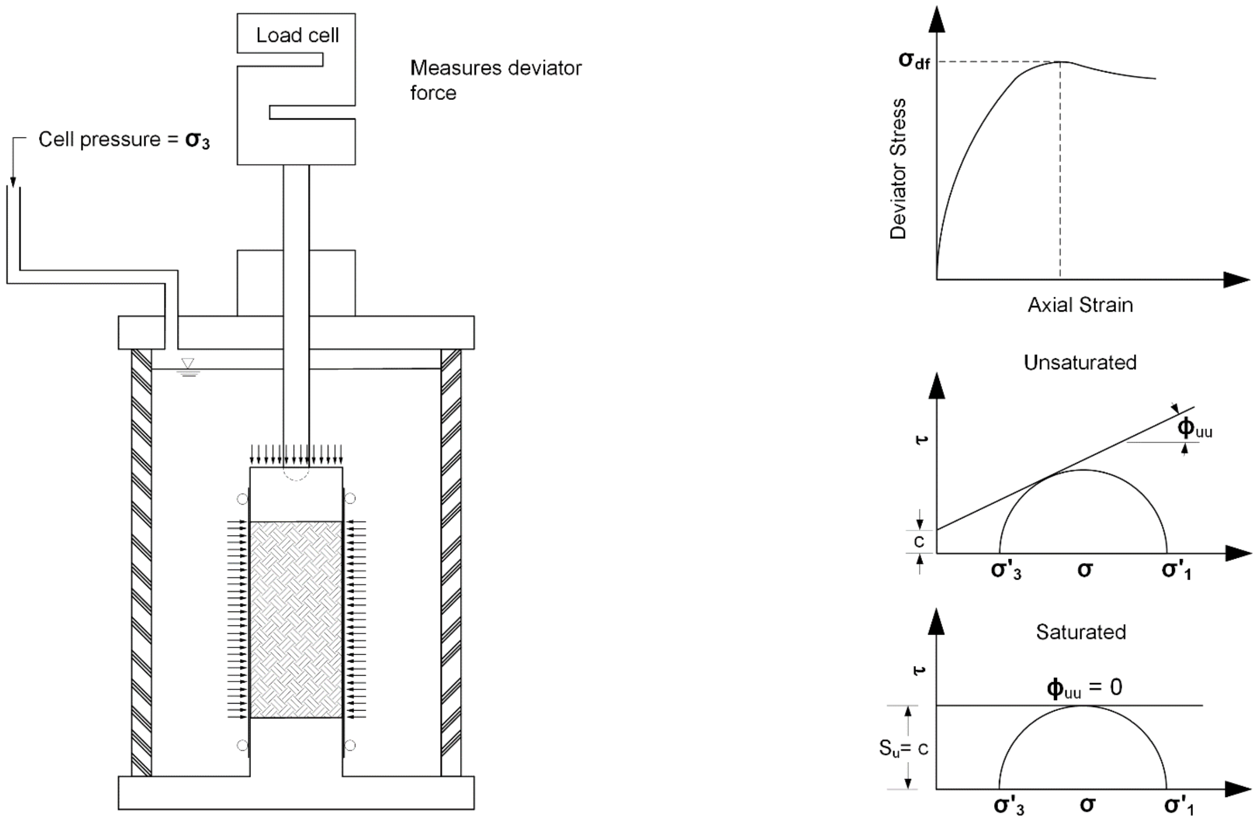


Figure 3-7 Basic elements of a UU Test Apparatus with Sample Data for a Single Test

One deficiency of the UU test is that it is challenging to test very soft soils. For soils that have an undrained shear strength less than about 250 psf, it can be very difficult to trim a test specimen, to mount the specimen in a triaxial cell, and to place a membrane over the specimen. It is very easy to disturb the specimen, and that tends to lower the shear strength even more. For very soft materials, it is best to use the laboratory miniature vane shear test (discussed below) or a fall cone test.

UU tests can also be conducted on partially saturated soils, and have often been used to determine the shear strength parameters for compacted clays. UU tests are the only viable test to determine the values of c and ϕ for partially saturated soils for use in end-of-construction analyses. Special compaction equipment is available to form triaxial test specimens of compacted soils.[9]

There are critics of the UU test, and many of the criticisms are valid (Ladd 1991). However, strengths resulting from UU tests have been validated by back analysis of failed slopes and found to be representative, and it remains a very popular test in engineering practice.

3-2.4.2.3 Consolidated Undrained (CU) Triaxial Test (ASTM D4767).

Since the CU triaxial test is sheared undrained, it is possible to obtain undrained or total stress strength parameters. However, this test has been misused for undrained strength determination in the past. It is not possible to determine viable values of c and ϕ from this test, yet these values are commonly reported by commercial laboratories. The correct way to use the CU test for undrained analyses is to associate the value of s_u (half the deviator stress at failure) with the isotropic consolidation stress. The CU triaxial test provides undrained shear strength values that are normally too high to be used in most analyses. Details of the use of the CU test for undrained strength determination is presented by Duncan and Wong (1983).

3-2.4.2.4 Consolidated Undrained Direct Simple Shear Test (ASTM D6528).

The direct simple shear (DSS) test (ASTM D6528 – Standard Test Method for Consolidated Undrained Direct Simple Shear Testing of Fine Grain Soils) was developed in the 1950s. Commercially-available apparatuses test a cylindrical specimen that is nominally 2.5 inches in diameter and up to 1 inch tall. A schematic of the basic elements of the DSS test is shown in Figure 3-8. The specimen is confined with a wire-reinforced membrane or a set of thin, stacked rings, often coated with Teflon, located outside of an unreinforced latex membrane. The intent of the confining rings is to prevent lateral strain from occurring when the vertical consolidation stress is applied, and to allow the test specimen to deform in the manner of pure shear. After the test specimen is consolidated, it is sheared undrained (technically at constant volume) by translation of the top platen relative to the bottom platen. The undrained shear strength (s_u) is assumed to be the maximum value of shear stress applied to the horizontal plane of the test specimen.

The DSS test was not a common test in geotechnical engineering for fifty years after its development. Few commercial laboratories were able to conduct the test. There are

[9] There are test apparatuses available for conducting triaxial tests on partially saturated soils, but few commercial labs are equipped to perform these tests.

valid criticisms of the DSS test (Saada and Townsend 1981). However, the popularity of this test has increased in recent years, and many more laboratories are able to run the test. The DSS apparatus provides an undrained shear strength that is comparable to that obtained with the field vane shear test (for the same vertical consolidation stress and *OCR*) and is appropriate for many engineering design cases. This test can only be conducted on saturated soils, and the ASTM standard only addresses fine-grained soils.

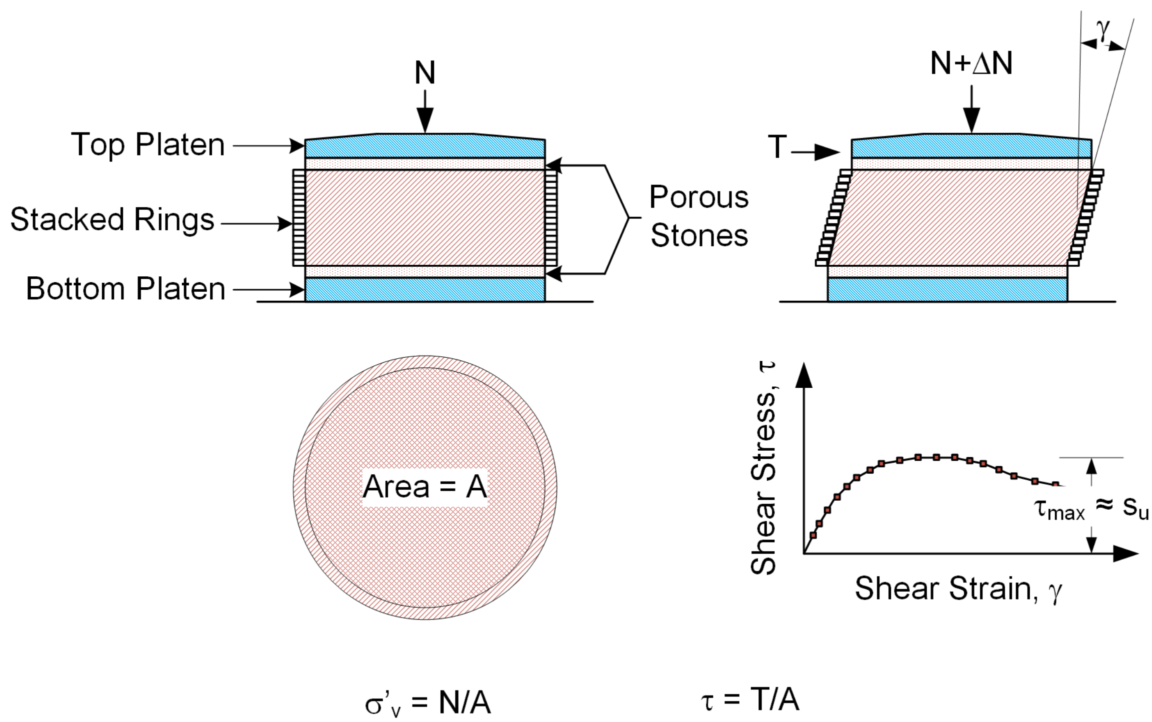


Figure 3-8 Basic Elements of the Direct Simple Shear Test (ASTM D6528)

3-2.4.2.5 Laboratory Miniature Vane Shear Apparatus (ASTM D4648).

The laboratory miniature vane shear apparatus (ASTM D4648 – Standard Test Methods for Laboratory Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil) is a scaled-down version of the field vane shear test. The vane sizes range from 0.5 inch × 0.5 inch to 1.0 inch × 1.0 inch. Vanes having a smaller diameter than the length can also be obtained to aid in determining anisotropic strengths. A photograph of a vane shear apparatus is shown in Figure 3-9. The vane is inserted into an intact or remolded test specimen and rotated at a constant rate while the torque is measured. The vane can be rotated by a hand crank or an electric drive unit. The torque can be measured by calibrated springs or by electronic load cells. Most legacy data for the miniature vane apparatus has been collected using the calibrated springs, and this is the preferred method.

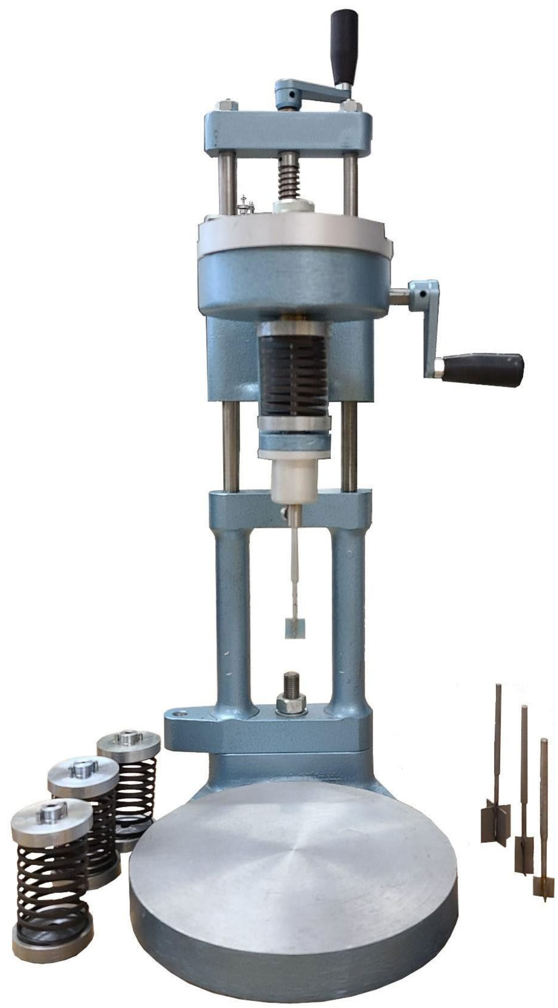


Figure 3-9 Laboratory Miniature Vane Shear Apparatus

Lab vane shear tests are not very common in geotechnical engineering practice, but this type of test can be especially useful in very soft clays. If a clay sample is too soft to be trimmed for a UU triaxial test, then a laboratory miniature vane test is a viable alternative.

3-2.4.2.6 Other Strength Tests.

There are other tests available to measure the laboratory undrained shear strength of soils that do not have specific ASTM standards available, or they are variations of the conventional ASTM tests.

There are two variations of the CU triaxial test that have limited use in geotechnical practice. The conventional CU triaxial test is normally conducted on test specimens that have been *isotropically* consolidated (vertical stress = horizontal stress during consolidation). These are often referred to as *ICU* triaxial tests. It is possible to anisotropically consolidate test specimens where the vertical stress is different than (usually greater) the horizontal stress. These are called *ACU* triaxial tests. The ASTM specifications address the basic components of ACU tests. ACU tests produce essentially the same effective stress strength parameters as ICU tests. ACU tests normally provide different undrained shear strengths than ICU tests, so the main usefulness of the test would be for projects where special undrained strengths are required.

A separate type of ACU test can be conducted where the ratio of the effective stresses during consolidation (minor effective stress/major effective stress) is equal to the at-rest earth pressure coefficient (K_0). These tests are sometimes called CK_0U triaxial compression tests. For these tests, the exact stresses are not specified, but determined to be the stresses necessary for no lateral strain to occur during consolidation. It is difficult to conduct these tests on manual triaxial apparatuses, but they can be easily conducted on fully-automatic apparatuses. These tests also provide essentially the same effective stress shear strength parameters as conventional ICU triaxial tests. Their main utility would be when undrained strengths are needed for special projects.

Another special type of triaxial test that is occasionally used in engineering practice is the *stress path triaxial test*. While most triaxial tests involve loading a test specimen axially while the cell pressure is constant, stress path tests vary both the vertical stress and the horizontal stress simultaneously to follow prescribed loading paths. The loading path is often selected to match field loading conditions. In some cases, the intent is to measure the strains obtained in the test specimen after the loading path has been applied. In other cases, the intent is to measure the strength of the test specimen for a specified system of stress changes. Fully-automated triaxial test apparatus are normally required to conduct these types of tests.

An alternative to the miniature laboratory vane shear test (ASTM D4648) for measuring the shear strength of very soft clay is the fall cone test. Although there currently is not an ASTM standard for this test, it is very popular in Europe, and there are standards in Norway, Germany, the U.K., and other countries. A photograph for the Norwegian apparatus is shown in Figure 3-10. This test involves dropping a weight cone onto the surface on an intact or remolded soil specimen and measuring the penetration. Cones are available with different weights for different penetration depths for soils having various consistencies. This test is also used to determine the liquid limit of soils in international geotechnical engineering practice.

Figure 3-10 Fall Cone Apparatus

3-2.5 Dynamic Tests.

Geotechnical earthquake engineering is a specialty area within geotechnical engineering. The methods of analysis used to predict the performance of structures during earthquakes can often be quite complex, and the tests to measure soil properties for use in these analyses can likewise be complex. Only a few geotechnical laboratories have the equipment to conduct these tests. Table 3-5 lists the common dynamic tests for soils.

Table 3-5 Dynamic Tests for Soils

ASTM #	Description	Parameters	Comments
D3999	Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus	E, D, ε_{DA}, ε_{SA}	Can be used for secant modulus and damping coefficients. Tests can be stress or strain controlled.
D4015	Modulus and Damping of Soils by Fixed-Base Resonant Column Devices	D, G, γ	Some apparatuses can allow anisotropic consolidation and large torsional strains.
D5311	Load Controlled Cyclic Triaxial Strength of Soil	multiple plots	Multiple tests should be conducted to determine the number of cycles to failure for different cyclic stress ratios.
D8296	Consolidated Undrained Cyclic Direct Simple Shear Test under Constant Volume with Load Control or Displacement Control	G, γ_{DA}, γ_{SA}	Multiple tests should be conducted to determine the number of cycles to failure for different cyclic stress ratios. Tests can be stress or displacement controlled.

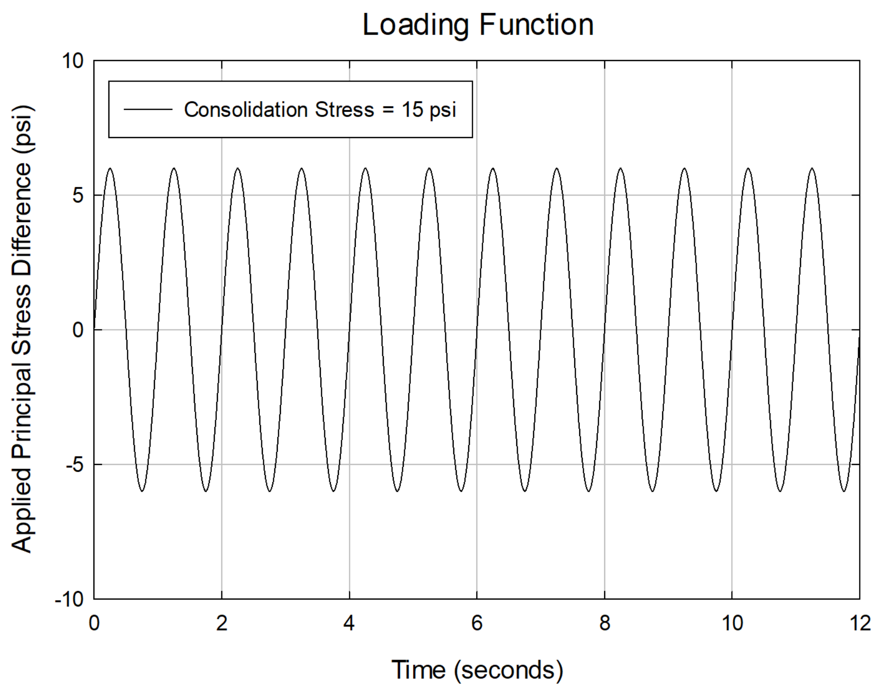
3-2.5.1 Cyclic Triaxial Test (ASTM D5311).

The cyclic triaxial test (ASTM D5311 – Standard Test Method for Load Controlled Cyclic Strength of Soil) is the most common of the dynamic tests, and it is one of the oldest, first being run since the 1960s or before. The cyclic triaxial test is a consolidated undrained (CU) test, and the initial portion of the test is the same as the static CU test (ASTM D4767). The back-pressure saturation and consolidation phases are essentially the same. The difference is in the manner of loading. Cyclic triaxial tests are normally loaded with a sinusoidal loading function, with the maximum stress difference specified by a *cyclic stress ratio* (CSR). The CSR is one-half of the applied deviator stress divided by the isotropic consolidation stress. An example of the loading function is shown in Figure 3-11. The loading frequency is ideally 1 Hz, but slower frequencies are often used owing to the difficulty of many commercial apparatuses in maintaining a constant 1 Hz throughout the test. The ASTM standard allows frequencies as slow as 0.1 Hz. Tests are normally conducted at three or four different values of CSR to determine the number of cycles until failure. A plot of the applied CSR versus the number of cycles until failure is used to define the cyclic strength of the soil.

Failure in a cyclic triaxial test can be defined in several different ways. The conventional definition of cyclic tests conducted on clean sands was when a 100% pore pressure ratio was achieved (pore pressure = confining stress). Soils with a significant amount of fines may not achieve failure by this definition, so it has become common to define failure based on axial strain. Strain values of ±2.5%, ±5% and ±10% axial strain have been used to define failure.

3-2.5.1.1 Cyclic Direct Simple Shear Test.

The cyclic direct simple shear test (CYCDSS) is popular in geotechnical earthquake engineering, and an ASTM standard is available (D8296). The test specimen can be loaded by either a cyclic stress or a prescribed displacement. These tests are normally performed using constant volume conditions where the height of the test specimen is not allowed to change during the test. A sinusoidal loading function is applied to the test specimen as a horizontal force to the top or bottom platen for a load-controlled test. A loading frequency of 1 Hz is desired, but some tests are conducted much slower frequencies, particularly for fine-grained soils.



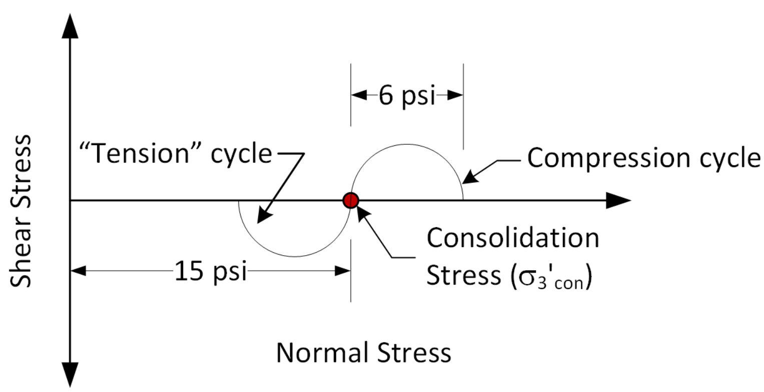


Figure 3-11 Loading Function and Stresses Applied for a Cycle of Loading in a Cyclic Triaxial Test for a Cyclic Stress Ratio of 0.2

CYCDSS tests are also specified in terms of cyclic stress ratio. The cyclic stress ratio is defined as:

$$CSR = \frac{\tau_{cyc}}{\sigma'_v} \qquad \textbf{(3-3)}$$

where:
τ_{cyc} = applied peak cyclic shear stress, and
σ'_v = vertical effective consolidation stress.

Failure is defined as a pore pressure ratio of 100% or a limiting cyclic shear strain. As with the cyclic triaxial test, the cyclic strength is normally represented as a plot of the applied cyclic stress ratio versus the logarithm of the number of cycles until failure.

3-2.5.1.2 Resonant Column Test (ASTM D4015).

The resonant column test (ASTM D4015 – Standard Test Methods for Modulus and Damping of Soils by Fixed-Base Resonant Column Devices) is a dynamic test that provides values of shear modulus for low shear strain amplitudes. The test is conducted in a modified triaxial cell and can be conducted on intact and remolded test specimens. A cylindrical test specimen is loaded by applying a cyclic torque to the top of the specimen while the resulting angular displacement is measured. The cyclic load normally follows a sinusoidal function, and the frequency of the load is varied until the resonant frequency of the test specimen is determined. This is a complex test and the results are used in specialized earthquake engineering analyses.

3-2.5.1.3 Cyclic Triaxial Test for Modulus and Damping (ASTM D3999).

A different version of the cyclic triaxial test can be used for determining the secant Young’s Modulus and Damping Coefficients (ASTM D3999 - Standard Test Methods for the Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus). This test can be conducted on intact or reconstituted saturated and partially saturated test specimens. Both fine-grained and coarse-grained soils can be tested. The main purpose of this test is to determine the dynamic properties for strains ranging from about 0.01% to 0.5%. The test specimen may be back-pressure saturated, or it may be tested in a partially saturated condition.

3-2.6 Compressibility Tests.

There are four ASTM tests used to measure the volume change of soils, which are summarized in Table 3-6. Two of these are categorized as *consolidation tests*, where the volume change of the soil is determined for a change in applied stress. The basic information obtained from a consolidation test is shown in Figure 3-12. The remaining two tests can be categorized as *response to wetting tests*, where the volume change of the soil is measured if the soil is given access to water or if the water content is reduced.

Table 3-6 Tests for Volume Change with ASTM Standards

ASTM #	Description	Parameters	Comments
D2435	One-Dimensional Consolidation Properties of Soils Using Incremental Loading	c_v, m_v, a_v, C_c, C_r, σ'_p, C_a	Can be performed on samples that are initially partially saturated.
D4186	One- Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled- Strain Loading	c_v, m_v, a_v, C_c, C_r, σ'_p, C_a	Provides a good compression curve for determination of σ'_p Fast, compared to D2435. Test specimens must be saturated.
D4546	One-Dimensional Swell or Collapse of Soils	ε_s, ε_c	Used to determine the "response to wetting" of compacted or intact soils.
D4829	Expansion Index of Soils	EI	Often cited in building codes.

3-2.6.1 Incremental Loading Consolidation Test (ASTM D2435).

The incremental loading or incremental stress consolidation test (ASTM D2435 – Standard Test Methods for One-Dimensional Consolidation Properties of Soil Using Incremental Loading) is over 80 years old and is a very common test in geotechnical engineering practice. Figure 3-13 shows the basic elements of the fixed-ring and floating-ring consolidometers. The test is normally conducted on saturated fine-grained test specimens, but it may also be conducted on partially-saturated soils, compacted soils, and remolded soils. The most common test specimen size in U.S. geotechnical engineering practice is a cylindrical specimen with a 2.5-inch diameter and 1-inch height, although other size apparatuses are commercially available. The test specimen is contained in a rigid ring that prevents lateral expansion of the soil during loading, thus all displacement is vertical. This type of test is also called a *one-dimensional compression test*. A porous stone is usually located above and below the test specimen to allow for *double drainage*. The fixed-ring consolidometer is the most common in geotechnical engineering practice, but the floating-ring consolidometer can be used if high friction between the ring and soil is anticipated (e.g. sandy clay).

As loads are applied to the test specimen, the displacement of the top platen is measured over time. Each load is normally applied for a specific time period (i.e. 24 hours) or until the *end of primary consolidation* (EOP) is achieved. An example *time-deformation curve* or *time curve* for one load increment is shown in Figure 3-12. The time curve is important in that the value of the coefficient of consolidation (c_v) is determined from this curve. Details on calculating the value of c_v from the time curve can be found in Chapter 5 or ASTM D2435.

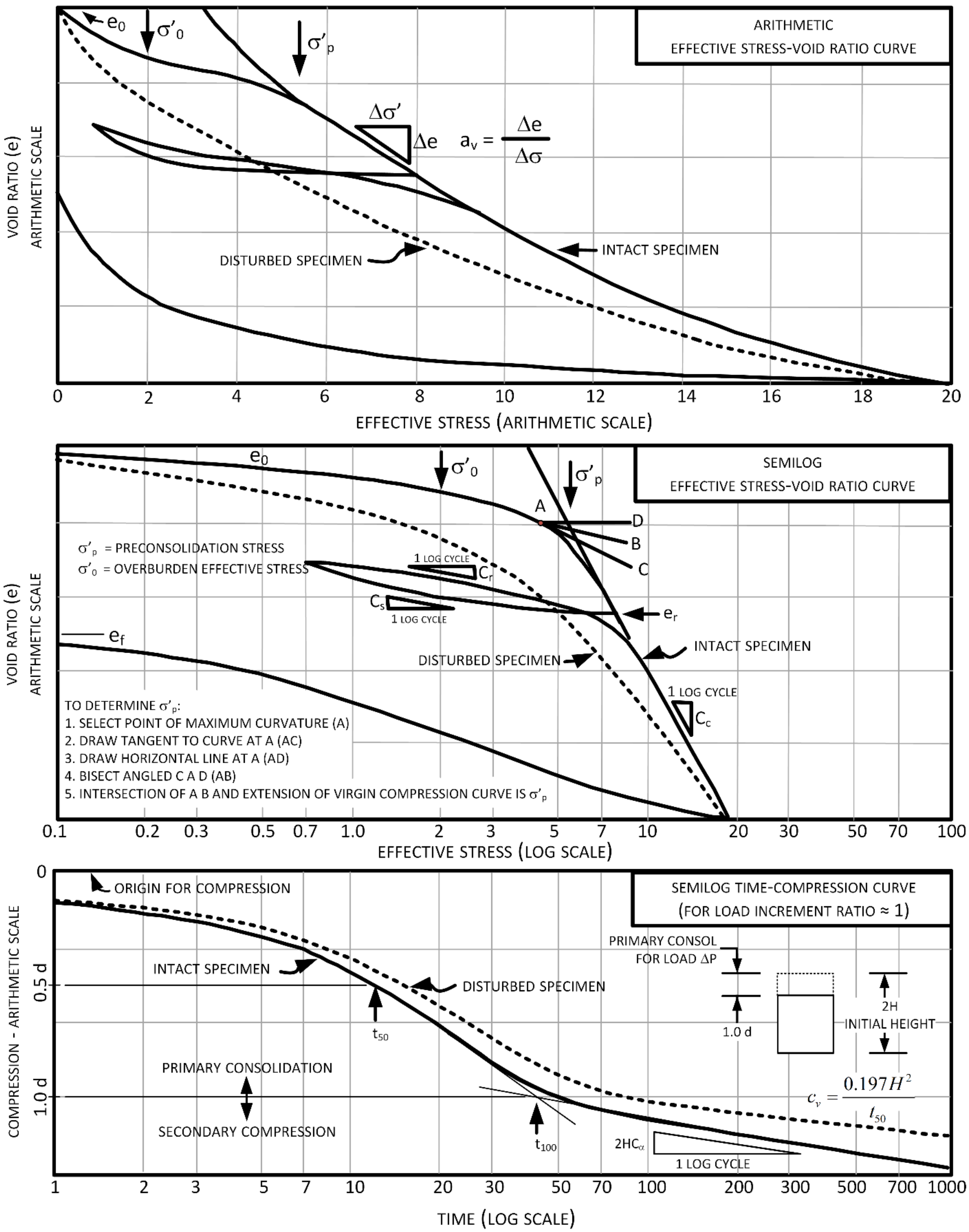
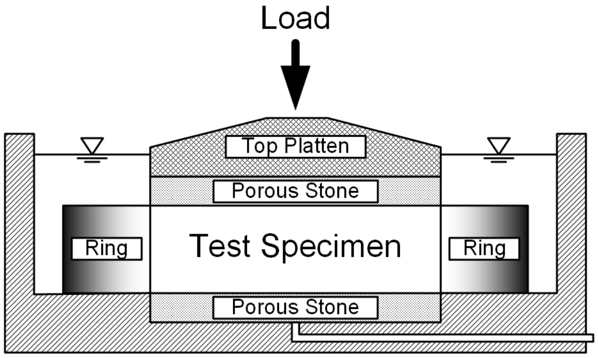


Figure 3-12 Basic Information Obtained from a Consolidation Test



a) Fixed ring consolidometer b) Floating ring consolidometer

Figure 3-13 Fixed-Ring and Floating-Ring Consolidometers

The load applied to the test specimen is usually doubled for each load increment. The *Load Increment Ratio* (LIR) is used to quantify the change in load to the test specimen, and is defined below:

$$LIR = \frac{\Delta\sigma}{\sigma_0} \quad \textbf{(3-4)}$$

where:
$\Delta\sigma$ = change in applied stress, and
σ_0 = initial total stress.

An LIR = 1 corresponds to doubling the load on the test specimen. For unloading, an LIR = -0.75 is often used, which means the immediately previous load is skipped. For reloading, an LIR = 4 is used, which follows the same stresses as the unloading cycle until the past load has been reached.

Each load applied to the test specimen; for unloading, rebound, and reloading cycles; provides a data point for the *compression curve*. An example compression curve is shown in Figure 3-12. The conventional method used to plot the compression curve is using void ratio (y-axis) and the logarithm of the effective vertical stress (x-axis).[10] The compression curve is used to determine the *preconsolidation pressure* or *maximum past pressure* (σ'_p or P_p) and the compression index (C_c) and the recompression index (C_r). The compression curve can also be plotted using axial strain instead of void ratio. For plots using strain, the compression parameters are $C_{\varepsilon c}$ and $C_{\varepsilon r}$ (instead of C_c and C_r). The strain or void ratio used in plotting the compression curve can either be the

[10] The compression curve is often called the “e-log p” curve in older geotechnical publications.

value at the end of the time increment or the value at the end of primary consolidation. It is important that the method used is indicated for the plot.

If a 24-hour load cycle is used for the incremental stress consolidation test, the test can take two to three weeks to complete, depending on the value of the maximum stress and the number of unload-reload loops. Laboratories often try to decrease the amount of time required by reloading the test specimen at the end of primary (EOP) consolidation as opposed to constant time intervals. If the test is conducted using an automated apparatus, the time corresponding to EOP is often determined by a computer program. The use of computer-calculated EOP times may incur errors, especially for low stresses where strains are small. If the test specimen is reloaded too quickly at early stages of the test, the remaining data may not be useable and the quality of the test may be compromised.

3-2.6.2 Constant Rate of Strain Consolidation Test (ASTM D4186).

The constant rate of strain (CRS) consolidation test (ASTM D4186 – Standard Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading) can be used as an alternative to the incremental stress consolidation test. The test specimens for the CRS test are the same size as for the incremental stress tests. One of the main advantages of the CRS test is that the compression curve can be obtained in much less time than the incremental stress test. A schematic of the basic test elements and the data acquired is given in Figure 3-14.

The CRS consolidation test can be conducted on intact soil specimens, and also on compacted and remolded soil specimens. However, it is necessary that the test specimen be saturated prior to compression. As shown in Figure 3-14, the consolidometer for the CRS test is very similar to a triaxial cell. The test specimen is back-pressure saturated in the same manner as a triaxial specimen. The cell pressure applied in the cell serves as back pressure in the process. The test specimen is drained only at the top, and during the loading process, the excess pore water pressures are measured at the bottom. Based on an assumed parabolic distribution of pore water pressure in the test specimen, the average effective stress can be calculated.

The test specimen is loaded at a constant strain rate ($\dot{\varepsilon}$). The strain rate is selected such that the excess pore water pressure measured at the base of the test specimen does not exceed 15% of the applied stress. The rate for unloading the test specimen is much slower than loading, and unload-reload loops may slow down the test considerably.

One advantage of the CRS consolidation test is that the compression curve is defined by many more data points than the incremental stress consolidation test. There are so many data points taken that the results are usually portrayed as a curve instead of discrete data points. This allows an increased resolution of the compression curve in the vicinity of the preconsolidation pressure, and allows a more accurate determination of its value. The CRS consolidation test also allows the determination of the coefficient of consolidation (c_v) over the entire load range as long as the excess pore pressures are in an acceptable range. This method of determining c_v removes some of the subjectivity involved in determining c_v using time curves with the incremental stress consolidation test.

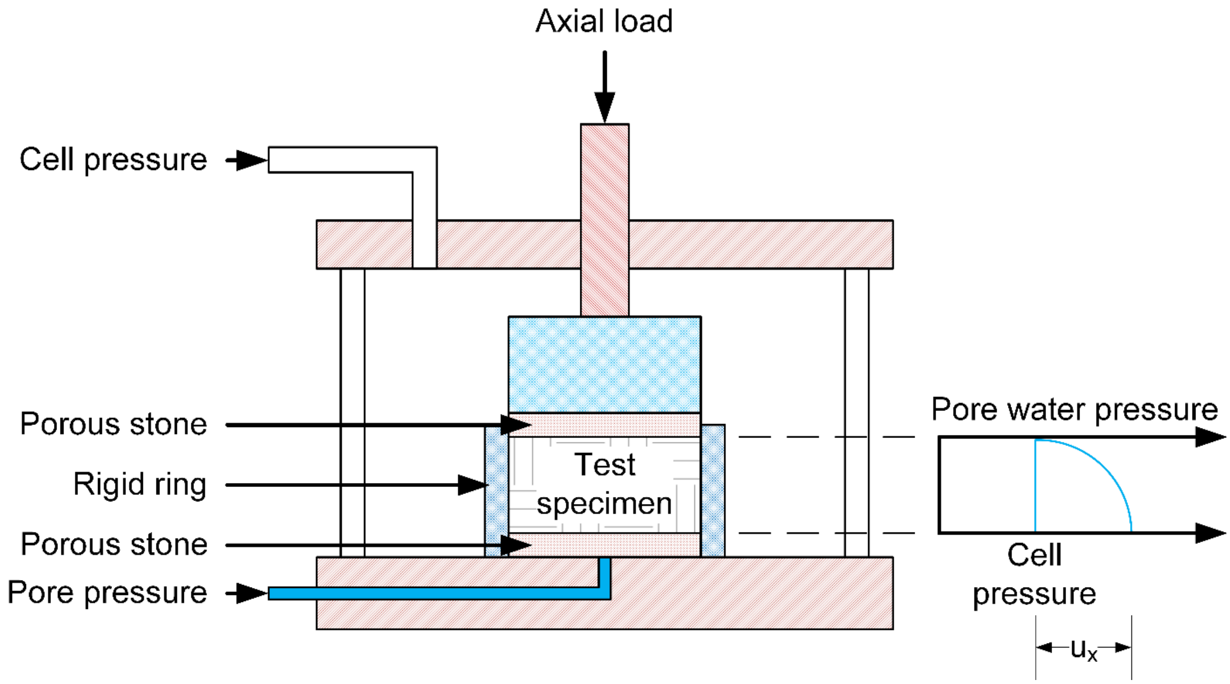


Figure 3-14 Basic Elements of a Constant Rate of Strain Consolidation Test

3-2.6.3 Swell and Collapse Test (ASTM D4546).

When a partially saturated natural soil or a compacted soil is given access to water, the soil can swell at low stresses or collapse at high stresses. ASTM D4546 (Standard Test Methods for One-Dimensional Swell or Collapse of Soils) allows the volume change of the test specimen to be measured as a function of the applied stress. If the soil has no confining stress applied, then *free swell* may occur. Often, free swell is measured under a nominal stress of 20 psf. If the pressure is varied to prevent any swell or volume change from occurring, this pressure is called the *swell pressure* for the soil. ASTM D4546 allows the amount of free swell, swell pressure, and volume change for other stresses to be determined.

The test is very similar to an incremental stress consolidation test, and the same consolidometer is used. Loads can be applied to the test specimen, and after the test specimen has achieved equilibrium under the load, the specimen is inundated. The swell or collapse volume change is measured after the test specimen achieves a new equilibrium. Shown in Figure 3-15 is an example curve that gives the volume change of the soil as a function of the stress at inundation.

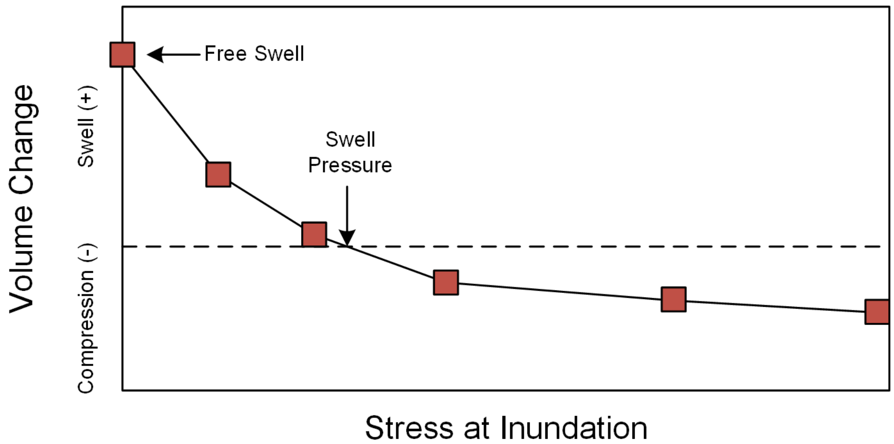


Figure 3-15 Volume Change of Soil as a Function of Stress at Inundation

3-2.6.4 Expansion Index Test (ASTM D4829).

The expansion index test (ASTM D4829 – Standard Test Method for Expansion Index of Soils) determines the swell potential of a soil, but it is less rigorous than D4546. It does not provide engineering design values to calculate volume change, but provides a simple index to assess the swelling potential of soil. This test is conducted on compacted soils. The main use of the expansion index test is to assess if a compacted fill might pose problems if structures are constructed on top of it. The compaction mold is approximately half the height of the 4-inch diameter (1/30 ft^3) compaction mold used for ASTM D698 and the same compaction hammer as used for D698 is used. The goal is to compact the test specimen using a D698 effort at a degree of saturation of 50%. A vertical stress of 1 psi is applied, and the specimen is allowed to equilibrate for 10 minutes. The specimen is then inundated and allowed to swell for 24 hours or until the swell has essentially ceased. The *Expansion Index* (EI) is equal to the percent swell multiplied by 10. The expansion potential is assessed using the criteria shown in Table 3-7.

Table 3-7 Potential Expansion for EI Values

Expansion Index, EI	Potential Expansion
0 – 20	Very Low
21 – 50	Low
51 – 90	Medium
91 – 130	High
>130	Very High

3-2.7 Hydraulic Conductivity (Permeability) Tests.

Test to measure the permeability or hydraulic conductivity of soils have been used since the 1930s. In general, permeability tests have been more widely used for fine-grained soils as opposed to coarse-grained soils. There are many correlations available for the permeability of coarse-grained soils, but few reliable correlations exist for fine-grained soils. Currently, there are two ASTM standardized tests for hydraulic conductivity. However, hydraulic conductivity can be calculated from incremental stress and constant rate of strain consolidation tests.

3-2.7.1 Compaction Mold Test (ASTM D5856).

The compaction mold test (ASTM D5856 – Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material using a Rigid-Wall Compaction-Mold Permeameter) is intended to be used on compacted soils having a hydraulic conductivity less than 10^{-3} cm/sec.

This test has a major deficiency in that the test specimen cannot be saturated, therefore the measured hydraulic conductivity may be too low. There also is a problem that leakage can occur between the compacted test specimen and the wall of the compaction mold. This test is best suited as a quality control test for compacted clay liners for landfills and reservoirs.

3-2.7.2 Flexible Wall Test (ASTM D5084).

The flexible wall test (ASTM D5084 – Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter) is the most common permeability test. The apparatus used is also called a *triaxial permeameter* because it is essentially a triaxial cell without the loading rod. The sample is enclosed in a flexible membrane, therefore the problem of side-wall leakage experienced in D5856 is not a problem. The membrane conforms to irregularities in the sides of the test specimen. ASTM D5084 also allows for test specimens to be back-pressure saturated in the same manner as CU and CD triaxial test specimens. The flexible wall permeability test also allows control of the effective consolidation stress. This is not possible with the compaction mold test.

This method is recommended only for soils having a hydraulic conductivity less than 10^{-4} cm/sec, so it is best suited to fine-grained soils or soils with a significant percentage of fines. Intact, remolded, and compacted test specimens can be used for this test. The test takes considerable skill to properly conduct, and there are six different methods to promote flow though the test specimen. The test measures vertical hydraulic conductivity, but intact samples can be trimmed at different orientations to measure anisotropy of hydraulic conductivity.

3-2.7.3 Hydraulic Conductivity from Consolidation Tests.

One of the purposes of conducting a consolidation test is to determine the coefficient of consolidation (c_v). For incremental stress consolidation tests, c_v is calculated from the time curves using one of several different methods. For the CRS consolidation test, c_v

can be calculated at every point where the excess pore water pressure, average stress, and strain are known.

The hydraulic conductivity of a soil is related to the value of c_v by the equation below:

$$k = c_v \cdot m_v \cdot \gamma_w \tag{3-5}$$

where:
k = hydraulic conductivity or permeability,
c_v = coefficient of consolidation,
m_v = coefficient of volumetric compressibility, and
γ_w = unit weight of water.

The coefficient of volumetric compressibility can be determined by plotting the strain (y-axis) versus the arithmetic effective stress (x-axis) and determining the slope of the plot corresponding to the stress where c_v is calculated. Consolidation tests are rarely conducted just to determine the value of permeability, but if these data are available for a project where additional values of permeability are useful, little effort is required to calculate the permeability.

It is also possible to determine the permeability from the consolidation phase of CU and CD triaxial tests. This normally requires that the test specimen only be drained at the ends (no filter paper drainage strips) and it may be necessary to consolidate the specimen in stages leading up to the final consolidation stress.

3-3 LABORATORY TESTS ON ROCK.

ASTM also addresses laboratory tests on rock specimens, but there are much fewer tests for rocks than for soils. Most of the common tests on rock focus on the strength in compression and tension. Table 3-8 lists the common rock tests that have ASTM standards available.

Table 3-8 Laboratory Rock Strength Tests with ASTM Standards

ASTM #	Description	Parameters	Comments
D3967	Splitting Tensile Strength of Intact Rock Core Specimens	σ_t	
D5607	Laboratory Direct Shear Strength Tests of Rock Specimens Under Constant Normal Force	c-ϕ, c'-ϕ'	Mainly interpreted as total stress strength parameters.
D5731	Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications	I_s, $I_{s(50)}$	Strength index often corrected for specimen diameter of 50 mm.
D7012	Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures	σ_u	

3-3.1 Unconfined Compression Test (ASTM D7012).

ASTM D7012 (Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures) encompasses more than just unconfined compression tests. There are four different methods of testing outlined in the standard, and two address the unconfined compressive strength. The other two address triaxial compression of rock, which is used less frequently than for soil.

The basic form of the unconfined compression test (Method C) does not measure axial strain during loading, and provides only the unconfined compressive strength. The resulting strength can be used for design or as an index property for the rock. The test is normally conducted on rock cores that are 1.85 inches in diameter, and they are trimmed to be at least 3.7 inches in height. This specimen diameter corresponds to an NQ core barrel, but larger rock cores can be used as well. The specimen can be loaded at a constant rate of load or a constant rate of strain which are chosen to cause failure in 2 minutes to 15 minutes. Unconfined compression tests of rock are normally conducted on many test specimens since there can be wide variations in the compressive strength due to the effects of planes of weakness (joints, fractures, and faults) and other inhomogeneities is rock. The main result of the unconfined compression test in the uniaxial compressive strength (σ_u).

3-3.2 Split Cylinder Test (ASTM D3967).

The *split cylinder test* (ASTM D3967 – Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens) is used as an alternative to the direct tensile test. The test specimen is loaded diametrically via hardened steel end platens. The test specimen thickness can range between 0.2 to 0.75 times the specimen diameter. The test specimen is loaded at a rate sufficient to obtain failure in 1 to 10 minutes. The main result of this test is the *splitting tensile strength (*σ_t). Although the tensile strength resulting from the split cylinder test should be essentially equal to that measured from direct tension tests, it is customary to preface the former with "splitting." Owing to the variability in the test results, split cylinder tests are often run on numerous test specimens.

3-3.3 Rock Direct Shear Test (ASTM D5607).

Rock direct shear tests (ASTM D5607 - Standard Test Method for Performing Laboratory Direct Shear Strength Tests of Rock Specimens Under Constant Normal Force) can be conducted on intact rock specimens, as well as on joints and discontinuities. Unlike the direct shear test conducted on soils, the rock direct shear test is normally considered to be an undrained test. The basic elements of this test are the same as for the soil direct shear tests. Rock direct shear tests are often conducted for a range of normal stresses to determine the strength envelope for the material. One major difference is that the test specimen is often encapsulated in a super strength gypsum cement to fix its position in the shear box. An example of the test fixture is shown in Figure 3-16.

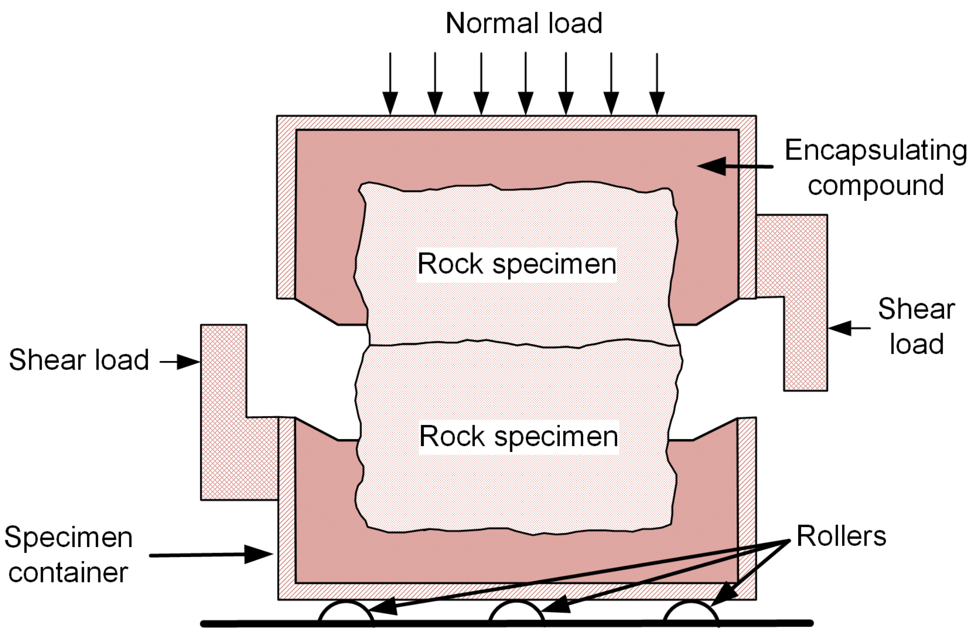


Figure 3-16 Specimen Container for Rock Direct Shear Test (after ASTM D5607)

Figure 3-17 Rock Direct Shear Apparatus for High Normal and Shear Loads

Rock direct shear tests are more complicated than the soil counterpart because of the great variety of loads and displacements the apparatus is required to measure. For large normal stresses, it can take 50,000 lbs. to fail an intact rock direct shear test specimen, and failure may occur at very small (<0.01 inch) displacements. For rock joints at low normal stresses, the failure load might be less than 100 lbs., and the displacement at failure may be greater than 0.1 inch. Shown in Figure 3-17 is a rock direct shear apparatus for high loads and normal stresses.

3-3.4 Point Load Test (ASTM D5731).

The point load test (ASTM D5731 – Standard Test Methods for Determination of the Point Load Strength Index of Rock and Application of Rock Strength Classifications) provides an index value of the rock strength. This test can be performed on rock cores or irregular pieces of rock having diameters in the range of 1 inch to 3 inches. A photograph of the point load apparatus is shown in Figure 3-18. The diameter of the test specimen is considered to be the thickness of the test specimen from loading platen contact points. The load platens are truncated cones, with the point being a semicircular arc of 0.2-inch radius.

Figure 3-18 Point Load Apparatus for Rock Index Testing

The point load test provides an *uncorrected point load strength index* (I_s). This value can be corrected to reflect differences in test specimen sizes, and is often normalized to an equivalent core diameter of 2 inches (50 mm). This corrected value is called the *size corrected point load strength index* ($I_{s(50)}$). The results of the point load test are used for rock classification and can be correlated to the uniaxial compressive strength, but the values are not considered to have sufficient reliability for design.

3-4 OTHER SOIL AND ROCK TESTS.

This section of the manual has addressed the tests that are the most common in geotechnical engineering practice in the U.S., but there are hundreds of other ASTM standardized tests. There are groups of tests that address partially saturated soils, soil-cement mixtures, peats and organic soils, geosynthetics, and many other materials used in engineering projects.

3-5 SUGGESTED READING.

Topic	Reference
General Laboratory Testing	Head, K. H. 2008. *Manual of Soil Laboratory Testing*, Vol. 1., 3rd Ed., Whittles, 416 pp.
	Head, K. H. and R. J. Epps 2011. *Manual of Soil Laboratory Testing Vol. II, Permeability Shear Strength, and Compressibility Tests*, 3rd Ed., Whittles, 512 pp.
	Head, K. H. and R. J. Epps 2014, *Manual of Soil Laboratory Testing Vol. III, Effective Stress Tests*, 3rd Ed., Whittles, 448 pp.
	Lambe, T. W. and R. V. Whitman 1969. *Soil Mechanics*, John Wiley and Sons, Inc. 553 pp.
Shear Strength	*Laboratory Shear Testing of Soils*, ASTM STP 361, American Society for Testing and Materials, 505 pp., 1964.
	Laboratory Shear Strength of Soils, ASTM STP 740, R. N. Young and F. C. Townsend, Eds., 717 pp, 1981.
	Research Conference on Shear Testing of Cohesive Soils, ASCE, University of Colorado, Boulder, CO, 1164 pp, 1960.
	Saada, A. S. and Townsend, F. C. 1981. "State of the Art: Laboratory Strength Testing of Soils," *Laboratory Shear Strength of Soils*, ASTM STP 740, R. N. Yong and F. C. Townsend, Eds., ASTM, pp. 7-77.
Triaxial Testing	*Advanced Triaxial Testing of Soil and Rock*, ASTM SPT 977, Robert T. Donague, Ronald C. Chaney, and Marshal L. Silver, Eds., American Society for Testing and Materials, Philadelphia, 896 pp, 1988.
	Bishop, A. W. and D. J. Henkel (1957), *Measurement of Soil Properties in the Triaxial Test*, Edward Arnold, Ltd., London, 190 pp.
	Lade, P. 2016. *Triaxial Testing of Soils*, John Wiley & Sons, Ltd., 500 pp.

3-6 NOTATION.

Symbol	Description
c	Total stress cohesion
C_c	Compression index
C_r	Recompression index
c_v	Coefficient of consolidation
c'	Effective stress cohesion
D	Diameter
D_r	Relative density
e	Void ratio
e_{max}	Maximum index void ratio

Symbol	Description
e_{min}	Minimum index void ratio
G_s	Specific gravity
H	Height
I_s	Uncorrected point load strength index
$I_{s(50)}$	Size corrected point load strength index
k	Hydraulic conductivity or permeability
K_0	At-rest earth pressure coefficient
L	Length
m_v	Coefficient of volumetric compressibility
n	Porosity
P_p	Maximum past pressure
RC	Relative compaction
S	Degree of saturation
S_t	Sensitivity
s_u	Undrained shear strength for a ϕ = 0 envelope for saturated soils
t	Thickness
V	Total volume
V_a	Volume of air
V_s	Volume of solids
V_v	Volume of voids
V_w	Volume of water
w	Water content
w_{opt}	Optimum water content
W_s	Weight of solids
W_t	Total weight of sample
W_w	Weight of water
γ_b	Buoyant unit weight or submerged unit weight

Symbol	Description
γ_d	Dry unit weight
$\gamma_{d\text{-}max}$	Maximum dry density from the compaction curve for a particular effort or maximum index dry density (corresponding to e_{min})
$\gamma_{d\text{-}min}$	Minimum index dry density (corresponding to e_{max})
γ_t	Total or wet unit weight
γ_{sat}	Saturated unit weight
γ_w	Unit weight of water
$\Delta\sigma$	Change in applied stress
$\dot{\varepsilon}$	Strain rate
σ_0	Initial total stress
σ_3	Confining pressure
σ'_p	Preconsolidation pressure
σ'_v	Vertical effective consolidation stress
τ_{cyc}	Applied peak cyclic shear stress
ϕ	Total stress friction angle
ϕ'	Effective stress friction angle

CHAPTER 4 DISTRIBUTION OF STRESSES

4-1 INTRODUCTION.

4-1.1 Scope.

This chapter describes the analysis of stress conditions within the ground, including stress at a point, changes in stress caused by the application of soil and structural loads, and empirical methods for estimating loads on buried pipes, conduits, shafts, and tunnels. The calculation of stresses and changes in stress using numerical methods, such as the finite element method, is also discussed.

4-1.2 State of Stress.

The state of stress within the ground can be analyzed assuming that either elastic or plastic conditions prevail. Elastic solutions are most appropriate for cases in which the shear stresses throughout the soil mass are significantly below the shear strength of the soil and shear failure is not likely. If the shear stress in the soil is less than about one-third of the ultimate shear strength, the stresses within the soil mass will be roughly equal to values calculated from elastic theory (Davis and Selvadurai 1996). The stress conditions calculated using the most of the methods in this chapter assume that elastic conditions prevail.

Plastic solutions assume full mobilization of the soil’s shear strength within a soil mass or along a specified failure surface. Plastic equilibrium is used for problems, such as slope stability (Chapter 7), foundation bearing capacity, and lateral earth pressures, where shear strength may be fully mobilized.

4-2 STRESS CONDITIONS AT A POINT.

4-2.1 Stress Conditions in Soil.

Soil consists of a compilation of discrete particles, water, and air in varying proportions. Similarly, rock may contain a combination of the mineral components and any void space that may be filled with water or air. These discrete systems are idealized in stress analysis by assuming the soil acts as continuous solid mass without holes or gaps. In this continuum manner, stress is simply conceived as force per unit area and the contact forces at the soil particle level are not considered.

Stress in soil is the result of forces from the self-weight of the overlying and surrounding soil plus any external loading, such as structures or ponded water. For a given plane, it can be particularly useful to consider stress in terms of its normal and shear components. The normal stress can be defined as the sum of the forces acting perpendicular to a plane divided by the area of that plane. Similarly shear stress in a particular direction is ratio of the force acting tangent to a plane divided by its area.

The total normal stress on any plane within the ground is based on the sum of all forces acting on the plane in question. The total stress may be divided into two parts: the effective normal stress and the pore pressure.

4-2.1.1 Total Vertical Stress.

The total vertical stress (or overburden stress) is the normal stress acting on a horizontal plane at some depth within the soil. The total vertical stress, σ_v, at a particular depth is calculated by multiplying the thickness (z_i) of all overlying materials by the total unit weight ($\gamma_{t,i}$) of each material:

$$\sigma_v = \sum_{i=1}^{n} z_i \gamma_{t,i} \quad \textbf{(4-1)}$$

It is imperative to include the weight of water resting on the ground surface (i.e., ponded water) in calculations of total vertical stress. Ponded water can be considered by adding a layer to the total stress calculations with thickness equal to the water depth and unit weight equal to the unit weight of water.

The calculation of total vertical stress is illustrated in Figure 4-1.

4-2.1.2 Pore Water Pressure.

The energy present in ponded water or groundwater is often expressed in terms of the total hydraulic head, which has pressure, elevation, and velocity components. The velocity component is typically ignored in most geotechnical applications. The pore water pressure (u) can be found from the pressure head (h_p) as

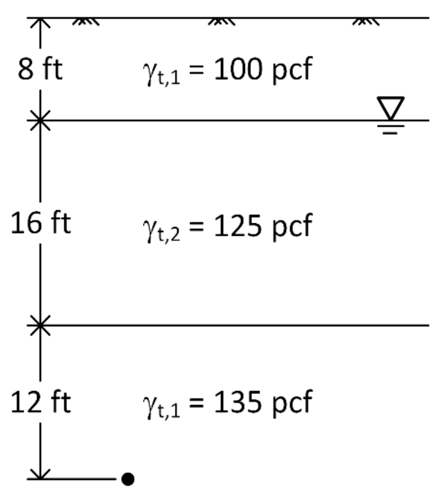
$$u = h_p \gamma_w \quad \textbf{(4-2)}$$

where:
γ_w = the unit weight of water (62.4 pcf or 9.81 kN/m^3).

When water is static (not flowing), the total head is constant throughout the system, and elevation head converts directly to pressure head. This is referred to as a *hydrostatic* condition, and the pressure head is simply equal to the distance below the groundwater table or phreatic surface.

Flowing water loses energy as it flows through the soil and the total head decreases in the direction of flow. For flowing water conditions, a flow net or some other type of seepage analysis must be performed. Pore water pressure at any point can be determined by first calculating the total head and the elevation head at any point in the ground. The pressure head for flowing water is found by subtracting the elevation head from the total head. Water pressures act in all directions equally because the water does not sustain shear stress. For this reason, orientation of the pore water pressure is not important. In some older publications, pore water pressure is also called *neutral stress.*

Vertical Stress and Pore Pressure Examples



Scenario 1

Layer 1: z_1 = 8 ft, $\gamma_{t,1}$ = 100 pcf
Layer 2: z_2 = 16 ft, $\gamma_{t,2}$ = 125 pcf
Layer 3: z_3 = 12 ft, $\gamma_{t,3}$ = 135 pcf

Total vertical stress

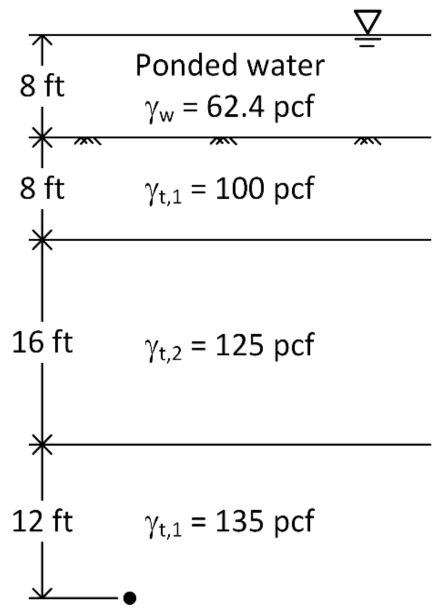
$$\sigma_v = z_1\gamma_{t,1} + z_2\gamma_{t,2} + z_3\gamma_{t,3}$$
$$= (8 \text{ ft})(100 \text{ pcf}) + (16 \text{ ft})(125 \text{ pcf}) + (12 \text{ ft})(135 \text{ pcf})$$
$$= 4420 \text{ psf}$$

Pore pressure

h_p = 16 ft +12 ft = 28 ft
u = (28 ft)(62.4 pcf) = 1747 psf

Effective vertical stress

$$\sigma'_v = \sigma_v - u = 4420 \text{ psf} - 1747 \text{ psf}$$
$$= 2673 \text{ psf}$$



Scenario 2

Water: z_w = 8 ft, γ_w = 62.4 pcf
Layer 1: z_1 = 8 ft, $\gamma_{t,1}$ = 100 pcf
Layer 2: z_2 = 16 ft, $\gamma_{t,2}$ = 125 pcf
Layer 3: z_3 = 12 ft, $\gamma_{t,3}$ = 135 pcf

Total vertical stress

$$\sigma_v = z_w g_w + z_1\gamma_{t,1} + z_2\gamma_{t,2} + z_3\gamma_{t,3}$$
$$= (8 \text{ ft})(62.4 \text{ pcf}) + 4420 \text{ psf}$$
$$= 4919 \text{ psf}$$

Pore pressure

h_p = (8 + 8 + 16 +12 ft) = 44 ft
u = (44 ft)(62.4 pcf) = 2746 psf

Effective vertical stress

$$\sigma'_v = \sigma_v - u = 4919 \text{ psf} - 2746 \text{ psf}$$
$$= 2173 \text{ psf}$$

Figure 4-1 Calculation of Vertical Stresses for Hydrostatic Conditions

4-2.1.3 Effective Vertical Stress.

The effective vertical stress (σ'_v) is found by subtracting the pore water pressure at any point from the total vertical stress at the same point

$$\sigma'_v = \sigma_v - u \quad \textbf{(4-3).}$$

4-2.1.4 Horizontal Stress.

Horizontal stress in a soil mass is influenced by the effective vertical stress, the geologic stress history, and lateral confinement conditions. Horizontal stress cannot be calculated directly from the soil profile and is typically calculated as a proportion of the effective vertical stress:

$$\sigma'_h = K \cdot \sigma'_v \quad \textbf{(4-4).}$$

The lateral earth pressure coefficient (K) depends on stress history and lateral confinement conditions. Common types, applications, and sources of lateral earth pressure coefficients are summarized in Table 4-1.

The total horizontal stress can be found by adding the pore water pressure at any point onto the effective horizontal stress

$$\sigma_h = \sigma'_h + u \quad \textbf{(4-5).}$$

Table 4-1 Lateral Earth Pressure Coefficients

Lateral earth pressure coefficient	Example applications	Method to obtain
At-rest, K_0	Level, natural ground Unyielding retaining wall	Estimate based on ϕ' and OCR Measure with field tests
Active, K_A	Near crest of slopes Behind yielding retaining walls	Calculate with analytical methods (see DM 7.2) Estimate based on experience
Passive, K_P	Near toe of slopes In front of retaining wall toe	

4-2.1.5 Applied Loads.

Many civil engineering applications must consider the effects of external (non-soil) loads applied at the surface or at some depth within the soil mass. The influence of existing loads must be included in total stress calculations. New loads cause changes in total stress within the soil. These load changes will cause changes in the pore water pressures as discussed in more detail in Chapter 5. The duration of the changes in pore water pressure will depend on the permeability and compressibility of the soil.

Analytical methods for calculating changes in stress are provided in Section 4-3, including methods for point loads, line loads, and uniformly loaded areas. In Section 4-6, numerical methods for calculating changes in stress are summarized.

Changes in total stress caused by applied loads should be within the soil mass to at least the critical depth. The critical depth is the depth over which soil compression caused by the changes in stress contributes to significant surface settlement. The critical depth in fine-grained soils corresponds to the depth at which the change in stress is less than 10% of the existing vertical effective stress. In coarse-grained soils, the critical depth occurs when the change in stress is less than 20% of the existing vertical effective stress.

Interactions between the applied load and the soil foundation must be considered, especially for changes in stress very close to the load. The flexibility of the structure that applies a distributed load to the soil affects the distribution of the change in stress. A completely flexible load, such as a soil fill, will apply a uniform stress to the soil because the load can deform in proportion to the soil. The elastic solutions presented in Section 4-3 assume that the load is completely flexible.

A foundation that is completely rigid with respect to the soil must undergo a uniform deformation. When a rigid foundation deforms uniformly into an elastic solid (i.e., undrained conditions for clay), the load must shift to the edges of the foundation, resulting in a pressure distribution that increases toward the edge (see Figure 4-2). In contrast, a rigid foundation on sand will cause yielding near the edges, resulting a pressure distribution that decreases toward the edge.

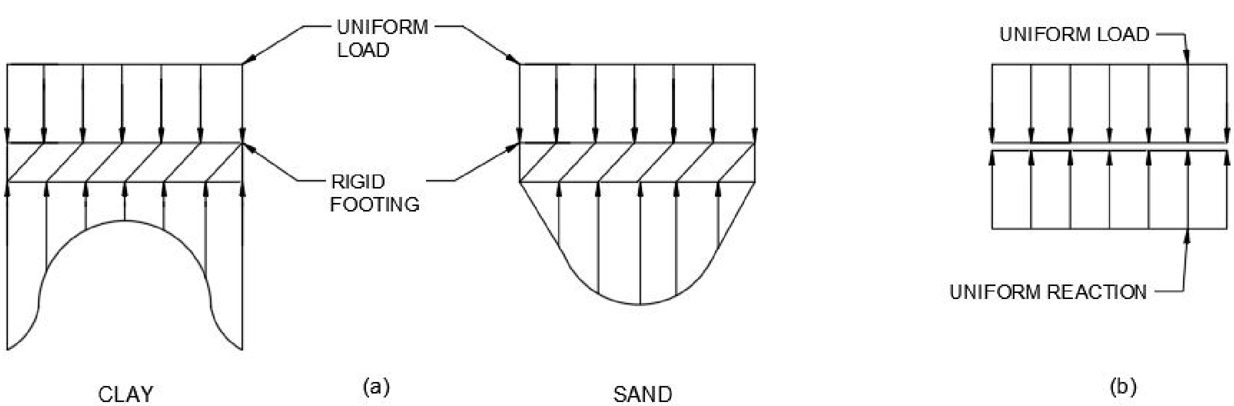


Figure 4-2 Variation in Contact Pressure – a) Rigid Foundation and b) Completely Flexible Foundation

4-2.2 Mohr Circle of Stress.

The normal and shear stress on a plane at any point within the ground depends on the orientation of that plane with respect to the orientation of the stress system. At any point, the will be three mutually perpendicular planes that have no shear stress, which are referred to as the principal planes. The normal stresses that act on these planes are defined as the principal stresses. The major principal stress (σ_1) has the largest magnitude. The minor principal stress (σ_3) has the smallest magnitude. The intermediate principal stress (σ_2) falls between σ_1 and σ_3. For two-dimensional problems, σ_2 is either assumed equal to σ_3 or ignored. For level ground conditions, the principal stresses are often assumed to be aligned with the horizontal and vertical directions with the horizontal normal stress being equal in all directions. The sign convention used herein assigns positive values to compressive stress, shear stress that causes counterclockwise rotation, and counterclockwise angles.

A Mohr circle of stress can easily be plotted from σ_1 and σ_3, or the normal and shear stresses on any two perpendicular planes. More information on the use of the Mohr circle can be found in Parry (2004). From the Mohr circle for a point, the normal and shear stress conditions on any plane can be determined by rotating an angle 2α about the center of the circle, where α is the angle between the major principal plane and the plane of interest. Figure 4-3 illustrates the Mohr circle and mathematical relationships between common stresses.

4-3 ELASTIC SOLUTIONS FOR STRESSES DUE TO APPLIED LOADS.

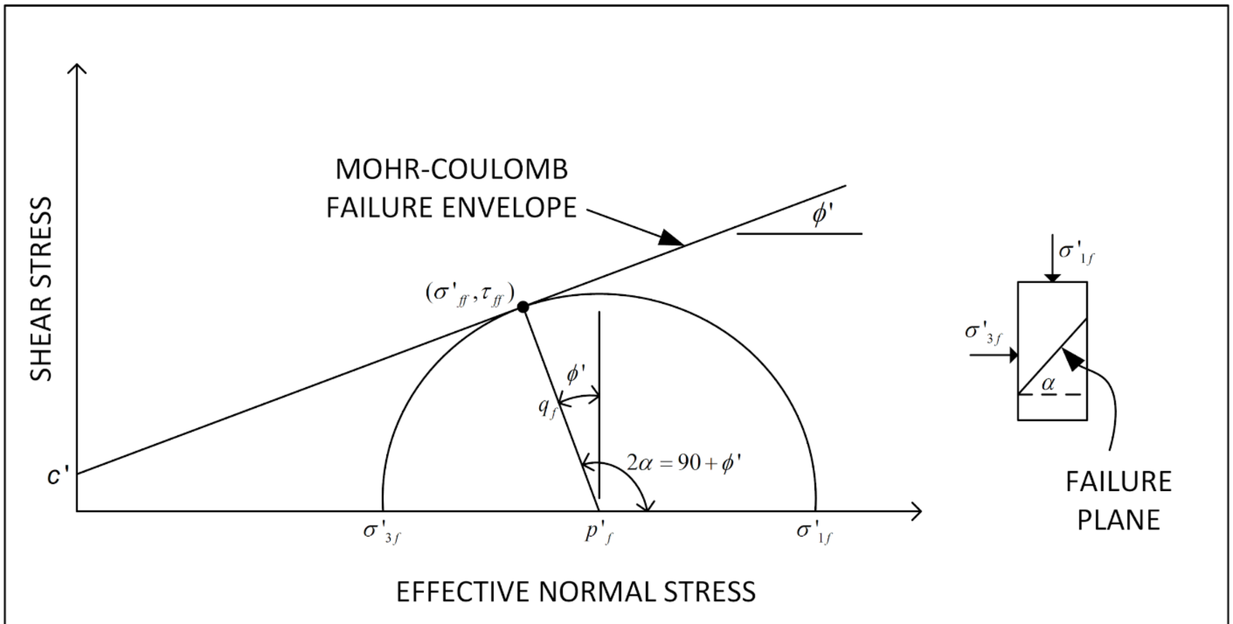
4-3.1 Use and Applicability.

The elastic solutions presented in this section are useful for simple analyses of changes in stress, especially consolidation settlement. These methods are also useful for understanding the principles of stress distribution and for checking more complicated numerical analyses.

4-3.2 Semi-Infinite Elastic Conditions.

4-3.2.1 Assumptions.

The Boussinesq and related solutions assume the soil is a homogeneous, elastic material in which continuity is maintained and static equilibrium is satisfied. The applied load is completely flexible and is applied at the surface of the material. For embankment loading, the load is strictly vertical and no shear stress is applied to the foundation by the embankment. As discussed in Section 4-2.1.5, the stress distribution below a rigid foundation is not uniform and may not conform to the assumptions of the Boussinesq solutions.



MOHR CIRCLE PROPERTIES		
CENTER: $p'_f = \frac{\sigma'_{1f} + \sigma'_{3f}}{2}$	RADIUS: $q_f = \frac{\sigma'_{1f} - \sigma'_{3f}}{2}$	FRICTION ANGLE: $\phi' = \sin^{-1}\left(\frac{q_f - c'/\cos\phi'}{p'_f}\right)$

FAILURE ENVELOPE RELATIONSHIPS	
$\sigma'_{ff} = p'_f - q_f \sin\phi'$	$\frac{\sigma'_{3f}}{\sigma'_{1f}} = \left(\frac{\sigma'_{ff} - c'\cos\phi'}{\sigma'_{ff} + c'\cos\phi'}\right)\left(\frac{1-\sin\phi'}{1+\sin\phi'}\right) = \tan^2\left(45 - \frac{\phi'}{2}\right) - 2c'\tan\left(45 - \frac{\phi'}{2}\right)$
$\tau_{ff} = c' + \sigma'_{ff}\tan\phi' = q_f \cos\phi'$	$\frac{\sigma'_{1f}}{\sigma'_{3f}} = \left(\frac{\sigma'_{ff} + c'\cos\phi'}{\sigma'_{ff} - c'\cos\phi'}\right)\left(\frac{1+\sin\phi'}{1-\sin\phi'}\right) = \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c'\tan\left(45 + \frac{\phi'}{2}\right)$

Figure 4-3 Mohr Circle Relationships

Loads with a length to width ratio (L/B) of at least five are commonly assumed to result in *plane strain* conditions, at least near the middle of the length. Under plane strain, deformation only occurs perpendicular to the long axis of the load and the changes in stress do not depend on the elastic properties of the material.

The Boussinesq solutions are not typically applicable to the calculation of shear stress for conditions where shear stress is becoming critical. In this case, the soil is approaching a state of plastic equilibrium and the assumption of elasticity no longer applies. In such cases, stability analysis methods, such as those in Chapter 7 and in DM 7.2, should be used.

4-3.2.2 Stress Distribution Formulas.

Formulas for homogeneous, semi-infinite, isotropic foundations are summarized in Table 4-2. These formulas can be used for hand calculations for simple computations and to check the results of more complex numerical analyses. Such formulas can also easily be programmed into a spreadsheet solution. Additional formulas for other geometric and loading conditions are summarized in Poulos and Davis (1974).

Horizontal and shear stresses caused by applied loads can also be determined from elastic solutions. In many cases, these calculations require a value of Poisson's ratio (ν) for the soil. Many of the common figures assume $\nu = 0.5$ making it important to verify the value of ν that was used. One application of horizontal stress calculations is for the loading of unyielding walls as discussed in DM 7.2. For conditions where elastic solutions are suitable, the calculation of shear stress is typically not required.

Table 4-2 Equations for the Calculation of Change in Vertical Stress Below Various Loading Conditions \1

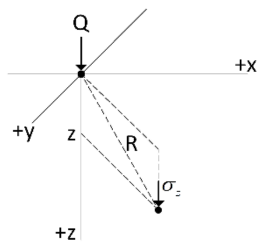
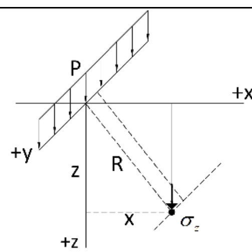
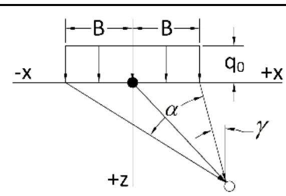
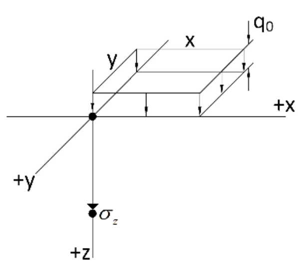
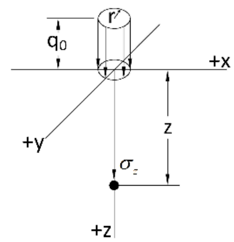
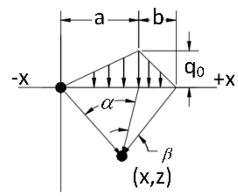
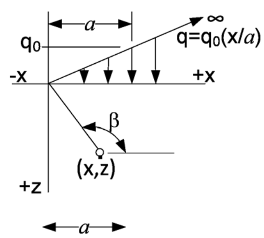
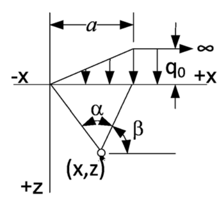
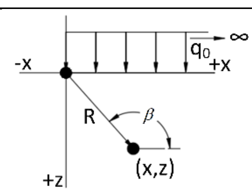
Loading Condition	Stress Diagram	Equation
Point Load		$\sigma_z = \frac{3 \cdot Q \cdot z^3}{2\pi \cdot R^5}$ $R = \sqrt{x^2 + y^2 + z^2}$
Uniform Line Load of Infinite Length		$\sigma_z = \frac{2 \cdot P}{\pi} \cdot \frac{z^3}{R^4}$ $R = \sqrt{x^2 + z^2}$
Uniform Strip Load (Figure 4-4)		$\sigma_z = \frac{q_0}{\pi}\left[\alpha + \sin\alpha \cdot \cos(\alpha + 2 \cdot \gamma)\right]$ Note: α and γ are in radians
Uniformly Loaded Rectangular Area (Figure 4-5)		$\sigma_z = \frac{q_0}{2\pi} \cdot \left[\tan^{-1}\left(\frac{y \cdot x}{z \cdot R_3}\right) + \frac{x \cdot y \cdot z}{R_3} \cdot \left(\frac{1}{R_1^2} + \frac{1}{R_2^2}\right)\right]$ $R_1 = \sqrt{y^2 + z^2}$ $R_2 = \sqrt{x^2 + z^2}$ $R_3 = \sqrt{x^2 + y^2 + z^2}$

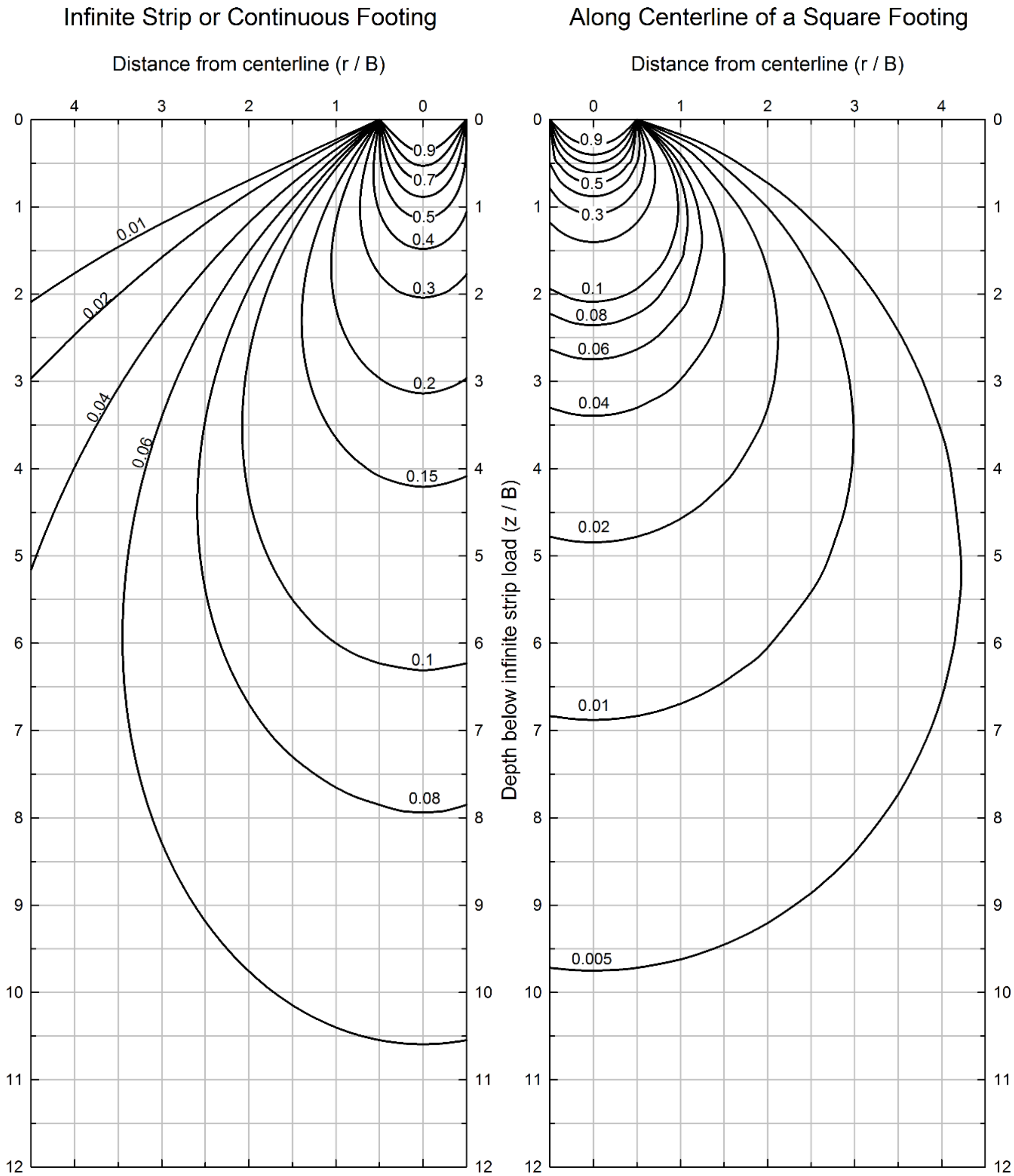
Table 4 2 (cont.) Equations for the Calculation of Change in Vertical Stress Below Various Loading Conditions

Loading Condition	Stress Diagram	Equation
Uniformly Loaded Circular Area (Figure 4-6)		$\sigma_z = q_0\left[1-\frac{1}{\left(1+(r/z)^2\right)^{3/2}}\right]$
Triangular Load		$\sigma_z = \frac{q_0}{\pi}\left[\frac{x\cdot\alpha}{a}+\left(\frac{a+b-x}{b}\right)\cdot\beta\right]$ Note: α and β are in radians
Slope Load		$\sigma_z = \frac{q_0}{\pi\cdot a}\left(x\cdot\beta+z\right)$ Note: β is in radians
Terrace Load		$\sigma_z = \frac{q_0}{\pi\cdot a}\left(a\cdot\beta+x\cdot\alpha\right)$ Note: α and β are in radians
Semi-infinite Uniform Load		$\sigma_z=\frac{q_0}{\pi}\left[\beta+\frac{xz}{R^2}\right]$

/**1**/

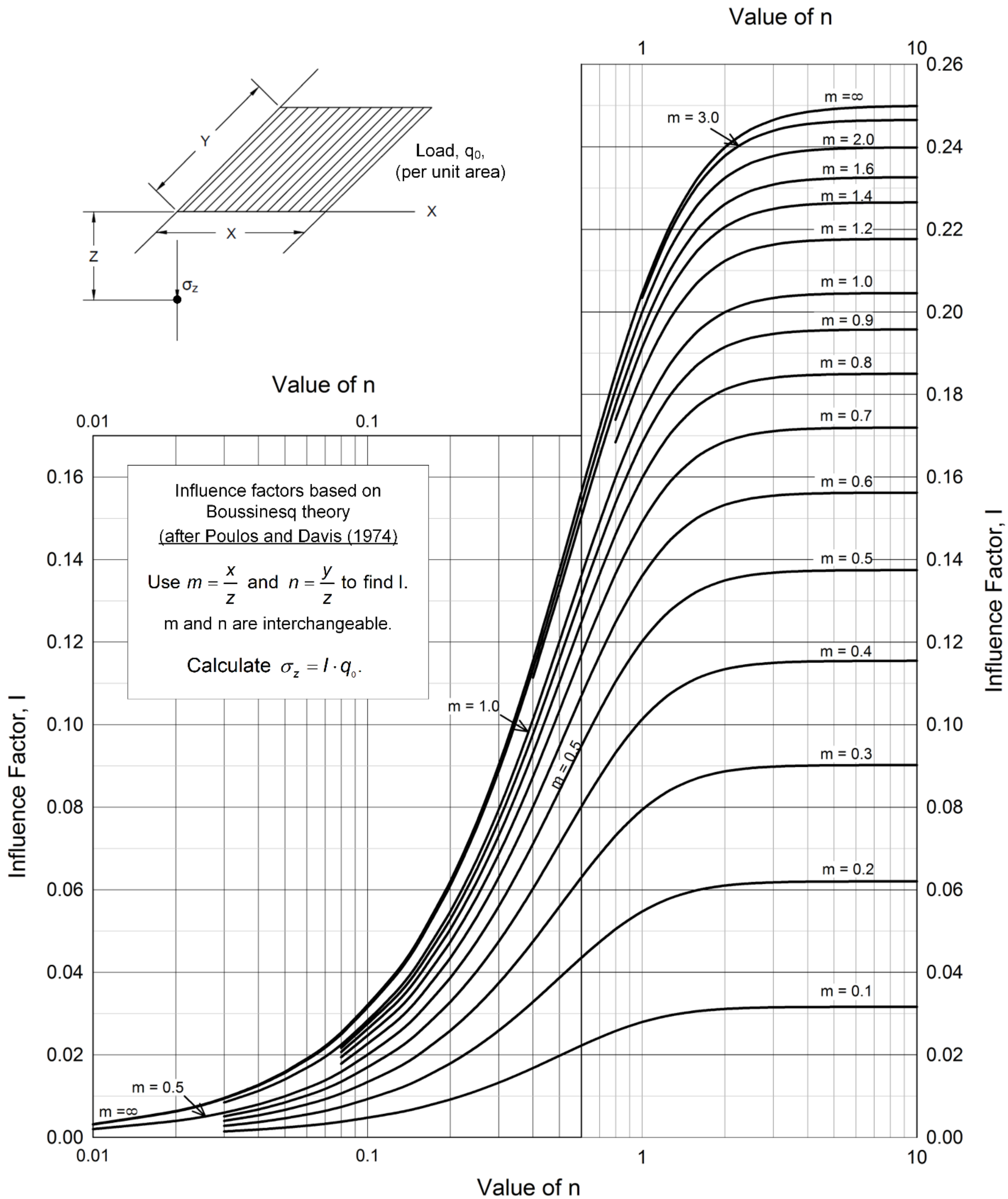
4-3.2.3 Chart Solutions for Vertical Stress beneath Regular Loads.

Figure 4-4 to Figure 4-7 provide chart solutions for regularly shaped loads and Boussinesq theory. These charts are all based on the assumption of ν = 0.5, where required, to determine the change in vertical stress. Example calculations are provided in Figure 4-9. Additional guidance on the calculation of changes in stress under elastic conditions can be found in Poulos and Davis (1974).



Variables: B = foundation width, r = horizontal distance from centerline of foundation, and z = depth below the applied load.
Numbers shown adjacent to contour lines are values of the influence factor, I.
For an applied foundation stress equal to q_0, the change in vertical stress is $\Delta\sigma_v = q_0 I$
Based on Boussinesq theory presented in Poulos and Davis (1972).

Figure 4-4 Vertical Stress Contours from Strip and Square Loaded Areas – Boussinesq



Influence Value for Vertical Stress Beneath a Corner of a Uniformly Loaded Rectangular Area

Figure 4-5 Influence Factors for a Rectangular Loaded Area – Boussinesq

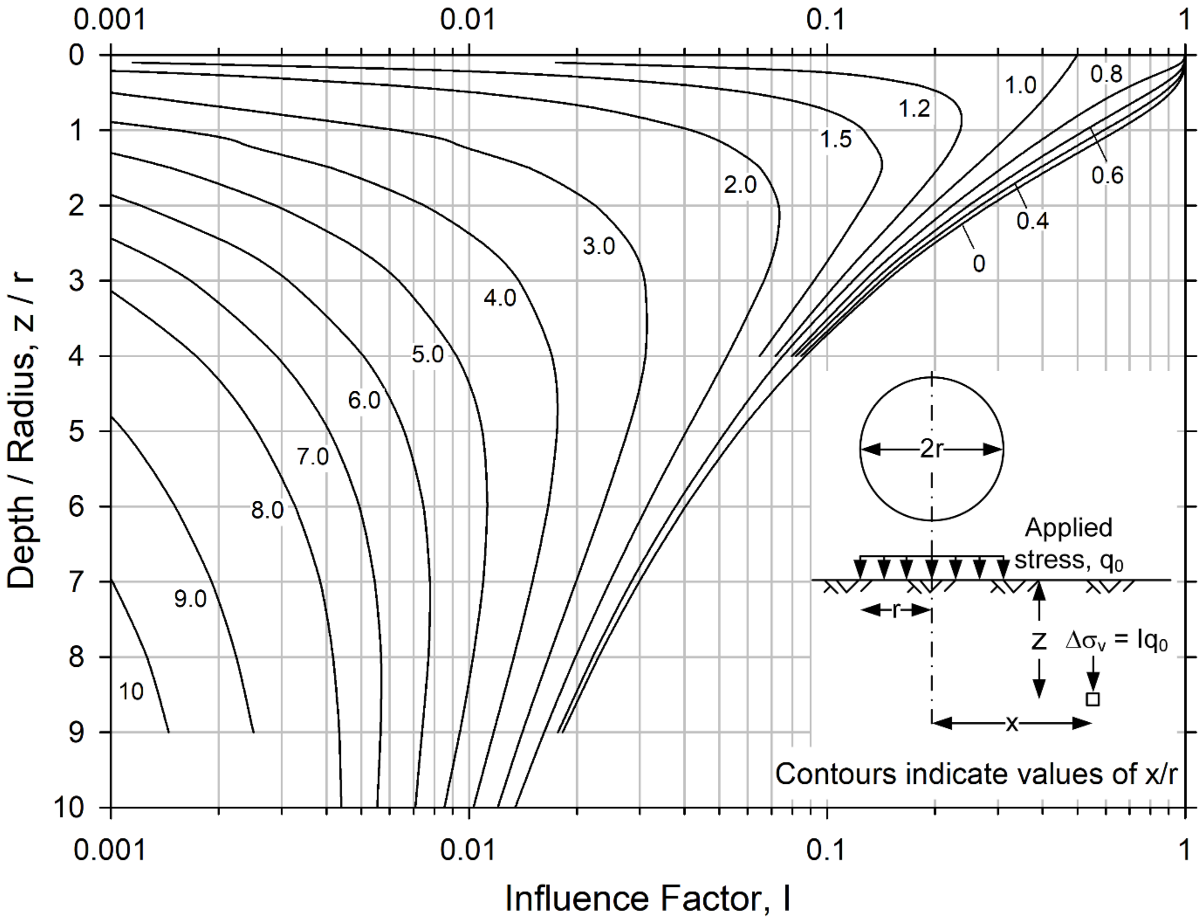


Figure 4-6 Influence Factors for a Circular Loaded Area – Boussinesq (after Ahlvin and Ulery 1962, Poulos and Davis 1974)

In the past, changes in stress caused by irregularly shaped loaded areas were calculated using chart solutions such as those proposed by Newmark (1942) and Jimenez Salas (1948). However, for complex loading conditions, numerical analysis has become the most common means to evaluate changes in stress.

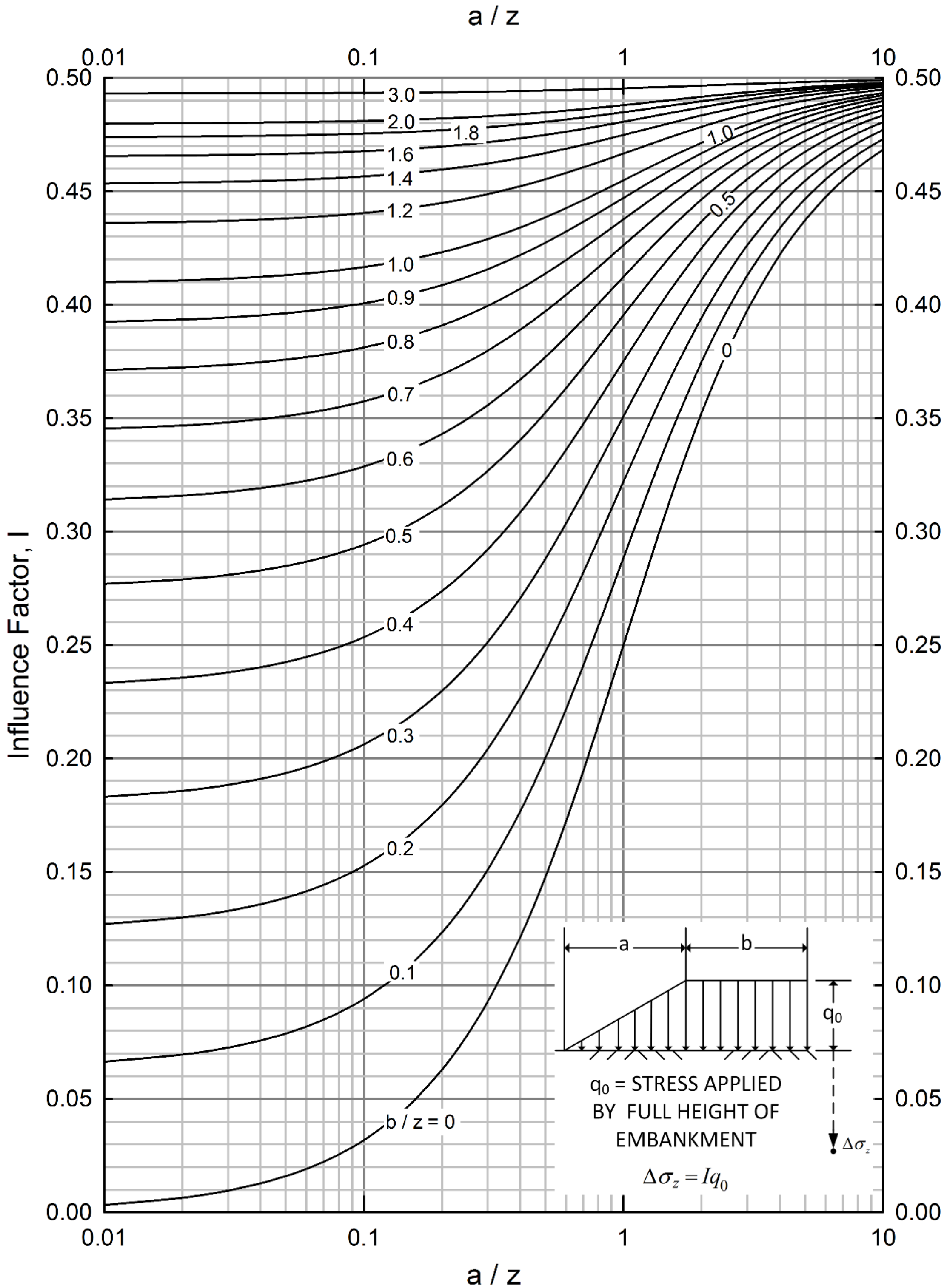
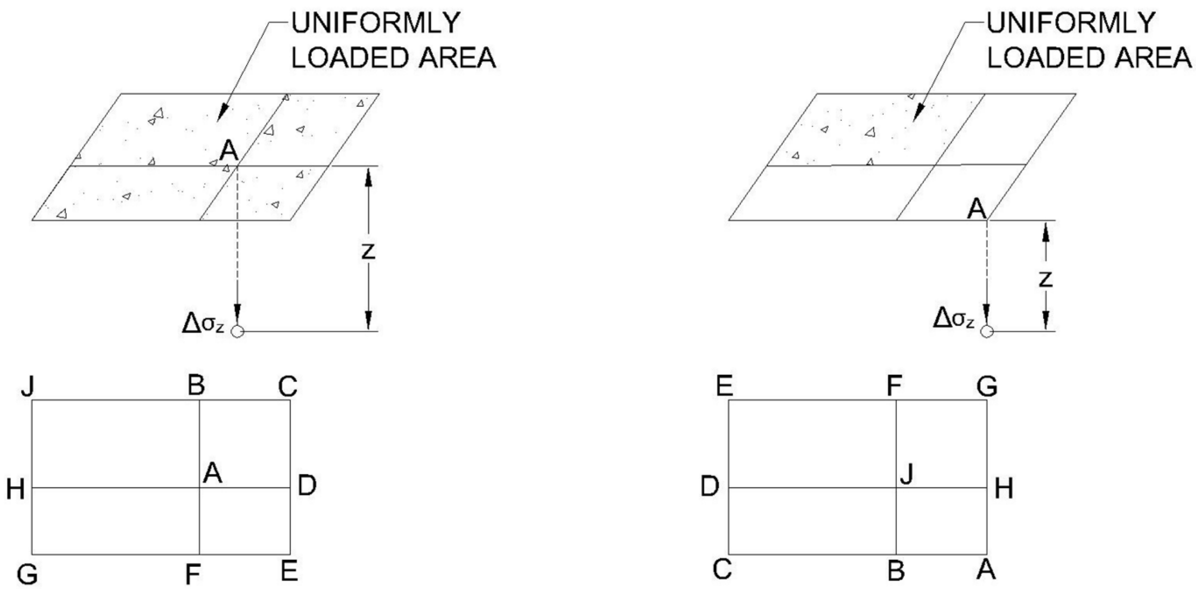


Figure 4-7 Influence Factors for Embankment Loading – Boussinesq (after Poulos and Davis 1974)

4-3.2.4 Superposition.

The assumption of linear elasticity inherent in the Boussinesq solutions allows for *superposition* of stresses that result from applied loads. This means that the change in stress from one load can be added or subtracted from those caused by other loads, provided the same point is being considered in all cases. This principle is especially useful for determining the change in stress below and outside of loaded areas as illustrated in Figure 4-8.



INFLUENCE FACTOR	RECTANGLE
I_1	ABCD
I_2	ABJH
I_3	AFGH
I_4	ADEF
$I_A = I_1 + I_2 + I_3 + I_4$	

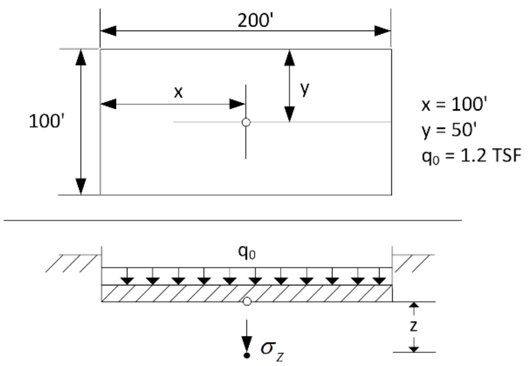
(a) Point below middle of rectangular area

INFLUENCE FACTOR	RECTANGLE
I_5	ACEG
I_6	ABFG
I_7	ACDH
I_8	ABJH
$I_A = I_5 - I_6 - I_7 + I_8$	

(b) Point outside of rectangular area

Figure 4-8 Use of Superposition to Determine Change in Vertical Stress

RECTANGULAR MAT FOUNDATION

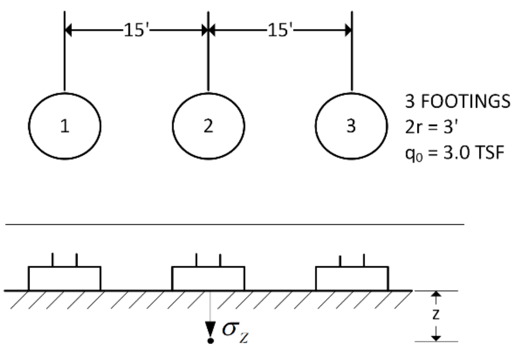


UNIT AREA LOAD (INCL. MAT) = 2 TSF, UNIT LOAD EXCAVATED = 0.8 TSF, NET AREA LOAD = 1.2 TSF. DETERMINE PROFILE OF APPLIED STRESS BENEATH CENTER OF MAT

REFER TO FIGURE 4-5 FOR INFLUENCE VALUE I FOR VERTICAL STRESS UNDER CORNER OF UNIFORMLY LOADED RECTANGULAR AREA TO FIND I FOR 1 OF 4 ADJOINING RECTANGULAR AREAS.

z (FT)	m	n	I 1 RECT.	4I 4 RECT.	$\sigma_z = 4Iq_0$ (TSF)
5	20	10	0.250	1.000	1.199
10	10	5	0.249	0.997	1.196
20	5	2.50	0.244	0.976	1.171
30	3.33	1.67	0.233	0.932	1.118
40	2.50	1.25	0.218	0.870	1.044
60	1.67	0.83	0.182	0.727	0.873
80	1.25	0.63	0.148	0.593	0.711
100	1.00	0.50	0.120	0.481	0.577

SEPARATE COLUMN FOOTINGS

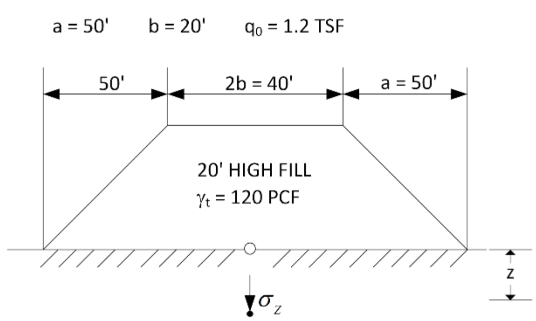


DETERMINE PROFILE OF APPLIED STRESS σ_Z BELOW CENTER OF MIDDLE CIRCULAR FOOTING (#2).

REFER TO FIGURE 4-6 (VERTICAL STRESS UNDER CIRCULAR LOADED AREA) TO DETERMINE INFLUENCE VALUE, I, FOR EACH FOUNDATION.

z (FT)	z/r	I_1 $x/r = 10$	I_2 $x/r = 0$	I_3 $x/r = 10$	∑ I	$\sigma_z = \Sigma I q_0$ (TSF)
2	1.33	0.000	0.646	0.000	0.646	1.939
4	2.67	0.000	0.200	0.000	0.200	0.600
6	4.00	0.001	0.087	0.001	0.088	0.265
10	6.67	0.002	0.035	0.002	0.039	0.117
15	10.00	0.003	0.015	0.003	0.021	0.062
20	13.33	0.003	0.009	0.003	0.015	0.045
25	16.67	0.003	0.007	0.003	0.013	0.039

EMBANKMENT LOAD



DETERMINE PROFILE OF APPLIED STRESS σ_Z BENEATH CENTER LINE OF EMBANKMENT OF INFINITE LENGTH. MAX STRESS, q_0 = (20 FT)(120 PCF) = 2400 PSF = 1.2 TSF

REFER TO FIGURE 4-7 FOR INFLUENCE VALUE I FOR VERTICAL STRESS UNDER EMBANKMENT LOAD OF INFINITE LENGTH. INFLUENCE FACTOR FROM THE CHART IS FOR 1/2 OF EMBANKMENT WIDTH.

z (FT)	a/z	b/z	I	2I	$\sigma_z = 2Ip$ (TSF)
5	10	4	0.499	0.999	1.199
10	5	2	0.496	0.992	1.190
20	2.5	1.0	0.476	0.952	1.142
30	1.67	0.67	0.445	0.889	1.067
40	1.25	0.50	0.410	0.819	0.983
60	0.83	0.33	0.343	0.686	0.824
80	0.63	0.25	0.289	0.578	0.694
100	0.50	0.20	0.247	0.494	0.593

Figure 4-9 Stress Distribution Examples

4-3.2.5 St. Venant's Principle.

St. Venant's principle is another useful concept for the calculation of change in stress due to applied loads. According to this principle, the change in stress caused by two statically equivalent loads becomes equal as the distance from the load becomes sufficiently large. Practically, this means that a square or circular load can be replaced with a point load, or a strip load can be considered a line load. It is commonly assumed that St. Venant's principle can be applied to the calculation of change in vertical stress, $\Delta\sigma_z$, for depths greater than three times the width of the applied load.

4-3.3 Layered or Anisotropic Foundations.

While the Boussinesq solutions offer a relatively simple means to calculate changes in stress, soil is not a homogeneous, isotropic, and semi-infinite medium. For example, different layers typically have different values of elastic modulus. Soil layers are often more rigid horizontally than vertically. These deviations from the assumptions of Boussinesq have led to the development of other methods for the calculation of changes in stress, most notably the Westergaard type of analysis.

4-3.3.1 Westergaard Analysis.

Westergaard analysis assumes that the soil below the load is reinforced by closely spaced horizontal layers that prevent horizontal displacement. This reinforcement effect causes the changes in stress predicted by Westergaard to be less than those calculated by the Boussinesq assumptions. The Westergaard type of analysis is most appropriate for soil profiles that have alternating layers of stiff and soft soils, such as soft clay with intermittent horizontal layers of sand. Figure 4-10 provides influence factors for points below the corner of a rectangular loaded area, assuming Westergaard theory.

4-3.3.2 Layered Foundations.

Soil profiles may have layers of significant thickness and very different elastic properties. The changes vertical stress induced in these cases differs significantly from that predicted by Boussinesq assumptions. Analytical and chart-based solutions have been suggested to account for such differences using rigidity factors (e.g., Mehta and Veletsos 1959). For these conditions, numerical analysis is the preferred method to determine changes in stress or as a means of comparison to simpler solutions.

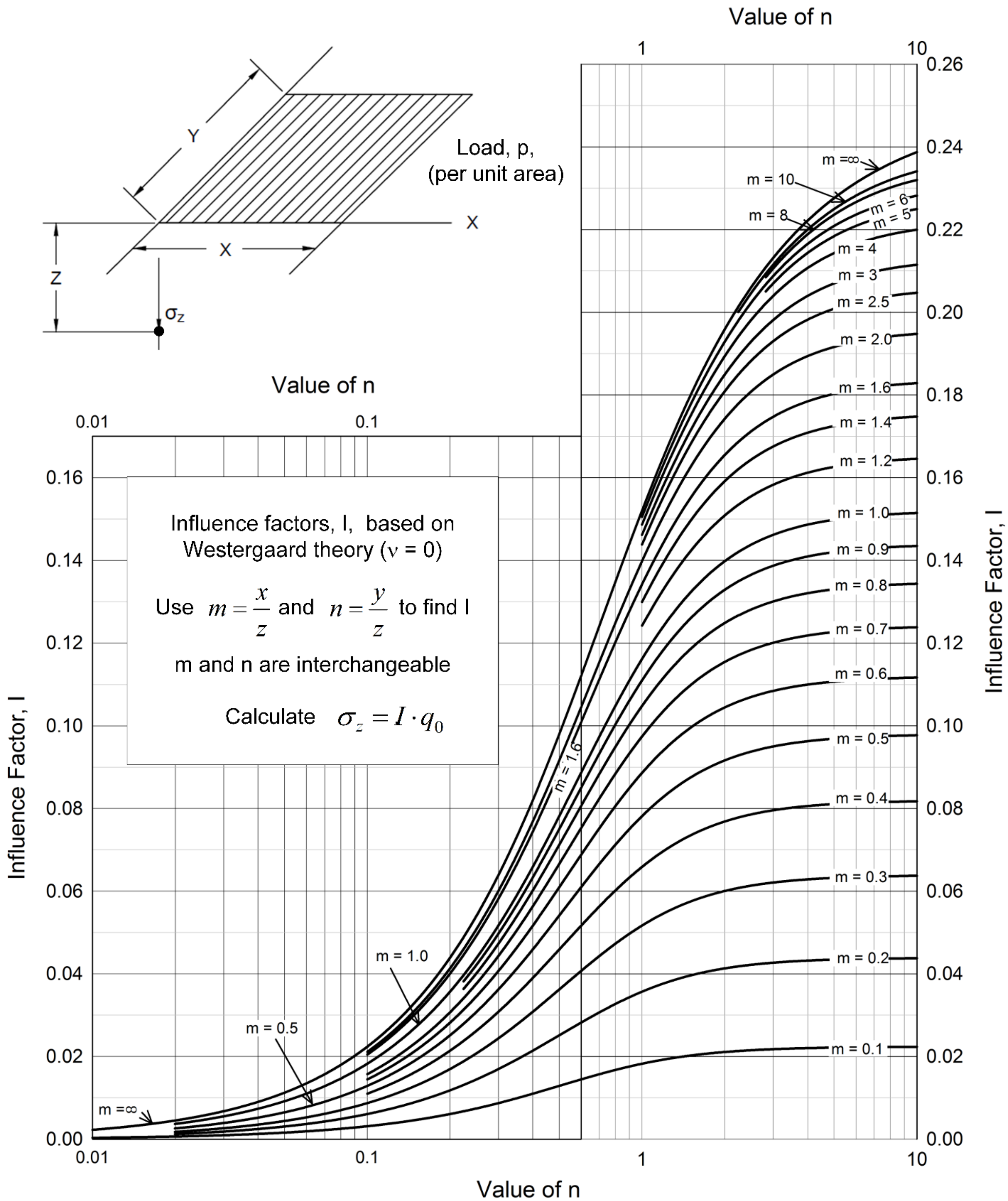


Figure 4-10 Influence Factors for a Rectangular Loaded Area – Westergaard

4-4 SHALLOW PIPES AND CONDUITS.

4-4.1 General.

The stresses on shallow pipes and conduits due to applied loads is one important application of concepts presented in this chapter. The factors influencing these stresses include the relative rigidity of the pipe to the soil, the depth of cover, the type of loading, the maximum width (span) of the structure, the method of construction, and the shape of the pipe.

This section presents simple empirical procedures based on observations. More detailed analysis can be conducted numerically or by consulting Moser (1990) or American Lifelines Alliance (2001).

4-4.2 Vertical Loads on Rigid Pipe.

Rigid pipes are those made of precast concrete, cast-in-place concrete, or cast iron.

4-4.2.1 Dead Load.

Estimates of the load caused by vertical stress on a rigid pipe can be made using the approach suggested by Marston and Anderson (1913) and subsequent work by Spangler (1948). The load per length of pipe (W_d) in a trench can be calculated as:

$$W_d = C_d \gamma_t B_d^2 \qquad \textbf{(4-6)}$$

where:
C_d = a load coefficient,
γ_t = the total unit weight of the soil, and
B_d = the width of the trench.

The value of C_d can be calculated as:

$$C_d = \frac{1 - e^{-K\mu'\left(H/B_d\right)}}{2K\mu'} \qquad \textbf{(4-7)}$$

where:
H = the depth of the trench above the top of the pipe,
K = a lateral earth pressure coefficient, and
μ' = the coefficient of friction for the trench fill.

Recommended values of γ_t, K, and μ' for use with this equation are provided in Table 4-3 as summarized by Moser (1990).

Table 4-3 Recommended Values for Trench Load Coefficient (after Moser 1990)

Soil type	Unit weight, γ (pcf)	Lateral earth pressure coefficient, K	Coefficient of friction, μ'	$K \times \mu'$
Partially compacted moist topsoil	90	0.33	0.5	0.17
Saturated top soil	110	0.37	0.4	0.15
Partially compacted moist clay	100	0.33	0.4	0.13
Saturated clay	120	0.37	0.3	0.11
Dry sand	100	0.33	0.5	0.17
Saturated sand	120	0.33	0.5	0.17

4-4.2.2 Live Load.

The primary live loads considered in the design of buried pipes are those from vehicles, including trucks, railroad, and airplanes. The stress at the top of the pipe is typically calculated using Boussinesq theory multiplied by an impact factors that account for dynamic effects. The equations presented in Table 4-2 can be used to estimate the vertical stress transferred to the top of the pipe from surface loading. Appropriate live load impact factors are summarized in Table 4-4.

Live load pressures (including an impact factor of 1.5) are summarized in Table 4-5. The values in this table indicate that the changes in stress become negligible below depths of 8 feet, 30 feet, and 24 feet for standard truck, railroad, and airport loads, respectively.

Table 4-4 Impact Factors for Live Loading of Buried Pipe (from American Lifelines Alliance 2001)

Depth of cover above pipe (ft)	Highway	Railway	Runway	Taxiways and aprons
0 to 1	1.50	1.75	1.00	1.50
1 to 2	1.35	1.50	1.00	1.35
2 to 3	1.15	1.50	1.00	1.35
Over 3	1.00	1.35	1.00	1.15

4-4.3 Vertical Loads on Flexible Pipe.

Flexible pipes include corrugated metal, plastic, and thin-wall smooth steel pipes. These pipes deform when loaded and develop horizontal restraining pressures on the sides that may be approximately equal to the vertical pressure if the backfill is well-compacted. The vertical pressure on the top of the pipe depends on the surrounding soil. In highly compressible soil, the vertical pressure may exceed the overburden pressure. In contrast, arching in coarse-grained soils may significantly reduce the overburden pressure.

Table 4-5 Live Load Pressures from Various Vehicle Loading (after American Lifelines Alliance 2001)

Depth of cover above pipe (ft)	Live load transferred to pipe (psi)		
	Truck Load (AASHTO HS-20)	Railway Load (Cooper E-80)	Airport (180 kip gear assembly)
1	12.5	Not recommended	
2	5.56	26.39	13.14
3	4.17	23.61	12.28
4	2.78	18.4	11.27
5	1.74	16.67	10.09
6	1.39	15.63	8.79
7	1.22	12.15	7.85
8	0.69	11.11	6.93
10		7.64	6.09
12		5.56	4.76
14		4.17	3.06
16		3.47	2.29
18		2.78	1.91
20	NA	2.08	1.53
22		1.91	1.14
24		1.74	1.05
26		1.39	
28		1.04	NA
30		0.69	

4-4.3.1 Dead Load.

For very flexible pipe with outside diameter (B_c) the Marston load theory predicts a load (W_c) of:

$$W_c = C_d \cdot \gamma_t \cdot B_c \cdot D \quad \textbf{(4-8)}$$

where:
C_d = the load coefficient for rigid pipe (see Equation 4-7),
γ_t = the total unit weight of the trench backfill, and
D = the outer diameter of the pipe (Moser 1990).

This method assumes that the pipe stiffness and soil stiffness are equal, which may lead to unconservative values of W_c.

The prism load is a more conservative approach for determining the dead load on a buried flexible pipe. The prism load (W_p) is simply the total weight of the soil above the pipe and is equal to:

$$W_p = \gamma_t \cdot H \cdot D \qquad \textbf{(4-9)}$$

where:
γ_t = the backfill total unit weight,
H = the depth of soil cover, and
D = the outer diameter of the pipe.

4-4.3.2 Live Load.

The Boussinesq approach described in Section 4-4.2.2 should also be used to calculate live loads on flexible pipes.

4-4.4 Long Span Metal Culverts.

The previously discussed methods do not apply to the calculation of stresses and design of long span metal culverts. The use of finite element analysis software specifically formulated for culverts, such as CANDE, is likely required. For additional guidance see Duncan (1979).

For the design of long span metal culverts, the engineer must distinguish between shallow and deep cover conditions (Duncan 1979). Shallow cover conditions apply to cases where the cover is less than one-fourth of the culvert span. Culverts with shallow cover must be designed for flexural stresses caused by live loads. The factor safety is calculated by comparing the predicted axial stresses and moment loading to the culvert capacity.

In contrast, deep cover conditions occur when the cover is greater than one-fourth of the span. Deep cover culverts only require design for ring compression, such that the seams don’t collapse under the design loads. Design axial ring loads are higher than those calculated solely based on ring compression theory. This occurs because the culvert is much stiffer in ring compression than the surrounding soil and a negative arching condition occurs.

4-5 DEEP UNDERGROUND OPENINGS.

4-5.1 General Factors.

Prior to excavation of a tunnel, the rock or soil is typically at a state of equilibrium under the stresses imposed by overburden and external loads. Excavation disturbs that equilibrium condition and requires load to transfer to surrounding rock, soil, or tunnel support system. The soil and rock will always exhibit an immediate response to the changes in stress caused by the excavation. Often a time-dependent response also occurs, especially in saturated compressible soils. A good discussion of the development of equilibrium conditions during and after tunneling in soft ground, as well as tunneling and support methods, is provided in FHWA (2009).

Changes in stress are typically accompanied by displacement of the rock, soil, or support structure. Similar to retaining walls, some movement is desirable to create a suitable balance between the load carried by the structure and the load distributed to the soil. Due to the effects of this soil-structure interaction, the type of support system and tunneling method used will significantly affect the deformations experienced during and after tunneling, and therefore the loading imposed on tunnel support.

The stresses acting on an underground opening will also depend on the depth of the opening below the ground surface and the characteristics of the surrounding soil or rock. One common distinction between the terms deep and shallow compares the depth of cover to the diameter of the opening. Openings for which this ratio is less than 2 should be considered shallow and arching of the soil or rock should be ignored. Deep openings have a cover to diameter ratio greater than 3 and benefit from the effects of arching.

For deep underground openings, deformation toward the opening allows the release of stress and the development of arching in the surrounding soil or rock. For this reason, the stresses are heavily dependent on the amount of deformation allowed during construction and the degree of restraint provided by the lining.

Numerical methods, such as finite element analysis, can be used to calculate stresses and deformations of underground openings. These methods can be quite accurate and account for significant complexity provided the soil and rock are characterized properly and the construction sequence is adequately modeled. The methods presented in this section are useful for simple calculations and to check the results of more complex numerical models.

4-5.2 Openings in Rock.

Rock can be separated into two groups for the purposes of determining stresses: (1) sound, non-swelling rock that can sustain considerable tensile stress and (2) fractured, blocky, seamy, squeezing, or swelling rock. For more detailed explanations of rock properties, see Chapter 1. The behavior of these two groups is distinguished primarily by the ability of the rock to resist tensile stress and/or significant deformation.

4-5.2.1 Sound Rock.

Elastic analysis can be used to determine stresses surrounding tunnels or openings in intact, isotropic rock (e.g., crystalline igneous, homogeneous sandstone and limestone). Analytical methods are summarized in rock mechanics texts such as Goodman (1989).

For these materials, stresses in rock surrounding spheroidal cavities are lower than those for tunnels with the same cross-section. Elastic analysis can be used to determine the best arrangement of openings and pillars, such that supports are provided at locations of stress concentration.

4-5.2.2 Broken and Fractured Rock.

Pressure on tunnels in chemically or mechanically altered rock must be analyzed by approximate rules based on experience, such as those presented in Table 4-6. The rock conditions used in Table 4-6 are compared to other common rock quality indices in Table 4-7.

4-5.2.3 Squeezing and Swelling Rock.

Rocks in categories 7 to 9 of Table 4-6 and Table 4-7 are the result of clay deposits that have been heavily preloaded during their geologic history. The transition from very dense soil to soft rock is not well-defined. In some cases, very dense clays that have not fully lithified may be included in this category.

Rock properties are closely tied to the properties of the minerals from which it is comprised. The rocks in this category contain significant amounts of clay minerals with properties ranging from the non-swelling kaolinite group to the highly swelling montmorillonite group. Soil and rock that has a high fraction of clay minerals will tend to expand, absorb water, and lose shear strength while undergoing stress relief. Thus, rocks with significant amounts of clay minerals will tend to swell as a result of the stress relief around an underground opening. Swelling leads to a loss of shear strength and a tendency of the tunnel walls to squeeze into the opening.

4-5.3 Loads on Underground Openings in Rock.

4-5.3.1 Vertical Rock Load.

A common starting point for the estimation of vertical roof pressure is found in Table 4-6. It should be noted that the values presented in this table were largely based on observations by Terzaghi (1946) for tunnel widths in the range of 16 to 32 feet (5 to 10 meters) prior to the advent of "modern" tunneling methods. Table 4-6 provides an approximate means of calculating the vertical pressure or rock load that must be supported by roof lining. The height of rock (H_p) that must be supported is a function of the tunnel width (B) for high quality rock and also the tunnel height (H_t) for lower quality rock. The total vertical pressure can be found by multiplying H_p by the total unit weight of the rock.

Table 4-6 Approximate Overburden Rock Load Carried by Roof Support

Rock Condition	Rock Load H_p (same units as B)	Remarks
1. Hard and intact	0	Sometimes spalling or popping occurs.
2. Hard stratified or schistose	0 to 0.5·B	Light pressures.
3. Massive, moderately jointed	0 to 0.25·B	Load may change erratically from point to point.
4. Moderately blocky and seamy	0.25·B to 0.35·$(B+H_t)$	No side pressure.
5. Very blocky and seamy	0.35 to 1.10·$(B+H_t)$	Little or no side pressure.
6. Completely crushed, chemically intact	1.10 ·$(B+H_t)$	Considerable side pressure. Softening effect of seepage towards bottom of tunnel.
7. Squeezing rock, moderate depth	(1.10 to 2.10) ·$(B+H_t)$	Heavy side pressure.
8. Squeezing rock, great depth	(2.10 to 4.50) ·$(B+H_t)$	Heavy side pressure.
9. Swelling rock	Up to 250 ft, not related to value of $(B+H_t)$	Very heavy pressure.

Notes:

1. After Proctor and White (1977) based on observations by Terzaghi (1946).
2. Rock loads apply to tunnels at depth greater than $1.5\cdot(B + H_t)$.
3. The roof of the tunnel is assumed to be located below the water table. If the tunnel is located permanently above the water table, the values given for Conditions 4 to 6 can be reduced by fifty percent.
4. Some very dense clays which have not yet acquired properties of shale rock may behave as squeezing or swelling rock.

5. Where sandstone or limestone contain horizontal layers of immature shale, roof pressures will correspond to rock condition “very block and seamy.”

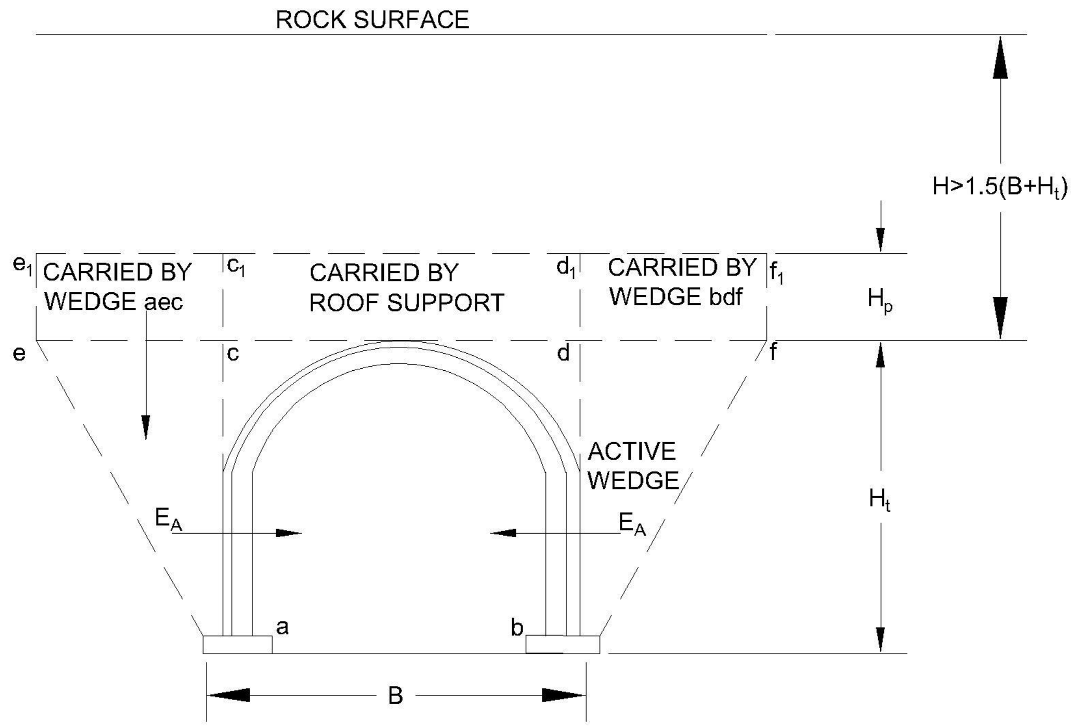


Table 4-7 Approximate Relationship Between Rock Quality Indices (after Deere et al. 1970, Barton et al. 1974, Bieniawski 1990, Hemphill 2012)

Rock Condition	RQD	Rock Tunneling Quality Index, Q^A	Rock Mass Rating, RMR^B
1. Hard and intact	95 to 100	≥ 200	> 80
2. Hard stratified or schistose	90 to 99	25 to 50	65 to 75
3. Massive, moderately jointed	85 to 95	10 to 20	60 to 65
4. Moderately blocky and seamy	75 to 85	2 to 6	50 to 60
5. Very blocky and seamy	30 to 75	0.4 to 1	40 to 50
6. Completely crushed but chemically intact	0 to 30	0.04 to 0.08	20 to 25
7. Squeezing rock, moderate depth	NA	0.01 to 0.03	10 to 20
8. Squeezing rock, great depth	NA	0.001 to 0.004	< 5
9. Swelling rock	NA	0.001 to 0.003	0

[A] After Barton et al. (1974)
[B] After Bieniawski (1990)

4-5.3.2 Horizontal Pressures.

Horizontal pressures acting on a tunnel can be approximated using an active wedge type analysis, such as Coulomb, with the diagram shown at the bottom of Table 4-6. The vertical forces included in these calculations are the weight of the active wedge and the weight of the rock for a height (H_p) above the wedge. Shear strength parameters can be assumed or selected using guidance in Chapter 3. The critical inclination of the active wedge may be determined by either the shear strength of the rock or by the rock structure. The possibility of movement along a weak bedding plane or stratum should be considered.

4-5.3.3 Other Methods for Tunnel Support Pressures.

Alternate empirical methods for estimating tunnel support pressures are available. The two most common are the rock tunneling quality index, Q, presented in Barton et al. (1974) and the rock mass rating system (e.g., Bieniawski 1976). These systems are described in more detail in Chapter 1. The roof pressure and support requirements for tunnels can be estimated from the value of Q and some of the joint properties. While not solely intended for tunneling applications, the RMR can be related to stand-up time, unsupported active span length, and roof pressure. See Bieniawski (1990) for additional comparison of methods for estimating tunnel support requirements.

4-5.4 Openings in Soft Ground (Soil).

4-5.4.1 Ground Behavior.

Selection of an appropriate method for tunnel construction in *soft ground* (i.e., soil tunneling) depends upon the response of the soil during and after excavation. This response is often referred to in terms of *stand-up time*, which is the amount of time the soil will support itself prior to the installation of tunnel supports. The stand-up time depends on the type of soil, the position of groundwater, and the size of the opening. Terzaghi's (1950) *Tunnelman's Ground Classification* provides a commonly used means of describing various types of ground response. The types of ground behavior for tunneling are summarized in Table 4-8.

Table 4-8 Types of Ground Behavior

Type of Ground	Applicable Soil Types	Support / Ground Behavior	Comments
Firm	Loess above water; hard clay; marl; lightly stressed cemented sand and gravel	No initial support required. Construction final lining before movement occurs.	None perceptible
Raveling (slow to fast)	Sand with clay binder (slow above water table, fast below); stiff fissured clays	Chunks or flakes of soil fall as a result of loosening, overstress, or brittle fracture. Time to start of raveling may be a few minutes (fast) or more (slow)	Stand-up time decreases with size of opening. Raveling ground can become running ground if the water table rises.
Running	Clean, dry coarse-grained soils unable to stand at an angle greater than angle of repose.	Support should be prior to excavation. Removal of side supports results in inflow of material.	Stand-up time is zero. In moist soils, suction may allow soil to stand briefly before running. This is referred to as "cohesive-running."
Flowing	Silt, sand, and gravel without clayey fines below water table; disturbed highly sensitive clay	Without support, material flows into opening from all sides like a viscous fluid. If unchecked, may completely fill the tunnel.	Material acts like a thick liquid.
Squeezing	Very soft to medium stiff clay at shallow depths; stiff to hard clay at great depth; soil with low frictional strength	Soil moves into tunnel gradually without indication of rupture or change in water content.	Stand-up time adequate. Behavior results from plastic flow caused by overstress. Rate of advance is related to the degree of overstress.
Swelling	High OCR clays with swelling minerals and PI greater than about 30.	Soil absorbs water over time, increases in volume, and expands toward the tunnel. Pressure on support members may increase with time.	Advances into opening occur due to an increase in volume allowed by stress relief.

In addition to the descriptions provided in Table 4-8, the behavior of fine-grained soils and silty sands above the water table can be evaluated using Table 4-9. The undrained stability factor (N_{crit}) is used to assess the ground behavior as suggested by Peck (1969). This factor is defined as:

$$N_{crit} = \frac{\sigma'_v - \sigma_t}{s_u} \quad \textbf{(4-10)}$$

where:
σ'_v = effective overburden pressure at the tunnel centerline,
σ_t = interior applied pressure from compressed air or breasting, and
s_u = undrained shear strength.

Table 4-9 Ground Behavior for Clayey Fine-Grained Soils and Silty Sand (after FHWA 2009)

Soil Type	Stability Factor, N_{crit}	Ground Behavior
Clayey Fine-Grained	1	Stable
	2 to 3	Small amount of creep
	4 to 5	Creeping, usually slow enough to permit tunneling
	6	May experience general shear failure. Clay likely to invade tail space too quickly to handle.
Silty Sand above Water Table	0.25 to 0.33	Firm
	0.33 to 0.5	Slow raveling
	0.5 to 1	Raveling

For coarse-grained soils, the ground behavior depends on the grain-size distribution, relative density, and the amount of clayey fines (binder) as indicated in Table 4-10. Uniform, loose materials (C_u < 3 and N < 10) with round grains run more freely than well-graded, dense materials (C_u > 6 and N > 30) with angular particles. Soils with properties between those listed in Table 4-10 will tend to exhibit intermediate ground behavior. Very high flowrates should be expected in tunnels below the water table through soils with relatively large particles, such as gravel and medium to coarse sand.

Table 4-10 Ground Behavior for Coarse-Grained Soils (after FHWA 2009)

Soil Description	Relative Density (SPT blow count)	Typical Ground Behavior	
		Above Water Table	Below Water Table
Very fine clean sand	Loose (N < 10)	Cohesive running	Flowing
	Dense (N > 30)	Fast raveling	Flowing
Fine sand with clay binder	Loose (N < 10)	Rapid raveling	Flowing
	Dense (N > 30)	Firm or slowly raveling	Slowly raveling
Sand or sandy gravel with clay binder	Loose (N < 10)	Rapid raveling	Rapid raveling or flowing
	Dense (N > 30)	Firm	Firm or slow raveling
Sandy gravel and medium to coarse sand	Any	Running	Flowing

4-5.4.2 Soft Ground Support Loads.

Support pressures on tunnels in soft ground are governed by many factors, including the unit weight of the overlying material, the groundwater level, soil properties, the amount deformation allowed during excavation, the interaction between soil and the supports, the opening shape, and the length of time between excavation and lining installation. Other factors should also be considered include the presence of other nearby openings, superimposed loads from neighboring structures, and the possibility of changes in groundwater conditions.

Figure 4-11 illustrates the loading mechanism surrounding soft ground tunnels. In coarse-grained soils, arching occurs above the tunnel. Arching transfers some of the overburden load to the surrounding ground so that only a portion of the total load above the tunnel is applied to the tunnel. In clay soils, undrained conditions tend to control. In this case, the undrained shear strength can be considered to provide support of a portion of the load above the tunnel.

A simplified approach to the selection of tunnel support loads is provided in Table 4-11 (FHWA 2009). More detailed guidance for the selection of tunnel support loads is summarized in Table 4-12. These tables are used by first determining the ground behavior type using Table 4-8 to Table 4-10.

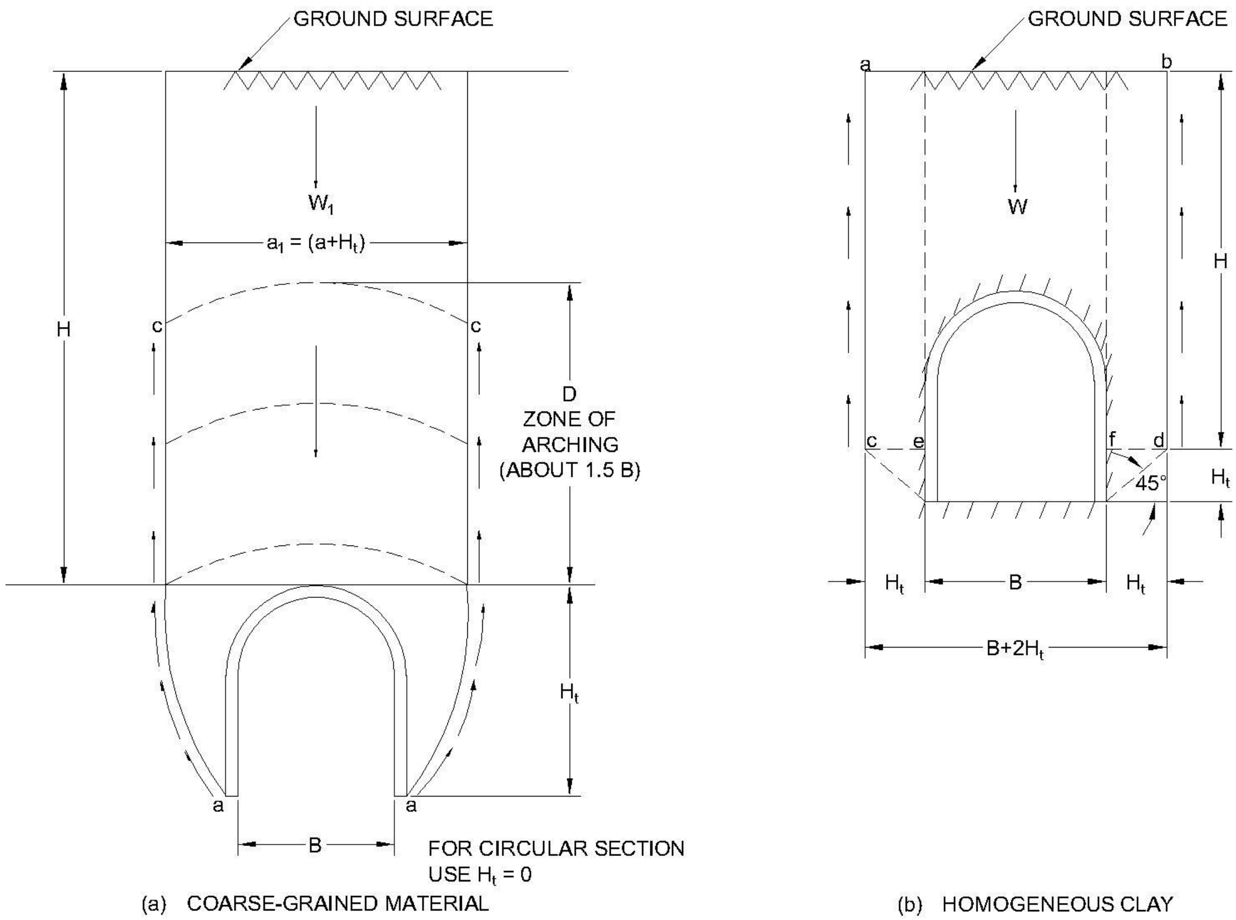


Figure 4-11 Loading Mechanisms for Soft Ground Tunneling

4-5.4.3 Loss of Ground.

As underground excavation is made, the surrounding ground starts to move toward the opening. These displacements occur as the soil around the opening expands due to stress release in addition to soil lost to the tunnel from raveling, runs, flows, etc. The resulting loss of ground causes settlement of the ground surface. The loss of ground associated with stress reduction can be predicted reasonably well, but the ground loss due to raveling, runs, flows, etc. requires a detailed knowledge of the subsurface conditions to avoid unacceptable amounts of settlement. A summary of methods to predict surface settlement resulting from lost ground can be found in FHWA (2009).

Table 4-11 Simplified Tunnel Support Loads based on Ground Behavior (FHWA 2009)

Ground Behavior	Design Load Thickness, H_p	
	Circular Tunnel[A]	Horseshoe Tunnel[A]
Running ground	$\min\begin{cases} H \\ B \end{cases}$	$\min\begin{cases} H \\ 2B \end{cases}$, See Note B
Flowing ground in air free	$\min\begin{cases} H \\ 2B \end{cases}$	$\min\begin{cases} H \\ 4B \end{cases}$, See Note C
Raveling ground above water table	$\min\begin{cases} H \\ B \end{cases}$	$\min\begin{cases} H \\ 2B \end{cases}$, See Notes B and C
Raveling ground below water table	$\min\begin{cases} H \\ 2B \end{cases}$	$\min\begin{cases} H \\ 4B \end{cases}$, See Note C
Squeezing ground	Depth to tunnel springline	
Swelling ground	Same as raveling ground	

[A] B is the tunnel width
[B] Floor is required in a horseshoe tunnel if compressed air is used, otherwise ignore compressed air.
[C] Stiff floor required in horseshoe tunnel

4-5.5 Pressure on Vertical Shafts.

In contrast to the methods presented in Section 4-3, the stress calculations for vertical shafts represent either active or passive earth pressure. These limiting earth pressure conditions correspond to a plastic rather than elastic state of stress within the soil.

4-5.5.1 Shafts in Coarse-Grained Soil.

During excavation of a vertical cylindrical shaft in coarse-grained soil, the horizontal pressures around the shaft approach active earth pressure values. If outward-directed forces from a structure (e.g., buried silo) move the structure walls into the soil, the earth pressures will approach passive conditions. Earth pressures are discussed in more detail in DM 7.2.

Active earth pressures for cylindrical shafts have been determined using analytical, limit equilibrium, slip line, numerical, and experimental methods. The active earth pressure coefficient depends on the shaft dimensions and the soil strength. For shallow shafts (i.e., depth ≤ two diameters), theoretical solutions tend to be applicable while the effects of horizontal arching become significant at greater depths (Tobar and Meguid 2010). Horizontal arching is taken into account in some solutions by the coefficient λ, which is the ratio of the circumferential stress to the vertical stress. The value of λ is equal to 1 in analytical solutions, such as Terzaghi (1943) but may be as low as K_0. Cheng et al.'s (2007) solution is plotted in Figure 4-12 for λ = 1 and $\lambda = K_0$.

Active pressures must be modified if rigid bracing at the top of the shaft prevents development of an active state. For restrained vertical shafts, horizontal pressures may be as large as the at-rest pressure on a long wall with plane strain conditions.

Table 4-12 Soft Ground Tunnel Support Loads for $H > 1.5 \cdot (B+H_t)$

Type of Ground	Tunnel Conditions	Design Load, H_p
Running	Above water	Loose: $0.5 \cdot (B+H_t)$ Medium: $0.4 \cdot (B+H_t)$ Dense: $0.3 \cdot (B+H_t)$
Running	Compressed air	Disregard air pressure; H_p, equal to that for running ground, above water table with equal density
Flowing	Free air	$\min \begin{cases} H \\ 2(B+H_t) \end{cases}$
Raveling	Above water	Multiply H_p for running ground by $\frac{T-t}{T}$
	Below water, free air	Multiply H_p for running ground by $\frac{T-t}{T}$
	Below water, compressed air	Using H_p for running ground: $2 \cdot \left(\frac{T-t}{T}\right) H_p - \frac{p_c}{\gamma_t}$
Squeezing[A]	Homogenous clay	$H - \frac{p_c}{\gamma_t} - \frac{H s_u}{\gamma_t (B+2H_t)}$
	Soft roof, stiff sides	$H - \frac{p_c}{\gamma_t} - \frac{H s_u}{\gamma_t B}$
	Stiff roof, soft sides	$H - \frac{p_c}{\gamma_t} - \frac{H s_u}{\gamma_t (B+6H_t)}$
Swelling[B]	Intact clay	Very small
	Fissured clay	Use H_p for raveling ground with same standup time
Variables:	p_c = tunnel air pressure, s_u = undrained shear strength, γ_t = total unit weight of soil t = stand up time, T = elapsed time between excavation and completion of permanent structure H = vertical distance between ground surface and tunnel roof, H_p = design load in terms of depth (multiply by γ_t to determine design pressure), H_t = height of the tunnel, and B = width of the tunnel	

[A] After complete blowout, p_c = 0

[B] Permanent roof support should be completed within a few days after excavation

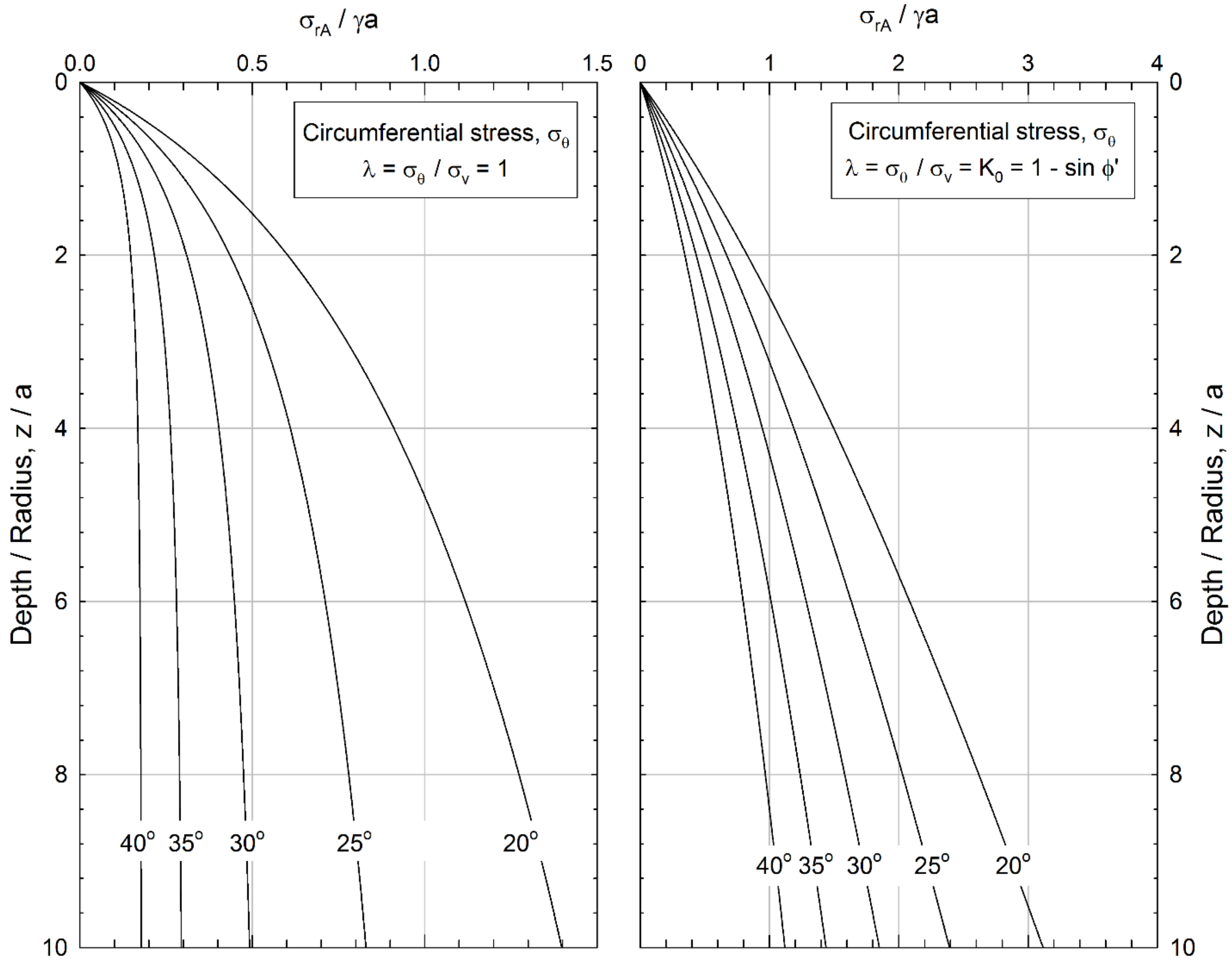


Figure 4-12 Radial Stress at the Sides of a Vertical Shaft in Sand (based on Cheng et al. 2007)

4-5.5.2 Shafts in Clay.

No support is needed from the ground surface to a depth of z_{crit} for shafts in clay. The critical depth (z_{crit}) is:

$$z_{crit} = \frac{2s_u}{\gamma_t} \tag{4-11}$$

where:
s_u = the undrained shear strength of the soil and
γ_t = the total unit weight of the soil.

At greater depths, the ultimate horizontal pressure (σ_h) on a shaft lining in soft clay can be estimated as:

$$\sigma_h = \gamma' \cdot z - s_u \quad \textbf{(4-12)}$$

where:
γ' = effective unit weight of the soil,
z = depth below the ground surface, and
s_u = undrained shear strength of the soil.

This pressure will likely occur after several months of unsupported excavation. The stability factors for fine-grained soils in Table 4-9 can be used as guidelines for the behavior of vertical shafts in clay.

In stiff, intact or fissured clays, the initial horizontal stress on vertical shaft walls will be small. Over time the pressure may increase to a value several times larger than the effective vertical stress (and ultimately to the swelling pressure if the shaft lining is sufficiently rigid). Local experience is important to provide useful information for soil pressures on vertical shafts in stiff clays.

4-6 NUMERICAL SOLUTIONS FOR STRESSES IN SOIL.

The analytical and chart-based solutions presented in this chapter are an excellent starting point for evaluation of stresses within a soil mass. However, their applicability is limited by the constraints and assumptions of each. These methods also struggle to effectively model complex subsurface profiles and loading conditions.

Computer programs and numerical solutions are an important part of geotechnical engineering practice. This section provides a brief overview of the application of numerical methods to the evaluation of stresses.

4-6.1 Numerical Analysis Types.

Some computer programs (e.g., Settle3D, CONSOL, SETOFF) are available that directly rely upon elastic solutions, such as those presented in this chapter, to calculate changes in stress. These programs are specifically formulated for the solution of consolidation settlement problems discussed in the next chapter. The benefit provided by these programs is the automated calculation of changes in stress and the ability to consider time-dependent changes. However, the solutions depend on the same assumptions as the elastic solutions on which they are based.

Many continuum-based numerical analysis techniques are available. The most common of these in geotechnical engineering are the finite element and finite difference methods, with the former being somewhat more popular for stress analysis problems.

These approaches divide the soil or rock into elements or grid points. The relationships between the external and gravitational forces acting on the elements (or grid) and the corresponding displacements are defined using constitutive (stress-strain) laws and failure criteria.

1\ The following sections provide a condensed overview focused on the calculation of stresses using the finite element method. The use of finite element analysis (FEA) to determine stresses is relatively straight-forward. Calculation of accurate deformations requires significantly more expertise and experience. For a practical introduction to the use of FEA in geotechnical engineering see Bradley and VandenBerge (2015). A more in-depth perspective can be found in the books by Potts and Zdravkovic (1999, 2001). /**1**/

4-6.2 Linear Elastic Stress Analysis.

The simplest FE analyses use linear elastic constitutive theory, which relates changes in stress linearly to strains (or displacements). For a linear elastic analysis, the only required material parameters are the elastic modulus, E, and Poisson's ratio, ν (or any other two elastic constants such as shear modulus or bulk modulus). For problems with only one material type (and one value of E), the calculated stresses will be independent of the value of E selected. However, when more than one material type is present, the relative values of E assigned to each material in the analysis can impact the calculated stresses because of arching and similar phenomena.

4-6.3 Nonlinear Elastic Stress Analysis.

The stress-strain behavior of geological materials is truly linear over only a small range of strains. A properly selected nonlinear constitutive model will provide a more accurate prediction of behavior but will require additional input parameters and expertise. VandenBerge et al. (2014) found that major principal effective stresses calculated for embankments with linear elastic analysis were typically within 10% of the values calculated using more rigorous and time-consuming nonlinear procedures.

One of the earliest and most common nonlinear constitutive theories for soil is the hyperbolic model proposed by Duncan and Chang (1970) and described in more detail in Duncan et al. (1980). This model can also consider stress dependent variations in Poisson's ratio (or bulk modulus). It can be used with either effective stress (drained) or total stress (undrained) problems, provided the model parameters are determined using the appropriate type of test.

The Duncan-Chang model is based on the following observations;

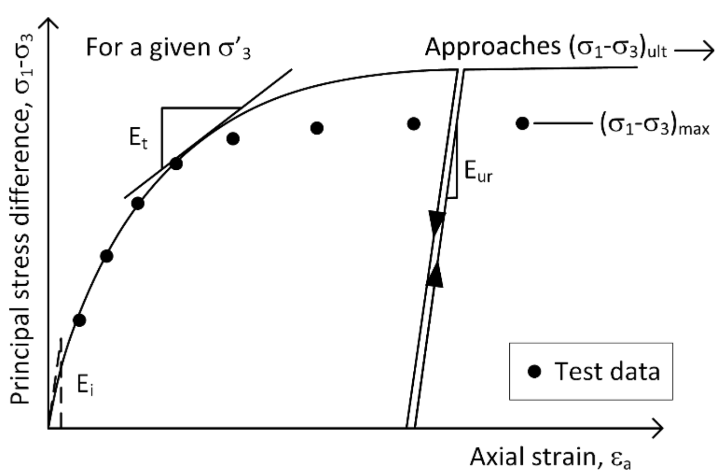
- The principal stress difference ($\sigma_1 - \sigma_3$) tends to vary in a hyperbolic manner with strain,

- The initial modulus (E_i) increases with increased confining stress in a manner that can be described by a power function,
- The ultimate value of ($\sigma_1 - \sigma_3$) predicted by the hyperbola tends to be greater than the value measured by the test,
- The bulk modulus (B_t) of soil increases with increased confining stress in a manner that can be described by a power function.

Soil tends to respond in a stiffer, approximately linear manner with modulus (E_{ur}) when unloaded and reloaded after some amount of shearing. The required parameters are summarized and illustrated in Table 4-13 and Figure 4-13.

Table 4-13 Summary of Model Parameters for Duncan-Chang Model

Duncan-Chang Parameter	Meaning / Use	Equation
K	Controls rate of increase of E_i with σ'_3	$E_i = KP_a\left(\frac{\sigma'_3}{P_a}\right)^n$
n	Controls nonlinearity of E_i relationship	
R_f	Reduces ($\sigma_1 - \sigma_3$) from its ultimate hyperbolic value to match maximum value measured by testing	$R_f = \frac{(\sigma_1 - \sigma_3)_{\max}}{(\sigma_1 - \sigma_3)_{\text{ult}}}$
K_b	Controls rate of increase in B_t with σ'_3	$B_t = K_b P_a\left(\frac{\sigma'_3}{P_a}\right)^m$
m	Controls nonlinearity of B_t relationship	
K_{ur}	Controls rate of increase of E_{ur} with σ'_3	$E_{ur} = K_{ur} P_a\left(\frac{\sigma'_3}{P_a}\right)^n$



<u>Calculate E_t using c' and ϕ'</u>

$$E_t = E_i\left[1 - \frac{R_f(1-\sin\phi')(\sigma_1 - \sigma_3)}{2c'\cos\phi' + 2\sigma'_3\sin\phi'}\right]^2$$

Figure 4-13 Parameters Used in Duncan-Chang Model

4-6.4 Numerical Modeling Best Practice.

Both linear and nonlinear finite element analysis can be used to make accurate predictions of stresses. The following guidelines have been found to yield the most consistent and uniform stress predictions (VandenBerge et al. 2014).

- Use isoparametric elements (i.e., 8-noded rectangles or 6-node triangles).
- Use a uniform mesh with elements of approximately the same shape, especially within any zones of interest.
- Use elements with an appropriate aspect ratio, preferably longest to shortest dimension, less than or equal to five.
- Keep the element size as small as practical with respect to the overall dimensions. A maximum element height of approximately 1 to 2% of the height of the problem domain is preferred.
- Remember to include the boundary water pressures from any impounded water present in the model.

4-6.4.1 Initial or Geostatic Stresses.

The initial stress state in a FE model is dependent on the process used to “turn on” gravity and stress within the model. Vertical stresses are governed mostly by gravity loading. As the mesh deforms in response to gravity, horizontal stresses will develop and tend toward at rest (K_0) conditions for a level, laterally-constrained mesh. For a linear elastic model, the value of K_0 will be equal to $\nu / (1-\nu)$. Calculation of initial horizontal stresses in this manner will yield correct results, and K_0 will be less than 1.0, which is always the case for primary loading. The calculation of initial horizontal stresses in this way will lead to initial deformation of the model and the layer thicknesses may no longer match the *in situ* conditions. These displacements are a numerical artifact and should be zeroed or removed prior to examining the effects of new loading conditions. Overconsolidated conditions with K_0 greater than 1.0 can be modelled by loading and then unloading the model, following the process by which K_0 > 1.0 conditions occur in nature.

In many cases, the details of the initial stress process are program specific. The engineer using FEA should become familiar with the various options available so that appropriate methods are applied.

4-6.4.2 Staged Construction or Stress History.

Finite element analysis allows the sequence of loading and construction staging to be modeled numerically. To a lesser extent, geologic stress history can also be modeled.

Within the model, this occurs by adding and subtracting elements (or their weight) in steps. Staged models are especially important for nonlinear analysis because the properties of the material change with stress level.

For example, a staged approach is required to predict stresses and displacements around open excavations and tunnels. The initial ground conditions should be modeled after which the effects of removing soil or rock can be considered.

For cases where only stress distributions are required, such staging is unnecessary in linear elastic analysis. The use of a staged model is required, even for linear elasticity, to predict correct patterns displacement.

4-6.5 Evaluation of Stress Due to Applied Loads.

Changes in stress due to applied loads can be evaluated using a staged FE model. The first stage(s) of the model are used to create the desired initial state of stress that best represents the *in situ* conditions. At this point, the new loading can be added to the model in various forms, including distributed loads, point loads, and new soil layers. The predicted changes in stress can then be evaluated by comparing the predicted stress at convenient points within the model between subsequent stages. Where possible, the changes in stress predicted by FE models should be checked with analytical solutions such as those presented earlier in this chapter.

Engineers should be aware of the limitations of their numerical analyses. For example, two-dimensional FEA are useful for predicting changes in stress below long foundations, embankments, and large area fills because such problems can be analyzed in a plane strain manner. However, a three-dimensional program would be required to predict changes in stress below more complex conditions, such as a rectangular foundation.

4-6.6 Evaluation of Stress within Embankments and Slopes.

The calculation of stresses is more complex for slopes and embankments compared with relatively level ground. First, no closed-form analytical solution is available for comparison because the soil in a slope is not laterally restrained. The lack of lateral restraint also means that K_0 conditions will not be present, especially close to the face of a slope.

Stresses near natural slopes are best evaluated by starting with level ground in the FE model and progressively removing (excavating) elements to form the slope. Multiple stages of analysis may be required to establish the initial conditions. The removal of elements mimics the process by which the slope was formed in nature.

Likewise, stresses in an embankment can be modeled by adding layers of elements in stages. The fill zone can be "built" within the FE model in thin layers, mimicking the actual construction process. Deformations caused by the initial application of gravity loading should preferably be removed. However subsequent deformations of each layer of fill under the weight of the overlying material are realistic. This approach allows the true pattern of displacements within the embankment to be examined.

4-7 SUGGESTED READING.

Topic	Reference
Stress and Mohr Circles	Parry, R. H. 2004. *Mohr circles, stress paths and geotechnics*, CRC Press, 2004.
Elastic Solutions	Poulos, H. G. and Davis, E. H. 1974. *Elastic Solutions for Soil and Rock Mechanics*, John Wiley & Sons Inc.
Stress on Pipes	Moser, A. P. 1990. *Buried Pipe Design*, McGraw-Hill Inc., (third edition also available by Moser and Folkman).
Underground Openings	FHWA. 2009. *Technical Manual for Design and Construction of Road Tunnels – Civil Elements, FHWA-NHI-09-010*, Federal Highway Administration.
Numerical Stress Analysis	Bradley, N. and VandenBerge, D. R. 2015. *Beginner's Guide for Geotechnical Finite Element Analyses*, CGPR Report No. 82, Center for Geotechnical Practice and Research, Virginia Tech.
	Potts, D. M. and Zdravkovic, L. 2001. *Finite Element Analysis in Geotechnical Engineering: Theory and Application*, ICE Publishing.

4-8 NOTATION.

Symbol	Description
B	Width of a foundation, loaded area, or tunnel
B_c	Diameter of a flexible pipe
B_d	Width of trench in pipe loading calculations
B_t	Bulk modulus of soil
C_d	Load coefficient in pipe loading calculations
C_u	Coefficient of uniformity (from grain-size distribution)
D	Outer diameter of pipe
E	Elastic modulus
E_A	Active earth pressure force

Symbol	Description
E_i	Initial tangent modulus
E_{ur}	Unload-reload modulus for Duncan-Chang model
h_p	Pressure head
H	Depth of soil cover or vertical distance between ground surface and tunnel roof
H_p	Design load thickness in terms of depth
H_t	Tunnel height
I	Influence factor for change in stress calculations
K_a	Active earth pressure coefficient
K_b	Bulk modulus parameter for Duncan-Chang model
K_0	At-rest earth pressure coefficient
K_p	Passive earth pressure coefficient
K_{ur}	Unload-reload modulus parameter Duncan-Chang model
N	Standard Penetration Test blow count
N_{crit}	Undrained stability factor
p_c	Tunnel air pressure
p'_f	Center of Mohr circle at failure (MIT stress path space)
P_a	Atmospheric pressure
u	Pore water pressure
q_f	Radius of Mohr circle at failure
q_0	Applied pressure or load
Q	Rock tunneling quality index
r	Horizontal distance from centerline of a foundation
R_f	Reduction factor for Duncan-Chang model
RMR	Rock mass rating
RQD	Rock quality designation
s_u	Undrained shear strength
t	Stand up time for tunneling in raveling soils

Symbol	Description
T	Elapsed time between excavation and completion of permanent structure
W_c	Flexible pipe load
W_d	Rigid pipe load
W_p	Prism load on pipe
z	Depth below an applied load
z_{crit}	Critical depth for unsupported shafts in clay soils
Z_i	Soil layer thickness
α	Angle between the major principal plane and the plane of interest
$\Delta\sigma_z$	Change in vertical stress
ϕ'	Effective stress friction angle
γ'	Effective unit weight
γ_t	Total unit weight
g_w	Unit weight of water
λ	Ratio of the circumferential stress to the vertical stress
μ'	Coefficient of friction for trench backfill
ν	Poisson's ratio
σ_1	Major principal stress
σ_2	Intermediate principal stress
σ_3	Minor principal stress
σ_h	Total horizontal stress
σ'_h	Effective horizontal stress
σ_t	Interior tunnel pressure from compressed air or breasting
σ_v	Total vertical stress
σ'_v	Effective vertical stress

This Page Intentionally Left Blank

CHAPTER 5 ANALYSIS OF SETTLEMENT AND VOLUME EXPANSION

5-1 INTRODUCTION.

5-1.1 Scope.

This chapter explains the practical aspects of the process of volume change in soil. Many of the cases relate to the compression of soil layers due to changed conditions, such as placement of an engineered fill, foundation loading, or lowering of the groundwater table. Compression of soil results in *settlement*, which is vertical displacement of the ground surface or a structure supported by the ground. Both immediate and long-term settlement will be considered, along with tolerable settlement criteria, the rate of settlement, and methods to reduce or accelerate settlement. Swelling soils can also change volume by expansion, which is often referred to as *heave*.

1\ Guidance on special cases, such as collapsing soils, is provided in DM 7.2 (UFC 3-220-20). Chapter 2 of this document provides guidance on methods for monitoring settlement. /**1**/

5-1.2 Occurrence of Settlement.

Settlement is the result of three primary mechanisms: (1) immediate *distortion* that occurs in response to the application of a new load, (2) *consolidation,* which is compression of the soil skeleton in response to changes in effective stress, and (3) *secondary compression*, which is rearrangement of the soil structure under constant effective stress. All three mechanisms will be explained in more detail in later sections of this chapter.

In saturated fine-grained soils, the settlement associated with the three mechanisms can be distinguished and separated for the practical purpose of estimating settlement magnitude. This separation is possible because these soils have low hydraulic conductivity and relatively high compressibility, which causes consolidation to occur over a measurable period of time. The processes and magnitudes of settlement typically associated with fine-grained soils are summarized in Table 5-1.

Coarse-grained soils are much less compressible than fine-grained soils and have higher hydraulic conductivity. Because of these characteristics, consolidation occurs very quickly and can be difficult to separate from immediate deformation. Much of the compression of coarse-grained soil is related to particle rearrangement under changed stress. Vibrations from earthquakes, blasting, or machinery can also cause settlement of coarse-grained soil. Submergence and soaking of coarse-grained soils, particularly fill materials, can lead to settlement as discussed in Section 5-9.

5-1.3 Occurrence of Heave.

Heave or swell occurs primarily due to the reduction of total vertical stress or the reduction of matric suction, which both lower the effective stress on the soil and therefore allow an increase in the void ratio. The reduction of total stress occurs as the result of excavation or erosion of soil, as well as the removal of man-made loading. The matric suction in a soil depends on the soil type and the past and present atmospheric conditions. Especially important is the degree of saturation of the soil. The factors affecting the degree of saturation include climate history, topography, vegetation, and groundwater level. The amount of swelling that occurs as a result of either mechanism depends on the size and type of minerals that comprise the soil. Clay minerals with very small particles and high specific surface area, such as montmorillonite and vermiculite, are most susceptible to swelling. Heave can also occur as a result of the formation of ice lenses in frozen soil. Volumetric expansion from chemical reactions, such as pyrite, can also cause heave.

5-1.4 Applicability.

The methods to analyze settlement that are presented in this chapter apply to conditions where shear stresses are well below the shear strength. In addition, these analyses of consolidation magnitude and rate as well as secondary compression assume that the soil is saturated.

Table 5-1 Settlement Calculation Methods for Different Soil Types (after Coduto et al. 2011, Salgado 2008)

Soil Type	Time Frame	Process	Relative Magnitude	Method of Calculation
Coarse-Grained	Short-Term	Distortion	Negligible to small	Semi-empirical immediate or “elastic” settlement
		Consolidation	Small to moderate	
	Long-Term	Secondary Compression	Negligible to small	Semi-empirical methods
	Other	Vibration, submergence	Small to moderate	Specialized methods
Fine-Grained	Short-Term	Distortion	Negligible to small	Semi-empirical immediate or “elastic” settlement
	Long-Term	Consolidation	Moderate to large	Primary consolidation calculations
		Secondary Compression	Small to large	Secondary consolidation calculations

5-2 MECHANICS OF CONSOLIDATION.

5-2.1 Consolidation Process.

Consolidation of soil is caused by changes in effective stress. For this reason, it is necessary to consider the process by which effective stresses change within a soil mass. Saturated soil consists of two relatively incompressible components, the mineral particles and water. In comparison, the overall soil structure is compressible because the particles can rearrange to encompass more or less void space. The compressible soil structure must strain or deform in order to support a change in stress.

When a soil mass experiences an abrupt change in the applied total normal stress, the soil must respond in one of two ways: (1) the compressible soil structure strains instantaneously, or (2) a pressure change occurs in the incompressible water within the soil voids. The first option is not possible because strain of the soil structure requires a change in the void ratio of the soil. The void ratio of a saturated soil can only change if the amount of water in the soil changes, and time is required for water to leave or enter the soil voids. Instead, the instantaneous soil response follows the second option, and a change in the pore water pressure occurs. This temporarily altered pressure is often referred to as *excess pore water pressure*, u_x. For saturated, one-dimensional conditions, the magnitude of u_x will be roughly equal to the change in total vertical stress, $\Delta\sigma_z$. Because $\Delta\sigma_z$ is balanced by u_x, the instantaneous change in effective stress is negligible, and there is no instantaneous settlement as a result of consolidation.

The excess pore water pressure in the soil creates a hydraulic gradient between the conditions within the soil and those at its boundaries. The gradient causes water to flow out of or into the soil, as time progresses following the application of $\Delta\sigma_z$. When $\Delta\sigma_z$ is positive, the soil volume decreases as the water flows out and the excess pore water pressures decrease. After a relatively long period of time, the excess pore water pressure dissipates completely (i.e., $u_x = 0$), all of the change in total vertical stress is transferred to the soil structure, and the consolidation settlement is complete. The time required to reach this state can range from seconds or minutes for thin layers of coarse-grained soils to years for thick layers of fine-grained soil.

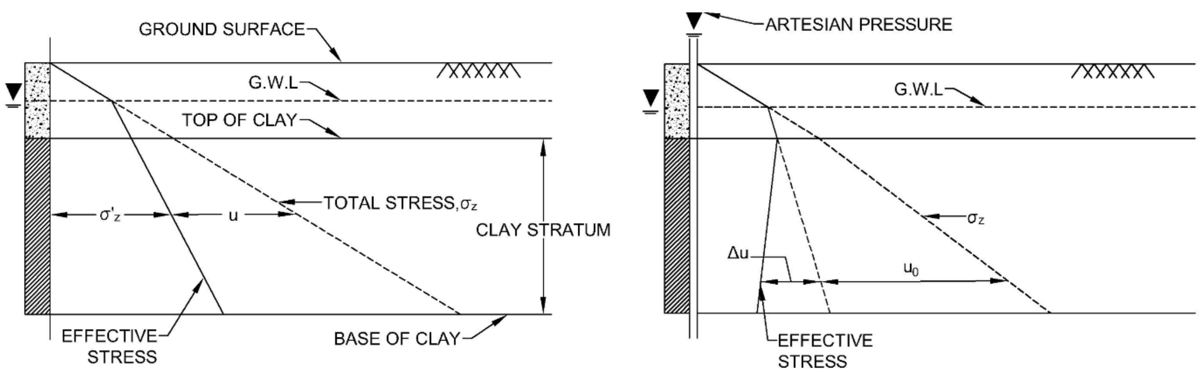
Estimates of the magnitude of consolidation require (1) knowledge of the initial vertical stress state, (2) prediction of the change in total stress caused by new loading, (3) an understanding of the stress history of the soils impacted by the changes, and (4) knowledge of the compressibility characteristics of those soils.

Estimates of the rate of consolidation settlement require knowledge of (1) the hydraulic boundary conditions, (2) the thickness, (3) the compressibility, and (4) the hydraulic conductivity of the compressible soil layers.

5-2.2 Initial Vertical Stress State.

Consolidation analysis focuses on volume change caused by changes in vertical stress. The initial geostatic vertical total stress (σ_{z0}), pore water pressure (u_0), and vertical effective stress (σ'_{z0}) should be calculated using methods discussed in Chapter 4. Figure 5-1(a) illustrates initial vertical stress conditions for hydrostatic water conditions.

Artesian water conditions are associated with confined aquifers in which higher pore water pressure is present in a more permeable soil layer below a confining stratum. Artesian conditions affect the calculation of pore water pressure within the compressible layer as well as the calculated vertical effective stress. As illustrated in Figure 5-1(b), the hydrostatic pore water pressure is labeled u_0 while the artesian pressure at any depth is Δu. The artesian pressure must also be subtracted from the total vertical stress in order to obtain the correct initial effective stress.



(a) Hydrostatic conditions (b) Artesian conditions

Figure 5-1 Initial Vertical Stresses for a) Hydrostatic and b) Artesian Pore Water Pressure Conditions

5-2.3 Stress History.

The *stress history* of a soil refers to the past stress states that the soil has experienced. It will affect the structure and behavior of the soil under new loading. This is especially true for fine-grained soils. Of particular importance is the highest vertical effective stress to which the soil has been consolidated, which is known as the *preconsolidation stress* or *maximum past* pressure*,* σ'_p. A method for determining the preconsolidation stress is shown in Figure 3-12.

For some soil deposits, the existing vertical effective stress is the highest vertical effective stress the soil has ever experienced and σ'_p is equal to σ'_{z0}. This type of soil deposit is referred to as *normally consolidated* and sometimes abbreviated “NC.”

More commonly, soil deposits have been preloaded or preconsolidated at some point in the past, and σ'_{z0} is less than σ'_p. This type of soil is referred to as *overconsolidated* and sometimes abbreviated "OC." The *overconsolidation ratio* (OCR) is a helpful measure of soil behavior and is found as:

$$OCR = \frac{\sigma'_p}{\sigma'_{z0}} \tag{5-1}$$

where:
σ'_p = preconsolidation stress and
σ'_{z0} = current vertical effective stress.

In situ vertical stress profiles for steady state conditions are summarized in Figure 5-2. In Figure 5-2(a), the clay layer is normally consolidated because the preconsolidation stress is equal to the effective vertical stress. The clay in Figure 5-2(b) is slightly overconsolidated as a result of a higher groundwater level compared to (a), which reduces the current vertical effective stress. Similarly, overconsolidation as a result of excavation (or erosion) and previous loading are depicted in Figure 5-2(c) and (d).

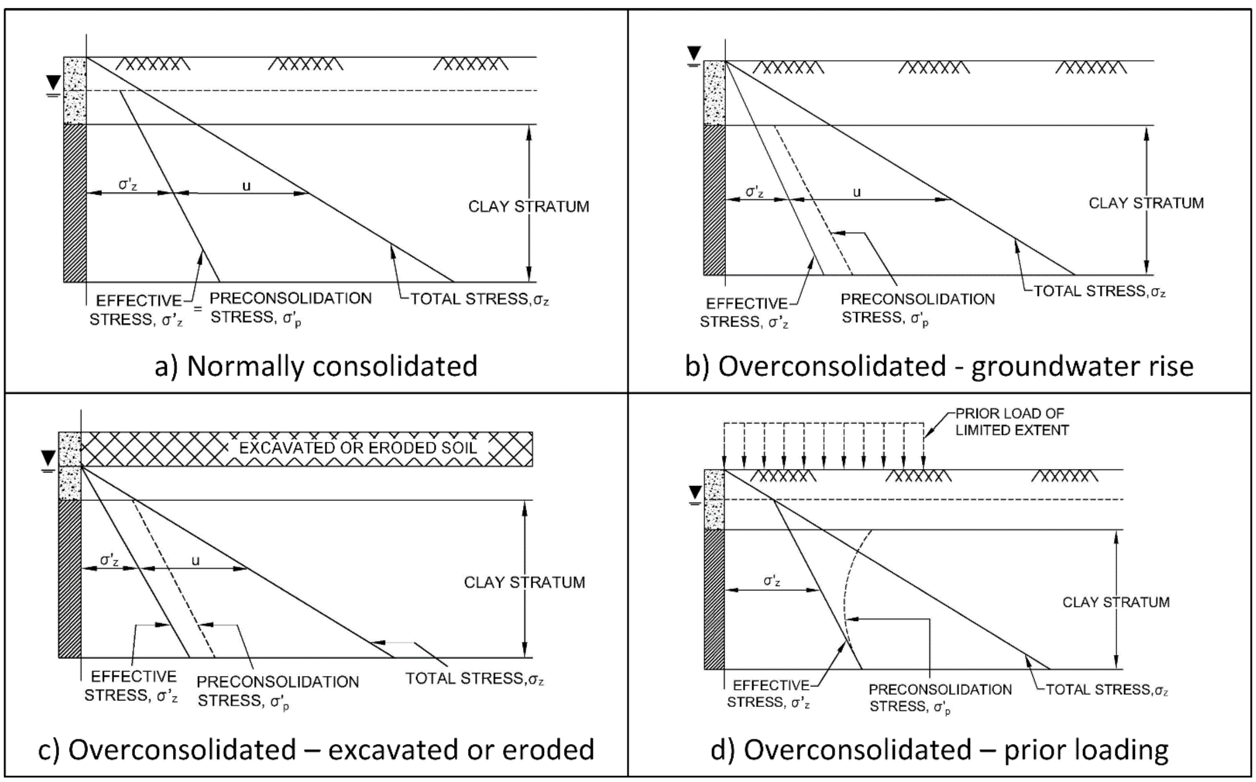


Figure 5-2 Vertical Stress History Examples

In some cases, a soil layer may be encountered that has not yet finished consolidating as a result of a prior change in effective stress. This state is referred to as *underconsolidated*. In this case, the pore water pressures in the soil have not yet reached equilibrium following a change in stress and are higher than the hydrostatic values. Two examples are provided in Figure 5-3. In the first example, the groundwater level has been lowered in the sand layers. The decrease in pore pressure (and corresponding consolidation) of the low permeability clay layer will be time-dependent. The second example is partial consolidation under a prior applied stress. In either case, the initial pore pressure variation with depth within the clay layer must be measured or estimated in order to calculate the variation of initial vertical effective stress within the soil.

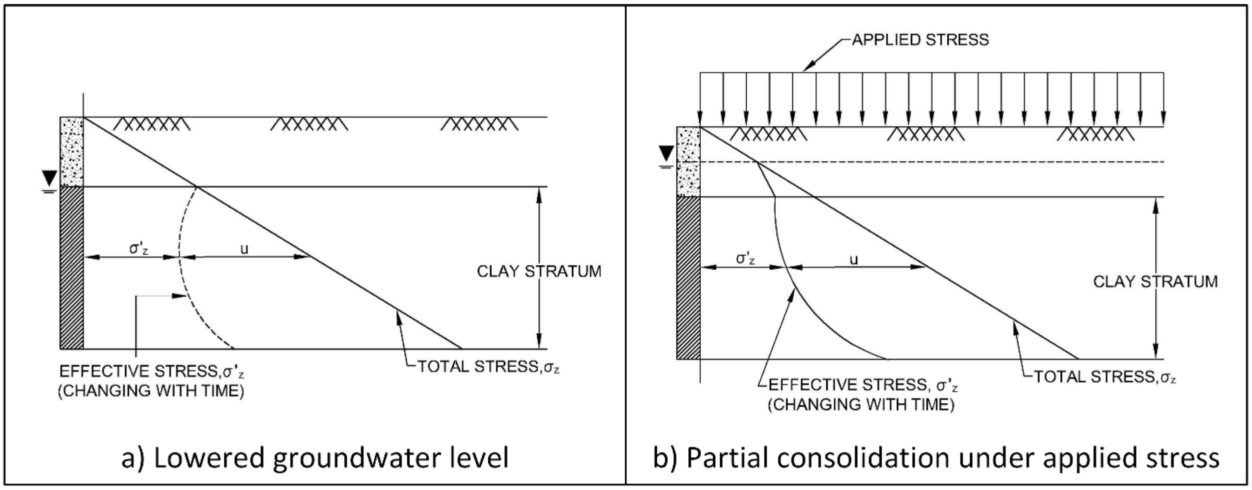


Figure 5-3 Vertical Stress Profile Cases – Transient

5-2.4 Evaluation of Existing Conditions.

For purposes of settlement calculations, the existing conditions at the start of construction or the application of a new load must be evaluated. At a minimum, this evaluation should include the following steps:

- Review the available site and geologic data. In particular, determine potential sources of overconsolidation (e.g., glaciation, erosion, human activity, groundwater fluctuations) and estimate the likely magnitude of preconsolidation and/or OCR.
- Determine the variation of the preconsolidation stress with depth from laboratory consolidation tests (see Chapter 3). Measurements of undrained shear strength can also be used along with correlations to provide additional estimates of preconsolidation stress. For example, undrained strength (s_u) is often related to the *in situ* vertical stress and the OCR by:

$$s_u \approx USR_{NC} \cdot \sigma'_{z0} \cdot OCR^m \quad \textbf{(5-2)}$$

where:
USR_{NC} = the soil's normally consolidated undrained strength ratio, and
m = an empirical coefficient (See Section 8-3).

Equation 5-2 can be rearranged to obtain:

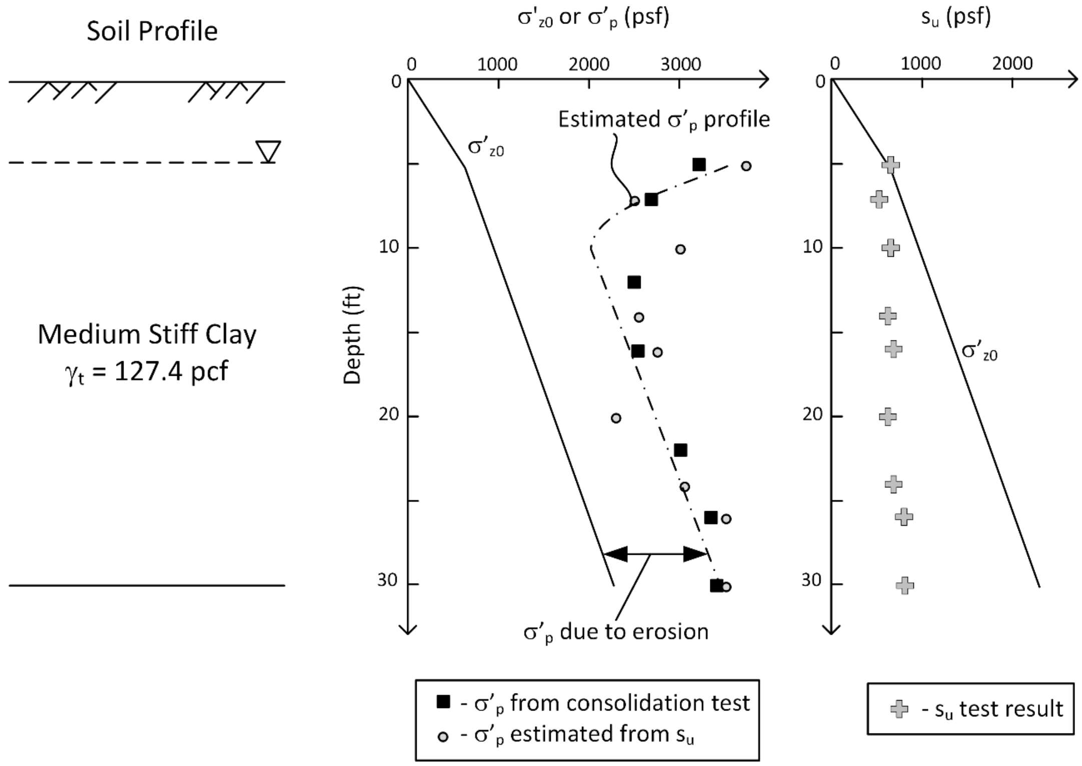
$$\sigma'_p \approx \sigma'_{z0} \left(\frac{s_u}{USR_{NC} \cdot \sigma'_{z0}} \right)^{1/m} \quad \textbf{(5-3)}$$

- Compare estimates of preconsolidation stress to current vertical effective stress. A helpful tool for this purpose is a plot showing the subsurface profile, the laboratory test data, and the variation of effective vertical stress with depth, such as that shown in Figure 5-4.

- If underconsolidation is expected or indicated, measurements of pore water pressure with depth are required to identify the extent of the underconsolidation.

Likely Sources of Overconsolidation

- Erosion of surficial soil (estimated magnitude = 10 ft x 125 pcf = 1250 psf)
- Groundwater fluctuation



Estimation of Preconsolidation Stress from Undrained Strength

At z = 10 ft, s_u = 600 psf and σ'_{z0} = 962 psf. Assume USR_{NC} = 0.25 and m = 0.8

$$\sigma'_p \approx (962\,psf)\left(\frac{600\,psf}{0.25(962\,psf)}\right)^{1/0.8} \approx 3000\,psf$$

Figure 5-4 Example Evaluation of Existing Conditions

5-2.5 Change in Vertical Stress.

The methods presented in Chapter 4 should be used to evaluate the change in vertical stress at the required depths within the compressible soil layer. Surcharge loads of wide lateral extent will result in constant value of $\Delta\sigma_z$. Most other loading conditions will result in $\Delta\sigma_z$ that varies with both depth and lateral location below the applied load. It is the responsibility of the engineer to determine the critical locations at which settlement will be evaluated.

5-3 SETTLEMENT CALCULATIONS.

5-3.1 Basic Formulation.

At the most basic level, settlement at the ground surface is equal to the change in thickness of the soil underlying a load. The change in thickness (ΔH) divided by the initial thickness (H) is equal to the vertical strain (engineering strain). Thus, settlement (s) is the sum of the vertical strain (ε_z) caused by $\Delta\sigma_z$ for each compressible soil layer multiplied by the initial thickness of each layer, or:

$$s = \Delta H = \sum_{i=1}^{n} \varepsilon_{z,i} H_i \quad \textbf{(5-4)}$$

where:
H_i = thickness of each layer in same units as s.

Most settlement calculations can be split into a component related to the vertical strain and a component related to the initial layer thickness. This concept can be used understand the calculation procedures at a deeper level.

Many of the settlement prediction methods in this chapter use foundation geometry to define influence factors or to select the appropriate procedure. The shortest dimension of the foundation or loaded area will be designated as B while the longest dimension is L. The applied stress at the base of the foundation is indicated by q_0.

5-3.2 Soil Layers in Settlement Calculations.

Calculations of distortion settlement of fine-grained soils and total settlement of coarse-grained soils often treat the soil as one layer. In this case, the effect of the variation in strain with depth below the load is built into the calculation procedure and influence factors. This approach is illustrated by Figure 5-5(a).

In contrast, consolidation settlement of fine-grained soils is typically calculated by dividing the soil into multiple layers. The vertical strain is determined for each soil layer, which allows the effects of load geometry and changing soil conditions to be considered explicitly. Figure 5-5(b) shows a layer of compressible soil divided into many thin layers of equal thickness. This method is flexible and theoretically sound but requires a large number of calculations that may be tedious if not automated. Figure 5-5(c) illustrates an approach in which the layer thickness increases with depth. This method recognizes that conditions change most quickly near the load. Regardless of the method used to define soil layers, soil properties within a given layer should be constant. Actual layer boundaries in the subsurface profile must supersede the layer division suggestions in Figure 5-5.

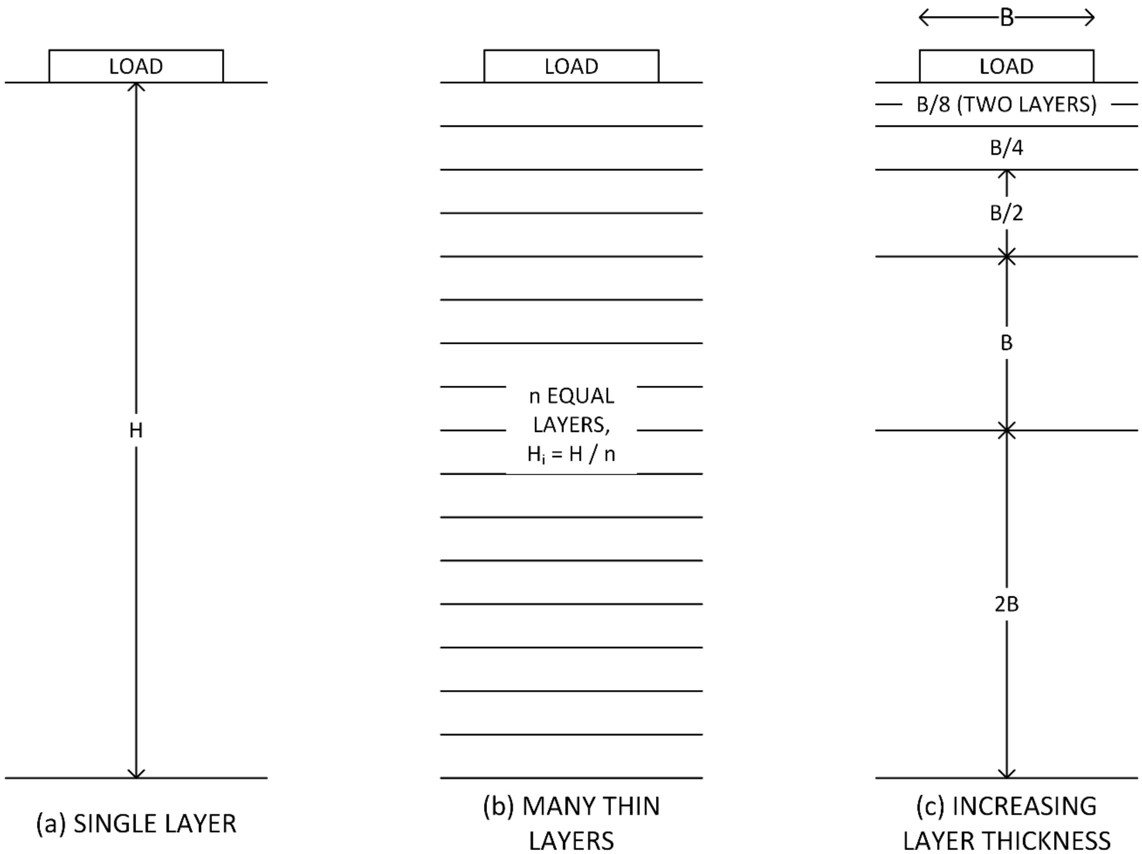


Figure 5-5 Three Possible Methods to Define Layers for Homogeneous Conditions

5-4 SETTLEMENT OF COARSE-GRAINED SOILS.

As indicated in Table 5-1, distortion and consolidation settlement occur in coarse-grained soils in a relatively short time span. If considered, secondary compression of these soils is typically estimated as a proportion of the calculated short-term settlement. For this reason, it is common practice to combine the components of settlement for coarse-grained soils. A variety of calculation methods are available. The soil properties for most of the methods are based on the results of field tests, such as CPT or SPT, due to the variability and difficulty of sampling coarse-grained soils.

5-4.1 Short Term Settlement of Coarse-Grained Soil.

5-4.1.1 Elastic Method.

If the soil supporting a load is idealized as an elastic medium with a modulus equal to E_s and Poisson's ratio of ν, the resulting settlement (s) is:

$$s = \frac{q_0}{E_s}\left(B\mu_0\mu_1\right) \quad \textbf{(5-5)}$$

where:
q_0 = stress applied by load,
B = width of the applied load,
μ_0 = influence factor associated with embedment of the load, and
μ_1 = influence factor associated with the problem geometry and Poisson's ratio.

Some sources report Equation 5-5 with a $(1-\nu^2)$ term. This term is often combined with the influence factors directly. When using charts and tables for μ_1, the engineer must check carefully to determine whether or not the $(1-\nu^2)$ term has been included and what value of ν has been assumed, if appropriate.

The influence factors, μ_1 and μ_0, can be found using Figure 5-6 for the ratios of L/B, H/B, and D/B represented by the problem geometry. Note that H/B ratios can theoretically be very high, when a significant depth of soil is present below a loaded area. However, based on the concept of critical depth (see Section 4-2.1.5), the zone that contributes to settlement typically has a thickness of $4B$ to $5B$ below the loaded area. The use of H/B ratios greater than 4 to 5 may overestimate settlement.

The settlement predicted by Equation 5-5 will be directly related to the value of E_s, which is a difficult parameter to measure or obtain. General guidance for the selection of E_s for coarse-grained soils is provided in Table 5-2. Most of the correlations summarized in this table are based on the results of Standard Penetration Test (SPT) blow counts. An average SPT value (N') is used to predict settlement in coarse-grained soils. In most cases, N' is equal the average N_{60} value from the bottom of the loaded area to a depth of B below the load. In dense, saturated silty sands, the value of N'_{SM} is calculated as:

$$N'_{SM} = 15 + 0.5\left(N' - 15\right) \quad \textbf{(5-6)}$$

where:
N' = average N_{60} value.

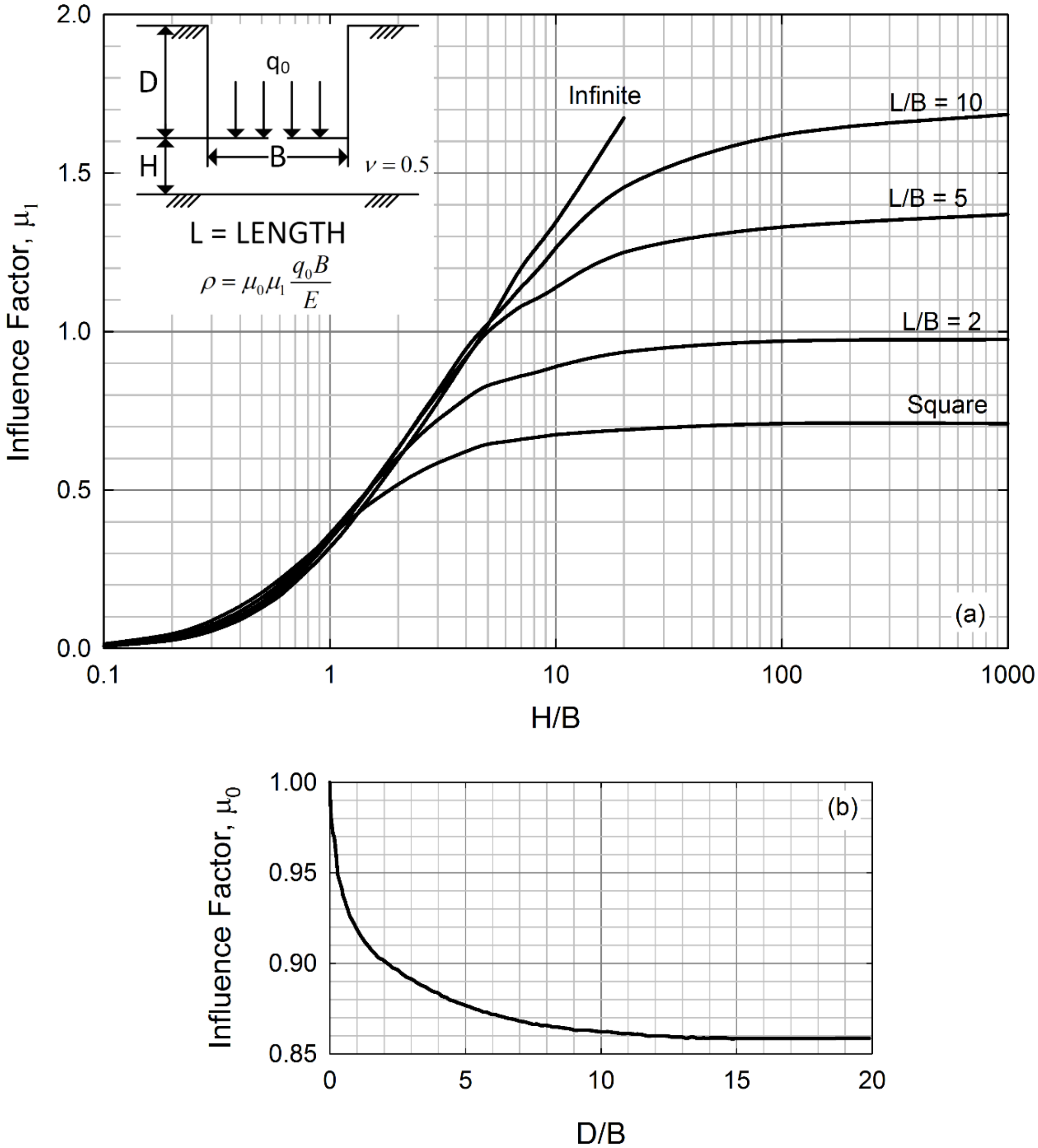


Figure 5-6 Elastic Influence Factors for $\nu = 0.5$ for (a) μ_1 (after Giroud 1972) and (b) μ_0 (after Burland 1970)

Table 5-2 Approximate Modulus Values for Coarse-Grained Soil (after Bowles 1996, Duncan and Mokwa 2001)

Soil Conditions		Normally Consolidated	Preloaded or Compacted
Loose Sand	D_r = 40%	200 to 400 ksf	400 to 800 ksf
Medium Dense Sand	D_r = 60%	300 to 500 ksf	500 to 1000 ksf
Dense Sand	D_r = 80%	400 to 600 ksf	600 to 1200 ksf
Dry or Moist Sand		Lower: $E_s = 11.5\ (N'+7.5)$ Upper: $E_s = 15\ (N'+30)$	$E_s = 20\ (N'+42)$
Clayey, Silty, or Saturated Sand		Lower: $E_s = 5.6\ (N'+9)$ Upper: $E_s = 7.7\ (N'+15)$	Not available

Note: Correlations provide values of E_s in ksf units.

5-4.1.2 Schmertmann Method.

The Schmertmann Method is a common approach for the calculation of settlement for coarse-grained soils. This method uses typical patterns of vertical strain below a rigid foundation along with estimates of modulus based on either CPT or SPT. The variation of the strain influence factor (I_z) with depth is based on observations from model scale tests as well as numerical simulations. As shown in Figure 5-7, I_z increases with depth below the loaded area up to a peak value (I_{zp}) and then decreases to zero at a depth of 2B for square footings and $4B$ for continuous footings. The magnitude of I_{zp} is a function of the applied load and the effective vertical stress (σ'_{zp}) at the depth of the peak influence factor.

The compressibility of the coarse-grained soil is incorporated through layer moduli estimated from CPT or SPT results. The soil profile immediately below the foundation is divided into layers with relatively constant cone tip bearing resistance, q_c (or SPT blow count). Schmertmann et al. (1978) recommend that CPT q_c values should be multiplied by 2.5 to obtain E_s for axisymmetric ($L=B$) conditions. Similarly, CPT q_c values should be multiplied by 3.5 to obtain E_s for plane strain ($L/B > 10$) conditions.

Schmertmann (1970) provided multipliers to estimate q_c from SPT blow count, N. Robertson and Cabal (2014) found a similar correlation between CPT and SPT. Table 5-3 combines the SPT-CPT correlation with the $q_c - E_s$ correlation to provide approximate correlation between N_{60} and E_s. The general values in Table 5-3 can be replaced by regional correlations that follow the principles provided in Schmertmann (1970) and Robertson et al. (1983).

Table 5-3 Estimates of E_s based on SPT N_{60} values.

Soil Type	Approximate E_s Value (ksf)	
	Axisymmetric ($L = B$)	**Plane Strain (L/B > 10)**
Silt, sandy silt, slightly cohesive silt-sand mixtures	$10 \cdot N_{60}$	$14 \cdot N_{60}$
Clean fine to medium sand, and slightly silty sand	$17.5 \cdot N_{60}$	$24.5 \cdot N_{60}$
Coarse sand and sand with little gravel	$25 \cdot N_{60}$	$35 \cdot N_{60}$
Sandy gravel	$30 \cdot N_{60}$	$42 \cdot N_{60}$

The settlement (s) is then calculated for n layers as:

$$s = C_1 C_2 \left(q_0 - \sigma'_{z0}\right) \sum_{i=1}^{n} \left(\frac{I_{z,i}}{E_{s,i}}\right) \cdot z_i \tag{5-7}$$

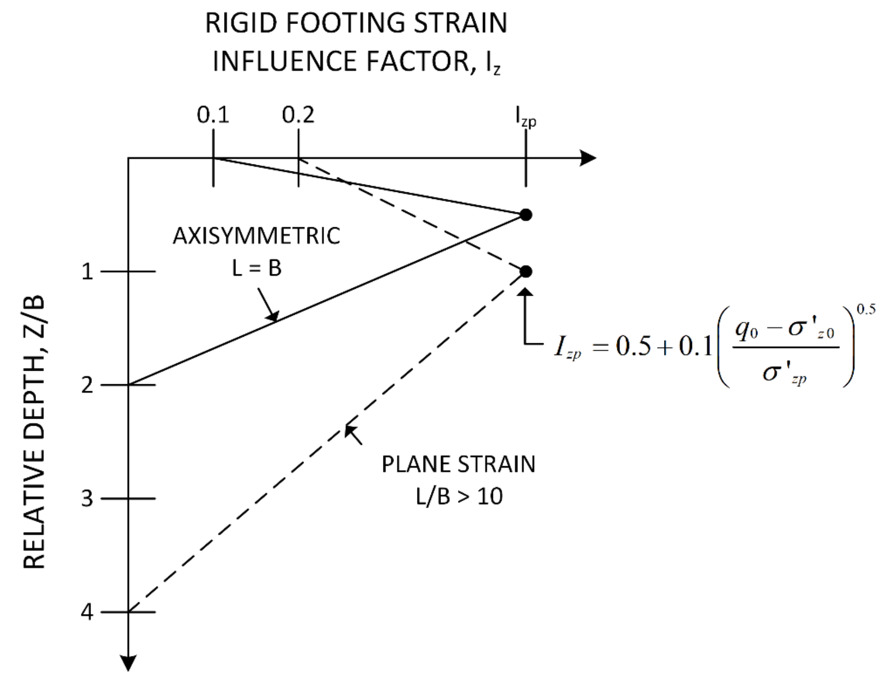
where:
C_1 = coefficient to correct for the effects of embedment,
C_1 = coefficient to correct for the effects of time,
q_0 = applied foundation pressure,
σ'_{z0} = the existing vertical effective stress at the bottom foundation,
$I_{z,i}$ = the average strain influence factor for the layer,
$E_{s,i}$ = the layer modulus, and
z_i = the layer thickness.

The correction for foundation embedment is found from:

$$C_1 = 1 - 0.5\left(\frac{\sigma'_{z0}}{q_0 - \sigma'_{z0}}\right) \geq 0.5 \tag{5-8}$$

The correction for time (t) in years after initial loading is:

$$C_2 = 1 + 0.2\log\left(\frac{t}{0.1\,\text{yr}}\right) \tag{5-9}$$



MODULUS CORRELATION

FOUNDATION CONDITION	E/q_C
AXISYMMETRIC L = B	2.5
PLANE STRAIN L/B > 10	3.5

STRESS VARIABLES & DIMENSIONS

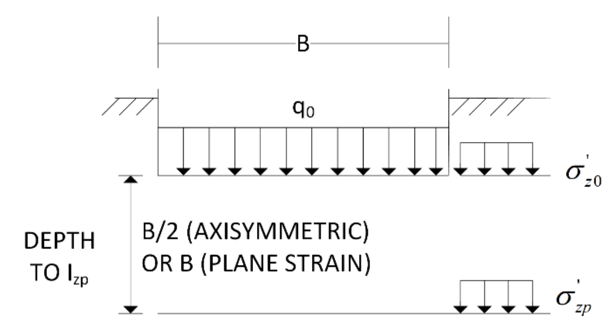


Figure 5-7 Influence Diagram and Modulus Correlation for Schmertmann CPT Method (Schmertmann 1970, Schmertmann et al. 1978)

5-4.1.3 Empirical Methods.

The difficulty of obtaining representative measures of compressibility or modulus for coarse-grained soils has led to the development of many different empirical methods. These methods are based on measurements and observations of load-settlement behavior from plate load tests as well as actual foundations. The underlying basis of these methods remains the elastic theory presented in Equation 5-5 but the soil modulus and influence factors are replaced with empirical correlations to SPT blow count and foundation dimensions. Three of the more popular relationships are provided in Table 5-4.

Table 5-4 Empirical Equations for Settlement of Coarse-Grained Soils

Method	Equation	Comments
Terzaghi and Peck (1967)	$s = \frac{6q_0}{N'}\left(\frac{B}{B+1}\right)^2$	s in inches B in ft q_0 in ksf A range of constants have been used.
Meyerhof (1965), Duncan and Buchiagnani (1987)	$s = \frac{2.5q_0}{(N'-1.5)C_B}$ $C_B = \begin{cases} 1.0 \text{ for } B < 4\text{ ft} \\ \text{Interpolate for 4 to 12 ft} \\ 0.8 \text{ for } B \geq 12\text{ ft} \end{cases}$	s in inches q_0 in ksf
Burland and Burbridge (1985), Terzaghi et al. (1996)[A]	$s = B^{0.75}\left(\frac{1.31}{N'^{1.4}}\right)q_0 C_s$ $C_s = \left[\frac{1.25(L/B)}{(L/B)+0.25}\right]^2$, $C_s \rightarrow 1.56$ for strip load	s in inches B in ft L in ft q_0 in ksf

A Settlement for load applied at the ground surface to normally consolidated sand. See the provided references for methods to correct for the effects of embedment and overconsolidation.

5-4.1.4 Accuracy and Reliability.

Tan and Duncan (1991) provide a helpful perspective for assessing the usefulness of the various settlement methods for coarse-grained soils. They evaluated the accuracy and "reliability"[11] of 12 SPT-based methods and the Schmertmann CPT Method using more than 90 case histories. The most accurate methods will make a reliably conservative estimate of settlement (i.e., greater than or equal to the actual value) only about half of the time. Likewise, more reliable methods, such as Terzaghi and Peck (1967), tend to greatly over-predict settlement, which is well-documented. Figure 5-8 can be used to select an appropriate method for determining settlement for each project based on considerations of accuracy and reliability. In cases where more accuracy is required, one of the methods that plots to the lower left may be used. Where it is critical not to exceed the calculated settlement, a method with higher reliability can be used.

[11] In this context, reliability was defined as the percentage of cases where the measured settlement was less than the predicted settlement. Reliability is not used in a formal probabilistic sense in this case.

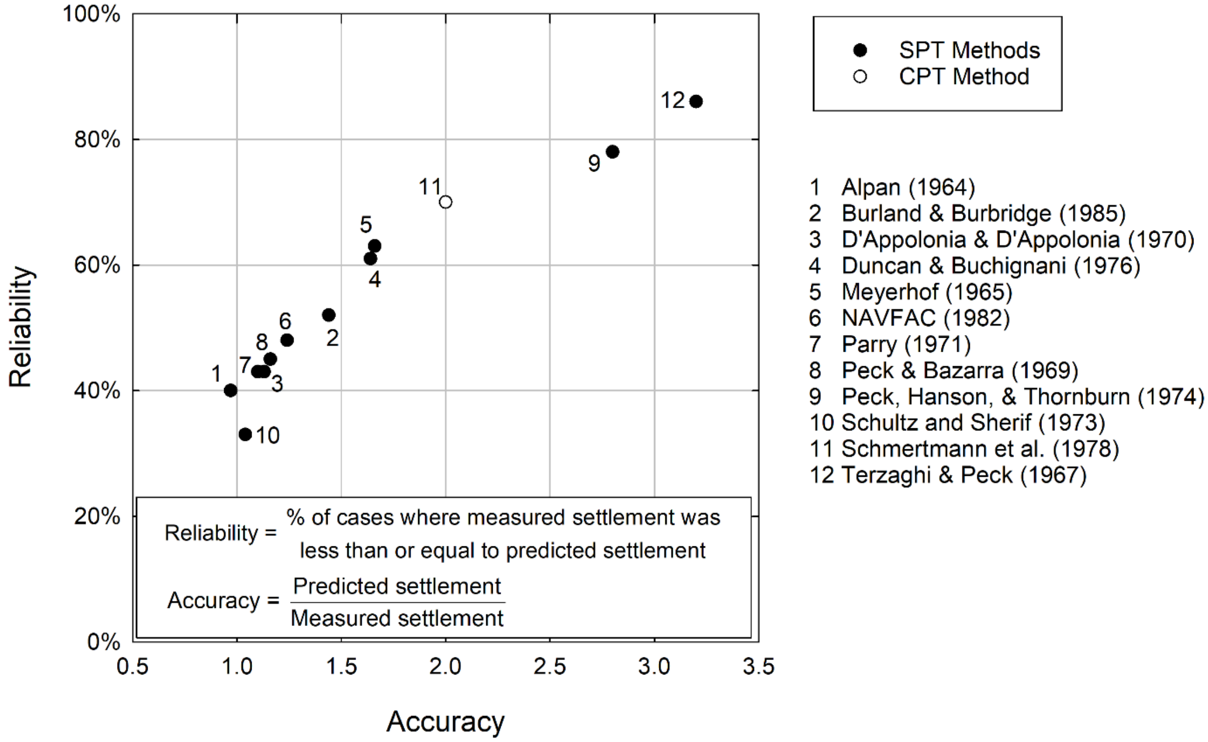


Figure 5-8 Comparison of Settlement Calculation Methods for Coarse-Grained Soils based on SPT Blow Count (after Tan and Duncan 1991)

5-4.2 Long-Term Settlement of Coarse-Grained Soil.

Creep or secondary compression of coarse-grained soil is sometimes considered by multiplying the calculated short-term settlement by a time-dependent influence factor. One suggested relationship is the creep factor (C_2) included in the Schmertmann Method. This factor can also be applied to the results of other coarse-grained settlement methods. Terzaghi et al. (1996) suggest a similar approach to calculate a creep factor (C_t) which is related to the magnitude of the applied stress. The resulting values of C_t for their approach are summarized in Figure 5-9 where the applied stress (q_0) is normalized by atmospheric pressure, P_a. For larger loads, this method predicts lower values of C_t because creep movements are a smaller proportion of the overall expected settlement. The creep factors for both methods have the same mathematical form. The total settlement at time (t) is found by multiplying the short-term settlement by the value of C_t.

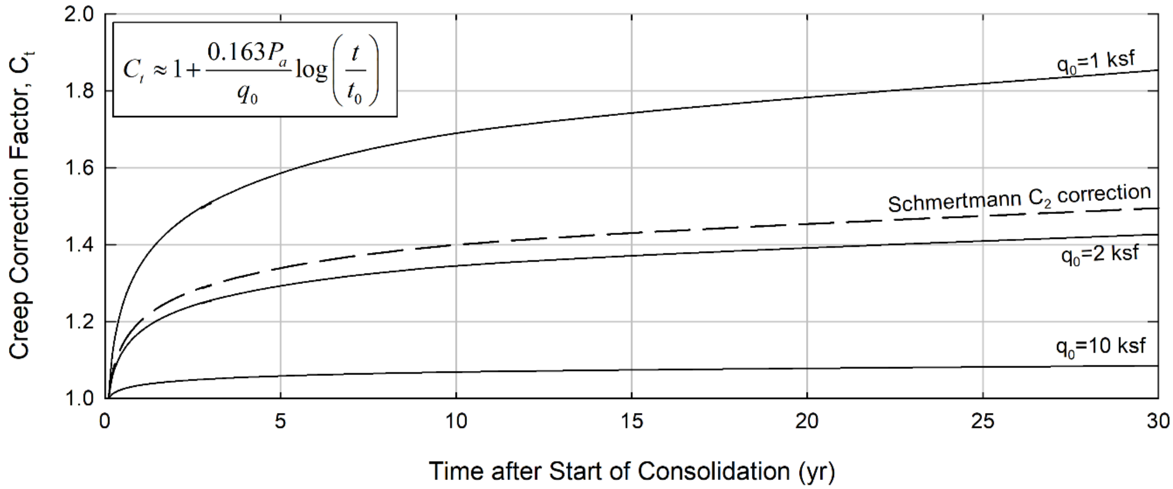


Figure 5-9 Creep Factors for Settlement of Coarse-Grained Soils (t_0 = 0.1 year and q_0 in same units as P_a) (after Schmertmann 1970, Terzaghi et al. 1996)

5-5 SETTLEMENT OF FINE-GRAINED SOILS.

5-5.1 Immediate Settlement of Fine-Grained Soils.

Immediate settlement of fine-grained soil is the result of one of two mechanisms: (1) “elastic” compression and volume change of the unsaturated soil or (2) distortion of saturated soil without volume change. Immediate settlement may be a significant proportion of settlement for unsaturated or heavily overconsolidated clay.

Similar to coarse-grained soil, immediate settlement of fine-grained soil can also be calculated using Equation 5-5 and the influence factors provided in Figure 5-6. For saturated clay, a Poisson’s ratio of 0.5, which is the value assumed in the construction of the figure. In most cases, the undrained modulus (E_u) should be used. Values of E_u can be measured in laboratory or field tests, such as the pressuremeter. Caution should be used as laboratory tests may underestimate the magnitude of E_u. Similarly, field tests typically load the soil horizontally rather than vertically, which may lead to erroneous results. Empirical correlations, such as those in Figure 5-10, can be used for comparison or in place of test values when appropriate. OCR can be estimated from empirical correlations or measured using one-dimensional consolidation tests as described in Chapter 3.

If the factor of safety against bearing capacity failure is less than about 3 (see DM 7.2), then the immediate settlement should be modified to account for partial yield of the soil. D’Appolonia et al. (1971) can be used to determine the appropriate adjustment for this condition.

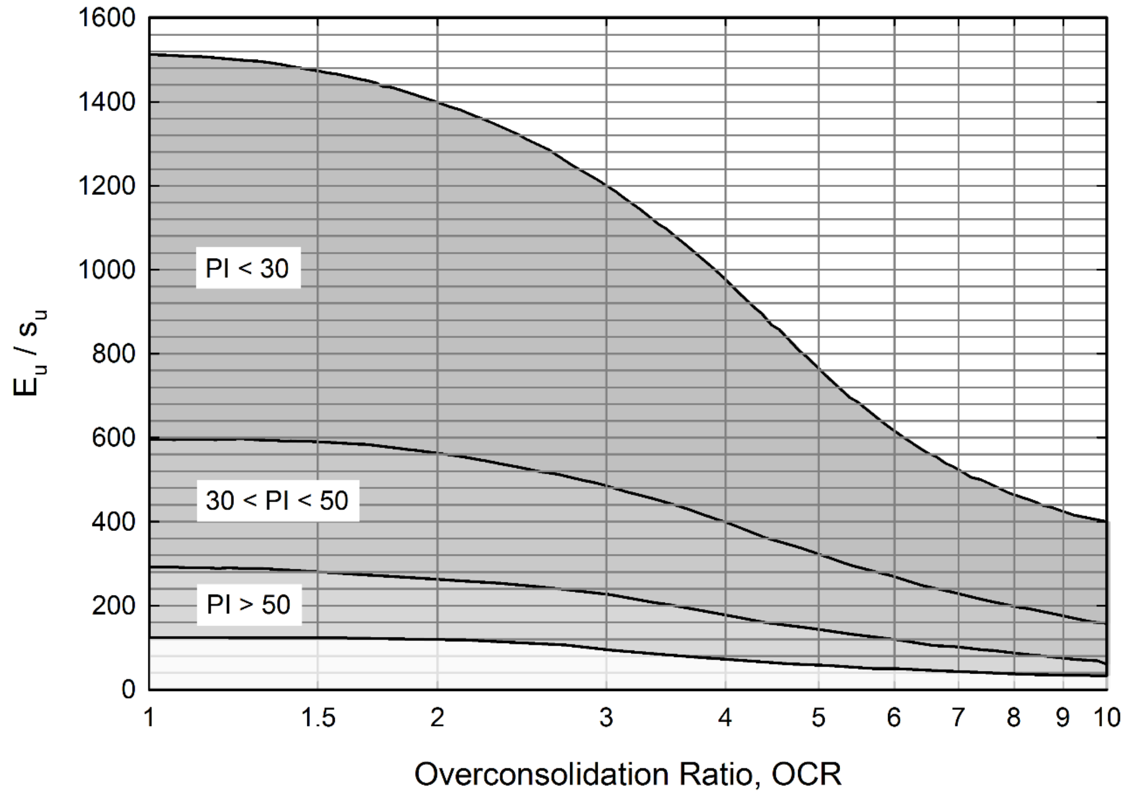


Figure 5-10 Correlation of Normalized Undrained Modulus and Overconsolidation Ratio (after Duncan and Buchignani 1987)

5-5.2 Primary Consolidation Settlement of Fine-Grained Soils.

Primary consolidation occurs as water flows from saturated soil and the excess pore water pressures caused by loading are able to dissipate. The magnitude of primary consolidation settlement can be predicted with reasonable accuracy when the soil's preconsolidation stress can be determined reliably and when the change in total stress can be accurately predicted. Settlement calculations involving recompression of overconsolidated soils tend to have the largest percent error. The amount of error for overconsolidated soils is related heavily to the quality of the samples used for consolidation tests, which affects the accuracy of the predicted recompression index and preconsolidation stress.

5-5.2.1 Use of Consolidation Test Results.

One-dimensional consolidation tests are used to predict swell, recompression, and virgin compression of soils. Specific details about the testing process are described in further detail in Section 3-2.6. The results of consolidation tests are typically plotted in terms of void ratio vs. vertical effective stress or vertical strain vs. vertical effective stress.[12] In either case, vertical effective stress (σ'_z) will be plotted on a logarithmic scale.

Ideally, the soil behaves in the manner depicted in Figure 5-11 with log-linear segments describing the volume change or vertical strain that occurs as the vertical effective stress changes. The initial condition corresponds to initial vertical effective stress (σ'_{z0}) and either the initial void ratio (e_0) or to zero initial vertical strain, ε_z = 0. From the initial condition, the loading of overconsolidated soil results in relatively elastic recompression until the preconsolidation stress is reached. Any increase in σ'_z that extends beyond σ'_p results in plastic deformation or virgin compression. The slopes of these two lines are defined by the *recompression index* (C_r) and the *compression index* (C_c). A normally consolidated soil (σ'_{z0} = σ'_p) will experience virgin compression due to any increase in σ'_z.

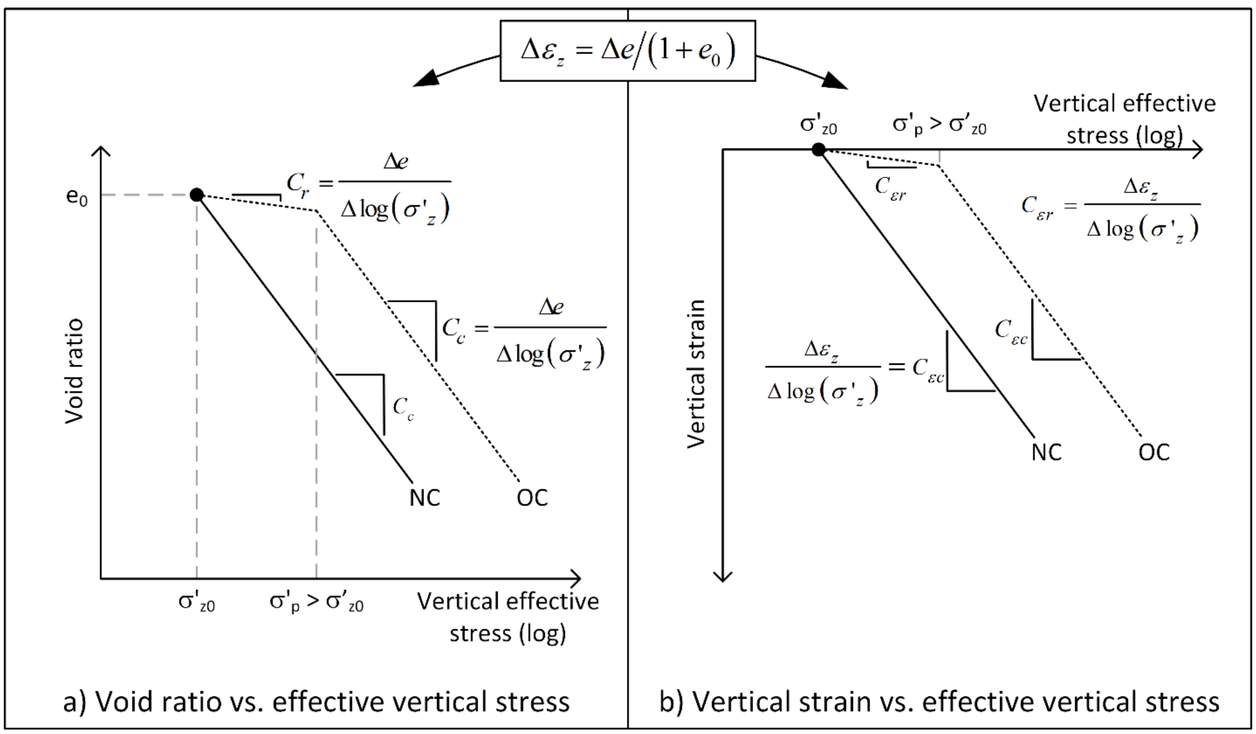


Figure 5-11 Consolidation Behavior based on (a) Void Ratio and (b) Vertical Strain

[12] In old soil mechanics references, the water content was often used in lieu of void ratio. For saturated soils, the water content is equal to the void ratio divided by the specific gravity.

Interpretation of consolidation tests in terms of vertical strain is often a more practical approach. This method emphasizes that prediction of strain is the intent of the calculations and will be used in much of the discussion in this chapter. The *modified recompression index* ($C_{\varepsilon r}$) and the *modified compression index* ($C_{\varepsilon c}$) are defined as:

$$C_{\varepsilon r} = \frac{C_r}{1+e_0} \qquad \textbf{(5-10)}$$

and

$$C_{\varepsilon c} = \frac{C_c}{1+e_0} \qquad \textbf{(5-11)}$$

where:
C_r = recompression index,
C_c = compression index, and
e_0 = initial void ratio.

Methods for determining C_r, C_c, and σ'_p from laboratory tests are illustrated in Figure 3-12. Many useful correlations have been developed between C_c and soil index properties. Table 5-5 provides a list of some of these correlations. Azzouz et al. (1976) found that correlations to e_0 produced the most accurate prediction of C_c. Nine of the correlations are compared in Figure 5-12. Additional correlations can be found in Chapter 8.

The recompression index is typically 5 to 10% of the magnitude of C_c. Typical values for C_r fall in the range of 0.015 to 0.035 with nearly all results between 0.005 and 0.05 (Leonards 1976).

Table 5-5 Correlations for Compression Indices

Basis	Correlation	Applicable soil type	Source
LL	$C_c = 0.009 \cdot (LL - 10)$	Inorganic soils with sensitivity less than 4	Terzaghi and Peck (1967)
	$C_c = 0.007 \cdot (LL - 7)$	Remolded clays	Skempton (1944)
	$C_c = 0.006 \cdot (LL - 9)$	Predominantly lean to fat clay	Azzouz et al. (1976)
e_0	$C_c = 1.15 \cdot (e_0 - 0.35)$	All clays	Nishida (1956)
	$C_c = 0.3 \cdot (e_0 - 0.27)$	Inorganic soil; silt; silty clay; some clay	Hough (1957)
	$C_c = 0.75 \cdot (e_0 - 0.5)$	Very low plasticity soils	Sowers (1970)
	$C_{\alpha c} = 0.15 \cdot e_0 + 0.017$	All clays	Elnaggar and Krizek (1971)
	$C_c = 0.4 \cdot (e_0 - 0.25)$	Predominantly lean to fat clay	Azzouz et al. (1976)
w_n	$C_c = 0.01 \cdot w_n$	Chicago clays	Osterberg (1972) (in Azzouz et al. 1976)
	$C_c = 0.0115 \cdot w_n$	Organic soils, peat	Moran et al. (1958)
	$C_{\alpha c} = (0.1 + 0.006 \cdot (w_n - 25))$	Varved clays	Prior NAVFAC DM 7.1
	$C_c = 17.6 \times 10^{-5} \cdot w_n^2 + 5.93 \times 10^{-3} \cdot w_n - 0.135$	Chicago clays	Peck and Reed (1954)
	$C_c = 0.01 \cdot w_n - 0.05$	Predominantly lean to fat clay	Azzouz et al. (1976)

Note: Liquid limit (LL) and natural water content (w_n) are in percent.

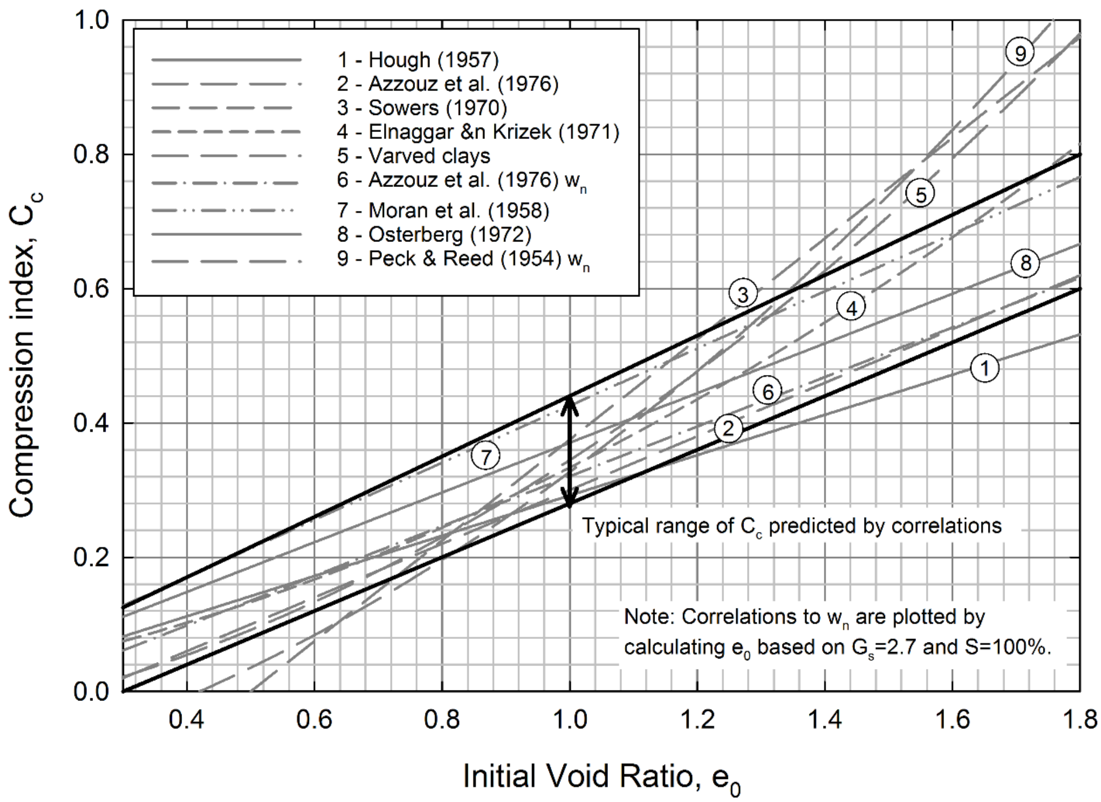


Figure 5-12 Common Compression Index Correlations

5-5.2.2 Magnitude of Primary Consolidation.

Primary consolidation settlement (s_c) should be determined for each compressible layer. Thick layers should be divided into a series of sublayers (e.g., Figure 5-5b and c). For each layer, the appropriate equation for s_c must be selected based on whether the soil is normally or overconsolidated and the relative magnitude of the change in vertical stress.

For normally consolidated soil ($\sigma'_{z0} \approx \sigma'_p$), calculate s_c as:

$$s_c = \left(C_{\varepsilon c} \log\left(\frac{\sigma'_{z0} + \Delta\sigma_z}{\sigma'_{z0}} \right) \right) H \quad \textbf{(5-12)}$$

where:
$C_{\varepsilon c}$ = modified compression index,
σ'_{z0} = initial vertical stress at the midpoint of the soil layer or sublayer,
$\Delta\sigma_z$ = change in vertical stress at layer midpoint, and
H = initial thickness of the soil layer or sublayer.

For overconsolidated soil layers in which the final stress is less than or equal to the preconsolidation stress ($\sigma'_{z0} + \Delta\sigma_z \leq \sigma'_p$), calculate s_c as:

$$s_c = \left(C_{\varepsilon r} \log\left(\frac{\sigma'_{z0} + \Delta\sigma_z}{\sigma'_{z0}} \right) \right) H \quad \textbf{(5-13)}$$

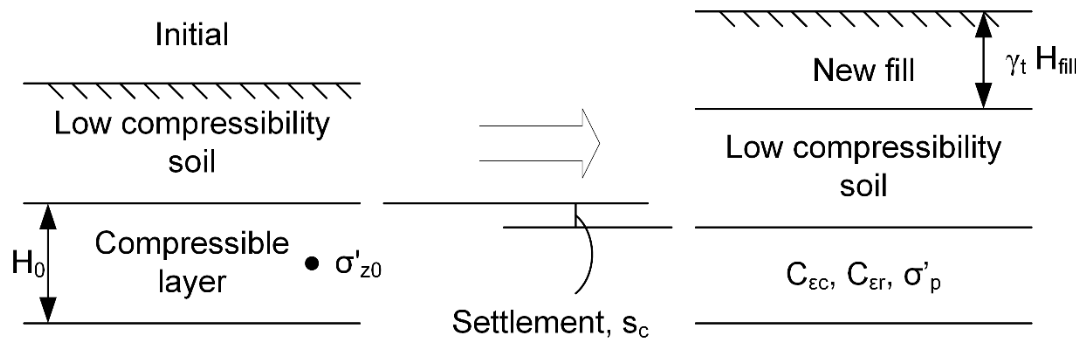
where:
$C_{\varepsilon r}$ = modified recompression index.

For overconsolidated soil layers in which the final stress is greater than the preconsolidation stress $\sigma'_{z0} + \Delta\sigma_z > \sigma'_p$), calculate s_c as:

$$s_c = \left(C_{\varepsilon r} \log\left(\frac{\sigma'_p}{\sigma'_{z0}} \right) + C_{\varepsilon c} \log\left(\frac{\sigma'_{z0} + \Delta\sigma_z}{\sigma'_p} \right) \right) H \quad \textbf{(5-14)}$$

where:
σ'_p = preconsolidation stress.

Equations 5-12 to 5-14 all follow a consistent pattern in which the compression or recompression index is multiplied by the logarithm of the change in stress to obtain the vertical strain. The strain is then multiplied by the layer thickness to obtain the change in thickness or expected settlement of the layer. In each of these equations, $C_{\varepsilon c}$ and $C_{\varepsilon r}$ can be replaced with C_c and C_r along with the initial void ratio, if desired, using Equations 5-10 and 5-11. Example calculations are shown in Figure 5-13.



Example:

$\sigma'_{z0} = 3000\,psf, \sigma'_p = 3500\,psf, \Delta\sigma_z = \gamma_t H_{fill} = 1000\,psf$

$H_0 = 10\,ft, C_{\varepsilon r} = 0.015, C_{\varepsilon c} = 0.2$

$\sigma'_{z0} + \Delta\sigma_z > \sigma'_p$, thus

$$s_c = \left[0.015\log\left(\frac{3500}{3000}\right) + 0.2\log\left(\frac{4000}{3500}\right)\right]10' = 0.13'\ or\ 1.5"$$

Figure 5-13 Primary Consolidation Example

5-5.2.3 Typical Construction Process.

An example of the primary consolidation caused by changes in stress associated with typical construction processes is illustrated in Figure 5-14. In this example, the clay is overconsolidated by past loading. The construction process involves lowering the groundwater level, excavating for a basement level, and applying the structural load. Some aspects of construction will cause increases in effective stress and settlement. Other phases, such as excavation and groundwater rise, will result in swelling. As noted, the amount of settlement or swell experienced during the first phases of construction will depend on the rate of construction as well as the rate at which pore water pressures dissipate in the clay layer.

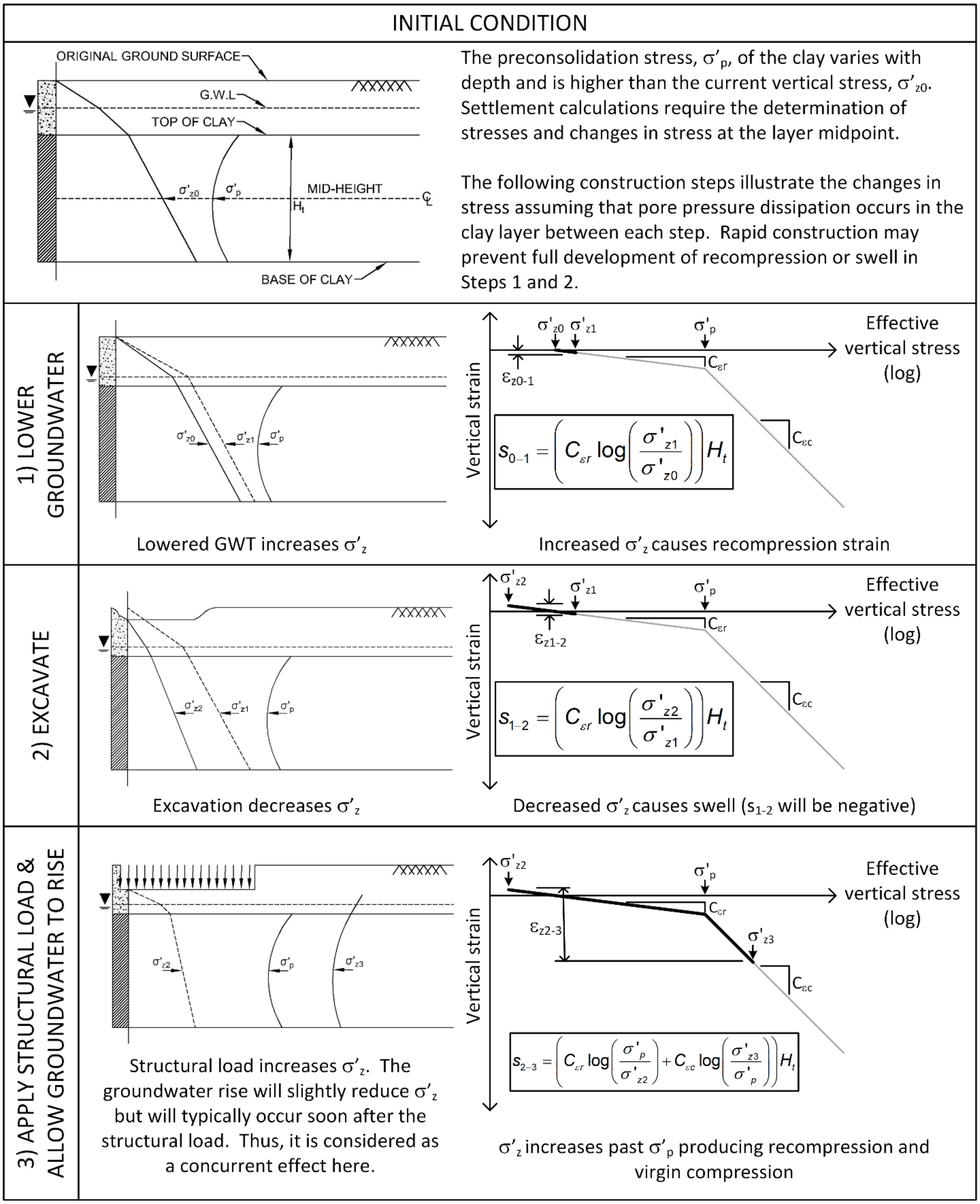


Figure 5-14 Vertical Movements during a Typical Construction Process

5-5.2.4 Corrections to the Magnitude of Consolidation Settlements.

Settlement of overconsolidated clay layers may be overestimated using Equations 5-13 and 5-14 for loads of limited lateral extent. For cases where the width of the load is less than four times the thickness of the clay layer, conditions deviate significantly from one-dimensional consolidation. Leonards (1976) recommended that the corrected primary consolidation settlement can be found by multiplying the calculated value (Equation 5-13 or 5-14) by a correction factor, α. Values of α can be found using Figure 5-15.

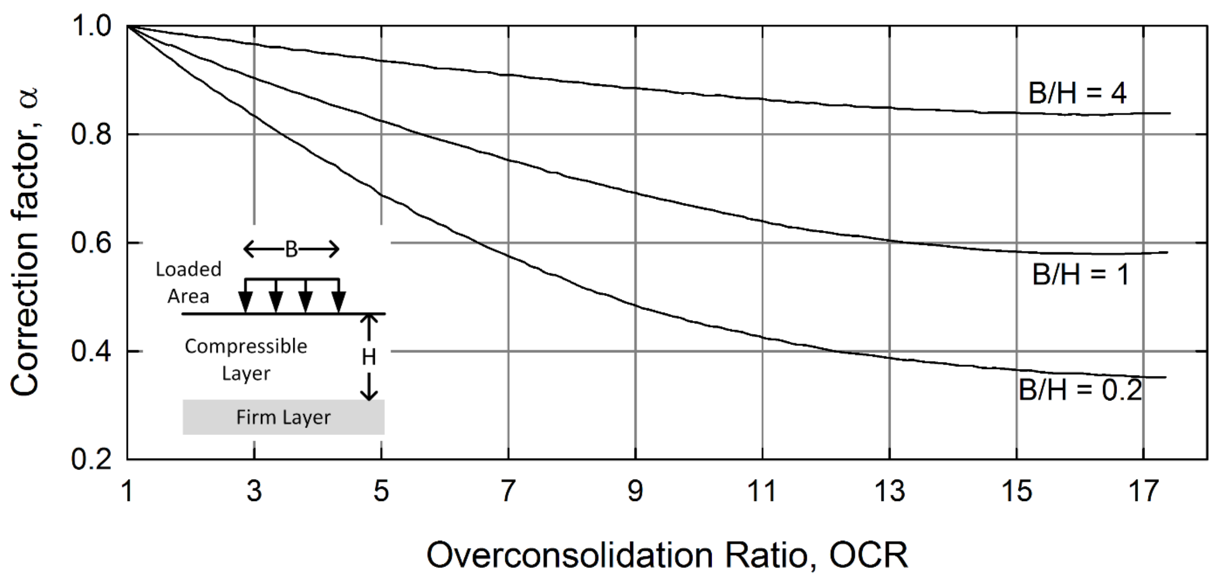


Figure 5-15 Correction Factor for Overconsolidated Clays and Loads of Limited Lateral Extent (after Leonards 1976)

5-5.3 Time Rate of Primary Consolidation.

The time rate of primary consolidation is considered for situations where predicted settlement exceeds tolerable values. In these cases, treatment of the foundation soil, such as acceleration of consolidation or placement of a surcharge to increase in preconsolidation stress, may be considered. Knowledge of the settlement rate or consolidation completed at a particular time is important for planning remedial measures for structures damaged by settlement.

Time rate calculations can be performed with greater accuracy and flexibility using numerical methods, such as the finite difference method. Various computer programs are available for this purpose. The analytical methods presented in this section are useful for understanding time rate of settlement concepts and checking the results of numerical methods.

The time rate of consolidation is typically assessed starting with one-dimensional theory applied to vertical drainage. The average *degree of consolidation* ($\bar{U}_z$) is the average percentage of the excess pore pressure that has dissipated at a particular time (t) following the addition of a load. The amount of settlement experienced at the ground surface is typically assumed to be proportional to $\overline{U}_z$. The value of $\overline{U}_z$ can be related to a time factor (T) for a given set of conditions. The time factor for vertical drainage (T_v) is calculated as:

$$T_v = \frac{c_v t}{H_{dr}^2} \quad \textbf{(5-15)}$$

where:
c_v = coefficient of consolidation for the soil layer in the vertical direction,
t = time after application of load, and
H_{dr} = drainage path length.

The relationship between T_v and $\overline{U}_z$ is provided in Figure 5-16.

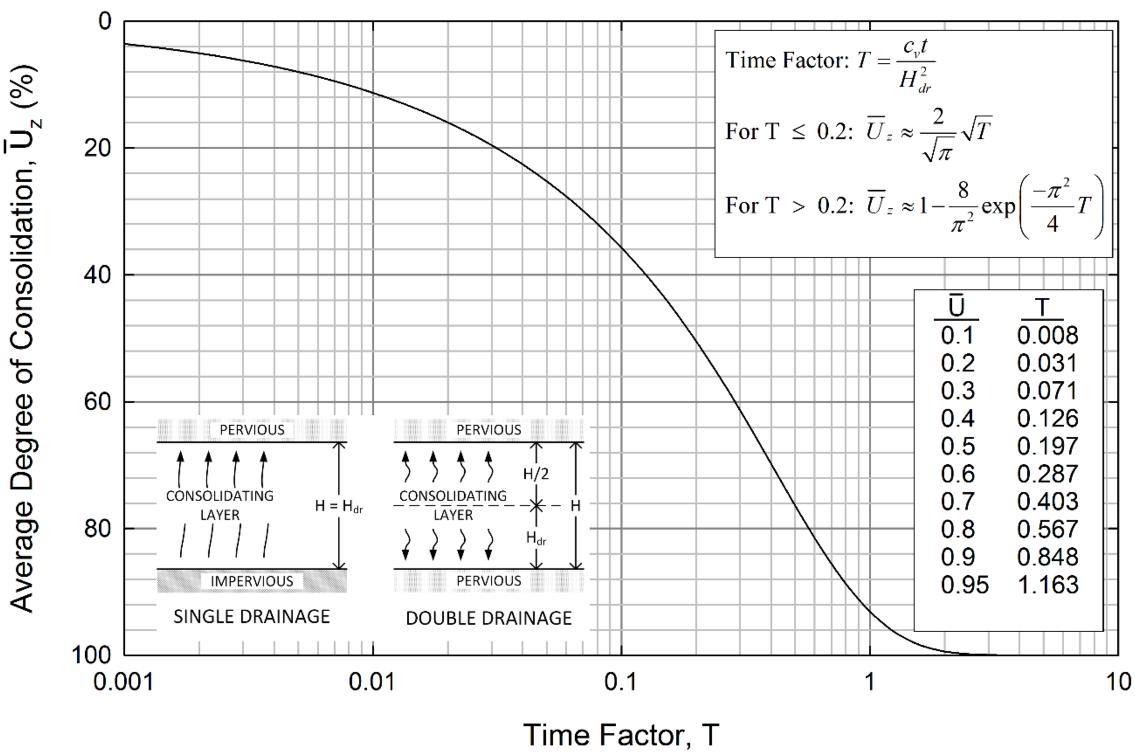


Figure 5-16 Degree of Consolidation for Instantaneous Uniform Loading and One-Dimensional Flow

Two conditions are typically considered for vertical drainage. Single (or one-way) drainage refers to conditions where water can flow one direction to leave the consolidating soil layer as shown in the inset to Figure 5-16. Double (or two-way) drainage occurs when pervious layers lie above and below the consolidating layer, and H_{dr} is half of the layer thickness (H) in this case.

The *degree of compression* (U_z) is the amount of pore water pressure that has been dissipated at a particular depth within the soil layer. The degree of compression will vary with time and depth within the consolidating layer as illustrated in Figure 5-17. It can be used to estimate the remaining excess pore pressures at any depth and time following application of a change in vertical stress. The upper half of this figure can be used for single drainage conditions.

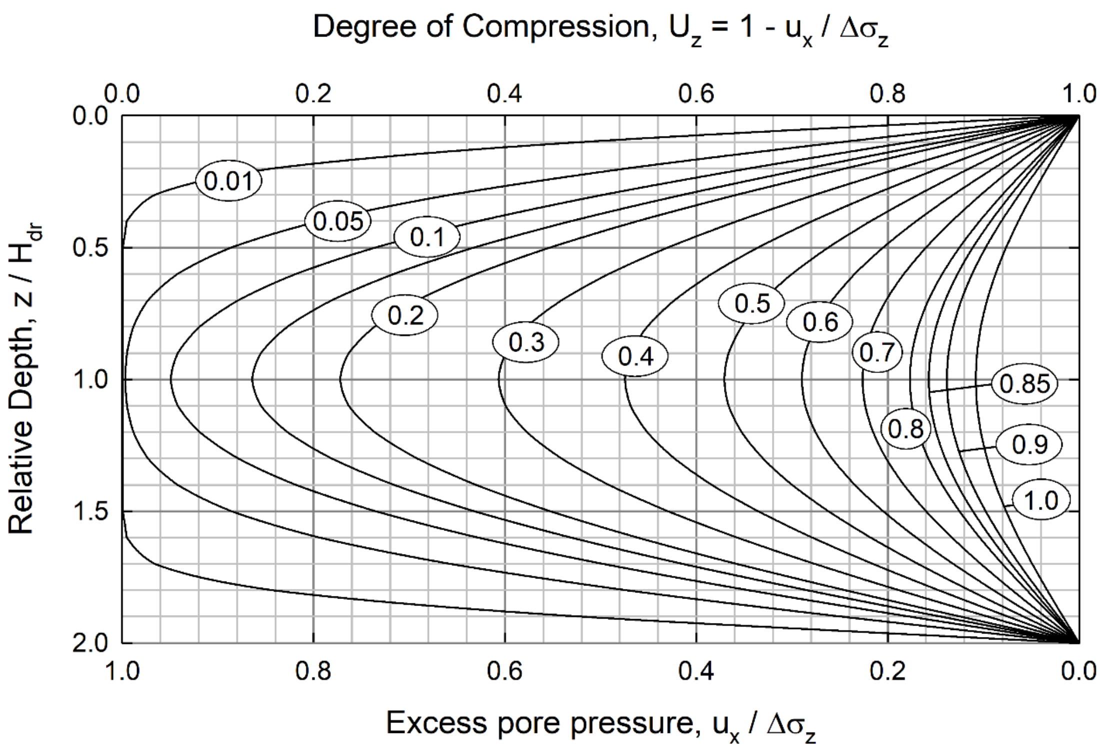


Figure 5-17 Degree of Compression and Excess Pore Pressure (Contours Indicate the Time Factor)

5-5.3.1 Effect of Initial Excess Pore Pressure Distribution.

The rate of consolidation can be affected by the initial distribution of excess pore water pressure, especially for single drainage conditions. The degrees of consolidation and compression predicted in Figure 5-16 and Figure 5-17 are appropriate for a uniform distribution of initial excess pore pressure, which is a reasonable assumption for relatively wide loads, regardless of the type of drainage.

Other scenarios, such as foundation loading and consolidation of hydraulic fill, can result in a distribution of initial excess pore pressure that is not constant with depth.

Figure 5-16 is also appropriate for double drainage when the distribution of initial u_x varies linearly. Solutions for single drainage and linearly varying distributions of initial u_x can be found in Terzaghi et al. (1996). However, for these more complex loading conditions, numerical solutions are preferred.

5-5.3.2 Accuracy of Time Rate Predictions.

The time rate of primary consolidation observed in field measurements is often faster than that predicted by the methods described in this section. This discrepancy is the result of a number of effects.

The theoretical conditions of one-dimensional consolidation and vertical drainage rarely mimic the *in situ* conditions. In most cases, loading and subsequent drainage is actually two or three-dimensional, which tends to increase the time rate of consolidation. As the width of the loaded area becomes small with respect to the thickness of the compressible layer, consolidation proceeds much more quickly. Figure 5-18 allows the time required to reach a degree of consolidation of either 50% or 90% to be corrected for two- and three-dimensional effects. The results are plotted for soil profiles with an impermeable layer below the compressible soil and for those with an underlying permeable layer. See Davis and Poulos (1972) for further details on these effects. Numerical methods can be used to account for some of these differences; however, many of the common programs used for consolidation calculations only consider one-dimensional flow.

Many clay soils contain thin seams of sand and silt, which have significantly higher permeability. These seams provide internal drainage boundaries, greatly reducing the maximum vertical drainage path length. For example, the presence of a single additional drainage layer can increase the time rate of settlement by a factor of four. In addition, soil deposits tend to have a higher horizontal hydraulic conductivity, which coupled with three-dimensional effects can increase the settlement rate. Figure 5-19 provides a simple means to account for effect of anisotropy in the coefficient of consolidation on the time required to reach 50% consolidation.

Finally, disturbance of soil samples tends to decrease the coefficient of consolidation measured in laboratory tests. Even high-quality samples and tests have some degree of disturbance, leading to lower c_v and slower time rate of settlement predictions.

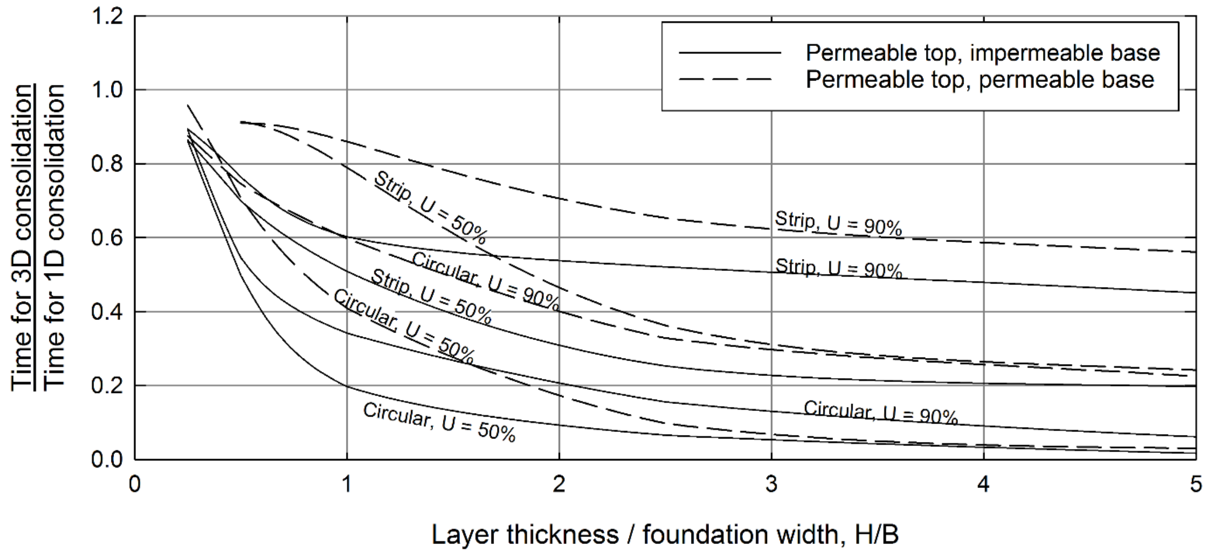


Figure 5-18 Effect of Load Geometry on Time Rate of Consolidation (after Davis and Poulos 1972)

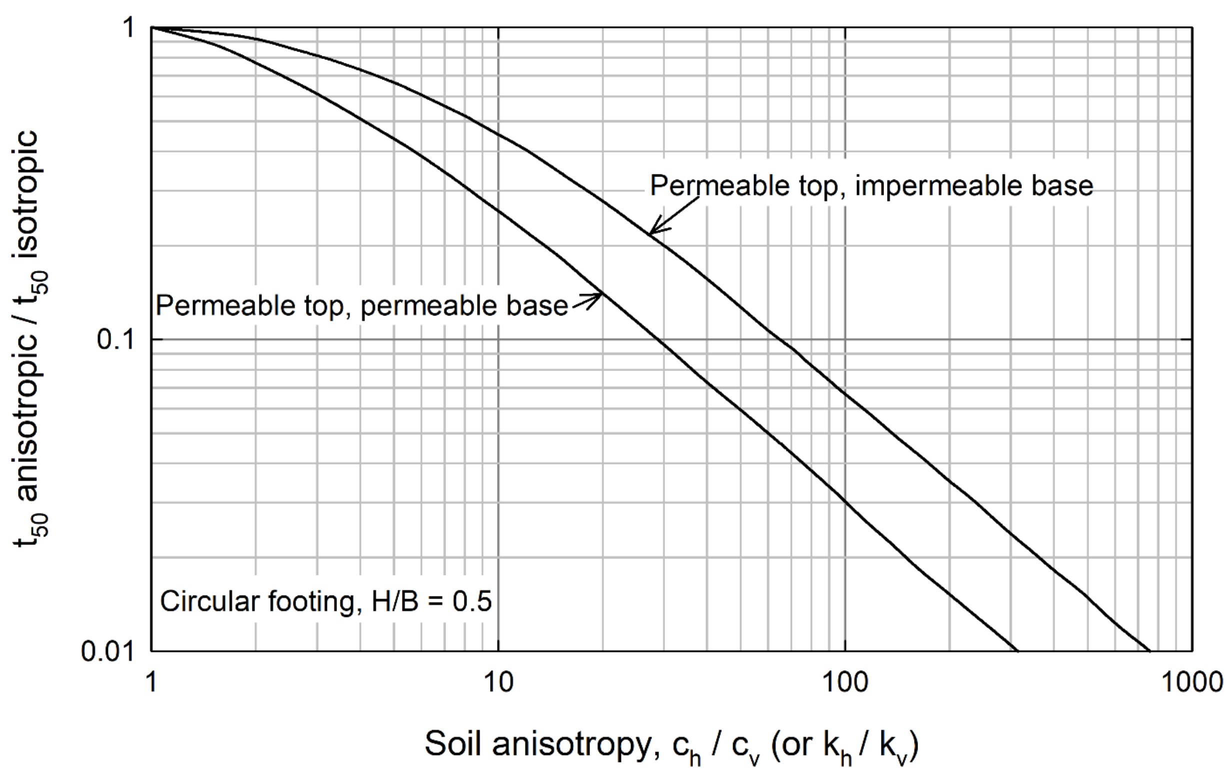


Figure 5-19 Effect of Anisotropy on Time Rate of Consolidation (after Davis and Poulos 1972)

5-5.3.3 Gradual Load Application.

The length of the construction period or the amount of time required to apply the load can also affect the time rate of primary consolidation. Gradual load application modifies the relationship between the degree of consolidation and the time factor. Figure 5-20 provides a method to account for gradual loading.

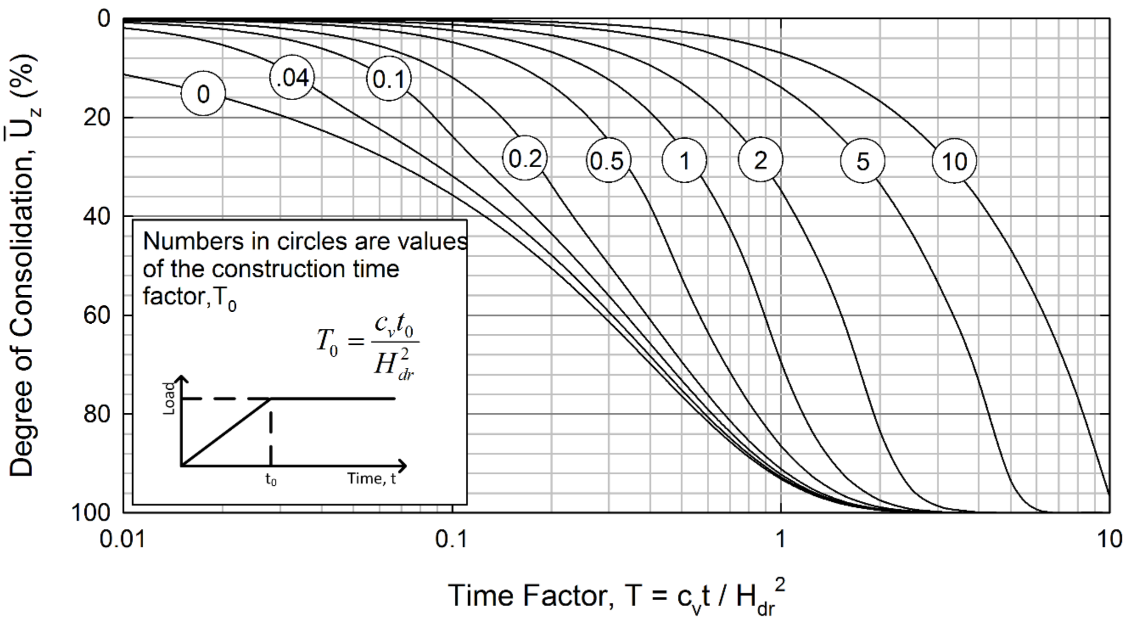


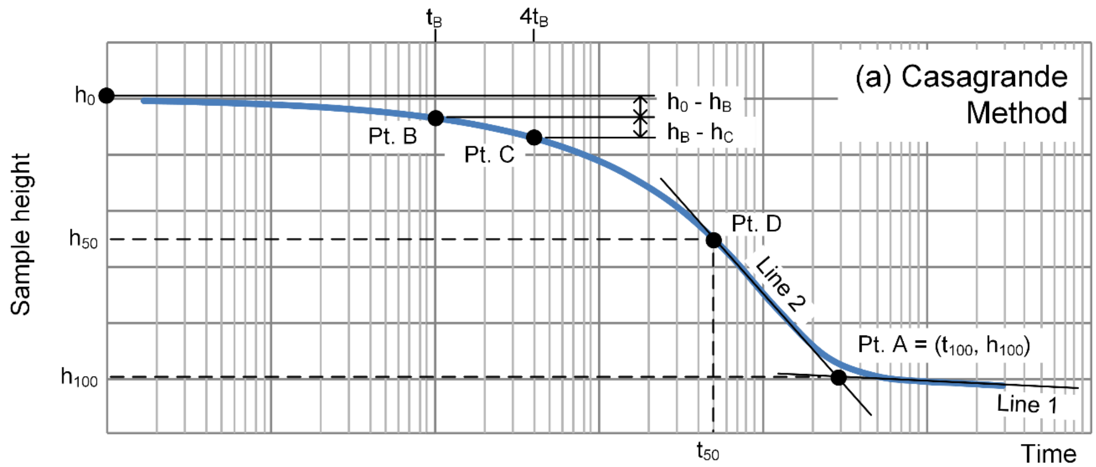
Figure 5-20 Degree of Consolidation for Gradual Load Application for Vertical Drainage (after Olson 1977)

5-5.3.4 Coefficient of Consolidation.

The coefficient of consolidation can be estimated based on index properties (see Chapter 8), calculated from volume change vs. time measurements in laboratory tests, or inferred from field measurements of pore pressure dissipation.

5-5.3.4.1 Laboratory Measurement of Coefficient of Consolidation.

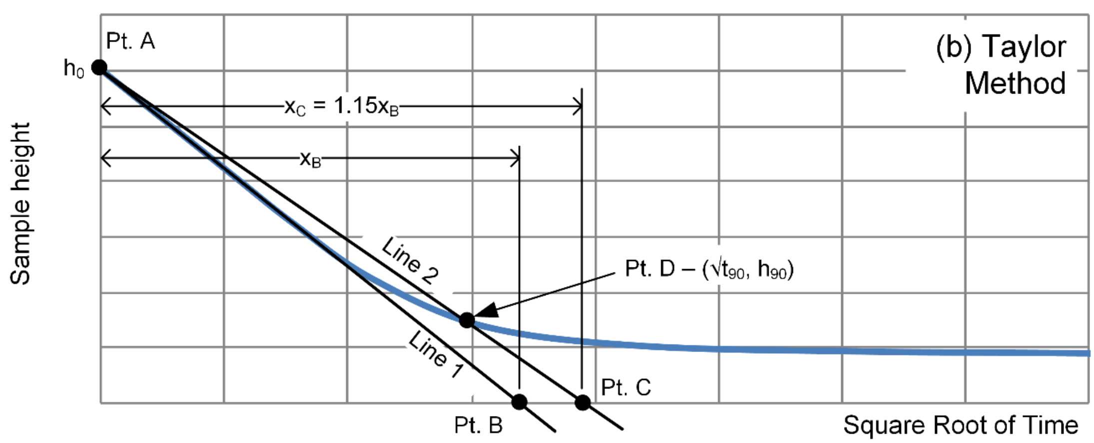
The vertical coefficient of consolidation, c_v, is often found from data obtained using incrementally loaded one-dimensional consolidation tests on vertically oriented specimens. The coefficient of consolidation in other directions can be determined by trimming and mounting specimens in other orientations in the testing equipment. Regardless of the specimen orientation, the data is normally assessed using either the Casagrande or the Taylor method, which are described in Figure 5-21. Volume change measured during the consolidation phase of shear strength tests can also be used with these procedures. Other methods exist for determining c_v from incrementally loaded consolidation tests, and a single equation can be used to determine c_v from constant rate of strain consolidation tests.



Instructions:

-Plot height (or void ratio) v. time (log) data
-Plot Line 1 through final linear portion of data
-Plot Line 2 through middle steepest portion of data
-Pt. A is the intersection of Lines 1 and 2 with coordinates, t_{100} and h_{100}.
-Pick two points, B and C, at low time such that $t_c = 4t_b$.
-Find the initial increment height, $h_0 = 2h_B - h_C$ (initial portion of the time curve is parabolic).
-Calculate $h_{50} = (h_0 - h_{100}) / 2$.
-Plot Pt. D on time curve at h_{50}. Read t_{50} from the plot.
-Calculate the coefficient of consolidation, c_v.

$$c_v = 0.197 h_{dr}^2 / t_{50}$$



Instructions:

-Plot height (or void ratio) v. √time from data
-Plot Line 1 initial linear portion of data to find the intersection point with the y-axis at Pt. A.
-Pt. B is the intersection point with the √time axis.
-Scale x_B from the plot and multiply by 1.15 to find x_C.
-Connect Pts. A and C with Line 2.
-Plot Pt. D ($\sqrt{t_{90}}$, h_{90}) where Line 2 crosses the data.
-Calculate the coefficient of consolidation, c_v.

$$c_v = 0.848 h_{dr}^2 / t_{90}$$

-If desired, h_{100} is equal to:

$$h_{100} = h_0 - \frac{h_0 - h_{90}}{0.9}$$

Figure 5-21 Determination of Coefficient of Consolidation from Laboratory Data (Note: the y-axis can also be plotted as volume or void ratio)

5-5.3.4.2 Use of Field Measurements.

Field observations of excess pore pressure dissipation with time can be used to measure the *in situ* coefficient of consolidation. At any given time after loading, the ratio of excess pore pressure to change in vertical stress ($u_x/\Delta\sigma_v$) can be measured and plotted at the appropriate normalized depth on Figure 5-17. The corresponding time factor can be estimated from the contours, and c_v can be calculated using Equation 5-15.

An example of both laboratory and field determination of c_v is provided in Figure 5-22.

5-5.3.5 Time Rate of Consolidation for Layered Profiles.

The consolidating soil may contain layers with varying values of c_v. In this situation, the behavior of a layered system can be approximated by conversion to an equivalent single layer system using the following procedure:

1. Select any layer (i) with properties $c_{v,i}$ and H_i.
2. Transform the thickness of every other layer with properties $c_{v,n}$ and H_n to an equivalent layer with the soil properties of layer i as follows:

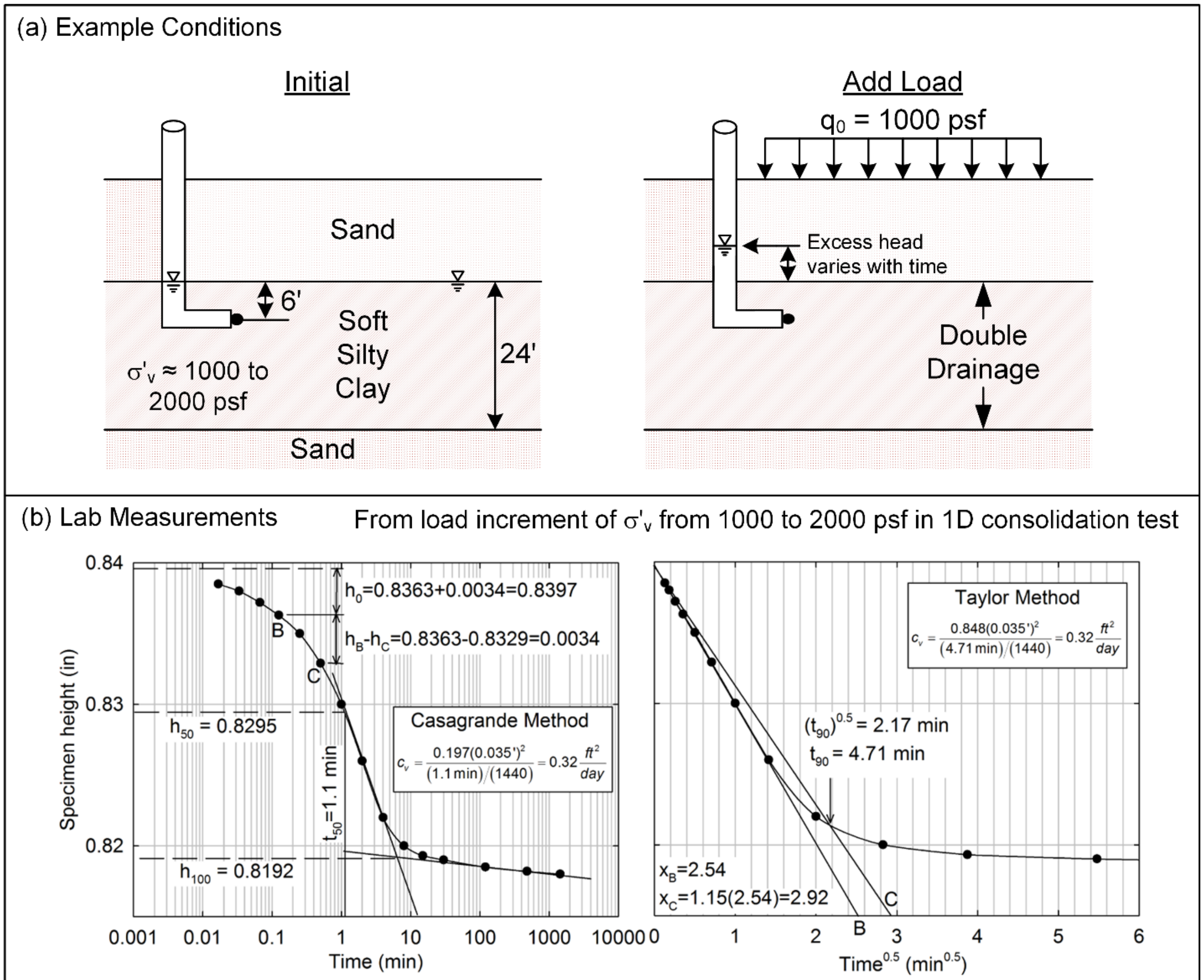
$$H'_n = H_n \sqrt{\frac{c_{v,i}}{c_{v,n}}} \qquad \textbf{(5-16)}$$

3. Calculate the total thickness (H'_t) of the transformed system as:

$$H'_t = \sum H'_n \qquad \textbf{(5-17)}$$

4. Treat the system as a single layer of thickness (H'_t) with coefficient of consolidation ($c_{v,i}$),
5. Use the appropriate method, such as Figure 5-16, to determine the percent consolidation at various times.

The complexity introduced by multi-layer problems is well-suited to the use of numerical analysis for the calculation of time rate of settlement. An example of multi-layer time rate of consolidation calculation is provided in Figure 5-23.



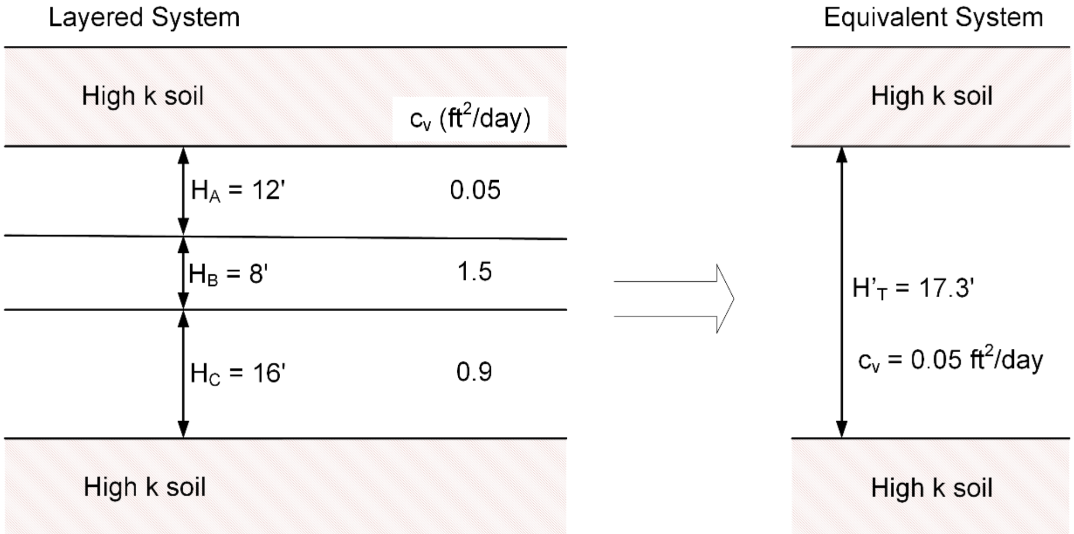
(c) Field Measurements

Piezometer Location: $H_{dr} = \frac{24'}{2} = 12'$ $\quad \frac{z}{H_{dr}} = 0.5$ $\quad U_z = 1 - \frac{u_x}{q_0}$

Time (days)	Excess Head in Piezometer (ft)	Excess u (psf)	U_z	T
30	12'	749	0.25	0.09
100	8'	499	0.5	0.26

$$c_v = \frac{\Delta T}{\Delta t} H_{dr}^{\ 2} = \frac{(0.26 - 0.09)}{(100\,days - 30\,days)}(12')^2 = 0.35\,ft^2/day$$

Figure 5-22 Determination of c_v from Lab and Field Data



Transform layer B : $H'_B = H_B \left(\dfrac{c_{vA}}{c_{vB}} \right)^{1/2} = 8' \left(\dfrac{0.05}{1.5} \right)^{1/2} = 1.5'$

Transform layer C : $H'_C = H_C \left(\dfrac{c_{vA}}{c_{vC}} \right)^{1/2} = 16' \left(\dfrac{0.05}{0.9} \right)^{1/2} = 3.8'$

Total : $H'_T = H'_A + H'_B + H'_C = 12' + 1.5' + 3.8' = 17.3'$

Assuming double drainage, the percent consolidation could be found for one year as:

$$T_{1YR} = \frac{c_v t}{H_{dr}^2} = \frac{(0.05\,\text{ft}^2/\text{day})(365\,\text{days})}{(17.3'/2)^2} = 0.24$$

From Fig. 5-15, $\bar{U}_z$ = 56%

Figure 5-23 Multi-layer Consolidation Example

5-5.4 Secondary Compression of Fine-Grained Soils.

Secondary compression settlement (s_s) occurs as soil particles rearrange and the soil structure creeps under constant vertical effective stress. For practical purposes, secondary compression can be assumed to occur after the end of primary consolidation and to follow a relatively linear trend with respect to time on a log scale such that:

$$s_s = \left(\frac{C_\alpha}{1+e_0} \log\left(\frac{t}{t_p}\right)\right) H_0 = \left(C_{\varepsilon\alpha} \log\left(\frac{t}{t_p}\right)\right) H_0 \quad \textbf{(5-18)}$$

where:
C_α = secondary compression index,
$C_{\varepsilon\alpha}$ = modified secondary compression index,
e_0 = initial void ratio,
t = time after loading,
t_p = time required to finish primary consolidation, and
H_0 = initial layer thickness.

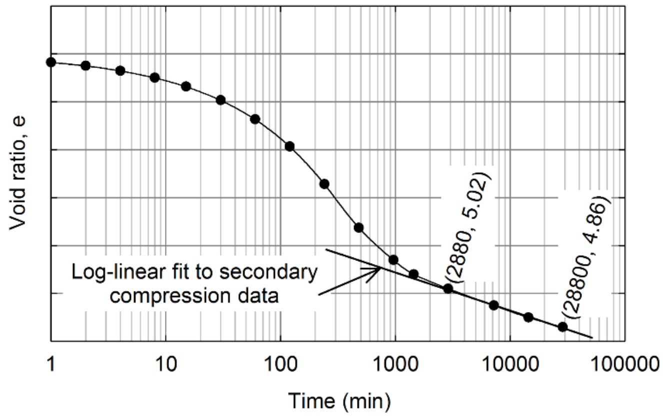
Values of C_α or $C_{\varepsilon\alpha}$ can be obtained from the results of a one-dimensional consolidation test that is allowed to creep for a significant length of time past the end of primary consolidation. The magnitude of C_α is stress dependent for a particular soil and should be determined at an effective stress similar to that expected *in situ*. For a variety of clays, silts, and organic soils, Mesri (1973) showed that $C_{\varepsilon\alpha}$ is approximately related to the natural water content, w_n, (in percent) by:

$$C_{\varepsilon\alpha} \approx 10^{-4} w_n \quad \textbf{(5-5-19)}$$

The secondary compression index is closely linked to the compression index, C_c. For this reason, an excellent method for estimating C_α is the use of the C_α / C_c ratio. Typical values of this ratio are found in Table 5-6. Recognizing that C_c is also stress-dependent, these ratios should be used with the slope of the laboratory virgin compression curve at the effective stress of interest (Mesri and Godlewski 1977, Mesri and Castro 1987) rather than the field corrected value typically used in consolidation calculations. An example of secondary compression settlement calculations is provided in Figure 5-24.

Table 5-6 Typical Values of C_α / C_c (after Terzaghi et al. 1996)

Soil Type	C_α / C_c
Granular soils including rockfill	0.02 ± 0.01
Shale and mudstone	0.03 ± 0.01
Inorganic clays and silts	0.04 ± 0.01
Organic clays and silts	0.05 ± 0.01
Peat and muskeg	0.06 ± 0.01



Example

- Organic clay: H_0=10'
- $w_n \approx 250\%$
- $e_0 \approx 6$
- $C_c = 3$ @ in-situ stress

Based on Lab Data

$$C_\alpha = \frac{\Delta e}{\log(\Delta\sigma)} = \frac{(5.02-4.86)}{\log\left(28800/2880\right)} = 0.16$$

$$C_{\varepsilon\alpha} = C_\alpha/(1+e_0) = 0.16/(1+6) = 0.023$$

Based on Table 5-6

$$C_\alpha/C_c = 0.05$$

$$C_\alpha = (0.05)(3) = 0.15$$

$$C_{\varepsilon\alpha} = C_\alpha/(1+e_0) = 0.15/(1+6) = 0.021$$

Based on Eqn. 5-19

$$C_{\varepsilon\alpha} \approx 10^{-4} w_n = 10^{-4}(250)$$

$$C_{\varepsilon\alpha} \approx 0.025$$

Based on the three methods $C_{\varepsilon\alpha} \approx 0.023$ and t_p = 1 year, the secondary compression settlement expected after 50 years, s_s, is approximately:

$$s_s = C_{\varepsilon\alpha} \log\left(\frac{t}{t_p}\right) H_0 = 0.023 \cdot \log\left(\frac{50\text{ yr}}{1\text{ yr}}\right)(10\text{ ft}) \approx 0.4\text{ ft} \approx 5\text{ in.}$$

Figure 5-24 Calculation of Secondary Compression

In many cases, one-dimensional consolidation tests are presented using the void ratio or vertical strain corresponding to the end of 24-hour load increments. Some amount of secondary compression will have occurred during this time period and is thus included in the laboratory consolidation curve. The engineer should be aware that consolidation settlements calculated with such data will account for some degree of secondary compression.

If secondary compression is expected to be important in the analysis, consolidation test results should be plotted based on the void ratio or vertical strain at the end of primary (EOP) consolidation for each load increment. Primary consolidation settlement calculated using the EOP consolidation curve can be added directly to estimates of secondary compression settlement.

5-5.5 Organic Soils and Peat.

Settlement of organic soils and peat can be calculated using the procedures for inorganic fine-grained soils. Primary consolidation tends to occur more rapidly in these soils due to their relatively high hydraulic conductivity. Large secondary compression is typically measured and contributes a significant portion of the total settlement.

5-6 DIFFERENTIAL AND TOLERABLE SETTLEMENT.

5-6.1 Differential Settlement.

For important structures, settlement should be calculated for a number of points across the footprint of the structure in order to establish the expected settlement pattern. Figure 5-25 illustrates various types of settlement profiles.

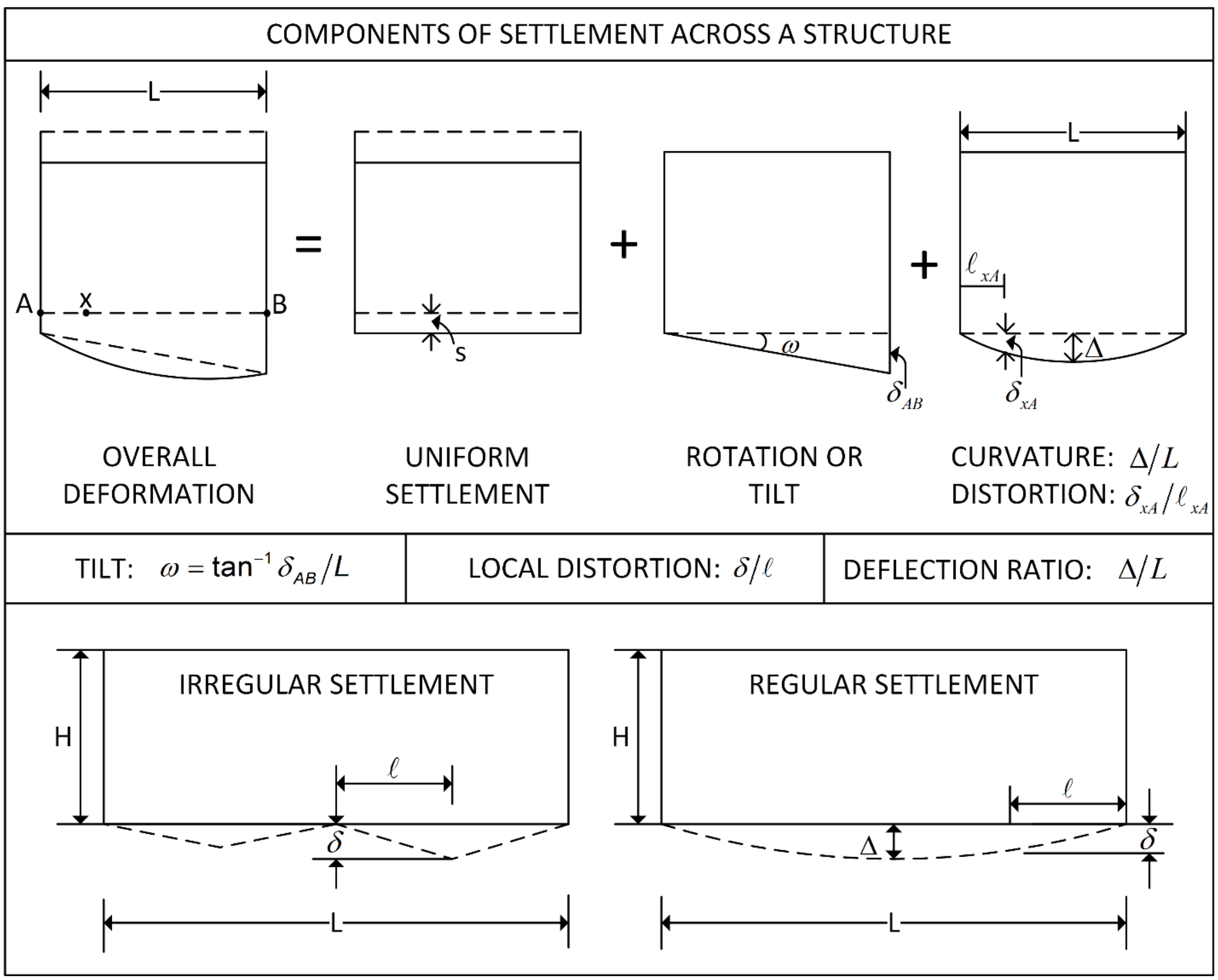


Figure 5-25 Components of Settlement (after Duncan and Buchignani 1987, Ricceri and Soranzo 1985)

Differences in settlement across a structure can be considered in multiple ways. The simplest is to consider the maximum difference in predicted settlement across the structure, which is often referred to as the *differential settlement,* δ_{max}. However, it is often necessary and more informative to consider the effects of the size and flexibility of the structure when evaluating the impact of differential settlement. In some cases, a structure will tilt over an angle (ω) which causes difference in settlement between various points but does not necessarily cause structural distress.

Differential settlement that results in non-uniform deflection or non-uniform tilt causes bending and tensile strain in the structure. Differential movement that causes a concave upward shape is referred to as *sagging* while a concave downward shape is called *hogging*. This type of movement can be quantified by either the angular distortion or the deflection ratio. *Angular distortion* (δ / l) is the slope of the expected settlement profile or the ratio of the settlement between two points to the distance (l) separating the points. The *deflection ratio* (Δ / L) is the maximum expected deviation from uniform settlement divided by the overall length of the structure and is an approximate measure of the curvature caused by settlement. These two measures have been shown to provide the best indication of structural distress.

Natural variation in soil deposits causes settlement calculations to be highly uncertain. For this reason, it may be sufficient to use approximate relationships to estimate differential based on magnitude of total settlement. For example, Terzaghi et al. (1996) suggest that the differential settlement for footings on sand will likely be 75% or less of the predicted total settlement. For clays, the differential settlement can sometimes approach the magnitude of the total settlement.

5-6.2 Tolerable Settlement.

5-6.2.1 Criteria.

Most of the guidance regarding acceptable settlement is based on experience with measured settlement of real structures and observations of the associated damage. Wahls (1981) summarizes four important points regarding settlement: (1) settlement must be expected, (2) some form of differential settlement is the most important to consider for structural distress, (3) structural design can reduce the level of differential movement, and (4) many structures can tolerate large settlements and remain safe.

Table 5-7 provides guidance for the selection of tolerable angular distortion for various types of structures. In some cases, the limits that are provided that include a margin of safety to reduce or prevent cracking or damage. Most of these guidelines ignore the size and stiffness of the structure, which control the magnitude of the strains in the structure.

Table 5-7 Angular Distortion Limits for Various Structures (after Skempton and MacDonald 1956, Polshin and Tokar 1957, Duncan and Buchignani 1987, and Day 1990)

Type of Structure / Condition	L/H	Tolerable d/l	
		Decimal	Ratio
Small slab-on-grade structures – damage to structure	---	0.01	1/100
Steel frame with flexible siding	---	0.008	1/125
Circular steel tanks on flexible base with fixed top	---		
Considerable cracking – brick and panel	---	0.0067	1/150
Structural damage begins	---		
Safe limit – flexible brick walls (includes safety factor)	> 4		
Tilting of high buildings becomes visible	---	0.004	1/250
Slab-on-grade structures – drywall cracking	---	0.0033	1/300
Overhead cranes			
Steel or reinforced concrete frame with insensitive finish such as dry wall, glass or moveable panels	---	0.002 to 0.003	1/500 to 1/333
Circular steel tanks on flexible base with floating top	---		
Tall slender structures, such as stacks, silos, and water tanks with rigid mat foundations	---	0.002	1/500
Safe limit –cracking of buildings (includes safety factor)	---		
Steel or reinforced concrete frame with brick, block, plaster, or stucco finish	≥ 5 ≤ 3	0.002 0.001	1/500 1/1000
Frames with diagonal bracing	---	0.00167	1/600
Machinery sensitive to settlement	---	0.0013	1/750
Load-bearing brick, tile, or concrete block walls	≥ 5 ≤ 3	0.0008 0.0004	1/1250 1/2500

Wroth and Burland (1974) proposed a deflection ratio criterion that allow the properties of the structure to be explicitly considered in terms of the controlling type of strain, the length to height ratio of the structure, and the structure's relative stiffness, E/G. Figure 5-26 plots these criteria for three different types of bending, assuming the critical strain for structural distress (ε_{crit}) is 0.075%. Other values of E/G and ε_{crit} can be considered using the equations provided on the figure.

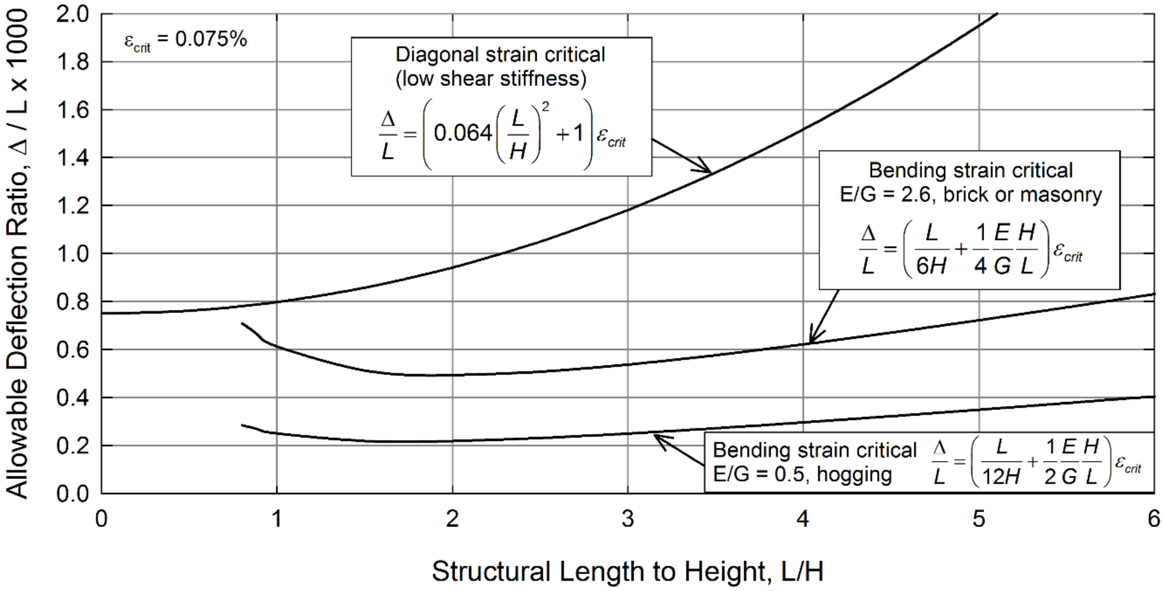


Figure 5-26 Allowable Deflection Ratios Related to Structural Proportions (after Burland and Wroth 1974, Wahls 1981)

5-6.2.2 Reduction of Differential Settlement.

The reduction of total settlement (Section 5-7) is also the primary means of reducing differential movement. Settlement that occurs early in the construction process doesn't generally contribute to structural distress. The sequence and rate at which the load is applied can be compared to the expected rate of consolidation to estimate the total and differential settlement that will be experienced by different parts of the structure. If the consolidation rate is relatively fast, building finishes and other sensitive components may be installed after much of the total settlement has occurred and thus will experience less differential settlement than the superstructure. Estimates of this type of effect are heavily dependent on the rate of construction and consolidation and must be considered on a project-specific basis.

Some buildings, such as light steel frame structures, are very flexible and can tolerate large settlements. In this case, limitation of damage to utilities and machinery housed in the facility may control design.

5-6.3 Differential Settlement of Mat Foundations.

Settlement calculations for mat or raft foundations are often made based on changes in stress calculated assuming uniform loading. The rigidity of the foundation structure will affect the accuracy of this assumption and the distribution of settlement. The flexibility of the foundation and the soil structure interaction can be difficult to assess. Predictions of differential settlement are often less accurate than those for total or average settlement for these reasons, especially for mat foundations.

Mat behavior can be estimated using a mat stiffness factor (K_m) which compares the foundation to the stiffness of the underlying soil. As indicated in Table 5-8, mats with low stiffness ratios can be considered completely flexible. Flexible mats will apply a relatively uniform pressure distribution, and the center, edges, and corners will settle differentially. Mats with high values of K_m will act in a rigid manner and will tend to settle uniformly. Influence factors for intermediate stiffness are provided by Brown (1969) and Frazer and Wardle (1976).

Table 5-8 Relative Mat Stiffness and Behavior (after Brown 1969, Frazer and Wardle 1976)

Foundation Shape	Mat Stiffness Factor, K_m	Mat Behavior		
		Flexible	Intermediate	Rigid
Circular	$K_m = 8 \frac{E_m(1-\nu_s)^2}{E_s} \frac{t_m^3}{B^3}$	$K_m \le 0.08$	$0.08 \le K_m \le 5$	$5 \le K_m$
Rectangular	$K_m = \frac{4}{3} \frac{E_m(1-\nu_s)^2}{E_s(1-\nu_m)^2} \frac{t_m^3}{B^3}$	$K_m \le 0.05$	$0.05 \le K_m \le 10$	$10 \le K_m$
Variables:	E_m = modulus of elasticity of mat, ν_m = Poisson's ratio of mat E_s = modulus of elasticity of soil, ν_s = Poisson's ratio of soil t_m = thickness of mat, B = diameter or width of mat (least dimension)			

5-7 METHODS OF CONTROLLING SETTLEMENT.

Methods for reducing or accelerating settlement are summarized in Table 5-9. Further details for some of the basic methods are discussed in the following sections. For a more in-depth summary of ground modification techniques that can be used to remove settlement potential, reduce excess settlement, or accelerate settlement, see FHWA's *Ground Modification Vol. 1 and 2* (2017).

5-7.1 Removal or Displacement of Compressible Soils.

Excavation and replacement is a simple method of reducing or eliminating settlement for cases were the compressible stratum is shallow and relatively thin. This method is particularly useful for sites where extensive earthwork is already required.

Surficial soils with low shear strength and high compressibility, such as organic soils, should be removed and replaced with engineered fill. The suitability of deeper soils to support the planned fill or structure will depend on the shear strength and compressibility of the underlying soils as judged by an appropriate subsurface exploration. A common example of removal and replacement is the removal of topsoil which occurs prior to the placement of most fills.

In some cases, partial excavation of very soft foundation soils can be accompanied by displacement caused by the weight of the new fill. The boundary between the new fill and the displaced soil should be kept as vertical as possible. This method is most applicable to the displacement of peat and muck deposits and has been used successfully for soft soils up to 65 feet deep. Jetting and blasting methods can be used in the fill and foundation to facilitate displacement of the soft soil. Caution should be used with partial displacement in fibrous organic soils, as these materials tend to resist displacement, which can result in trapped pockets and differential settlement.

Table 5-9 Methods to Reduce, Accelerate, or Prevent Excess Settlement (after FHWA 2017)

Primary Purpose	Method / Technology	Description / Comments
Reduce amount of soft soil	Removal and replacement	Full or partial removal of compressible soil reduces or eliminates settlement potential. Displacement methods may include jetting or various types of blasting.
	Partial displacement	
Reinforce soft soil	Column-supported embankments	Compressible soil is bypassed by much stiffer, reinforcing elements, typically columns. The columns transfer most of the load from the fill or structure through the soft soil to deeper and stiffer materials. A reinforced load transfer platform is often required at the ground surface. In some cases, the reinforcing elements also improve the surrounding soil.
	Reinforced load transfer platforms	
	Non-compressible columns	
	Stone columns	
	Rammed aggregate piers	
Improve soft soil	Deep mixing methods	Compaction and/or chemical modification of soft soil can reduce its compressibility and reduce settlement potential. Compaction methods are typically more effective on coarse-grained materials.
	Vibro-compaction	
	Dynamic compaction	
Accelerate consolidation of soft soil	Surcharge	Increased gradients cause the consolidation process to proceed more quickly. Final settlements can be equal to or greater than the settlement caused by the design load. Often used along with vertical drains.
	Pumping or vacuum	
	Electro-osmosis	
	Prefabricated vertical drains (PVDs)	Vertical drainage elements are used to shorten the drainage path. This allows pore pressures to dissipate and consolidation to occur more quickly.
	Aggregate columns or sand drains	
Reduce applied load to soft soil	Balanced / compensated foundation	Reduction of the applied stress will reduce the magnitude of the consolidation settlement. This can be accomplished by permanent excavation or the use of lightweight construction materials.
	Lightweight granular fill	
	Geofoam or foamed concrete	

5-7.2 Balancing Load by Excavation.

The *balanced load approach* (a.k.a. *compensated foundation* or *floating foundation*) can sometimes be used to support heavy structures over compressible strata. In this approach, the weight of the structure is balanced, completely or partially, by soil that is permanently excavated from the building footprint. The construction of a permanent basement level is required to create stress relief. This method works particularly well for situations where a stronger surface layer overlies a compressible stratum.

Excavation for the structure results in vertical stress relief and some amount of swelling or heave. If the weight of the structure is equal to or less than the weight of the excavated material, the total settlement experienced by the structure will be the result of recompression of the compressible strata. The magnitude of swelling and subsequent recompression will depend on construction and site factors, such as the amount of time between excavation and loading, the construction sequence, and the subsurface drainage conditions.

Dewatering may be required to facilitate the construction of a balanced foundation. If the groundwater is significantly lowered, the amount of heave and subsequent recompression will be reduced because of negative excess pore pressures in the soil.

Settlement for balanced foundations can be predicted using the methods in Sections 5-3 to 5-5. The net vertical stress ($q_{0\text{-}net}$) is found by subtracting the vertical stress reduction ($\sigma_{z\text{-}red}$) from the building load, q_0. The final groundwater conditions affect the value of $\sigma_{z\text{-}red}$. For cases where the groundwater is not lowered or is allowed to return to its initial condition following construction, $\sigma_{z\text{-}red}$ is equal to the total vertical stress at the foundation level prior to construction. If the groundwater is lowered permanently below the foundation level, $\sigma_{z\text{-}red}$ is equal to the effective vertical stress at the foundation level prior to construction.

5-7.3 Preconsolidation by Surcharge.

A surcharge causes some or all of the consolidation to occur prior to construction. This method works well for fill beneath paved areas, for large floor loadings, and for structures with relatively light column loads. For heavier structures, improvement by surcharging may not be sufficient to provide adequate bearing resistance. In this case, a portion of the surficial layer of the compressible soil may need to be replaced with a more rigid compacted fill or reinforced fill.

A portion of the predicted consolidation and secondary compression can be removed by surcharging as illustrated in Figure 5-27. The calculations in this figure assume that the time rate of consolidation is the same under both the surcharge load and the final load. This should be approximately true provided the coefficient of consolidation is not significantly different under the two loading conditions. In order to eliminate the settlement due to primary consolidation under the final load, the degree of consolidation required under the surcharge ($\overline{U}_{f+s}$) is:

$$\overline{U}_{f+s} = \frac{\log\left[1+\dfrac{q_f}{\sigma'_{z0}}\right]}{\log\left[1+\dfrac{q_f}{\sigma'_{z0}}\left(1+\dfrac{q_s}{q_f}\right)\right]} \tag{5-20}$$

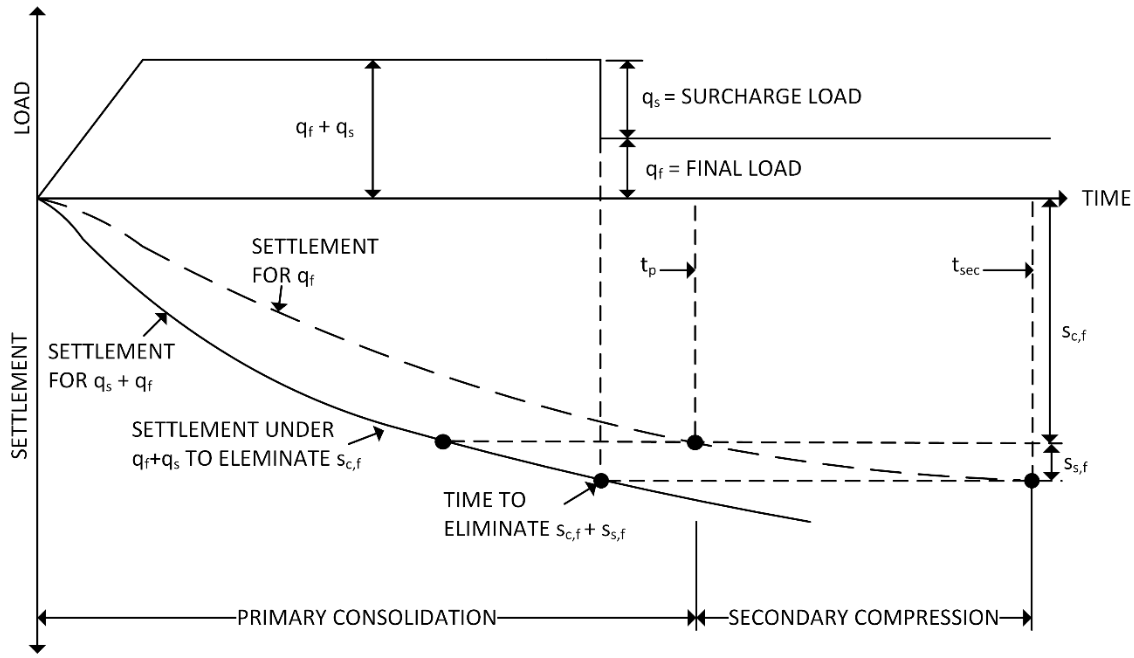
where:
q_f = final applied load,
q_s = additional surcharge load, and
σ'_{z0} = initial vertical effective stress at midpoint of the consolidating layer.

If some amount of secondary compression must also be removed by surcharging, the required degree of consolidation becomes:

$$\overline{U}_{f+s} = \frac{\left[\log\left(1+\dfrac{q_f}{\sigma'_{z0}}\right)+\dfrac{C_\alpha}{C_c}\log\left(\dfrac{t}{t_p}\right)\right]}{\log\left[1+\dfrac{q_f}{\sigma'_{z0}}\left(1+\dfrac{q_s}{q_f}\right)\right]} \tag{5-21}$$

where:
q_f = final applied load,
q_s = additional surcharge load,
σ'_{z0} = initial vertical effective stress at midpoint of the consolidating layer,
C_α / C_c = ratio of secondary to primary compression indices,
t_p = time required for primary consolidation, and
t = time after loading for which secondary compression is considered.

An example of the calculations for the surcharge approach is provided in Figure 5-28. The major limitations of the surcharge method are time and cost. The time required for consolidation to occur may not fit within the construction schedule. Use of vertical drains as described in the following section can alleviate this difficulty. In soft soils, shear failure can be induced at the edge of the surcharge. This should be considered using slope stability methods (Chapter 7) or bearing capacity theory (DM 7.2).



BY SELECTING AN APPROPRIATE SURCHARGE LOAD & DURATION OF SURCHARGE LOADING, ALL OR PART OF THE SETTLEMENT UNDER FINAL LOADING CAN BE ELIMINATED

σ'_{z0} = EXISTING OVERBURDEN PRESSURE
s_{cf} = SETTLEMENT DUE TO PRIMARY CONSOLIDATION UNDER q_f
s_{sf} = SETTLEMENT DUE TO SECONDARY CONSOLIDATION UNDER q_f
$s_{c,f+s}$ = SETTLEMENT DUE TO PARTIAL PRIMARY CONSOLIDATION UNDER $q_f + q_s$

$\overline{U}_{f+s} = \frac{s_{c,f}}{s_{c,f+s}}$ or $\frac{s_{c,f} + s_{s,f}}{s_{c,f+s}}$ = DEGREE OF CONSOLIDATION UNDER $q_f + q_s$ REQUIRED TO ELIMINATE PRIMARY CONSOLIDATION OR PRIMARY + SECONDARY UNDER q_f

t_p = TIME REQUIRED FOR COMPLETION OF PRIMARY CONSOLIDATION UNDER q_f OR $q_f + q_s$.
t_{sec} = TIME TO COMPLETE SPECIFIC AMOUNT OF SECONDARY COMPRESSION

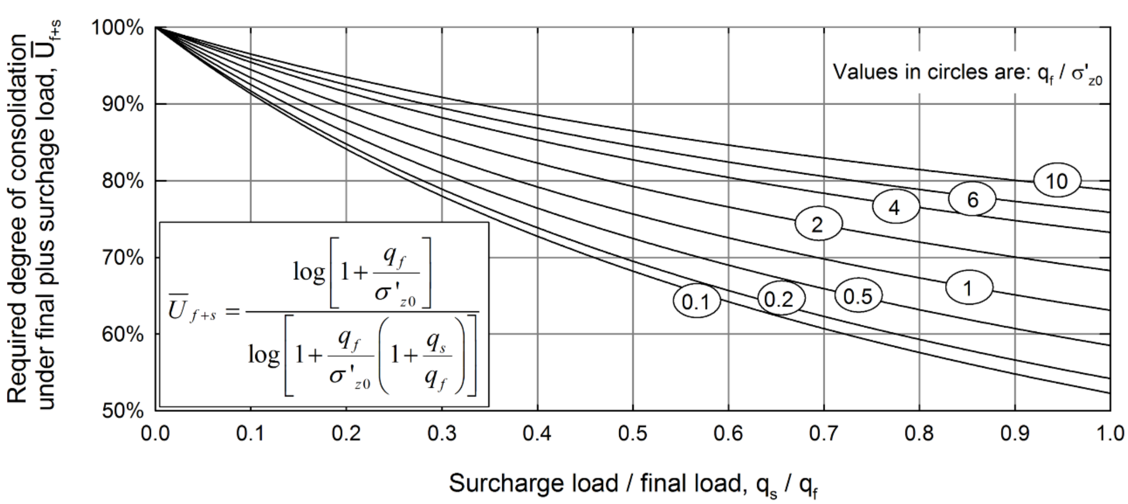
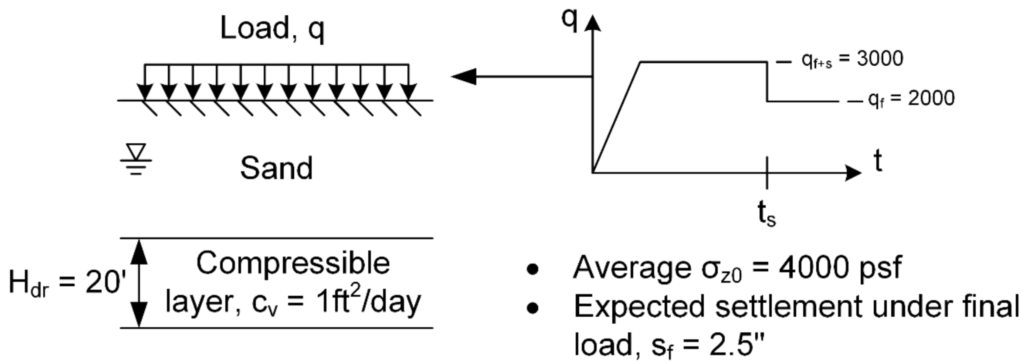


Figure 5-27 Surcharge Load and Consolidation Required to Eliminate Settlement under Final Load



<u>How long must surcharge be applied to remove 100% of s_f?</u>

$$\frac{q_f}{\sigma'_{z0}} = \frac{2000\,psf}{4000\,psf} = 0.5 \qquad \frac{q_s}{q_f} = \frac{1000\,psf}{2000\,psf} = 0.5$$

From Fig 5-27:
$$\overline{U}_{f+s} = \frac{\log\left[1+\frac{q_f}{\sigma'_{zo}}\right]}{\log\left[1+\frac{q_f}{\sigma'_{zo}}\left[1+\frac{q_s}{q_f}\right]\right]} = \frac{\log[1+0.5]}{\log[1+0.5[1+0.5]]} = 72\%$$

The time factor can be found using Fig 5-15, and the amount of time the surcharge must remain in place is:

$$T = -\frac{4}{\pi^2}\ln\left[\frac{\pi^2}{8}(1-\overline{U}_{f+s})\right] = 0.44 \qquad \text{Time, } t_s = \frac{T\,H_{dr}^{\,2}}{c_v} = \frac{0.44(20\,ft)^2}{1\,ft^2/day} = 176\,\text{days}$$

Figure 5-28 Surcharge Loading Example

5-7.4 Vertical Drains.

Vertical drains are constructed or inserted vertically through compressible soil layers. The drains intercept horizontal water flow. The water is then transmitted to a drainage layer at the surface and/or to underlying coarse-grained soil, depending on the drainage conditions. The drains are typically installed in triangular or square patterns as shown in Figure 5-29 with spacing ranging from 3 to 6.5 feet. Drains typically shorten the maximum drainage path to 8 feet or less. While vertical drains were constructed mostly of sand prior to the 1980s, current practice is to use drains comprised of a plastic core encased in geotextile fabric, typically referred to as *prefabricated vertical drains* (*PVD*). For detailed information on PVD materials and drain construction practices, see FHWA (2017).

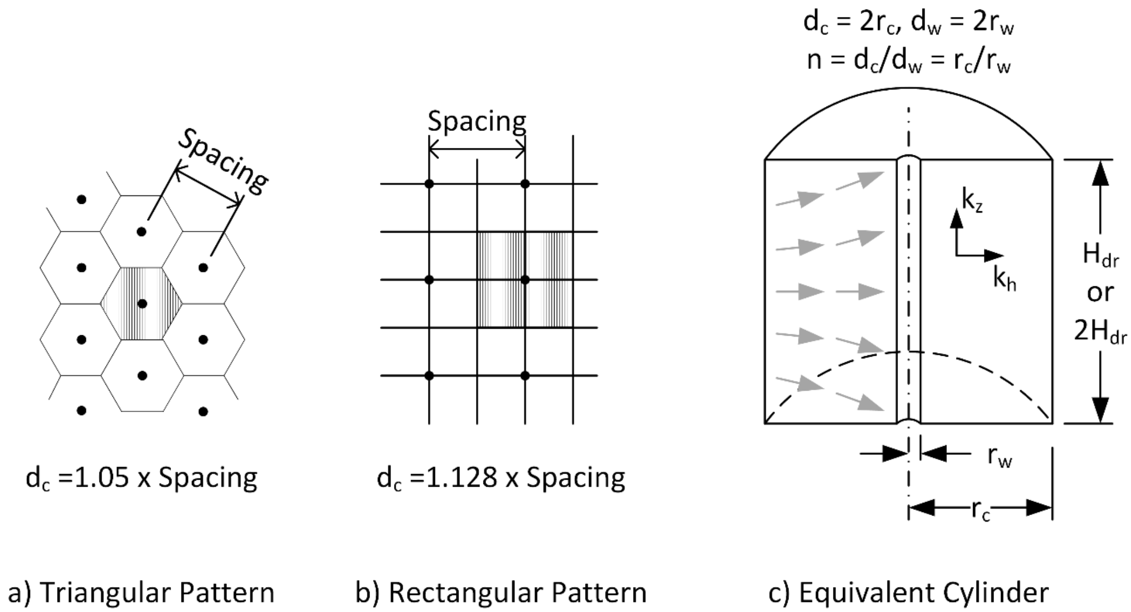


Figure 5-29 Vertical Drains – (a) Triangular Pattern, (b) Rectangular Pattern, and (c) Equivalent Cylinder for Theoretical Solutions

In addition to shortening the drainage path, vertical drains take advantage of the higher hydraulic conductivity and coefficient of consolidation often found in horizontal direction in many soils. While the vertical coefficient of consolidation can be measured in laboratory tests or estimated based on index tests (see Chapters 3 and 8), the horizontal coefficient of consolidation (c_h) is rarely measured directly. More often, c_h is assumed to be about 1.5 to 4 times higher than c_v, depending on the amount of horizontal layering present. Higher ratios of c_h to c_v are encountered when layers of silt and sand are present. Asaoka (1978) presents a method for determining c_h from field measurements on a test fill.

Many analytical and numerical methods have been proposed for radial drainage theory, most based on Barron (1948). The differences in the methods tend to have less effect on predictions of consolidation rate than the uncertainty and variability in c_h. Using the calculation method presented by FHWA (2017), the time factor (T_r) for a desired degree of radial consolidation ($\overline{U}_r$) is found by:

$$T_r = \frac{1}{8}\left(F_n + F_s + F_r\right)\ln\left(\frac{1}{1-\overline{U}_r}\right) \qquad \textbf{(5-22)}$$

where:
F_n = factor related to drain spacing,
F_s = factor related to soil disturbance (smear), and
F_r = factor related to well resistance in the drain.

If smear and well resistance are ignored, F_s and F_r are set equal to zero.

Figure 5-29 illustrates the relationship between the drain configuration and the *effective drainage diameter*, d_c. The drain spacing is often expressed in terms of the ratio (n) between the drainage diameter and the diameter of the well, d_w. The drainage factor (F_n) is equal to:

$$F_n = \frac{n^2}{n^2-1}\ln(n) - \frac{3n^2-1}{4n^2} \approx \ln(n) - 0.75 \qquad \textbf{(5-23)}$$

where:
n = ratio of d_c to d_w.

The error in the approximation is less than 10% for n greater than 4 and less than 1% for n greater than 12.

Most PVDs have a rectangular cross section while the solutions to radial consolidation problem assume a circular drain. Hansbo (1979) found that the equivalent drain diameter can be approximated as:

$$d_w = \frac{2(a+b)}{\pi} \qquad \textbf{(5-24)}$$

where:
a and b = PVD dimensions.

Values of d_w for modern PVDs range from 1.5 to 5.5 inches. A diameter of 2 inches is commonly used, which results in n values in the range of 20 to 50 for typical drain spacing.

Given the uncertainties with the measurement or estimation of soil properties, the effects of soil disturbance or smear around the drains and drain resistance are often ignored (FHWA 2017). Smear tends to be important mostly for drains in high plasticity clays or sensitive soils, or where c_h has been directly and accurately measured. In order to account for smear, the soil disturbance factor (F_s) can be calculated as

$$F_s \approx \frac{k_h}{k_s}\ln(s) \qquad \textbf{(5-25)}$$

where:
k_h = hydraulic conductivity of the soil layer,
k_s = hydraulic conductivity of the disturbed zone, and
s = ratio of the diameter of the disturbed zone to the diameter of the drain.

Resistance to water flow within the drain can also decrease the effectiveness of vertical drains. If desired, this effect can be estimated by:

$$F_r = \pi z\left(2L_m - z\right)\frac{k_h}{q_w} \qquad \textbf{(5-26)}$$

where:
z = depth along the drain,
L_m = maximum distance water must flow through the drain, and
q_w = discharge capacity of the drain.

5-7.4.1 Combination of Vertical and Horizontal Drainage Effects.

Prediction of the degree of consolidation from vertical drainage can be combined with the effects of horizontal drainage to vertical drains using the method proposed by Carrillo (1942). The combined degree of consolidation ($\overline{U}_c$) in percent is:

$$\overline{U}_c = 100 - \frac{\left(100-\overline{U}_r\right)\left(100-\overline{U}_z\right)}{100} \qquad \textbf{(5-27)}$$

where:
$\overline{U}_r$ = degree of consolidation for radial drainage, and
$\overline{U}_z$ = degree of consolidation for vertical drainage.

5-7.4.2 Vertical Drain Design.

Vertical drain design involves the selection of the appropriate drain type, drain spacing, and construction procedures based on the time available for consolidation, design degree of consolidation for that time period, and soil properties. The appropriate time factor for radial drainage (T_r) can be determined from Equation 5-22 or from Figure 5-30 or Figure 5-31. Figure 5-30 plots the relationship between $\overline{U}_r$ and T_r for a range of drain spacing for three smear conditions. Figure 5-31 provides solutions for gradual loading and radial drainage. From T_r and the time available for consolidation (t) the required effective drain diameter (d_c) can be calculated as:

$$d_c = \sqrt{\frac{c_h t}{T_r}} \qquad \textbf{(5-5-28)}$$

where:
c_h = coefficient of consolidation in the horizontal direction.

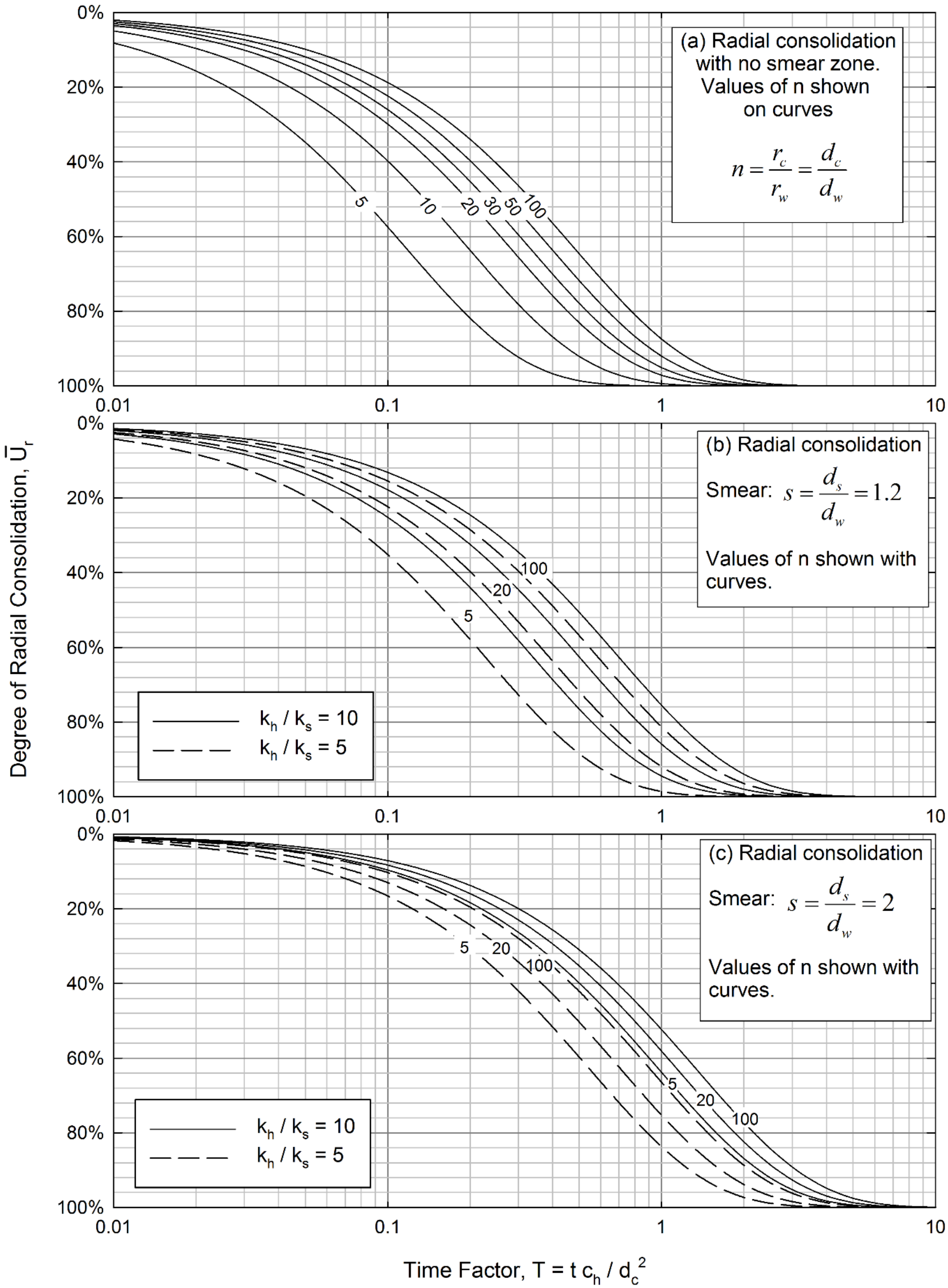


Figure 5-30 Degree of Radial Consolidation

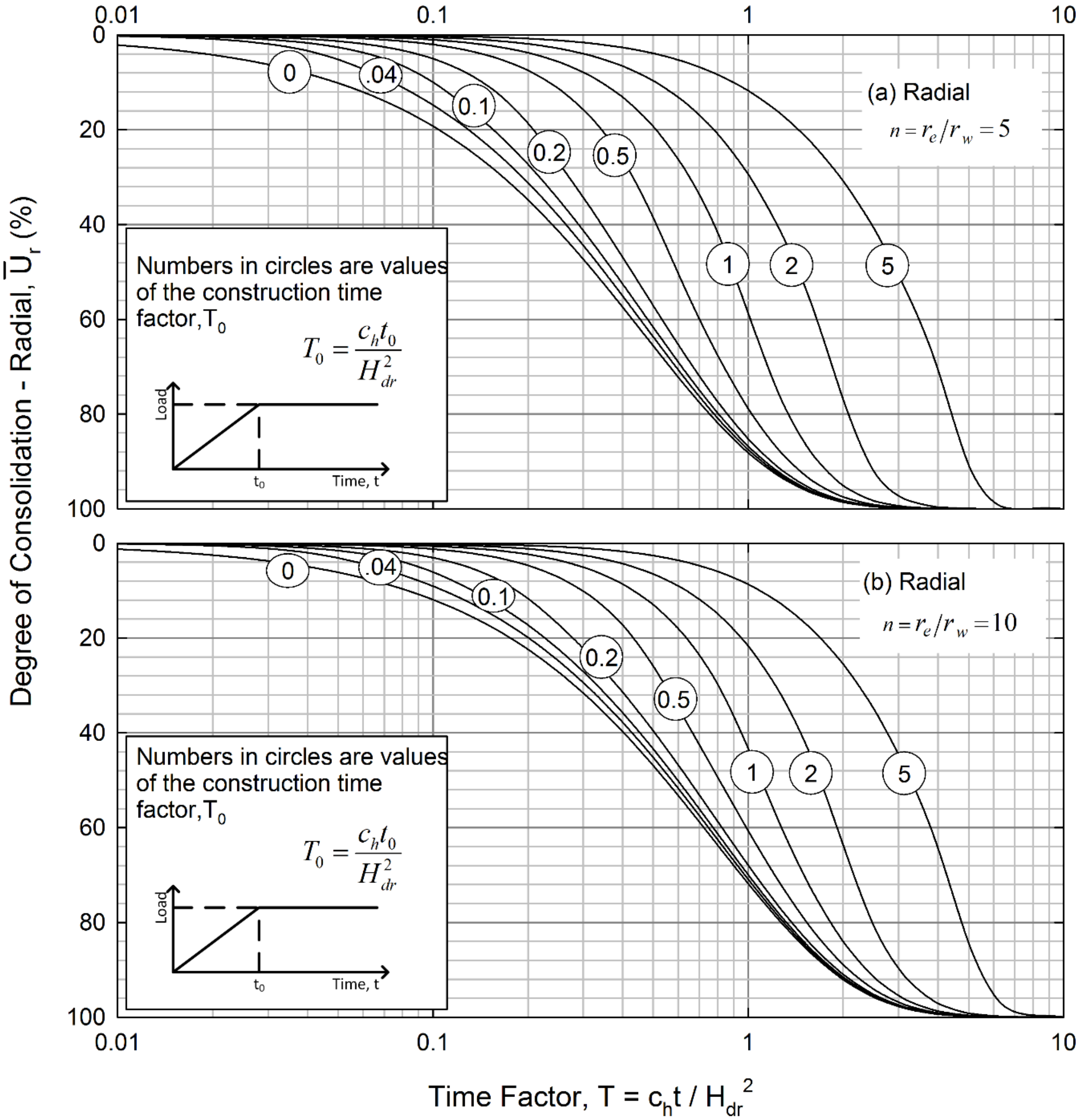


Figure 5-31 Radial Consolidation with Gradual Loading (after Olson 1977)

An alternative approach is provided in the design chart in Figure 5-32. This chart allows the spacing to be selected directly based on the other properties and variables. Other drain design considerations include stability against foundation failure and provision of adequate flow in the surface drainage blanket. An example of vertical drain design is provided in Figure 5-33.

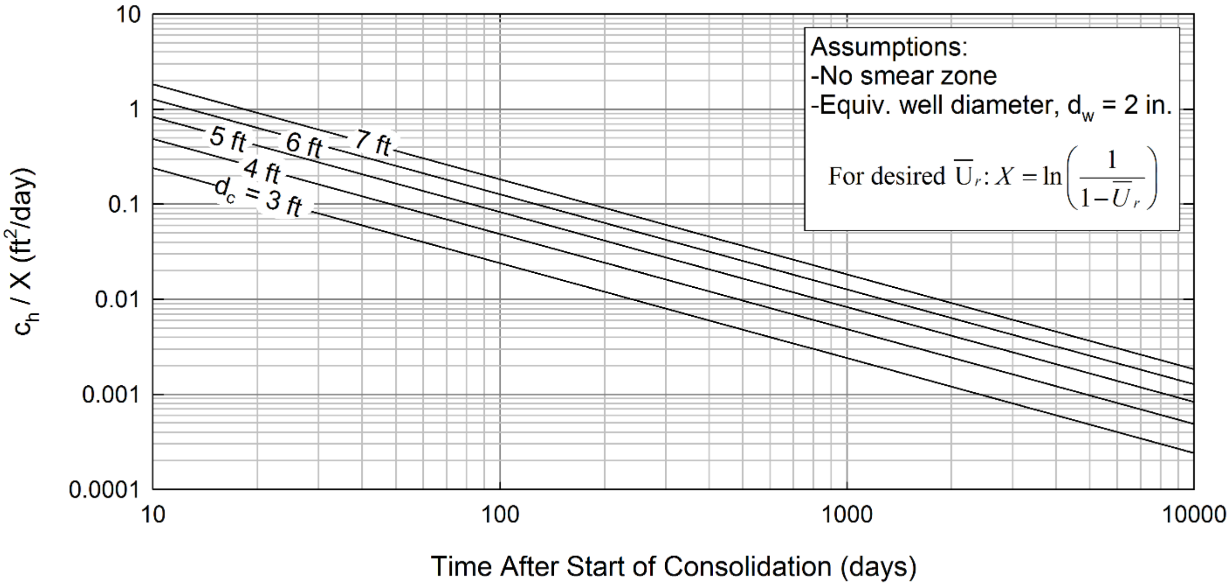


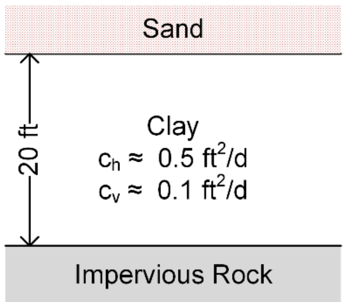
Figure 5-32 Design Chart for Radial Drainage

5-7.4.3 Vertical Drains with Surcharge.

In some cases, a surcharge is used along with vertical drains to accelerate the rate of settlement and reach the final settlement more quickly. Surcharges are especially important for soil conditions in which a large amount of secondary compression is likely to occur. The method presented in Figure 5-27 can also be used with vertical drains.

5-7.4.4 Construction Control Requirements.

Extensive discussion of specifications, quality assurance, site preparation, and installation procedures for vertical drains can be found in FHWA (2017). Field instrumentation should be installed to monitor performance of the drains, progress of consolidation, and horizontal deformations. The type of instrumentation required depends on the application. For cases where instability is not likely, such as a low height fill of large lateral extent, the primary purpose of instrumentation is to monitor progress of consolidation. Settlement plates are sufficient for this purpose. On the other hand, stability and pore pressure dissipation is a concern for the construction of large embankments over soft soil. Piezometers should be used to monitor the dissipation of excess pore pressure during consolidation. Inclinometers should be installed to monitor horizontal deformations in the foundation soil.



Proposed Vertical Drain Design

-Triangular pattern with spacing of 6 ft
-Equiv. well diameter, d_w = 2 in. = 0.167 ft
-Ignore smear and well effects

A) Determine the time required to reach 90% degree of consolidation based on radial drainage alone.

Equivalent diameter, d_c = 1.05 x spacing = 1.05 (6 ft) = 6.3 ft

$n = d_c / d_w$ = 6.3 ft / 0.167 ft = 38

$F_n \approx \ln(n) - 0.75 = \ln(38) - 0.75 = 2.88$, assume $F_s = 0$ and $F_r = 0$

From Eqn. 5-22: $T_r = (1/8)\ F_n \ln(1 / (1 - U_r)) = 0.125\ (2.88) \ln(10) = 0.83$

(Also matches value obtained for n = 38 and U_r = 90% on Fig. 5-25a)

Time required:

$$t = \frac{T_r \cdot d_c^2}{c_h} = \frac{0.83(6.3\,ft)^2}{0.5\,ft^2 / day} = 66\,days$$

B) Determine the combined degree of consolidation including vertical drainage after 66 days.

Vertical time factor:

$$T_v = \frac{t \cdot c_v}{H_{dr}^2} = \frac{(66\,days)(0.1ft^2/day)}{(20\,ft)^2} = 0.017$$

From Fig. 5-15:

$$\overline{U}_z = 0.14$$

Combined $\bar{U}_c$:

$$\overline{U}_c = 100\% - \frac{(1-\overline{U}_r)(1-\overline{U}_z)}{100\%} = 100\% - \frac{(1-90\%)(1-14\%)}{100\%} = 91\%$$

Figure 5-33 Radial Consolidation Example

5-8 VOLUME EXPANSION.

5-8.1 Mechanics of Volume Expansion.

Positive volume change or volume expansion of soil is controlled by a variety of factors. For fine-grained soils, these factors include physical particle interactions, chemical interactions, mineralogy, soil fabric or structure, stress history, temperature, and pore water chemistry.

Unloading or reduction in effective stress is the most important physical process that causes swelling in non-frozen soils. This unloading can be the result of a decrease in the total stress, such as that caused by an excavation, or as the result of increased positive pore water pressure from a raised groundwater level.

Various theories have attempted to explain the chemical processes associated with swelling, including osmotic pressure theory and water adsorption theory (Mitchell 1993). These theories predict the *swell pressure*, which is the pressure exerted by the swelling soil on an unyielding boundary. While such theories have a limited degree of accuracy and are not typically useful for practical application, they provide insight into general trends in soil behavior. The osmotic pressure concept shows that pore water with low electrolyte concentration leads to higher swell pressures. Similarly, according to water adsorption theory, the specific surface area of the clay particles is the most important factor for determining the amount of water required for hydration. For this reason, clay minerals with very thin particles with high surface area, such as montmorillonite, smectite, and vermiculite, are the most susceptible to swelling. The liquid limit and clay fraction are indicators of the amount of these swelling clay minerals present in a soil (Terzaghi et al. 1996).

Soil and rock that has been consolidated to a relatively low void ratio is the most susceptible to swelling. Low void ratios are the result of either high normal stresses or high levels of matric suction (ψ) under unsaturated conditions. The deformation experienced during consolidation stores energy in the soil particles. In addition, the water content in these soils may be lower than that required to fully hydrate the clay particles. If either the normal stress or the suction is lowered, the clay will tend to swell to release the stored energy and to hydrate the clay minerals. Some clay minerals, such as kaolinite, exhibit swelling mostly at the low void ratio associated with heavy overconsolidation. Clays containing more active minerals, such as sodium montmorillonite, experience similar amounts of swell regardless of void ratio because the swelling behavior is dominated by hydration.

Clay shales and shales containing pyrite (iron sulfide) or anhydrite (calcium sulphate) are also susceptible to swelling when exposed to water and/or air. The oxidation and hydration of pyrite and anhydrite can cause a volumetric expansion of ten times the original volume.

Soils can also experience volume expansion caused by freezing and the formation of ice lenses within the soil. Silts, silty sands, and fine sands are particularly susceptible to frost-related swell. These soils have moderate hydraulic conductivity which allows water to flow easily and a small enough void space to permit a significant level of capillary rise. For design of foundations in frost-susceptible soils, see ASCE (2001).

5-8.2 Effects of Volume Expansion.

Below an excavation, the total vertical stress is reduced, which initially causes a reduction in pore water pressure. As the pore water pressures return to equilibrium, the effective stress on the soil reduces and the soil swells. In most cases, excavation is followed by the construction of a building and the application of a pressure (q_0) that meets or exceeds the reduction in total stress. In this case, the heave caused by stress reduction will be cancelled out by reloading. Movements during these stages of construction are typically difficult to predict.

Negligible heave is observed for excavations in coarse-grained soils above the water table. Soft clays will experience immediate distortion-related swell that can be predicted using the method in Section 5-5.1. However, the required elastic modulus can be very difficult to predict. Over time, clay soils will experience an increase in water content and swell as a result of the change in effective stress.

In arid climates, changes in water content tend to vary depending on the location below a structure. The soil below the middle of the structure interacts less with the environment, and the water content in this zone tends to increase with time. This results in swell below the middle of the structure. Around the edges, the soil experiences more fluctuation in water content and can shrink, leading to perimeter settlement. The combination of these two mechanisms can result in the hogging shape of differential movement described earlier.

5-8.3 Estimates of Heave or Swell Pressure.

Many methods have been proposed to estimate one-dimensional heave (vertical movement) or swell pressure. Some of these methods are empirical, based mostly on index properties of the soil. Other methods use theory and oedometer testing to predict swelling caused by both changes in total stress and changes in suction.

Most methods predict a swell percentage or vertical strain of the soil, which must be multiplied by the thickness of soil that experiences swell. The thickness of soil that swells as a result of a change in total stress, such as an excavation, is related to the size of the excavation. This depth of influence can be estimated using the methods presented in Chapter 4. The thickness of soil that swells due to changes in suction is related to the depth of the groundwater table and the depth of seasonal water content fluctuations, which is commonly in the range of 3 to 15 feet depending on climate.

In some cases, it is helpful to consider the swell pressure that an expansive soil or rock can develop against an unyielding support or structure under a certain set of initial conditions. ASTM D4546 provides three different methods to measure the swell pressure in a one-dimensional consolidation apparatus. The swell pressure mobilized *in situ* is often less than that measured in the laboratory (Terzaghi et al. 1996).

5-8.3.1 Empirical Relationships.

Some of the available empirical correlations related to swelling are summarized in Table 5-10. These methods are mostly based on the Atterberg limits, clay fraction, and initial soil state as described by unit weight and water content. A few of the correlations require the soil's specific gravity or initial matric suction.

Table 5-10 Empirical Correlations to 1D Heave and Swell Pressure and Required Input Parameters (after Rao et al. 2011, Vanapalli and Lu 2012)

Empirical Method for Prediction of:	**Source**	**Atterberg Limits**	**Grain-Size Distribution**	**Initial State (γ, w)**	**Specific Gravity**	**Initial Suction**
1D Heave	Seed et al. (1962)	X	X			
	Van der Merwe (1964)	X	X			
	Ranganatham and Satyanarayan (1965)	X	X			
	Vijayvergiya and Ghazzally (1973)	X		X		
	McCormack and Wilding (1975)		X	X		
	O'Neil and Ghazzally (1977)	X		X		
	Johnson and Snethen (1978)	X		X		
	Weston (1980)	X		X		
	Bandyopadhyay (1981)	X	X			
	Chen (1975)	X				
	Cokca (2002)	X	X			X
	TXDOT (2014)	X	X	X		
Swell Pressure	Komornik and David (1969)	X		X		
	Nayak and Christensen (1971)	X	X	X		
	Schneider and Poor (1974)	X		X		
	McCormack and Wilding (1975)		X	X		
	Johnson (1978)	X				
	Nayak (1979)	X				
	Erzin and Erol (2004)	X		X		
	Sridharan and Gurtug (2004)			X	X	
	Thakur and Singh (2005)					X
	Erzin and Erol (2007)	X		X		X

Correlations, such as those listed in Table 5-10, are useful because of their simplicity and the ready availability of input information. However, the correlations are based on limited data sets and are most appropriate for application in similar soils. In addition, correlations that are only based on Atterberg limits and clay fraction will not be able to account for differences caused by initial soil conditions. None of the correlations presented in Table 5-10 is able to account for the contribution of change in stress to heave or the effects of total normal stress on swelling.

5-8.3.2 Stress-Strain-Suction Relationships.

More rigorous predictions of one-dimensional swelling consider the vertical strain that results both from changes in total stress and from changes in suction. These methods require measurement of the soil's stress-strain relationship, often at different levels of controlled suction. Suction-controlled oedometer tests and coefficient of linear extensibility tests are two means to obtain this data.

A variety of methods have been developed to predict the swelling strain caused by changes in total stress and changes in suction (or water content). Terzaghi et al. (1996) describes how the swelling process can be described in a manner analogous to consolidation. Vanapalli and Lu (2012) summarize many different methods to account for the stress-strain-suction relationship in the calculation of vertical strain based on the results of one-dimensional swell pressure measurements, suction-controlled oedometer tests, and coefficient of linear extensibility tests. Some of the methods also require measurement of matric suction as a function of water content. Terzaghi et al. (1996) also emphasizes that the deterioration of the clay structure during swelling often leads to a significant amount of time-dependent secondary swelling.

While theoretically sound, predictions of swell based on stress-strain-suction relationships are usually impractical. The amount of swell predicted by these methods is heavily dependent on soil moisture conditions at the start of construction, which cannot be accurately predicted during the design phase. In addition, the advanced soil testing required to use these methods is typically unavailable.

5-8.4 Design in Expansive Soils.

In many cases, heave and swell pressure estimates are used mostly to make decisions regarding remedial treatment of expansive soils and rock because of the uncertainties inherent in these estimates. Design of structures and pavements focuses on efforts to eliminate or reduce the effects of shrink-swell behavior of expansive soils and rock that are deemed to be problematic. Table 5-11 summarizes common approaches to foundation design in expansive soil and rock.

Table 5-11 Foundation Design Approaches in Expansive Soil (after Bowles 1996)

Approach	Comments
Alter the soil	Possible admixtures include lime, cement, or kiln dust. The admixtures reduce the hydration demands of the clay minerals and also increase bonding that resists swelling. Limited to depths for which it is practical to mix and recompact the soil.
Wet compaction	Compaction on the "wet" side of the line of optimums results in degree of saturation greater than 80 to 85%. High initial saturation reduces the potential for swelling but will increase shrinkage potential in areas exposed to the atmosphere. Wet compaction results in lower dry unit weight that may have lower shear strength and stability.
Control direction of swelling	Construct void zones within the foundation system, such as waffle slabs. If the soil has a tendency to swell, it will first swell into the voids prior to affecting the structure.
Eliminate changes in water content	Environmentally driven changes in water content cause most problematic swelling. Swelling can be bypassed by extending the structure below the zone of active water content change. If the structure cannot be constructed at this depth, the excavation can be filled with soils that are not susceptible to swelling and have low hydraulic conductivity.
Use a capillary break	In cases where the source of water is migration from deeper soils, a capillary break of coarse-grained material or geomembrane may be useful.
Use a sealing compound	Asphaltic sealing compounds can be used on expansive shale to reduce or prevent water from reaching the rock.
Design against swelling	The foundations can be extended below the active zone depth and designed with sufficient uplift capacity to resist the forces applied to the structure by swelling soil. Drilled piers with a bond break along the side of the shaft in the active zone are one common approach using this method.
Balance swell pressure	For some structures, the structural loads can be concentrated to increase the bearing pressure to levels that meet or exceed the swell pressure. This approach is not practical for most low-rise buildings because the structural loads are too light. In addition, the bearing pressure required to resist swell may exceed the allowable bearing capacity of the soil.

5-8.5 Construction Practices in Expansive Soils.

Good construction and maintenance practices in expansive soils and rock are primarily related to limiting exposure to the atmosphere and changes in water content. For swelling caused mostly by a temporary reduction in vertical stress, swelling can be reduced by collecting and removing surface water, pumping down groundwater, and placing a concrete mudmat immediately after excavation. Inert shale should be protected from wetting both during construction and long-term through the elimination of underdrainage, use of impervious backfill, and placement of appropriate surface drainage features. Excavations in shale should not be completed to final grade until foundation concrete is ready for placement. Some level of temporary and permanent protection can be provided through asphaltic coatings.

Some structures extend below future surface water or the groundwater table. In this case, access to water is impossible to avoid. The methods described in Table 5-11 can be used to reduce or restrict swelling. Where rock is shallow, rock bolts can be used with appropriately reinforced slabs and foundations to resist swelling.

For buildings in semi-arid and arid climates, changes in suction within the soil are the major cause of shrinking and swelling. Efforts should be made to collect surface and rain water near structures to prevent wetting of the soils during wet periods. During dry periods, evaporation and transpiration remove water from soil and increase suction leading to shrinkage. These effects can be limited through the use of pavement and avoiding placement of vegetation around structures.

Engineered fill constructed from high plasticity clays will tend to shrink and swell in response to the climate. In addition to deformation, this volume change results in a time-dependent reduction in shear strength that must be accounted for in slope design. If possible, high plasticity clays should not be used for the portions of embankments exposed to fluctuation in water content. Swelling of high plasticity clay fill can be avoided by compaction at high water content (i.e., wet of the line of optimums). Fill compacted wet will have lower dry unit weight, lower shear strength, and higher compressibility. High plasticity clay can be placed wet for structural fill below lightly loaded buildings provided the lower bearing capacity is considered. Consistent relative compaction is important to avoid differential settlement. Admixtures, such as cement or lime, can also be mixed with high plasticity clay fill during construction to reduce swelling potential.

5-9 HYDROCOMPRESSION.

Hydrocompression refers to the volume change of compacted soil when wetted following construction. This phenomenon is especially problematic in deep fills constructed from sandy clays and clayey sands (Brandon et al. 1990). Significant settlement can occur in the regions of deep fill while net swelling may result in areas of relatively shallow fill depth. Damage to structures by hydrocompression tends to be worst over locations where the fill depth is changing rapidly and strains are extensional at the surface. The damaging effects of hydrocompression can be reduced by increasing the relative compaction of the fill and/or increasing the compaction water content.

The magnitude of hydrocompression can be predicted using the procedure described in Brandon et al. (1990). Specimens of the fill material can be compacted and loaded incrementally in one-dimensional consolidation to a range of total vertical stresses corresponding to those present in the planned or existing fill. After the intended total vertical stress is applied, the specimen is inundated with water and the volumetric strain caused by wetting is measured. In this manner, the relationship between volumetric strain caused by wetting and confining stress can be estimated. The expected hydrocompression can be found by dividing the fill depth into thin sublayers (see Figure 5-5c) and determining the change in thickness from the corresponding strain.

5-10 SUGGESTED READING.

Topic	Reference
Settlement Calculations	Duncan, J. M. and Buchiagnani, A. L. (1987). *Engineering Manual for Settlement Studies,* CGPR #2, Center for Geotechnical Practice and Research, Virginia Tech, 94 pp.
Vertical Drains	Federal Highway Administration (FHWA) (2017). *Ground Modification Methods Reference Manual – Volume I*, FHWA-NHI-16-027, Geotechnical Engineering Circular 13, Washington D.C.
Volume Expansion	Vanapalli, S. K. and Lu, L. (2012). “A state-of-the-art review of 1-D heave prediction methods for expansive soils.” *International Journal of Geotechnical Engineering*, 6, 15-41.

5-11 NOTATION.

Symbol	Description
B	Shortest dimension of foundation or loaded area
C_1	Schmertmann coefficient to correct for the effects of embedment
C_2	Schmertmann coefficient to correct for the effects of time (creep)
C_c	Compression index
$C_{\varepsilon c}$	Modified compression index
c_h	Coefficient of consolidation in horizontal direction
C_r	Recompression index

Symbol	Description
$C_{\varepsilon r}$	Modified recompression index
C_t	Creep factor for coarse-grained settlement methods
c_v	Coefficient of consolidation in vertical direction
C_α	Secondary compression index
$C_{\varepsilon\alpha}$	Modified secondary compression index
d_c	Effective drainage diameter
d_w	Equivalent diameter of well or PVD
e_0	Initial void ratio
E_m	Modulus of elasticity of mat
E_s	Modulus of elasticity of soil
E_u	Undrained modulus
E/G	Relative stiffness for structures
F_n	Radial drainage factor related to drain spacing
F_r	Radial drainage factor related to well resistance
F_s	Radial drainage factor related to soil disturbance (smear)
H	Initial thickness in settlement calculations
H_{dr}	Drainage path length
H_i	Thickness of each soil layer (may be listed without subscript)
H'_t	Total thickness of transformed soil system
I_z	Schmertmann strain influence factor
I_{zp}	Schmertmann peak influence factor
k_h	Hydraulic conductivity in horizontal direction
K_m	Mat stiffness factor
k_s	Hydraulic conductivity of the disturbed zone
k_v	Hydraulic conductivity in vertical direction
l	Distance between two points along a structure
L	Longest dimension of a foundation or loaded area
LL	Liquid limit
L_m	maximum distance water must flow through a vertical drain
m	Empirical exponent used to relate undrained shear strength to OCR

Symbol	Description
N_{60}	Standard Penetration Test corrected blow count
n	Vertical drain spacing ratio
N	Standard Penetration Test blow count
N'	Average Standard Penetration Test value
N'_{SM}	Standard Penetration Test blow count for saturated silty sands
OCR	Overconsolidation ratio
P_a	Atmospheric pressure
q_c	Cone tip bearing resistance
q_0	Applied stress at the base of the foundation or structure
$q_{0\text{-}net}$	Net vertical stress applied by the structure
q_f	Applied stress following removal of surcharge
q_s	Surcharge load
q_w	Discharge capacity of the drain
s	Ratio of the disturbed zone diameter to the diameter of the drain
s	Settlement
s_c	Primary consolidation settlement
s_s	Secondary compression settlement
s_u	Undrained shear strength
t	Time after start of consolidation
T	Time factor
t_m	thickness of mat
t_p	Time required to finish primary consolidation
T_r	Time factor for radial consolidation
T_v	Time factor for vertical drainage
u_0	Initial pore water pressure
$\bar{U}_c$	Combined degree of consolidation
$\bar{U}_{f+s}$	Degree of consolidation following surcharge application
$\bar{U}_r$	Degree of radial consolidation
USR_{NC}	Undrained strength ratio for normally consolidated conditions
u_x	Excess pore water pressure

Symbol	Description
U_z	Degree of compression
$\bar{U}_z$	Average degree of consolidation
w_n	Natural water content
z	Depth along vertical drain
z_i	Layer thickness for settlement calculations
α	Settlement correction factor
γ_w	unit weight of water
δ / l	Angular distortion
δ_{max}	Differential settlement
ΔH	Change in layer thickness
Δ/L	Deflection ratio
$\Delta\sigma_z$	Change in total vertical stress
ε_{crit}	Critical strain for structural distress
εz	Vertical strain
μ_0	Influence factor associated with embedment of the load
μ_1	Influence factor associated with problem geometry and Poisson's ratio
ν	Poisson's ratio
ν_m	Poisson's ratio of mat
ν_s	Poisson's ratio of soil
σ'_p	Preconsolidation stress
σ'_z	Vertical effective stress
σ'_{z0}	Initial or *in situ* vertical effective stress
σ'_{zp}	Initial vertical effective stress at depth of Schmertmann peak influence factor
σ_{z-red}	Vertical stress reduction
ψ	Matric suction
ω	Tilt angle due to differential settlement

CHAPTER 6 SEEPAGE AND DRAINAGE

6-1 INTRODUCTION.

6-1.1 Scope.

This chapter discusses methods for analyzing seepage in soils and bedrock and provides design guidance for drainage elements in structures and foundations. The chapter provides a summary of available methods for analyzing the seepage regime, descriptions and analysis methods for internal erosion mechanisms, and discussion of seepage and internal erosion mitigation methods.

6-1.2 Background.

Seepage is the flow of water through interstitial voids of soil or rock. Seepage is driven by differential potential energy of water (i.e., *hydraulic head*) acting across the soil or rock mass, resulting in the flow of water from higher to lower potential energy.

Seepage is a common phenomenon in geotechnical engineering applications and can occur as natural groundwater flow, seepage through dams and levees or their foundations, or flow into excavations extending below the groundwater surface. While the movement of water occurs in unsaturated soils above the groundwater table, this chapter deals only with seepage that occurs under saturated conditions.

Undesirable consequences of seepage can include internal erosion, excessive water loss or accumulation, and excessive pore water pressures. Under the right conditions, seepage can result in erosion of soil or rock, or internal erosion. Several different mechanisms of internal erosion have been identified that can occur by one of several mechanisms. In cases where seepage quantities are large, problems can occur, including: excessive water loss from reservoirs, flooding of excavations, and unstable ground due to excess moisture. Seepage may also result in excess water pressures under structures leading to instability and uplift forces.

This chapter also discusses a number of strategies and methods for mitigating the undesirable effects of seepage discussed in the previous paragraph. Each method utilizes one or a combination of three basic strategies: 1) blocking or lengthening the seepage pathway, 2) draining the excess water pressures in a controlled manner, and 3) filtering the seepage to block the transportation of soil particles.

6-2 SEEPAGE ANALYSES.

6-2.1 Hydraulic Head.

Hydraulic head is a measure of the energy of the water acting on or within geologic media, expressed in terms of length units and referenced to a consistent datum. The total hydraulic head (h_t) at any given point is composed of three components: the pressure head (h_p), the elevation head (h_z), and the velocity head (h_v). In geologic media, the velocity head is typically negligible and the total head is expressed as:

$$h_t = h_p + h_z = \frac{u}{\gamma_w} + z \quad \textbf{(6-1)}$$

where:
u = the water pressure at the point of interest,
γ_w = the unit weight of water, and
z = the elevation of the point of interest above the elevation datum.

The total hydraulic head (h_t) at a point is the height above the elevation datum that water would rise in a piezometer if the tip of that piezometer were located at the point of interest as illustrated in Figure 6-1a. The total hydraulic head will vary within a flow regime unless conditions are completely static (i.e., no flow is occurring).

As an example, consider the pressurized tank in Figure 6-1b. Piezometers have been set at two points in the side of the tank and the water rises in the piezometer above the elevation of the tank due to the pressure in the tank. The pressure head (h_p) is the height that the water rises above the point of interest and the elevation head (h_z) is the height of the point of interest above the datum that has been set below the tank. The total head (h_t) is the combined heights of h_p and h_z and is the total height that the water rises above the set datum. Since there is no flow within the tank, h_t is constant throughout the tank although h_p and h_z vary with elevation.

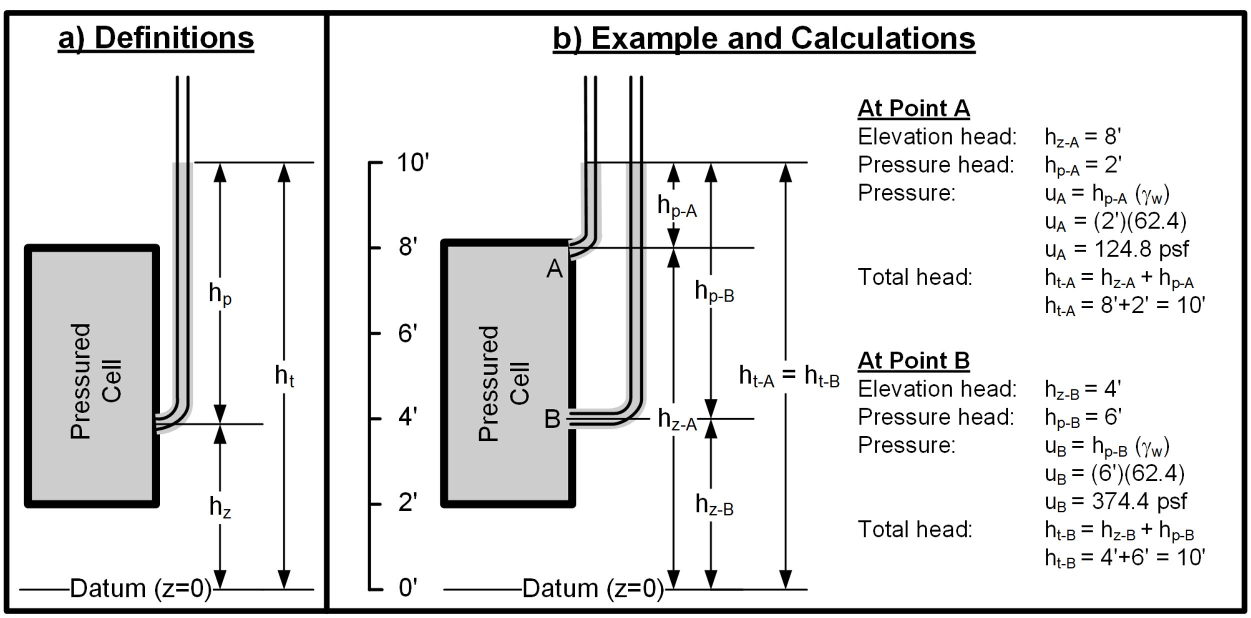


Figure 6-1 Example of the Components of Hydraulic Head

6-2.2 Darcy's Law and One-Dimensional Flow.

The principles of seepage mechanics and analysis of the seepage regime are best illustrated by considering the example of one-dimensional flow illustrated schematically in Figure 6-2. A soil-filled conduit with a cross section of area (A) and a length (L) is attached to water reservoirs with different total heads. The difference in water height in piezometers at each end of the conduit indicates the differential total head (h_L) or head loss across the soil. This head also represents the amount of energy that must be dissipated as the water flows through the soil. The differential head creates a *hydraulic gradient* (i), which is defined as:

$$i = \frac{h_L}{L} \tag{6-2}$$

where:
i = the hydraulic gradient,
h_L = the differential total head (or head loss), and
L = the length over which h_L occurs.

The hydraulic gradient forces the water to flow through the soil at a *volumetric flow rate* (q) that is sufficient to create the head loss associated with h_L. The volumetric flow rate is defined as the flow volume that passes through the soil per unit of time.

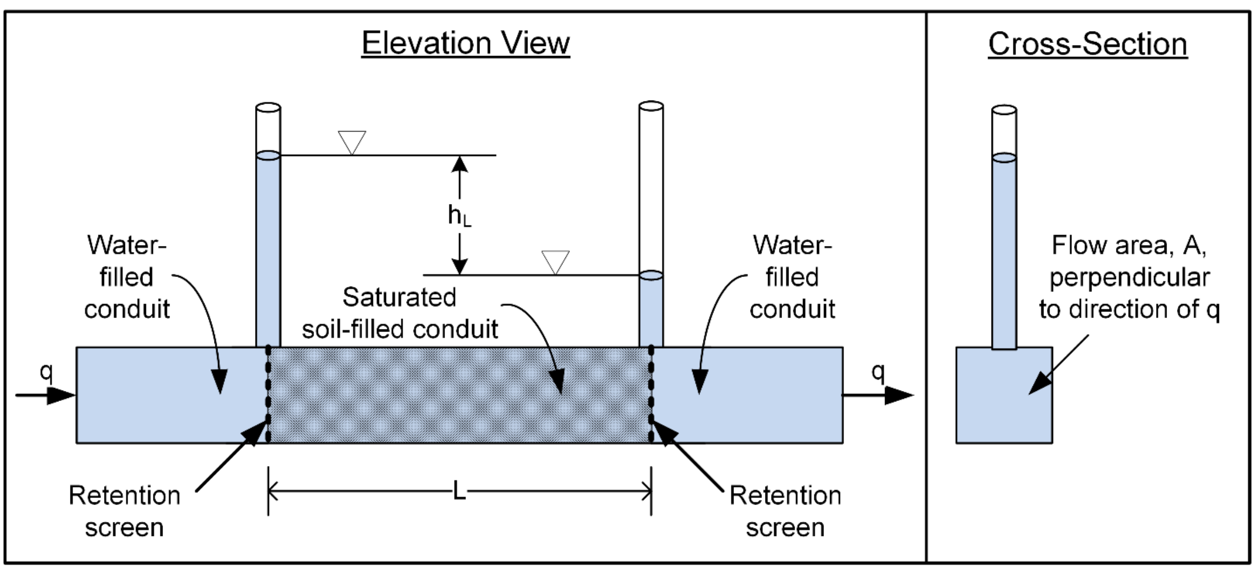


Figure 6-2 One-Dimensional Flow through Soil

One-dimensional flow is governed by Darcy's Law:

$$q = kiA \quad \textbf{(6-3)}$$

where:
q = the volumetric flow rate through the soil,
k = the hydraulic conductivity of the soil,
i = the hydraulic gradient across the flow region, and
A= the cross sectional area of the flow region perpendicular to the flow direction.

If the flow region has a constant height and an extended width (perpendicular to the page), the flow area (A) can be defined by the height of the flow region times a unit width. In this case, the flow rate per unit length of the model is:

$$q = kiy \quad \textbf{(6-4)}$$

where:
q = the flow rate per unit length of the model,
k = the hydraulic conductivity of the soil,
i = the hydraulic gradient across the flow region, and
y = the height of the flow region.

The *discharge velocity* (v_d) can be calculated by dividing the volumetric flow rate by the cross-sectional area:

$$v_d = \frac{q}{A} = ki \quad \textbf{(6-5)}$$

It should be noted that v_d is not a true particle velocity but rather the velocity based on the total area of the flow region. Since the water only flows through the pore space of a soil or rock, a water particle actually flows faster through than v_d. The *seepage velocity* (v_s) which measures how fast a water particle moves as a result of the hydraulic gradient, is calculated as:

$$v_s = \frac{v_d}{n} = v_d \frac{1+e}{e} \quad \textbf{(6-6)}$$

where:
n = the porosity of the soil and
e = void ratio.

Darcy's law is valid for conditions where the seepage flow is laminar, which includes most cases of seepage through soils. High velocity flows through coarse, open-graded gravels may fall in the transition between laminar and turbulent flow. Turbulent flow results in more resistance to seepage and thus a lower volumetric flow rate than predicted by Darcy’s law.

6-2.3 Two-Dimensional Seepage.

Analysis of seepage in a two-dimensional regime requires expansion of Darcy’s law. The governing equation for steady state, two-dimensional flow is the LaPlace equation:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0 \qquad \textbf{(6-7)}$$

where:
h = total hydraulic head and
x and y = coordinate directions.

The LaPlace equation is derived by applying the conservation of mass principle to an element of soil, thereby using equilibrium to spatially link changes in total head within the flow region. The first term in Equation (6-7) represents the change in hydraulic gradient in the x direction through an element of soil while the second term represents the change in gradient in the y direction in the same element. Derivation and further discussion of the LaPlace equation can be found in books on groundwater, such as Bear (1979) or Freeze and Cherry (1979).

Solutions to the LaPlace equation can be performed through (1) graphical solutions such as flow nets, (2) closed-form equations such as the method of fragments or the U.S. Army Corps of Engineers blanket theory equations (USACE 2000), or (3) numerical solutions such as finite element analyses.

6-2.4 Flow Nets.

Flow nets are a relatively quick graphical solution tool for analyzing two-dimensional flow regimes using few resources; namely a pencil, paper, and a good eraser. The act of drawing of a flow net also helps the engineer to visualize and understand the behavior of seepage flows. The understanding gained by drawing a flow net is often deeper than that gained by numerical analyses.

A flow net for seepage in an isotropic soil layer beneath an impermeable dam is presented in Figure 6-3. The flow region is divided into *flow elements*, most of which resemble squares or are as close to square as possible. The long-short dashed lines represent *equipotential lines* or contours of constant total head within the soil. Note that the level upstream ground surface is an equipotential line since the reservoir level applies a constant total head along this boundary. The level downstream ground surface is also an equipotential line since the pressure is constant on the surface (equal to zero pressure head) and the elevation is constant (constant elevation head). If the downstream exit face were sloped and not submerged, the total head would not be constant and it would not be an equipotential line. The short dashed lines are *flow lines,* which represent average paths that water particles will follow while flowing through the soil. The bottom impervious boundary and the bottom of the impervious structure are also flow lines.

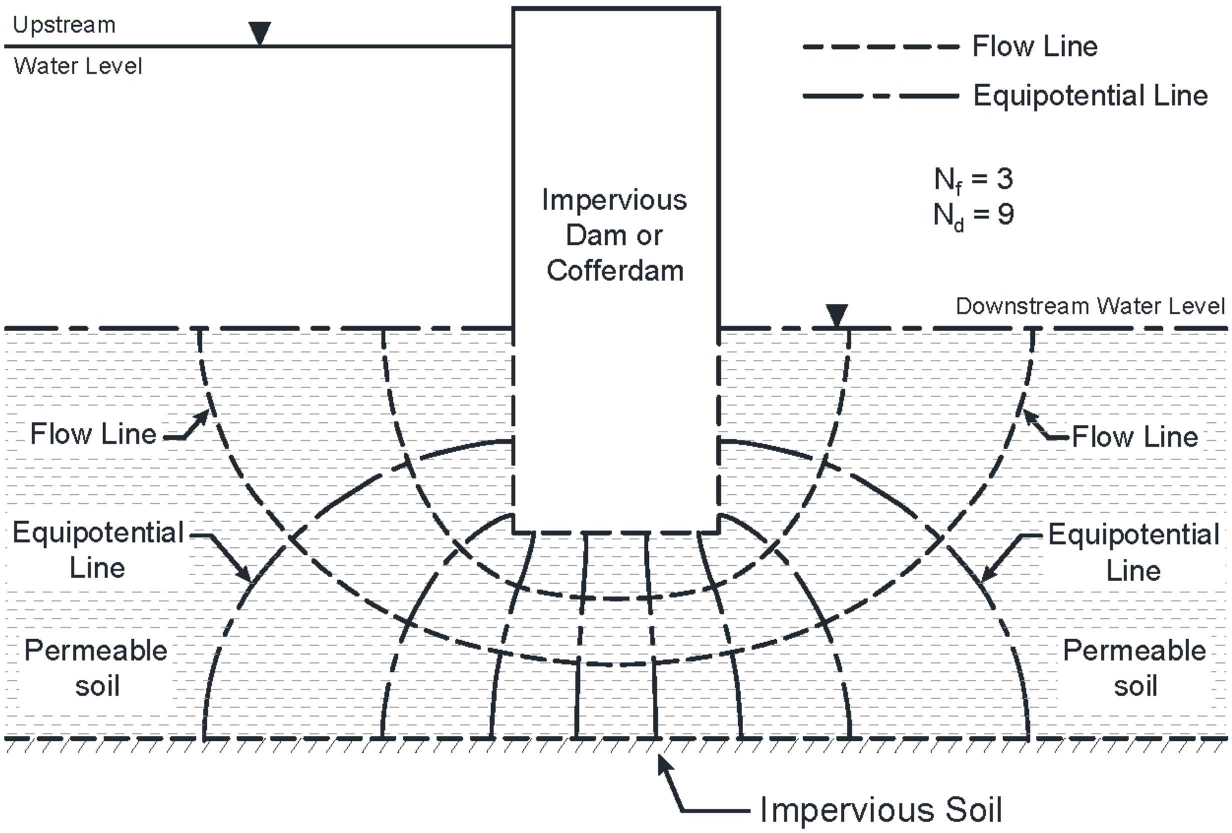


Figure 6-3 Flow Net for Seepage Through an Isotropic Soil Layer Beneath an Impermeable Dam

6-2.4.1 Drawing Flow Nets.

Flow nets for seepage through soil with isotropic permeability must comply with the following rules in order to be correct:

a. Flow lines and equipotential lines should intersect at right angles.
b. The flow elements formed between the flow lines and equipotential should resemble curvilinear squares. A circle can be inscribed in a curvilinear square and touch all four boundaries of the flow element. More guidance on the shape of admissible flow elements can be found in USACE (1986).
c. An impermeable boundary will act as a flow line. Common examples are the top of an underlying layer and the bottom of an impermeable dam or levee.

d. Submerged inflow or outflow boundaries through which seepage passes are equipotential lines with head equal to the water level elevation.
e. Where the flow is unconfined (such as through an embankment) the top flow line will be the phreatic surface. Points on this line will have pressure equal to zero and, consequently, the total head is equal to the elevation of the line (see Equation 6-1).
f. Along a phreatic surface for unconfined flow, equipotential lines will intercept the phreatic surface at equal vertical intervals.

Flow nets constructed according to the above rules will have the following characteristics:

a. Each flow channel, bounded by two adjacent flow lines, will convey the same amount of flow as the other flow channels in the flow net.
b. Each total head drop, bounded by two adjacent equipotential lines, represents the same decrease in total head as the other head drops in the flow net.
c. The flow elements can be subdivided into regions representing partial head drops and partial flow channels.

Flow nets can be drawn for flow through non-homogenous soil profiles and soil with anisotropic hydraulic conductivity. In stratified soil profiles, the flow will be dominated by the permeable layers. If the ratio of a layer's hydraulic conductivity compared to that of the most permeable layer exceeds 10 to 100, the layer can be considered impermeable. If this ratio is less than 10, the flow will be through both layers. However, the flow lines and equipotential lines will be deflected at the interface as illustrated in Figure 6-4.

Flow through soil with anisotropic permeability can be transformed into an equivalent isotropic region using the transformation factor (a):

$$a = \sqrt{\frac{k_{\max}}{k_{\min}}} \qquad \textbf{(6-8)}$$

where:
a = isotropic transformation factor,
k_{max} = the maximum hydraulic conductivity in anisotropic soil, and
k_{min} = the minimum hydraulic conductivity in anisotropic soil.

The dimensions of the flow region are transformed by dividing all of the dimensions of parallel to the direction of k_{max} by a. A flow net is drawn for the transformed system following the rules for isotropic hydraulic conductivity. For example, if k is largest in the horizontal direction, then all of the x-coordinates will be divided by a in the transformed system. If needed, the flow region and flow net can be transformed back to "real space" by multiplying the dimensions parallel to the direction of k_{max} by a.

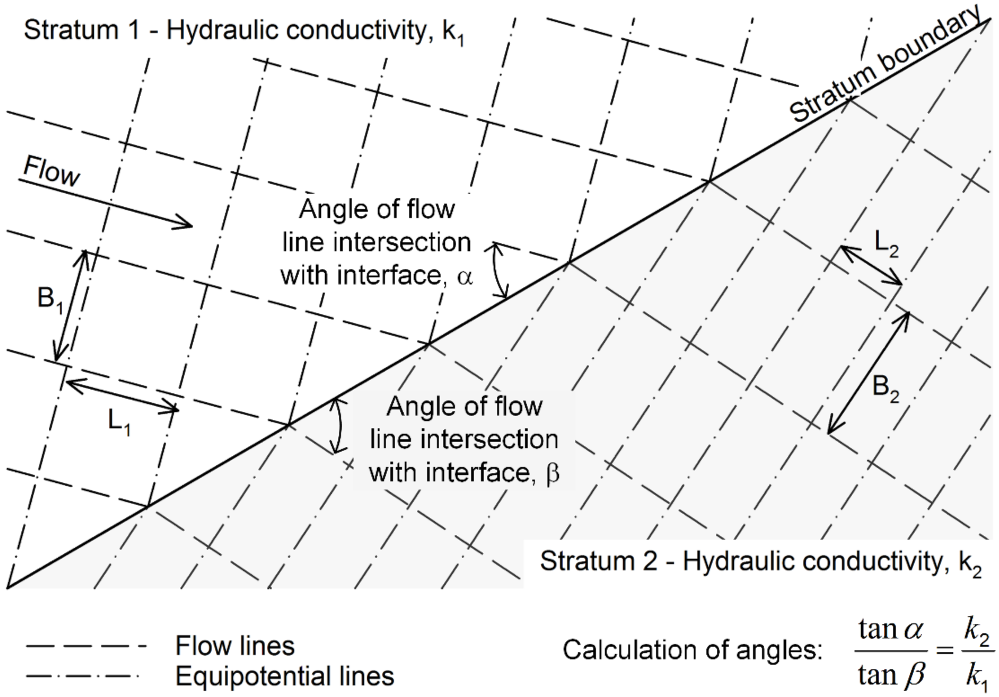


Figure 6-4 Deflection of Flow at a Boundary with Changed Permeability

6-2.4.2 Interpreting Flow Nets.

Once drawn, flow nets can be used to calculate a number of properties including: seepage quantities, pore pressures, uplift forces, and hydraulic gradients. The volumetric flow rate through a flow net section can be calculated as:

$$q = k \cdot h_L \cdot \left(\frac{N_f}{N_d} \right) \cdot W \qquad \textbf{(6-9)}$$

where:
h_L = the total differential head or head loss across the flow net,
k = the isotropic hydraulic conductivity (use $\sqrt{(k_{max} \cdot k_{min})}$ for transformed flow nets),
N_f = the number of flow channels in the flow net,
N_d = the total number of equipotential (head) drops in the flow net, and
W = the width of the system perpendicular to the page, often taken as a unit width.

The ratio N_f / N_d from the flow net is sometimes referred to as the *shape factor* (SF). The shape factor incorporates the influence of geometry into the calculation of flow. Two flow nets with a different number of flow lines but the same value of SF will predict the same flow rates, total heads, and pore pressures.

The flow net divides the total head loss across the system into N_d equal head drops. The head loss associated with each head drop is:

$$\Delta h_L = \frac{h_L}{N_d} \quad \textbf{(6-10)}$$

where:
Δh_L = the total differential head or head loss across one head drop,
h_L = the total differential head or head loss across the flow net, and
N_d = the total number of head drops in the flow net.

The total head at any point within the flow net can be calculated by reference to the known total head at either the upstream or downstream boundary. The change in head from the boundary for any point is equal to the number of head drops from the boundary multiplied by Δh_L. By knowing the total head and elevation at a point of interest, the pore water pressure at any point can be calculated from the flow net as:

$$u = h_p \gamma_w = \left(h_t - h_z\right)\gamma_w \quad \textbf{(6-11)}$$

where:
h_p = the pressure head at the point in question,
h_t = the total head at the point in question,
h_z = the elevation head at the point in question, and
γ_w = the unit weight of water.

The hydraulic gradient can be calculated between any two points in the flow region by dividing the change in total head that occurs between two points by the distance over which the head loss occurs. When calculating gradients, it may be useful to subdivide flow net sections for more precision.

Figure 6-5 presents an example flow net with example calculations for discharge, uplift pressure, and hydraulic gradient.

6-2.5 Closed-Form Equations.

The *method of fragments* and *blanket theory* are two closed-form solutions for calculation of seepage flow below water retaining structures. The method of fragments (Pavlovsky 1956, Harr 1977) subdivides the flow region into fragments of standard geometry. Based on the geometry, the SF for each fragment is determined along with the overall SF for the problem. The overall flow rate and pore pressures at particular points can be determined from the results. The blanket theory equations are based on the method of fragments and are particularly useful for seepage analyses of levees. These equations are specifically derived for a levee foundation condition consisting of a low-permeability “blanket” layer overlying a high-permeability “foundation” layer. The potential for soil heave occurring on the landside of the river can be readily assessed.

Both methods can be implemented in a spreadsheet application. For further information on the method of fragments and blanket theory equations, see Holtz et al. (2011) and Appendix B of USACE (1986), respectively.

Other common solutions have been developed for: (1) flow, heave potential, and exit gradients into excavations, (2) relief well design, and (3) dewatering well design. These specific solutions are presented in the later sections of this chapter.

Example

Using the flow net in Figure 6-3, calculate the flowrate per foot of structure and the pore pressure at the middle of the base. Assume the following:

- -Head loss from upstream to downstream: h_L = 36 ft
- -Hydraulic conductivity of permeable soil: k = 1×10^{-3} cm/s = 2.8 ft/day
- -Thickness of permeable soil: 40 ft
- -Depth of embedment of the structure: 20 ft

Flowrate, q, per foot of structure (i.e., W=1)

$$q = kh_L\left(\frac{N_f}{N_d}\right)W = \left(2.8\frac{ft}{day}\right)(36\,ft)\left(\frac{3}{9}\right)(1ft) = 34\frac{ft^3}{day}$$

Pore pressure at base of structure

There are 4.5 equipotential drops from the upstream to the middle of the structure. Each drop represents a head loss of:

$$\Delta h_L = \frac{h_L}{N_d} = \frac{36\,ft}{9} = 4\frac{ft}{drop}$$

Setting the datum at the base of the permeable soil, the total head at this point is:

$$h_{t,base} = h_{t,up} - (\text{Number of drops})\Delta h_L = 76\,ft - (4.5\,drops)(4\,ft/drop) = 58\,ft$$

The elevation head at the base of the structure is 20 ft, which means the pressure head is:

$$h_{p,base} = h_{t,base} - h_{z,base} = 58\,ft - 20\,ft = 38\,ft$$

The pore pressure is then calculated as:

$$u_{base} = h_{p,base}\gamma_w = (38\,ft)(62.4\,pcf) = 2371\,psf$$

Figure 6-5 Flow Net Example Calculations

6-2.6 Numerical Seepage Analysis.

Numerical analysis, such as finite element or finite difference, is the appropriate tool for most seepage analysis problems. These methods are user-friendly and allow easy input of soil properties and complex geometric configurations, while providing rich graphical output. Numerical analyses also can be extended to three-dimensions and used to model unsaturated soils and transient flow conditions. However, those topics are beyond the scope of this chapter. The graphical and analytical methods discussed in Sections 6-2.4 and 6-2.5 provide an important means of validating numerical seepage models.

Finite element analysis (FEA) is the most common numerical approach used for seepage analysis, and this section is written from the perspective of FEA. Other numerical approaches, such as finite difference, will also provide suitable results but may use slightly different terminology.

6-2.6.1 General Concepts of Finite Element Seepage Analysis.

In finite element analysis, the flow region is divided into areas or volumes (referred to as elements) within which the flow of water can be easily defined. Elements are formed by connecting points in space (referred to as nodes) with lines. Two-dimensional elements are often three-node triangles or four-node quadrilaterals. Within each element the flow is defined with a system of equations that relate the hydraulic head at each node with the hydraulic gradient and flow within the element. These equations are described in an element matrix by linking the values of the common nodes. The equations (matrices) for each of the elements are assembled into a global matrix that represents a set of equations that define the flow through the entire system. For each node there is one equation and one unknown value for each node.

In the simplest form of element, the direction and magnitude of the hydraulic gradient throughout the element are constant. This results in the hydraulic head varying linearly along the element boundaries and within the elements themselves. In more advanced element types, the head varies according to a polynomial equation. Before solving the problem, the one unknown for each node is either (1) the total head at the node or (2) the total flow into and out of the system associated with the node. In general, nodes within the body of the problem and along no-flow boundaries have unknown head and total flow of zero (i.e., flow in equals flow out). At boundaries where flow enters the system, the flow is unknown but the head is generally specified.

6-2.6.2 Boundary Conditions.

Boundary conditions describe the head, pressure, and flow conditions at the boundaries of the model. Table 6-1 describes the most common boundary conditions used in basic finite element models. Table 6-2 illustrates the application of boundary conditions to finite element models.

6-2.6.3 Interpreting Output.

The primary mathematical result of a finite element analysis are values of total hydraulic head and nodal flow for each node in the finite element mesh. By post-processing the total head and flow results from the FEA, the hydraulic gradient, hydraulic velocity, volumetric flow rate, pressure head, and uplift force along a boundary segment can be obtained. Most of the commercially available finite element seepage analysis software have post processors that will calculate these values through interpolation algorithms. Several of these interpretations are discussed below.

Table 6-1 Common Finite Element Analysis Boundary Conditions

<table>
<tr><th colspan="2">Boundary Condition</th><th>General Description</th><th>Specific Description</th><th>Common Usage</th></tr>
<tr><td rowspan="2">Specify head</td><td>Constant Head</td><td rowspan="2">Flow allowed to enter or exit the system along the boundary.
Nodal heads are known.
Nodal flow is calculated during the analysis.</td><td>Total head held at a constant value along the boundary</td><td>Submerged boundaries (total head = water surface elevation)
Horizontal seepage exits (total head = ground surface elevation)
Sides of numerical models</td></tr>
<tr><td>Constant Pressure</td><td>The pressure head held at a constant value along the boundary.</td><td>Seepage exits (pressure head = 0)
Internal drains (pressure head = 0)</td></tr>
<tr><td rowspan="3">Specify flow</td><td>No-Flow (impermeable boundary)</td><td rowspan="3">Total nodal flow is specified. May be specified as zero for no-flow boundaries
Nodal heads are unknown.
Nodal heads are calculated during the analysis.</td><td>Flow is not allowed across the boundary.</td><td>Boundaries with impermeable soil, rock, or structures
Sides of numerical models</td></tr>
<tr><td>Nodal Flow</td><td>The inflow or outflow rate from the system is specified for a node (often an internal node).</td><td>Injection or extraction well</td></tr>
<tr><td>Infiltration</td><td>Inflow along an external boundary is specified.</td><td>Rainwater or other infiltration along a surface</td></tr>
<tr><td colspan="2">Unknown or Variable</td><td colspan="2">The boundary is set to be either a no-flow or constant pressure boundary, depending on the results of the analysis.</td><td>Seepage exit areas where the phreatic surface is unknown, such as the downstream slope of a dam or levee</td></tr>
</table>

6-2.6.3.1 Pore Water Pressure.

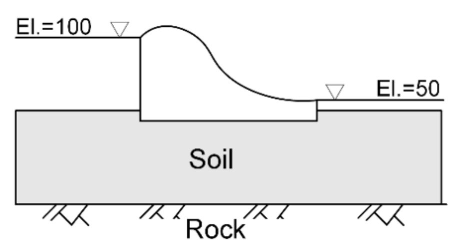
The pore water pressure is calculated from the total head and the elevation using Equation 6-11. Generally, commercial software will calculate the hydraulic pressure for each node and provide a contour map of the pressure throughout the flow region.

6-2.6.3.2 Uplift Force.

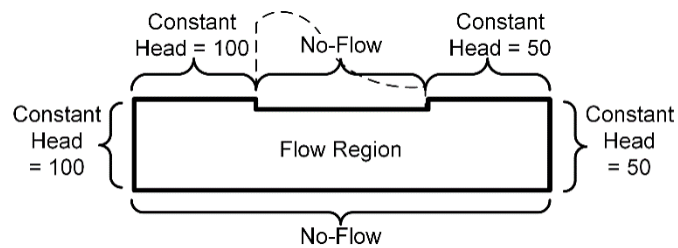
Uplift force due to hydraulic pressure on a structure or mass of soil is calculated by integrating the hydraulic pressures along a specified set of the boundary segments in the model. A simple estimate of the uplift force can be calculated by plotting the pore water pressure contours and assigning a representative area along the boundary segment to each contour interval. The total uplift force can be calculated by summing product of the interval length and the representative pressure for each interval.

Table 6-2 Examples of Boundary Condition Usage

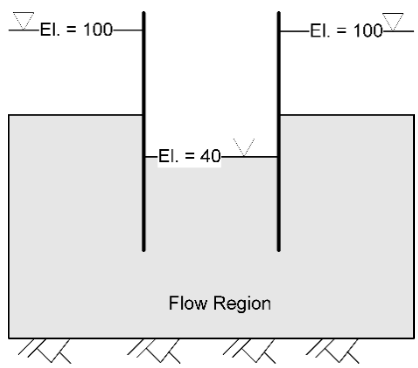
<table>
<tr><th>Schematic of Seepage Regime</th><th>Model and Boundary Conditions</th></tr>
<tr><th colspan="2">Impermeable Dam</th></tr>
<tr><td>



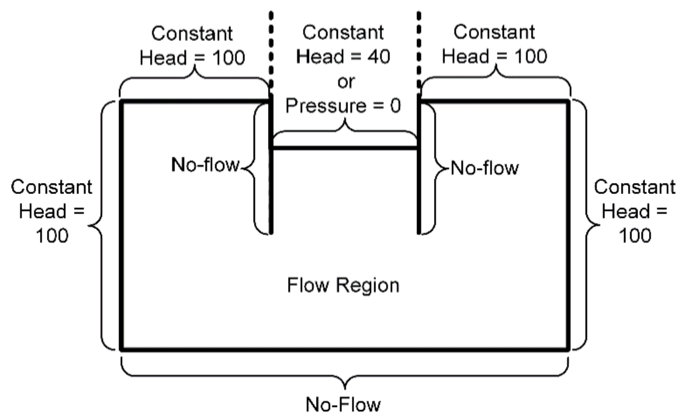
</td><td>



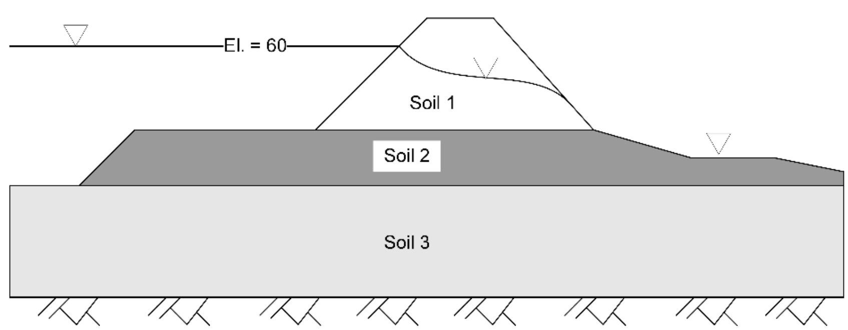
</td></tr>
<tr><th colspan="2">Coffer Dam</th></tr>
<tr><td>



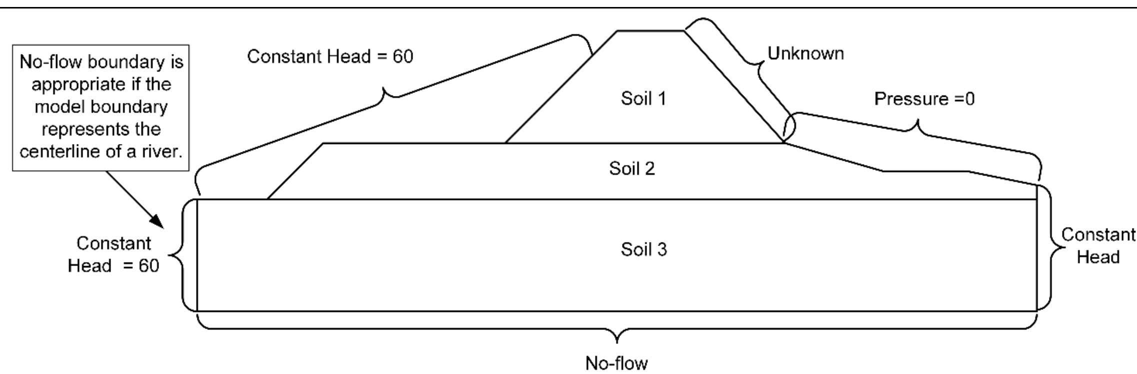
</td><td>



</td></tr>
<tr><th colspan="2">Permeable Dam or Levee</th></tr>
<tr><td colspan="2">



</td></tr>
<tr><td colspan="2">



</td></tr>
</table>

6-2.6.3.3 Hydraulic Gradients.

Hydraulic gradients are calculated for each element based on the hydraulic heads at the element nodes. Strictly speaking for simple elements, the hydraulic gradient in a given direction should be constant within each element. However, commercial software will often interpolate contours of hydraulic gradient based on the calculated head at each node. For higher order elements, the hydraulic gradient in a given direction may vary within the element. In these cases, the calculated gradients may be interpreted by plotting its variation within the flow region.

As a note of caution, the calculated hydraulic gradient will vary depending on the size of the element used near sharp corners in the flow region (often termed singularities). In this case, the calculated hydraulic gradients will increase as the element size decreases. As the element dimension approaches zero, the calculated hydraulic gradient may approach infinity. At these locations, the hydraulic gradients should be calculated over a distance consistent with the mechanisms of concern and known ground conditions. For example, the hydraulic gradient at the toe of a levee resting on a blanket layer of low k soil should be calculated across the thickness of the blanket.

6-2.6.3.4 Discharge Velocity.

Discharge velocity is calculated from the hydraulic gradient and the hydraulic conductivity assigned to the element using Equation 6-5.

6-2.6.3.5 Seepage Flow Volume.

Seepage volumes are calculated for elements using Darcy's law (Equation 6-3). For flow across a model boundary, the flow rate through each element is calculated, using the vector component of hydraulic gradient perpendicular to the boundary, the hydraulic conductivity assigned to the element, and the area of the element boundary along the model boundary. The flow rate across a portion of an FEA model can be assessed by calculating the flow across a line using a similar methodology applied to the area associated with the elements intersected by the line.

6-3 HYDRAULIC CONDUCTIVITY (COEFFICIENT OF PERMEABILTY).

One of the most varied soil properties in geotechnical engineering is *hydraulic conductivity*, which can be defined as the discharge velocity of water through a unit area under a unit hydraulic gradient. Common hydraulic conductivity values can range from less 10^{-8} cm/sec for high plasticity clay to in excess of 1 cm/sec for open graded gravels; a range of over 8 orders of magnitude. Small changes in soil gradation, especially changes in the fines content, can result in significant variation in hydraulic conductivity.

Terminology regarding hydraulic conductivity is varied across the profession. The term *coefficient of permeability* is used as a synonym for hydraulic conductivity in literature. The practicing geotechnical community commonly uses the term "permeability" interchangeably with hydraulic conductivity. However, this is technically incorrect as permeability is a property of the porous media alone and does not consider the viscosity of the permeant fluid. Hydraulic conductivity is the preferred term, but both hydraulic conductivity and permeability are used in this manual.

Hydraulic conductivity is most often required for *in situ* soil conditions. Hydraulic conductivity can be assessed for these conditions by several strategies: 1) laboratory testing, 2) field testing, and 3) empirical correlations including equations, charts, and tables. Each of these are discussed in the following subsections.

6-3.1 Laboratory Testing.

Laboratory tests can be performed on intact samples or reconstituted samples. Details of laboratory testing procedures are presented in Section 3-2.7. While laboratory tests can measure the hydraulic conductivity of a wide range of soils, the limitations of laboratory testing must be acknowledged. First, laboratory tests use a small sample of soil or rock and usually test the vertical permeability because the samples are obtained from boreholes. As a result, laboratory test results may not be representative of the large-scale properties of a soil deposit if the layering and structure of the deposit is not considered. Natural soils usually exhibit anisotropy with the horizontal permeability being larger than the vertical. Thus, laboratory tests are likely to result in lower values than are appropriate for many types of analyses. Finally, intact samples of coarse-grained soils cannot be obtained using normal sampling procedures. Laboratory tests on reconstituted specimens of these materials are likely no more reliable than correlations. With the above in mind, laboratory permeability testing is most appropriately reserved for reconstituted samples for applications such as fill materials, cutoff wall backfills, pond liners, and filter materials.

6-3.2 Field Testing.

Two classes of field hydraulic conductivity testing are borehole tests and field pumping tests. Details of field testing procedures are presented in Chapter 2. Borehole tests are effective in measuring the permeability of the soil in the general area of the borehole. To measure permeability characteristics over a broader area, a pumping test can be performed.

6-3.3 Empirical Relationships for Hydraulic Conductivity.

Numerous empirical and semi-empirical relationships have been developed for correlating hydraulic conductivity with other soil properties (predominantly grain size and gradation). The simplest of these relationships relate soil type to typical values of ranges of k. Figure 6-6 correlates k with soil classification types for various unit systems.

The United States Bureau of Reclamation (USBR 2014) has determined typical values for the horizontal hydraulic conductivity of natural soil and rock deposits based on field testing as indicated in Table 6-3 and the vertical hydraulic conductivity of embankment fill materials based on laboratory testing as summarized in Table 6-4.

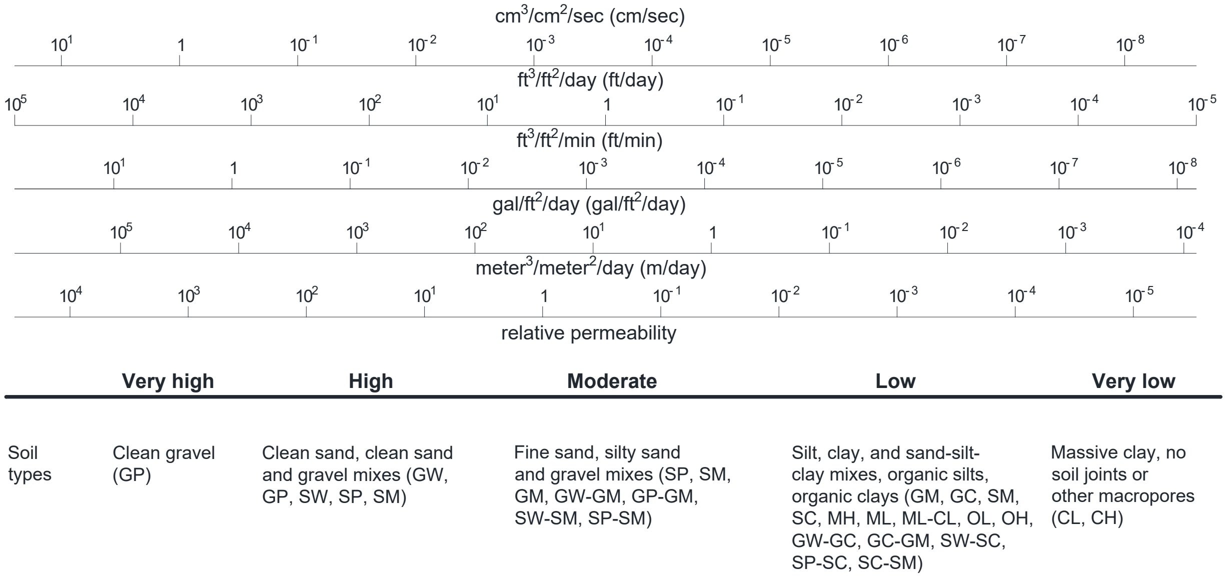


Figure 6-6 Variation of Hydraulic Conductivity with Soil Type for Various Unit Systems (after Freeze and Cherry 1979)

Table 6-3 Typical Ranges of Horizontal Hydraulic Conductivity for Natural Soil and Unfractured Rock Deposits (after USBR 2014)

Soil Type	k_h (cm/sec)
Gravel, open-work	> 2
Gravel (GP)	2×10^{-1} to 2.
Gravel (GW)	1×10^{-2} to 1
Sand, coarse (SP)	1×10^{-2} to 5×10^{-1}
Sand, medium (SP)	1×10^{-3} to 1×10^{-1}
Sand, fine (SP)	5×10^{-4} to 5×10^{-2}
Sand (SW)	1×10^{-4} to 5×10^{-2}
Sand, silty (SM)	1×10^{-4} to 1×10^{-2}
Sand, clayey (SC)	1×10^{-6} to 1×10^{-3}
Silt (ML)	1×10^{-6} to 1×10^{-3}
Clay (CL)	$< 3 \times 10^{-6}$

Rock Type	k_h (cm/sec)
Sandstone, medium	1×10^{-4} to 2×10^{-1}
Sandstone, silty	$< 5 \times 10^{-3}$
Limestone	$< 1.5 \times 10^{-2}$
Granite, weathered	2×10^{-4} to 1×10^{-5}
Schist	$< 2 \times 10^{-3}$
Tuff	$< 1 \times 10^{-3}$
Gabbro, weathered	5×10^{-5} to 5×10^{-4}
Basalt	$< 5 \times 10^{-5}$
Dolomite	$< 5 \times 10^{-6}$
Gneiss	$< 2 \times 10^{-6}$

Note: Materials with no indicated lower bound can range from practically impervious to the upper limit indicated in the table.

Table 6-4 Typical Range of Vertical Hydraulic Conductivity for Compacted Soil in Embankments (after USBR 2014) \1

Embankment Core Materials	
Unified Soil Classification	**k_v (cm/sec)**
GM-SM	< $1x10^{-5}$
GM or GC	< $1x10^{-5}$
SP-SM	< $1x10^{-5}$
SM	< $1x10^{-5}$
SM-SC	< $3x10^{-6}$
SC	< $3x10^{-6}$
ML	< $1x10^{-5}$
ML-CL	< $1x10^{-6}$
CL	< $1x10^{-6}$
MH	< $1x10^{-7}$

Embankment Shell Materials	
Unified Soil Classification	**k_v (cm/sec)**
GP	$2x10^{-3}$ to 1.0
GW	$1x10^{-3}$ to $1x10^{-1}$
GP-SP	$1x10^{-3}$ to $5x10^{-1}$
GW-SW	$5x10^{-4}$ to $5x10^{-3}$
GM	$1x10^{-5}$ to $5x10^{-4}$
SP (medium to coarse)	$1x10^{-2}$ to $2x10^{-2}$
SP (fine to medium)	$5x10^{-3}$ to $1x10^{-2}$
SP (very fine to fine)	$5x10^{-4}$ to $5x10^{-3}$
SW	$3x10^{-4}$ to $5x10^{-3}$
SP-SM	$1x10^{-5}$ to $1x10^{-3}$
SM	$1x10^{-5}$ to $5x10^{-4}$

Note: Materials with no indicated lower bound can range from practically impervious to the upper limit indicated in the table.
/**1**/

The size of the pore spaces is one of the most important factors controlling the hydraulic conductivity of a soil, especially for coarse-grained materials. The *effective diameter* or *effective grain size* (D_α) is the grain size that has the primary influence on the average pore size of the soil. In terms of the effects on hydraulic conductivity, the α refers to a particular percent passing on the grain-size distribution and typically has been assigned a value of 5, 10, 15, or 20. In other words, the effects of pore size on hydraulic conductivity has been found to correlate best with particle diameters corresponding to the 5 to 20% passing size. Correlations that relate hydraulic conductivity to an effective grain size or grain-size distribution can be expressed as (Kenney et al. 1984):

$$k = \beta_\alpha D_\alpha^x \quad \textbf{(6-12)}$$

where:
k = hydraulic conductivity,
B_α = empirical or semi-empirical coefficient,
D_α = effective grain size,
α = percent passing corresponding to effective grain size, and
x = exponent - theoretically equal to 2 and empirically slightly above 2.

Most of the published correlations for the hydraulic conductivity of coarse-grained soils can be expressed in terms of Equation 6-12. These correlations are summarized in Table 6-5. Some of the relationships also account for the effect of void ratio on k.

Table 6-5 Estimating Hydraulic Conductivity based on Effective Grain Size

Source	Reported Application	α	β_α (cm/sec/mm²)	x
Kenney et al. (1984)	Sand and fine gravel, C_u = 1 to 12	5	1	2
Hazen (1892, 1911)	Loose sands with D_{10} between 0.01 and 0.3 cm	10	Varies by source from 0.01 to 10 Often taken to equal to 1	2
Slichter (1905) and (McCook 2010)	Sands with D_{10} between 0.01 and 0.5 cm	10	$0.0147\exp\left(\frac{9.3071e}{1+e}\right)$	2
Chapuis (2004)	Sand	10	$2.4622\left(\frac{e^3}{1+e}\right)^{0.7825}$	1.565
Carrier (2003)	Sand, assuming uniform spheres	10	$5.52\left(\frac{e^3}{1+e}\right)$	2
Sherard et al. (1984)	Sand and gravel with low fines content	15	Average = 0.35, range = 0.2 to 0.6	2
Notes: k is estimated in cm/sec, C_u = coefficient of uniformity = D_{60} / D_{10}, e = void ratio				

The Kozeny-Carman equation (Carrier 2003) can be used to account for the effect of the entire grain-size distribution and the particle shape: **1**\

$$k = 1.99\times10^2 \frac{cm}{s\cdot mm^2}\left[\frac{100\%}{\sum \frac{f_i}{D_{li}^{0.404}\times D_{si}^{0.596}}}\right]^2 \left(\frac{1}{S^2}\right)\left(\frac{e^3}{1+e}\right) \quad \textbf{(6-13)}$$

/**1**/ where:
k = hydraulic conductivity (cm/sec),
f_i = fraction of particles (by mass) between two adjacent sieve sizes,
D_{li} = the particle size of the coarser sieve (mm),
D_{si} = the particle size of the finer sieve (mm),
S = surface area factor ranging from 6 for spheres to 8.5 for angular particles, and
e = void ratio.

For a given soil, the ratio of hydraulic conductivities under two different void ratios can be considered by (Kozeny 1927):

$$\frac{k_1}{k_2} = \frac{1+e_2}{1+e_1}\frac{e_1^3}{e_2^3} \quad \textbf{(6-14)}$$

where:

k_1 = hydraulic conductivity for void ratio, e_1, and
k_2 = hydraulic conductivity for void ratio, e_2.

For fine-grained soils, the hydraulic conductivity would be expected to decrease as liquid limit, plasticity index, or fines content increase. Figure 6-7 shows that hydraulic conductivity decreases as the fine content (percent passing the No. 200 sieve) increases. For a given fines content, the range of k_v is 2.5 to 3 orders of magnitude with sandy and silty soils having higher k_v than clayey soils.

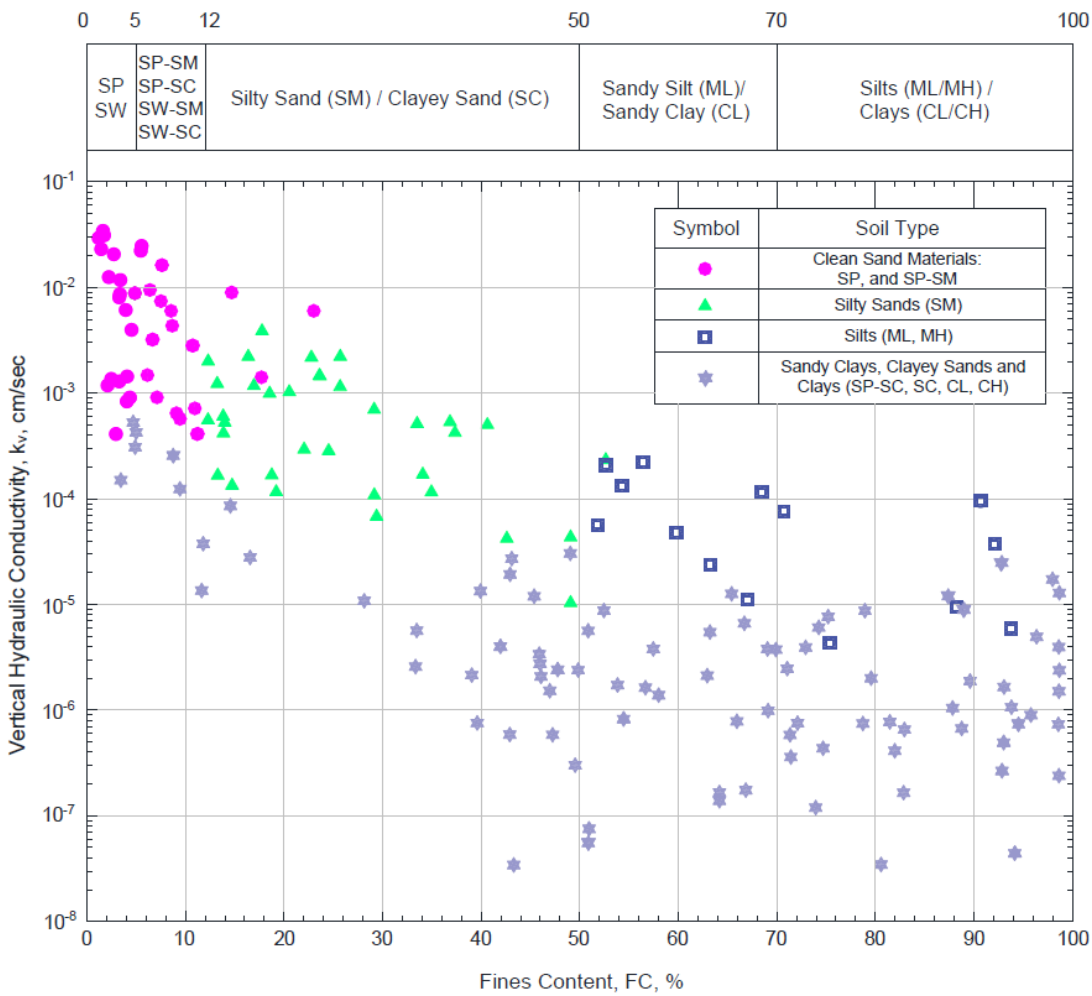


Figure 6-7 Variation of Hydraulic Conductivity with Fines Content (after California Department of Water Resources 2013)

6-3.4 Anisotropy.

More often than not soils exhibit anisotropy with respect to hydraulic conductivity. In natural soils this is usually a consequence of depositional layering of the soil and results in horizontal hydraulic conductivity greater than in the vertical direction. However, in some cases, often related to the formation and filling of vertical cracks, the vertical hydraulic conductivity can be greater than the horizontal. In engineered fills, anisotropy can form as a consequence of soil variation between lifts, differential compaction between the top and bottom of lifts, and planes that form between lifts. Table 6-6 and Table 6-7 present typical values for anisotropy in natural soil deposits and compacted fill.

Anisotropy can greatly affect the seepage behavior in a soil deposit and can have a significant effect on the calculated pressures, flows, and hydraulic gradients in the seepage regime.

Table 6-6 Typical Values of Anisotropy in Natural Soils (after USBR 2014)

Formation	k_h / k_v		Ratio depends on:
	Lower	Upper	
Stratified Deposits	10	1000	Range of k for laminations
Intact Soil or Rock	1	3	Particle shape and orientation
Fractured Bedrock	0.1	10	Arrangement and orientation of apertures and joints
Loess	0.02	2	Orientation of fissures and cracks that form during consolidation and desiccation

Table 6-7 Typical Values of Anisotropy in Engineered Fill (after USBR 2014)

Fill Zone or Method	k_h / k_v	
	Lower	Upper
Core Zone, USBR Compaction Procedures	4	9
Core Zone, Standard Compaction Procedures	9	36
Hydraulic Fill	64	225
Embankment Shell, USBR Compaction Procedures	4	9
Embankment Drains, USBR Compaction Procedures	1	4
Note: USBR compaction procedures are based on Standard Proctor (ASTM D698). Requirements for compaction water content and relative compaction and/or relative density vary based on grain-size distribution and embankment height.		

6-4 INTERNAL EROSION.

About half of dam failures and accidents can be attributed to internal erosion through the foundation and/or through the embankment or along a penetration through the embankment (e.g., Foster et al. 2000). *Internal erosion* is a generic term that describes erosion of particles caused by water seeping through a body of soil or rock. The water may be seeping through the interstitial voids of a soil or rock mass, or may be flowing along pathways of preferential flow (cracks or other defects).

Terminology describing the various mechanisms of internal erosion has evolved in recent years as understanding of the mechanisms of erosion have developed. Nomenclature for these mechanisms has been and continues to be inconsistent in practice and in the literature due to this rapid evolution of understanding and nomenclature. For example, the terms “piping” and “seepage-related erosion” have been used as generic terms for internal erosion, and the term “internal erosion” has been used to denote a specific internal erosion mechanism.

In 2014, the International Commission on Large Dams (ICOLD) adopted a system of nomenclature describing the various mechanisms of internal erosion. The ICOLD nomenclature is summarized in the following sections along with additions to the nomenclature where necessary.

6-4.1 Heave.

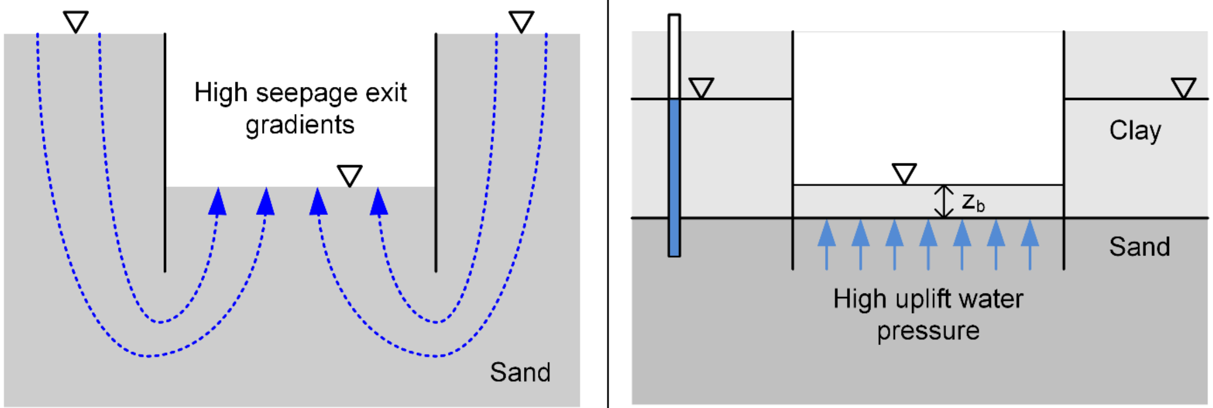
Effective stress heave (a.k.a., quick condition) is the uplift of a mass of coarse-grained soil due to a high hydraulic gradient acting on soil particles at an unprotected exit. Seepage forces developed through viscous drag tend to lift the soil mass, resulting in uplift or a quick condition, as illustrated in Figure 6-8a.

Coarse-grained soils with high vertical hydraulic exit gradients are susceptible to effective stress heave. These gradients may occur at the base of deep excavations into sand and at the toe of hydraulic structures founded on sand.

Total stress heave (a.k.a., blowout) is the uplift of a mass of low-permeability soil due to high hydraulic pressure in an underlying aquifer as shown in Figure 6-8b. When the pressure beneath a layer with low hydraulic conductivity exceeds the total weight of the layer, uplift occurs and often results in cracking of the upper layer. Total stress heave occurs in fine-grained soils with underlying aquifers, such as deep excavations into clay and fine-grained blankets.

(a) Effective stress heave

(a) Total stress heave



<u>Example:</u>
The sand has a total unit weight of 115 pcf. The critical gradient for effective stress heave is:

$$i_{crit} = \frac{\gamma_t - \gamma_w}{\gamma_w} = \frac{115 - 62.4}{62.4} = 0.84$$

If the calculated exit gradient is 0.75, the factor of safety is:

$$FS = \frac{i_{crit}}{i_{exit}} = \frac{0.84}{0.75} = 1.12$$

<u>Example:</u>
The clay has a total unit weight of 105 pcf and z_b is 5 ft. The total stress at the base of the clay is:

$$\sigma_v = z_b \gamma_t = (5 \text{ ft})(105 \text{ pcf}) = 525 \text{ psf}$$

If the calculated uplift water pressure below the clay is 700 psf, the factor of safety is:

$$FS = \frac{\sigma_v}{u} = \frac{525 \text{ psf}}{700 \text{ psf}} = 0.75$$

Figure 6-8 Heave – (a) Effective Stress and (b) Total Stress

6-4.2 Erosion and Stoping.

Backward erosion piping (a.k.a., classical piping) is the successive removal of soil particles at an unprotected exit resulting in the formation of an open pathway or *pipe* that progresses toward the source of the seepage. A stable roof prevents collapse of the pipe and allows its progression, as illustrated in Figure 6-9a. The toes of dams and levees are especially susceptible to backward erosion piping, along with unprotected exits, such the ground surface, internal voids or pathways, or defects in a conduit or outlet.

General backward erosion (a.k.a., progressive sloughing or internal migration) is the successive removal of soil particles at an unprotected exit resulting in progressive sloughing of a slope. This type of erosion initiates similar to backward erosion piping, but the lack of a “roof” prevents the progression of a pipe (Figure 6-9b). Slopes and embankments consisting of coarse-grained soils with high seepage flows are susceptible to general backward erosion.

Stoping (a.k.a., sinkhole) is the near-vertical progression of a void caused by successive collapse into a cavity as shown in Figure 6-9c. The cavity is often the result of another internal erosion mechanism. Stopes often manifest as sinkholes at the ground surface and occur in embankments with moderate to low cohesive strength.

Concentrated leak erosion (a.k.a., scour) is erosion that occurs along a concentrated flow path and is caused by shear forces imposed by the flowing water (Figure 6-9d). Concentrated leaks may be cracks within the soil or rock, gaps between soil and a conduit or structure, or other pathways of low flow-resistance capable of carrying eroded soil particles. Conditions that are susceptible to concentrated leak erosion include cohesive embankments, outlet pipes and structures in embankments, and dam and levee fill placed along steep rock abutments.

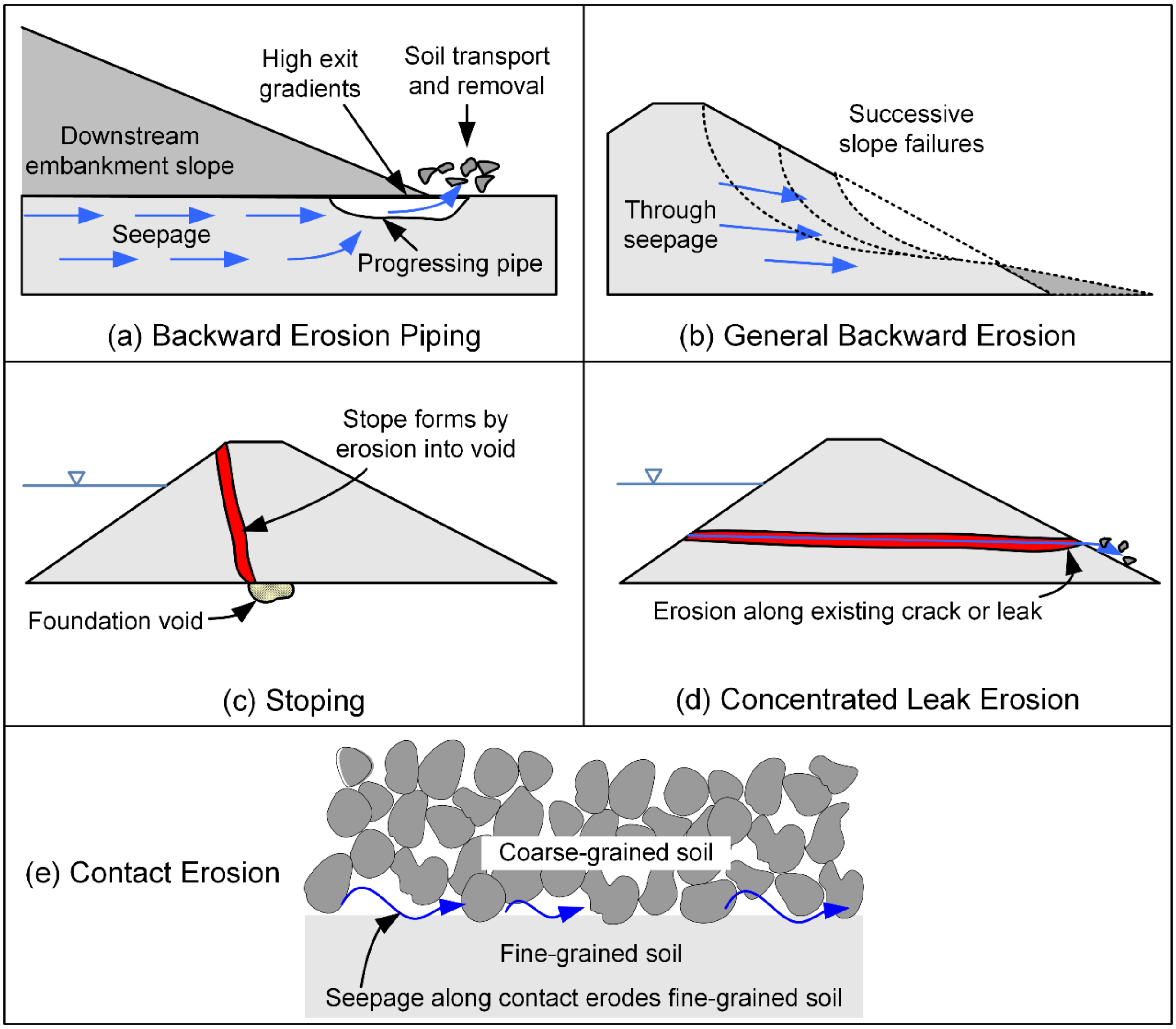


Figure 6-9 Erosion and Stoping Mechanisms

Contact erosion (a.k.a., scour) is erosion that occurs along a contact between a highly permeable material and an erodible soil. Contact erosion is caused by shear forces imposed by high seepage velocities in the highly permeable material as illustrated in Figure 6-9e. The contacts between erodible soil and open-graded gravel or open joints in bedrock are locations susceptible to this type of erosion.

6-4.3 Internal Instability.

Soils can be internally unstable such that fine-grained particles erode from within a framework or "skeleton" of coarse-grained particles as illustrated in Figure 6-10. The process is called *suffusion* if the coarse-grained particles are in contact with each other before erosion. Thus, no volume change results from suffusion. The process is called *suffosion* if the coarse-grained particles are not in contact with each other before erosion. Suffosion results in volume change or collapse. Well-graded, gap-graded, and glacial till soils can be susceptible to either suffusion or suffusion.

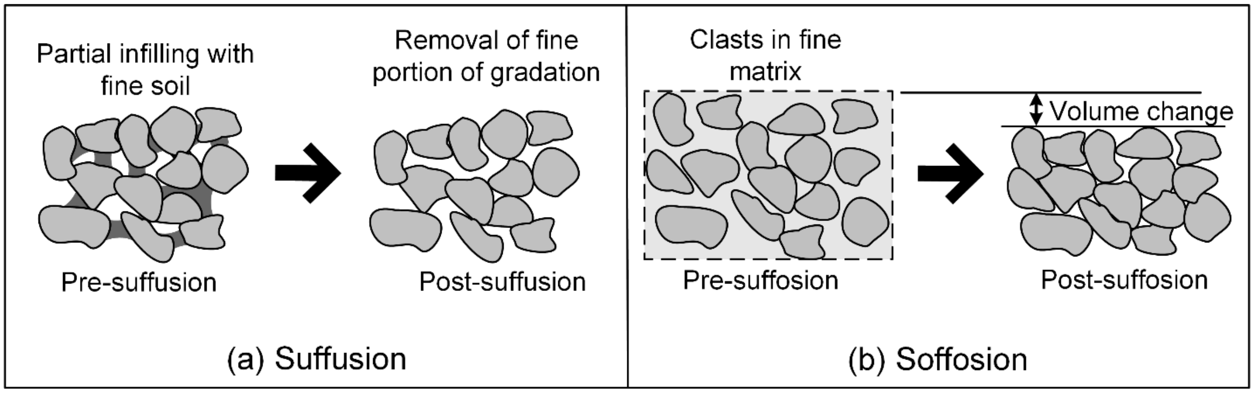


Figure 6-10 Internal Instability – (a) Suffusion and (b) Suffosion

6-5 SEEPAGE AND INTERNAL EROSION MITIGATION METHODS.

6-5.1 Problems and General Strategies.

Seepage occurs through all earthen dam and levee embankments and their foundations, into excavations below the water table, and below other structures subjected to differential water pressure conditions. In many cases, the quantity of seepage is such that it poses no adverse consequences or risk to the structure. However, if seepage is excessive or the pressures and forces associated with the seepage are too great, mitigation of the seepage issues may be required. Problems associated with seepage can be classified into three categories:

a. Excess volumetric flow rate of seepage
Undesirable consequences of excess flow include the loss of valuable water from a reservoir, flooded or soft ground in excavations, and wet ground conditions below a dam or levee that prevent activities or usage of the land.

b. High pore water pressures
High pore water pressures can result in unacceptable uplift forces beneath or within dams and levees that lead to instability with respect to sliding or overturning. Excessive water pressure forces can also act on buildings, retaining walls, and other appurtenant structures.

c. Internal erosion potential
Some seepage conditions may create a condition where internal erosion is likely through one of the mechanisms described in Section 6-4. Internal erosion problems are often tied to high pore water pressures. Assessment of internal

erosion potential should be paired with an evaluation of the severity of seepage. Table 6-8 provides a means to evaluate seepage severity and assess if further investigation is required. This approach recognizes that the flow rate must be sufficiently high for problematic internal erosion to occur

Table 6-8 Seepage Severity Categories (after Duncan et al. 2011, USACE 1956)

$q / h_L / W$ (cfs per foot of head per foot of levee)	Severity of Seepage	Seepage Remediation Needed
$> 2.2 \times 10^{-4}$	Heavy	Yes
1.1×10^{-4} to 2.2×10^{-4}	Medium	Possible
2.2×10^{-5} to 1.1×10^{-4}	Light	Marginal
$< 2.2 \times 10^{-5}$	Negligible	Not Needed
Notes: q = estimated volumetric flow rate, h_L = head loss across the structure, W= width 1 cfs/ft of head/ft. of levee = 44,883 gpm/ft of head/100 ft. of levee		

If one or more of the problems described above must be mitigated, the mitigation typically employs one of three general strategies:

a. Seepage barriers
This strategy consists of constructing an element that either directly blocks the seepage pathway or lengthens the seepage pathway. Blocking seepage can result in increased hydraulic pressures and hydraulic gradients in some locations within an embankment or foundation. When methods to block seepage are used, the engineer must assess whether the resulting pressures and gradients will be detrimental to structural stability and the internal erosion potential.

b. Providing controlled drainage
In locations where high pore water pressures result in either high hydraulic gradients or uplift forces, the pressures can be reduced by providing a controlled drainage system. The control in such a system involves assuring that the water can be drained without causing internal erosion or resulting in excessive water losses. Controlled drainage typically increases the volumetric flow rate.

c. Providing Filtration
In locations where there is potential for internal erosion, the progression of erosion can be halted by providing adequate filtration of the eroding soil particles. The most reliable and long-lasting filters are constructed using sands and gravels graded to specifications that provide both soil particle retention and adequate seepage flow capacity.

Specific methods for seepage and internal erosion mitigation options are provided in the following sections.

6-5.2 Seepage Barriers.

Seepage barriers include a range of options for (1) blocking flow through a high-permeability layer of soil or rock or (2) extending the seepage pathway to reduce seepage volume and hydraulic gradients.

6-5.2.1 Vertical Barriers.

Vertical barriers or seepage cutoff walls are zones with low hydraulic conductivity that are constructed (1) through permeable dam and levee embankments, (2) through dam and levee foundations with permeable layers, (3) surrounding excavations below the ground water table, or (4) blocking aquifers to prevent the spread of groundwater contamination. Vertical barriers are generally classified based on the excavation or construction method and the backfill type.

The various construction methods, their application, characteristics, and requirements are summarized in Table 6-9. Continuous slurry trenches are generally backfilled using one of three material types: Soil-Bentonite (SB) backfill, Cement-Bentonite (CB) backfill, and Soil-Cement-Bentonite (SCB) backfill. Element slurry walls are generally backfilled with concrete or plastic concrete using the Tremie method that fills the element from the bottom up while displacing the slurry. The characteristics of vertical barrier backfill materials are presented in Table 6-10.

Table 6-9 Construction Methods for Vertical Seepage Barriers (Cutoff Walls)

Construction Method/Type	Description and Applicability	Characteristics and Requirements
Steel Sheet Piles	Interlocking steel sheets are typically driven into the ground with a vibratory hammer with rapid installation in mixed soils with limited amounts of gravel and cobbles. Interlocking of steel sheets becomes difficult with increased driving depth, increased soil density, and increased gravel and cobbles.	Leakage occurs only through interlocks, making performance reliant on maintaining interlock integrity. Predrilling in soil with gravel and cobble improves chances of interlock integrity. Seepage resistance tends to increase with age due to clogging and oxidation along the interlocks. Corrosion may be a concern for structural integrity.
Vinyl Sheet Piles	Interlocking vinyl sheets are pushed into very soft ground or installed in excavated trenches. Depth is limited by excavation stability (see slurry walls).	Leakage occurs only through interlocks, making performance reliant on interlock integrity. Corrosion is not a concern although chemical stability in harsh environments should be assessed.
Continuous Slurry Trench Wall	Wall constructed in a continuous trench that is excavated with a long-reach excavator and/or clamshell. Trench is stabilized with slurry consisting of either a mixture of bentonite and water or a polymeric slurry. Wall material can vary from SB and SCB backfill to self-hardening CB slurry (see Table 6-10).	Continuous construction avoids construction joints but is susceptible to “windows” in the wall due to partial trench wall collapse or sand settling from slurry. Walls are generally ductile but of low strength and high erodibility. Backfill compressibility can result in vertical and lateral consolidation leading to distress to overlying and adjacent structures. Stability of long excavations can be a concern. Generally limited to soil and soft rock.
Element Slurry Wall	Continuous wall constructed by sequentially overlapping vertical elements. Slurry-supported rectangular elements are excavated using a hydraulic clamshell in soils and soft rock and using a hydrocutter in moderate to hard rock. Circular elements can overlap to form a secant wall. Backfill is usually concrete or plastic concrete placed from the bottom up using the tremmie method.	The length of elements is determined by considering trench and embankment stability, backfill procedures, and other construction considerations. Care should be taken to ensure good connection with construction joints. Excavation stability is less of a concern because of the limited duration of excavation. Elements can be excavated into most soils and rock using a variety of excavation equipment.
Vertical Membrane	Insertion of a geotextile membrane into an excavated trench forms a very low hydraulic conductivity barrier. Membranes are often placed in slurry trench excavations. Interlocking elements are glued or welded to edges of membrane sheets to form interlocks with adjacent sheets.	Membrane creates a very low hydraulic conductivity continuous seepage barrier. Membranes are often used in environmental applications where very small leakage volumes are critical.

Table 6-9 Construction Methods for Vertical Seepage Barriers (Cutoff Walls)

Construction Method/Type	Description and Applicability	Characteristics and Requirements
Deep Mixing Method	*In situ* soils are mixed in-place with a slurry consisting primarily of bentonite, cement, and water to produce a soil-cement material that has reduced permeability and increased strength. The soil mixing can be performed using the multi-axis mixing or vertically-mixing cutter soil mixing techniques. Multi-axis mixing uses overlapping soil augers that are drilled into the ground as the slurry is pumped through the tips of the augers.	Sets of three or more augers are drilled at one time and overlapped with adjacent sets to provide continuity of the wall. This method often results in layering in the wall as the augers encounter different soil types with depth. Cutter soil mixing uses a continuous cutter (resembling a very large chain saw) to mix the entire column of soils simultaneously in a vertical column. This method results in more uniform wall properties with depth. Strength and permeability of the "soil-cement" can be adjusted by the components and dosing of the slurry. Deep mixing is limited to soil and very soft rock.
Jet Grout Walls	Jet grout columns are constructed with a probe that uses high-pressure jets to simultaneously erode soil and fill the column with a grout mixture. Soil-cement is formed as varying amounts of eroded soil are mixed with water and grout. The procedure can be performed with single-, double-, and triple-fluid methods. The single-fluid method injects the cement grout out of a single nozzle that simultaneously erodes the soil and provides the grout. The double-fluid method uses a double nozzle that shoots a stream of grout through a shroud of air, increasing the range of the grout jet so that a larger diameter column can be produced. The triple-fluid method uses a jet of water shrouded in air to cut the column followed by a jet of grout to fill the column.	Because the column is formed by jets, walls can be constructed that seal against irregular rock or concrete surfaces that are otherwise difficult with rigid excavation. Equipment is adaptable for construction in limited-space and low-overhead conditions. Due to very high pressures, the risk of hydrofracturing embankments is high, limiting the applicability in dams and levees. The jet grout method is typically more expensive than other methods, thus limiting its use to limited access and special needs projects.

Table 6-10 Backfill Material Description and Characteristics for Vertical Seepage Barriers (Cutoff Walls)

Backfill Type	Description and Applicability	Characteristics and Requirements
Soil-Bentonite (SB) Backfill	SB backfill consists of a mixture of the excavated soils and bentonite and is used primarily for continuous slurry trenches. The SB mixture is often created by adding the trench slurry to the trench spoils on the ground adjacent to the trench. The mixing is often done using a bulldozer or a soil-mixing machine.	SB backfill is a low-strength, high-ductility, and low-hydraulic conductivity material. While the material is highly compressible, friction on the sidewalls may reduce vertical stress on the backfill, causing it to remain in an underconsolidated state in the trench. The SB may be susceptible to vertical and horizontal consolidation and hydraulic fracture.
Cement-Bentonite (CB) Backfill	CB backfill is a self-hardening slurry that is used to support continuous slurry trenches and then hardens into a consistency similar to stiff clay. The slurry is mixed in a batch plant and may contain additives to increase strength or retard setup.	CB is less prone to consolidation than SB. The strength of CB can be adjusted but generally has the consistency of very stiff to hard clay.
Soil-Cement-Bentonite (SCB) Backfill	SCB backfill is often blended and placed similar to SB backfill but with the addition of cement to give strength to the backfill for a more robust element within the embankment. Primarily used as backfill for continuous slurry trenches.	SCB is less prone to consolidation than SB. The strength of SCB can be adjusted. It should be noted that some SCB walls have been found to have discontinuities or windows near the bottom of the wall. These windows are thought to be the result of premature setting of the backfill that breaks into blocks due to the slumping that occurs during normal placement.
Soil Cement	Soil cement is a term often used to describe the product of deep soil mixing. In the wet method, a slurry consisting primarily of bentonite, cement, and water is blended with the *in situ* soil (see deep mix method in Table 6-9). The less common dry method injects cement and bentonite powders directly into the soil for mixing.	The strength and permeability of soil cement will vary depending on the amount of cement and bentonite in the slurry and the type of soil it is mixed with. Gravelly or clean coarse-grained soils will tend to have higher strength and higher permeability than sands and silts that are mixed with the same amount of an identical slurry.
Plastic Concrete	Plastic concrete is conventional concrete with bentonite added to increase ductility with the intent of making the wall more compliant with the surrounding soils, decreasing cracking of the wall and surrounding soils.	The bentonite results in reduced strength and erosion resistance of the concrete. Thus, a balance of robustness and compliance should be considered when choosing between conventional and plastic concrete.
Conventional Concrete	Conventional concrete adds a robust element to an excavation or dam/levee embankment that is high-strength, stiff, and highly erosion resistant.	The rigidity of the wall may cause stress concentrations in other elements of the embankment, resulting in cracking of the wall or surrounding soil.

6-5.2.2 Required Penetration for Cutoff Walls in Supported Excavations.

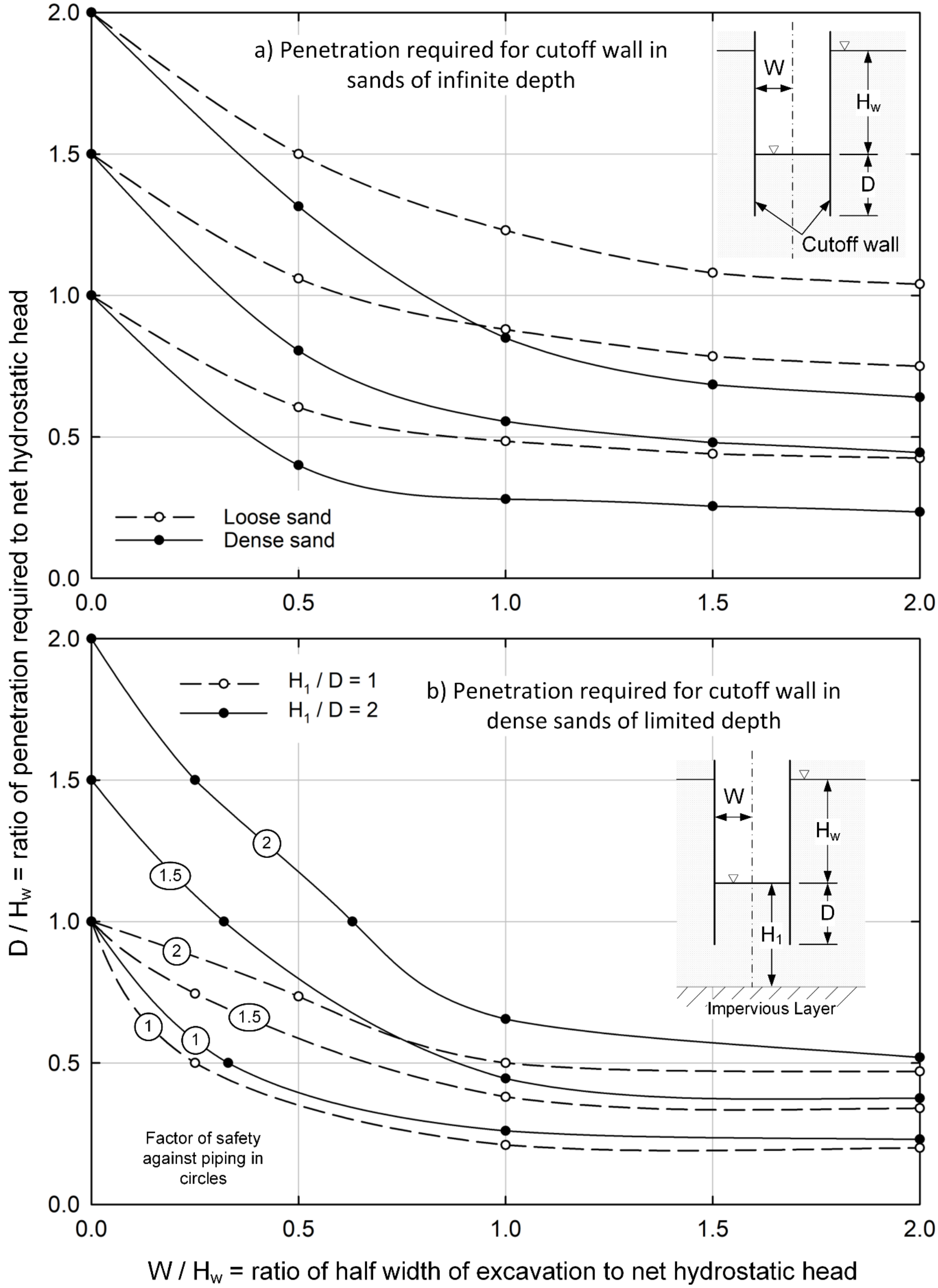
To prevent instability of the base of supported excavations due to heave (i.e., quick condition or blowout), the vertical cutoffs must extend deep enough to reduce hydraulic gradients or uplift pressures to acceptable levels. The first option to consider for embedment is to extend the cutoff to a low-permeability layer having considerable thickness. However, this is not always feasible.

In uniform pervious sands, critical hydraulic gradients may develop at the base of the excavation. The required wall penetration to provide a factor of safety against effective stress heave (quick condition) and piping in homogenous, isotropic sands can be calculated using Figure 6-11. For homogenous, anisotropic sands, the penetration depth can be reduced by the transformation factor, a (see Section 6-2.4.1 Equation 6-8). For clean sand, exit gradients greater than about 0.5 to 0.75 will cause unstable conditions for men and equipment operating on the subgrade. To avoid instability, provide sheeting penetration for a safety factor of 1.5 to 2 against effective stress heave as calculated in Figure 6-8.

In layered sands, variation in permeability results in a change of seepage conditions from that assumed in Figure 6-11. Figure 6-12 presents guidance for situations with layered sands. In layered soils with layers of very fine sand, silty or clayey sand, or silt and clay, the risk of bottom heave (total stress heave) must be considered. Figure 6-13 presents guidance for avoiding bottom heave in excavations. Alternatively, the conditions can be assessed using flow nets or finite element analyses, and Figure 6-11 through Figure 6-13 can be used to confirm the results.

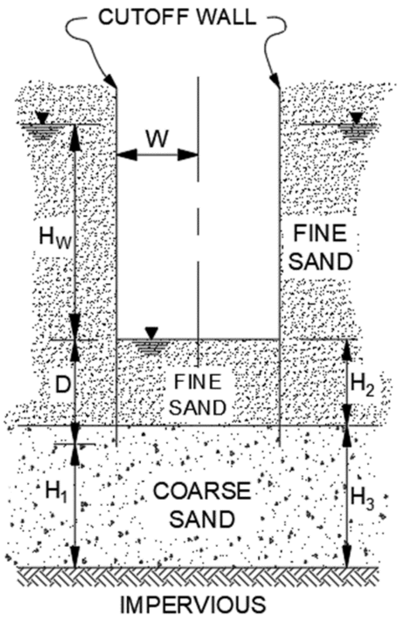
The relationships presented in Figure 6-11 through Figure 6-13 were developed based on the results of laboratory modeling performed by Marsland (1953). The results were reported for loose and dense sands. Loose sands were placed “with a water jet” while the dense sands were placed “with an electrically vibrated” hammer. No relative densities were reported although porosities of 42 percent and 37 to 38 percent were reported for the loose and dense sands, respectively.

1\



/1/

Figure 6-11 Required Depth of Penetration of Cutoff Wall-Supported Excavations in Homogenous Isotropic Sand (after Marsland 1953)

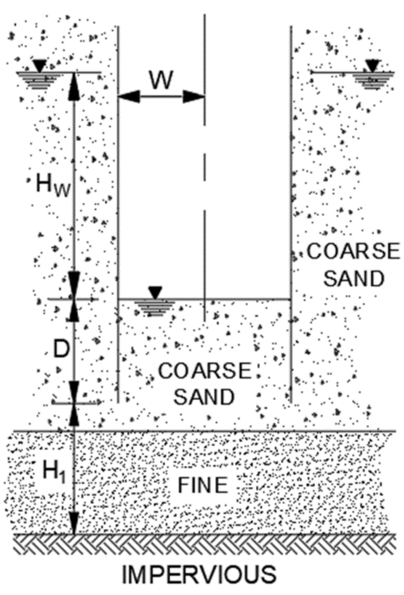


Coarse Sand Underlying Fine Sand

The presence of the coarse sand layer makes flow in the fine sand nearly vertical and generally increases hydraulic gradients in the fine sand layer when compared with the homogenous case.

If the top of the coarse sand layer is at a depth greater than the excavation width below the depth of the cutoff, the safety factors for the homogenous case apply.

If the top of the coarse sand layer is at a depth less than the excavation width below the depth of the cutoff, the uplift pressures will be greater than for the homogenous case. If the permeability of the coarse layer is more than 10 times the permeability of the fine layer, the failure head (H_w in Figure 6-9) will equal the thickness of the fine layer, H_2.



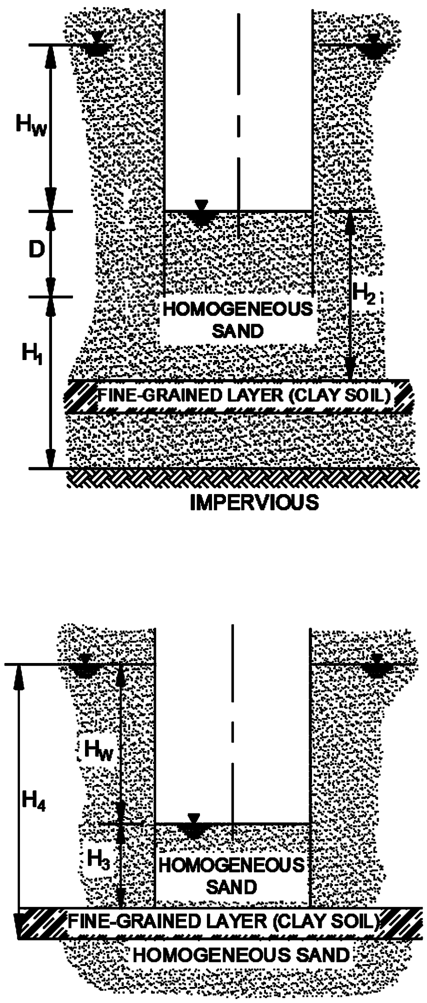
Fine Sand Underlying Coarse Sand

The presence of the fine sand constricts the flow beneath the cutoff wall and generally decreases hydraulic gradients at the base of the excavation when compared with the homogenous case.

If the top of the fine sand layer is below the depth of the cutoff, the safety factors are intermediate between those for the homogenous case (calculated using Figure 6-9) for an impermeable boundary located between the top and bottom the fine layer.

If the top of the fine sand layer is at a depth less than the depth of the cutoff, the factors of safey for the homogenous case (calculated using Figure 6-9) will be somewhat conservative.

Figure 6-12 Corrections to Required Depth of Penetration of Cutoff Wall-Supported Excavations for Stratified Sand (after Marsland 1953)



Fine-Grained Layer Within Homogenous Sand Stratum

If the top of the fine layer is at a depth greater than the excavation width below the depth of the cutoff wall, the safety factors for the homogenous case (in Figure 6-13) apply, assuming the impervious base is at the top of the fine layer.

If the top of the fine-grained layer is at a depth less than the excavation width below the depth of the cutoff, pressure relief is required so that the differential head (H_w) does not exceed the height of soil above the fine layer (H_2).

If the fine-grained layer lies above the final base of the excavation, the final condition is safer than the homogenous case. However, dangerous conditions may arise during excavation above the base of the fine layer and pressure relief may be required as outlined above.

To avoid bottom heave, the weight of the soil above the base of the fine layer ($\gamma_t \cdot H_3$) should be greater than the water pressure acting at the base of the fine-grained layer ($\gamma_w \cdot H_4$),

where:

γ_t = the total unit weight of the soil
γ_w = unit weight of water

Figure 6-13 Corrections to Required Depth of Penetration of Cutoff Wall-Supported Excavations in Sand Containing Fine-Grained Layers (after Marsland 1953)

6-5.2.3 Seepage Blankets and Berms.

Upstream seepage blankets are constructed upstream of a dam or levee to increase the seepage pathway as depicted in Figure 6-14a. Upstream blankets are constructed of compacted fill with low hydraulic conductivity or a geomembrane protected with a coarse-grained soil cover. The increased seepage pathway will tend to decrease the amount of seepage, decrease uplift pressures below the dam or levee, and decrease exit gradients. The primary design concern of seepage blankets is providing a uniform foundation for the blanket. Differential settlement of the blanket under reservoir loading can result in tearing or cracking of the blanket and concentrated leakage, decreasing the effectiveness of the blanket.

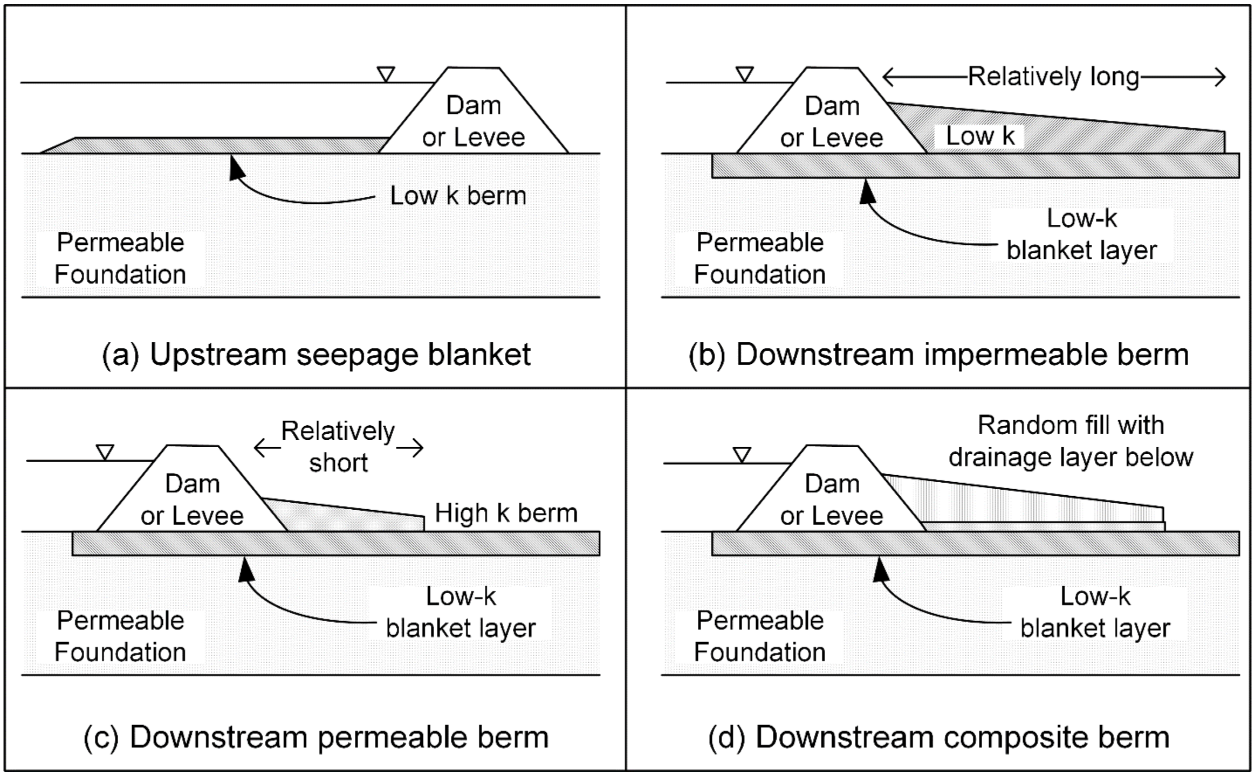


Figure 6-14 Seepage Blankets and Berms

Downstream seepage berms are designed to prevent excessive hydraulic pressures on the downstream side of a small dam or levee. Often these pressures are the result of a low hydraulic conductivity soil layer (blanket layer) that blocks the exit of seepage water. Seepage berms are usually constructed using one of three designs: (1) an impermeable berm, (2) a permeable berm, or (3) a composite berm.

The concept of an impermeable berm used to resist uplift pressures on a low-permeability blanket layer is presented in Figure 6-14b. The berm is constructed of generally low-permeability soils and is designed to increase the weight of the blanket layer thereby resisting total-stress heave. For blanket layers that allow some seepage, the impermeable berm will increase the resistance to seepage flow through the blanket layer, resulting in higher pressures below the levee and downstream toe. This also requires the berm to extend long distances from the levee in order to produce low uplift pressures beyond the berm.

A permeable seepage berm is illustrated in Figure 6-14c. The permeable berm is constructed of permeable materials (generally sand) that increase the total weight on the blanket without significantly increasing seepage resistance. Where the blanket layer is sufficiently permeable allow seepage on the landside, permeable berms can be much shorter than impermeable berms. A disadvantage of this berm type is that appropriate high-permeability soils can be very expensive in some locales.

A composite seepage berm consists of an upper layer of undifferentiated fill underlain by a drain and filter layer (see Figure 6-14d). Thus, the berm acts similar to the permeable berm but is less expensive because less of the filter material is required. The drainage layer must be designed with adequate flow capacity to prevent the buildup of water pressure in the layer. In some cases, pipes have been included in the drainage layer to increase flow capacity. However, such pipes increase the amount of maintenance needed for the berm.

6-5.2.4 Other Types of Seepage Barriers.

6-5.2.4.1 Cutoff Trench.

Cutoff trenches are constructed in the foundations of dams and levees as part of the original construction. The cutoffs are generally a broad trench with sloped sidewalls that is backfilled with low hydraulic conductivity material. The trench extends partially or fully through permeable soil and rock layers in the foundation. In addition to the seepage control offered, cutoff trenches provide an opportunity to visually inspect the subsurface conditions beneath the dam or levee. Care should be taken to ensure that the downstream side of the berm is properly filtered (see Section 6-5.3) to prevent internal erosion into permeable foundation soil or rock.

6-5.2.4.2 Foundation Grouting.

Foundation grouting is performed by pumping stabilized cement grout into boreholes to fill joints and voids in bedrock and reduce the effective hydraulic conductivity of the formation. Foundation grouting can be performed prior to dam construction or after construction as a remedial measure. Grout is pumped into discrete depth intervals of the boring by sealing off an interval using inflatable bladders called packers. Grout lines consisting of evenly spaced boreholes are typically aligned parallel to the axis of the dam although other configurations may be applicable for special circumstances. In many cases, multiple grout lines (grout curtains) are installed along the dam axis with the boreholes inclined in opposite directions to increase the chances of encountering all of the joints and voids in the rock.

6-5.2.4.3 Liners.

Leakage from ponds and reservoirs can be reduced by installing a liner in the base of the pond or reservoir. Such liners can consist of compacted clay, synthetic geomembrane liners, or native soils supplemented with bentonite or other materials to reduce hydraulic conductivity. Similar to upstream blankets, the foundation for the liner must be sufficiently uniform to prevent differential settlements under the reservoir loading, which could tear or crack the liner.

6-5.3 Filters and Drains.

Drainage systems provide relief of hydraulic pressures in foundations, intercept paths of concentrated seepage, and control the release of the drained water to prevent internal erosion. Properly designed drainage elements will have adequate flow capacity to reduce the pressures for which they are designed while being filter compatible with the surrounding soils to prevent internal erosion through the drainage elements.

Filters and drains are essential components for the drainage systems of a dam, levee, excavation or other geotechnical construction. A *filter* prevents the migration of the base soil into another soil layer or zone, into a drain, or out of the system through surface flow. The *base soil* is the material from which the seepage flow is exiting. A *drain* removes collected water from the collection point to a suitable discharge location. Drains can consist solely of coarse-grained soil that allows rapid seepage through its interstitial voids or can include drainage pipes that collect water from the surrounding coarse-grained drain material.

6-5.3.1 Mineral Filter Criteria.

In order to satisfy its purpose, the filter must (1) have a gradation fine enough to prevent the migration of the base soil into the filter, (2) have high enough hydraulic conductivity to not restrict flow from the base soil, and (3) have the ability to collapse so that cracks in the base soil are not propagated through the filter. Mineral filters consist of sand and gravel that are specifically graded to meet these criteria. Design procedures for mineral filters are have been developed by most U.S. agencies involved in dam design. These criteria have been summarized by FEMA (2011). A brief summary of the design procedure is provided in this section.

In the design procedure, the soil being filtered is the base soil and characteristics of the base soil gradation will be followed by a B (e.g. the grain size of which 85 percent of the base soil is passing will be denoted: $D_{85}B$). Similarly, the filter gradation will be followed by an F (e.g. $D_{15}F$). Examples of the grain sizes associated with filter design are provided in Figure 6-15.

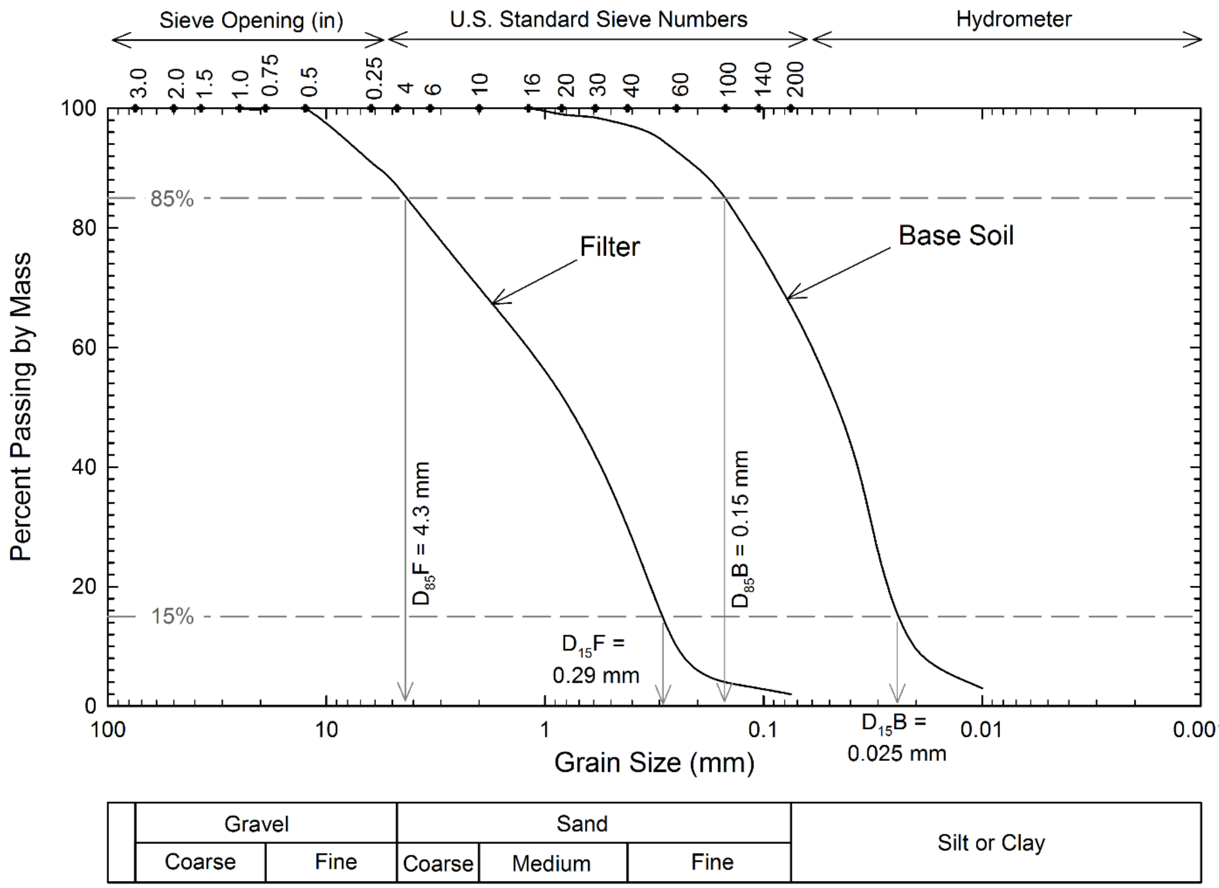


Figure 6-15 Example Base Soil and Filter Gradations

Based on FEMA (2011), filter design is completed using the following steps:

Step 1. Plot the grain-size distributions for the base soil and assess whether the base soils contain dispersive soils (e.g., soils that disaggregate when in contact with water). ASTM D6572 and D4647 can be used to identify dispersive soils.

Step 2. Assess if the base soil has particles larger than the No. 4 sieve or is gap graded. Gap graded soil may be susceptible to internal instability. Special consideration should be given to a gap graded soil to insure the fine portion of the base soil is protected from erosion.

Step 3. If the base soil contains particles larger than the No. 4 sieve, regrade the grain-size distribution to include only the portion of the distribution finer than the No. 4 sieve. FEMA (2011) provides details on the regrading procedure.

Step 4. Determine the base soil category using Table 6-11.

Table 6-11 Base Soil Categories for Mineral Filter Design (after FEMA 2011)

Base Soil Category	Percent Finer Than No. 200 Sieve (0.075-mm) (after re-grading where applicable)	Base Soil Description
1	> 85	Fine silt and clays
2	40 –85	Sands, silts, clays, and silty sands
3	15 –39	Silty and clayey sands and gravels
4	< 15	Sands and gravels

Step 5. Determine the filter criteria for base soil retention by calculating the maximum $D_{15}F$ based on the criteria in Table 6-12. The retention criteria are based on the principle that the larger particles in the base soil (represented by $D_{85}B$) must be retained by the voids in the filter (controlled by $D_{15}F$). By providing a maximum $D_{15}F$, the criteria ensure that the filter voids are sufficiently small. If the base soil has a range of grain-size distributions, the smallest value of $D_{85}B$ should be used for the retention criteria.

Table 6-12 Restraint Criteria for Mineral Filter Design (after FEMA 2011)

Base Soil Category	Filtering Criteria–Maximum $D_{15}F$	
	Non-Dispersive Soil	Dispersive Soil
1	$\text{Max } D_{15}F \leq 9 \cdot D_{85}B$ $\text{Max } D_{15}F \geq 0.2\,\text{mm}$	$\text{Max } D_{15}F \leq 6.5 \cdot D_{85}B$ $\text{Max } D_{15}F \geq 0.2\,\text{mm}$
2	$\text{Max } D_{15}F \leq 0.7\,\text{mm}$	$\text{Max } D_{15}F \leq 0.5\,\text{mm}$
3	$\text{Max } D_{15}F \leq \left[\frac{40-A}{25}\right]\left[B-C\right]+C$ where: A = % passing No. 200 sieve, B = 4 × $D_{85}B$ ≥ 0.7 mm, and C = 0.7 mm	$\text{Max } D_{15}F \leq \left[\frac{40-A}{25}\right]\left[B-C\right]+C$ where: A = % passing No. 200 sieve, B = 4 × $D_{85}B$ ≥ 0.5 mm, and C = 0.5 mm
4	$\text{Max } D_{15}F \leq 4 \cdot D_{85}B$	$\text{Max } D_{15}F \leq 4 \cdot D_{85}B$

Note: $D_{85}B$ and percent passing No. 200 sieve are determined after regrading.

Step 6. Determine the flow criteria for the filter by calculating the minimum $D_{15}F$ based on the criteria in Table 6-13. The permeability criteria are based on the principle that the filter's hydraulic conductivity is strongly related to $D_{15}F$. By providing a minimum $D_{15}F$, the filter will have sufficient flow capacity in comparison to the base soil. If the base soil has a range of grain-size distributions, the largest value of $D_{15}B$ should be used for the permeability criteria. Plot the minimum and maximum $D_{15}F$ on a gradation plot and adjust the minimum $D_{15}F$ to ensure that the ratio between the minimum and maximum $D_{15}F$ is not greater than 5 (i.e., $Min\ D_{15}F\ /\ Max\ D_{15}F$).

Table 6-13 Flow Criteria for Mineral Filter Design (after FEMA 2011)

US Agency	Filter Permeability Criteria
USBR	$Min(D_{15}F) \geq 5 \cdot D_{15}B$
USACE	$Min(D_{15}F) \geq (3 \text{ to } 5) \cdot D_{15}B$
NRCS	$Min(D_{15}F) \geq (4 \text{ to } 5) \cdot D_{15}B$
All	$Min(D_{15}F) \geq$ 0.1 mm

Note: $D_{15}B$ is determined prior to regrading.

Step 7. Filters should also have a coefficient of uniformity ($C_u = D_{60}F / D_{10}F$) is between 2 and 6.

Step 8. Limit the amount of oversized material and fines in the filter. Most agencies require that the maximum particle size of the filter ($D_{100}F$) be less than 2 inches (51 mm) although the USACE allows particles up to 3 inches (76 mm). The minimum particle size associated with 5% passing for the filter (D_5F) is the No. 200 sieve or 0.075 mm. Any fines present in the filter soil should be non-plastic (i.e., PI = 0).

Step 9. Limit segregation potential of the filter by determining the maximum $D_{90}F$ from Table 6-14. Segregation occurs more easily if a wide range of particle sizes is present.

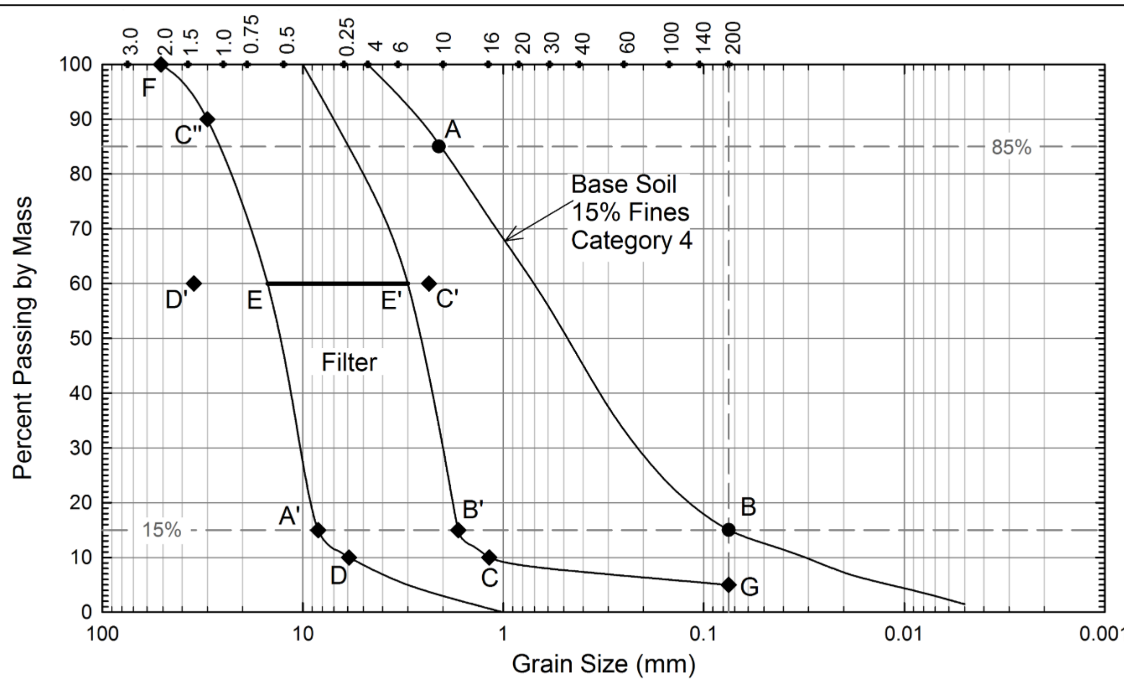
Table 6-14 Segregation Criteria for Mineral Filter Design (after FEMA 2011)

Minimum $D_{10}F$ (mm)	Maximum $D_{90}F$ (mm)
< 0.5	20
0.5 – 1.0	25
1.0 – 2.0	30
2.0 – 5.0	40
5.0 – 10	50
10 – 50	60

Step 10. Plot the criteria for minimum D_5F, minimum and maximum $D_{15}F$, maximum $D_{90}F$, and maximum $D_{100}F$ on a gradation plot to create an acceptable gradation band for the filter. Compare candidate filters with the criteria and gradation band.

Design for Drainpipe Perforations. If the filter is to contain a drainage pipe, the filter soil around the pipe is referred to as the envelope material. The smallest value of $D_{50}E$ (E stands for envelope) allowed by the gradation should be larger than the size of the maximum pipe perforation.

An example of a filter design for a Type 4 base soil is presented in Figure 6-16.



<u>Steps 1-3</u>: Plot the grain size distribution(s) for the base soil. If necessary, regrade the grain size distribution to include only the portion of the distribution finer than the No. 4 sieve.

<u>Step 4</u>: Determine the base soil category using Table 6-12. The example soil falls in Category 4.

<u>Step 5</u>: $D_{85}B$ = 2.1 mm for the base soil (Pt. A). To satisfy the criteria for base soil restraint or retention, the maximum $D_{15}F$ should be ≤ 4 × $D_{85}B$ of base soil, or 8.4 mm (Pt. A').

<u>Step 6</u>: $D_{15}B$ = 0.075 mm for the base soil (Pt. B). To satisfy the flow criteria the minimum $D_{15}F$ should at least 5×$D_{15}B$, or 0.375 mm. The minimum $D_{15}F$ should also be at 1/5 of the maximum $D_{15}B$, or 1.7 mm. The larger of these two values is plotted as Pt. B'.

<u>Step 7</u>: Select a range of $D_{60}F$ values to keep C_u between 2 and 6.

(a) Find the minimum $D_{10}F$ size and plot as point *C*: $D_C \approx D_{B'}$ × 0.7 = 1.7 × 0.7 = 1.18 mm
(b) Find the minimum $D_{60}F$ size for C_u= 2 (point C'): $D_{C'} = D_C$ × 2 = 1.18 × 2 = 2.36 mm
(c) Find the maximum $D_{10}F$ size and plot as point *D*: $D_D \approx D_{A'}$ × 0.7 = 8.4 × 0.7 = 5.9 mm
(d) Find the maximum $D_{60}F$ size for C_u=6 (point *D'*): $D_{D'} \approx D_{A'}$ × 6 = 5.9 × 6 = 35.4 mm
(e) Select a "sliding bar" defined by points E and E' where: D' > E > *E'* > *C'* and E = E' × 5, This bar can be adjusted back and forth between points *D'* and *C'*.

<u>Step 8</u>: The maximum $D_{100}F$ size is 51 mm (2 in.) shown as point F. The minimum D_5F size is 0.075mm (No.200 sieve), shown as point G.

<u>Step 9</u>: In order to prevent possible segregation during construction, select the maximum $D_{90}F$ size. The minimum $D_{10}F$ size is 1.18 mm (Pt. C), the maximum $D_{90}F$ size is 30 mm (Pt. C'').

<u>Step 10</u>: Compare the grain size distributions of candidate filters to the range delineated by curves D-A'-E-C''-F and G-C-B'-E'.

Figure 6-16 Example Filter Design

6-5.3.2 Geotextile Filter Criteria.

In some cases, geotextiles can be used for soil filtration and drainage in lieu of mineral filters and gravel drains. In general, the FEMA (2011) guidelines do not recommend the use of geotextiles in critical areas of dams. The term *geotextiles* refers to a wide variety of synthetic, fabric-like products that vary depending on the types of fibers used in the manufacturing and how these fibers are interconnected. The most common forms include woven, nonwoven, and knitted fabrics. Woven geotextiles are manufactured by weaving two perpendicular sets of synthetic fibers to form a fabric. Nonwoven geotextiles have a random orientation often resembling a felt fabric and are manufactured by either needle punching, spun bonding, or resin bonding. Knitted geotextiles consist of interlocking series of loops of fiber yarns that form a fabric.

A common drainage and filtration application for geotextile filter fabrics is a subsurface drain such as presented in Figure 6-17. In this application the drainage is provided by the poorly-graded gravel drainage rock and the slotted outlet pipe. The role of the geotextile is to prevent migration of the surrounding soils into the drainage rock and pipe. In this way, the geotextile prevents erosion of the surrounding soil and/or clogging of the drain. Other applications include drains within retaining wall backfill and drainage blankets below embankments.

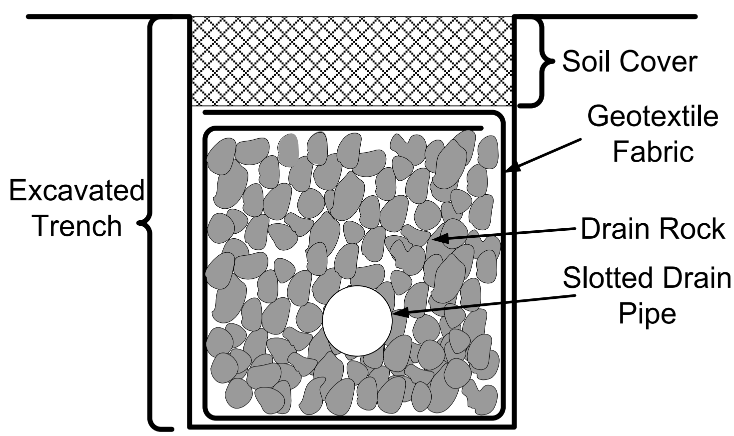


Figure 6-17 Subsurface Drain Constructed of Filter Fabric, Drainage Rock, and a Slotted Pipe

For the geotextile fabric in Figure 6-17 or other applications to perform adequately, the geotextile should be designed to have the ability to: (1) retain particles of the base soil to prevent migration through the fabric, (2) allow the passage of water without significant buildup of water pressure, and (3) resist clogging due to accumulation of fine soil particles, chemical precipitates, and biological precipitates.

Criteria for retention of soil particles was proposed by Giroud (2010) based on D_{20B} and the soil's *linear coefficient of uniformity* (C'_u). As shown in Figure 6-18, a log-linear approximation is used to represent the base soil's gradation curve. The linear particle size (D'_x) is the obtained the log-linear approximation. The values of D'_{100} and D'_0 are defined by the ends of a straight line drawn through the middle part of the gradation plot (i.e., through D_{10} and D_{60}).

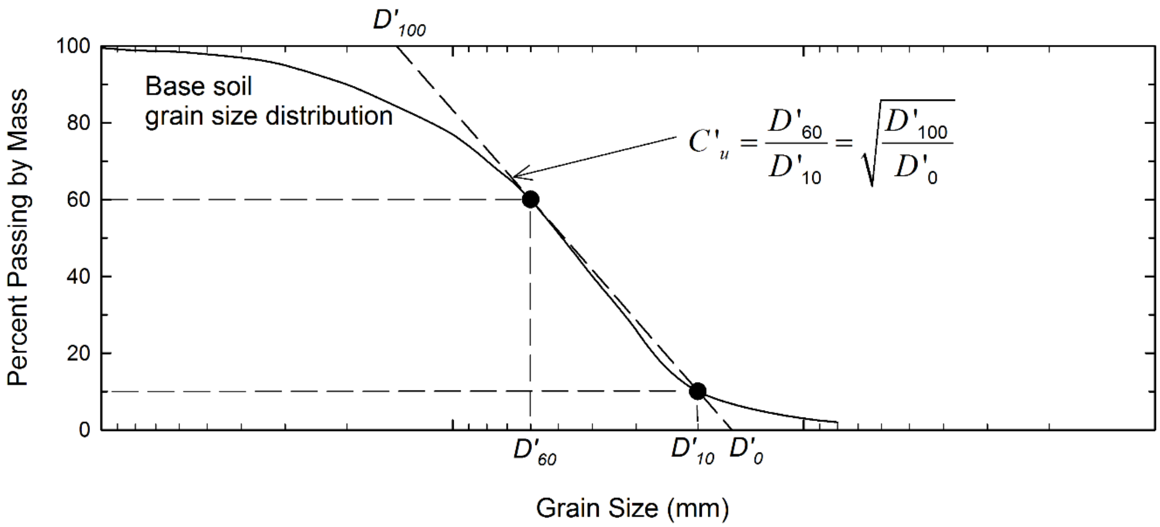


Figure 6-18 Linear Coefficient of Uniformity (after Giroud 2010)

Geotextiles are designed for retention based on the *geotextile opening size* (O_{95}), which indicates the size at which 95 percent of openings are smaller. According to Luettich (1992), geotextile retention criteria for soils with less than 10% fines can be selected using the base soil gradation and Table 6-15.

For soils with more than 10% fines and PI greater than 5, the geotextile should have O_{95} less than 0.21 mm, provided the soil is non-dispersive. For dispersive soils with more than 20% clay sized particles, a filter of 75 to 100 mm of sand should be placed between the base soil and the geotextile, and the geotextile should be designed to retain the filter sand. Retention of non-plastic soils with more than 10% fines can be designed using Table 6-15.

Geotextile filters also must have a much higher hydraulic conductivity than the base soil. A filter cake of trapped particles often forms on the face of a geotextile. These particles must not reduce the hydraulic conductivity of the geotextile to the point that it restricts seepage flow out of the base soil. However, clogging is difficult to quantify. Some clogging will occur when the geotextile is put into service. The geotextile must remain sufficiently open so that accumulation of particles and chemical and biological precipitates will not reduce the hydraulic conductivity to the point where the filter cake/geotextile system becomes less permeable than the base soil. The USBR (2014) recommends the following considerations be taken to assess clogging potential:

- Use the largest opening size that satisfies the retention criterion.
- Do not use geotextile filters in environments where precipitates are likely to form. Avoid high alkalinity groundwater, which can form calcium, sodium, or magnesium precipitates. Also avoid acidic seepage, which can form iron and aluminum hydroxide precipitates.
- Avoid use of geotextiles with internally unstable (C_u > 20) or dispersive soils.
- Avoid organic-rich environments such as agricultural runoff, landfill leachates, and sites known to form iron bacteria.
- Make sure that the geotextile filter makes intimate contact with the soil.
- Do not place geotextile filters against cohesive soils containing voids.

Table 6-15 Geotextile Opening Size Criteria for Soils with Less than 10% Fines (after Luettich et al. 1992)

Base Soil Description					Geotextile Retention Criteria
Primary Category Description	**Secondary Characteristic**	**Gradation Description**		**Relative Density (D_r)**	
Less than 10% fines and less than 90% gravel	Stable Soil ($1 < C_c < 3$)	Obtain C_u from straight line drawn through D_{60} and D_{30}	Widely Graded ($C'_u > 3$)	Loose D_r < 35%	$O_{95} < \frac{9}{C'_u} D'_{50} B$
				Medium dense 35% < D_r < 65%	$O_{95} < \frac{13.5}{C'_u} D'_{50} B$
				Dense 65% < D_r	$O_{95} < \frac{18}{C'_u} D'_{50} B$
	Unstable Soil ($C_c < 1, 3 < C_c$)	Obtain C_u from straight line drawn through D_{30} and D_{10}	Uniformly Graded ($C'_u < 3$)	Loose D_r < 35%	$O_{95} < C'_u D'_{50} B$
				Medium dense 35% < D_r < 65%	$O_{95} < 1.5 \cdot C'_u D'_{50} B$
				Dense 65% < D_r	$O_{95} < 2 \cdot C'_u D'_{50} B$

The permeability requirement for a geotextile can be stated as:

$$FS_g = \frac{k_g}{k_s} = \frac{\psi_g \cdot t_g}{k_s} \quad \textbf{(6-16)}$$

where:
FS_g = factor of safety for geotextile permeability,
k_g = hydraulic conductivity of the geotextile across the plane of the fabric,
k_s = hydraulic conductivity of the base soil,
ψ_g = permittivity of the geotextile, provided by manufacturers or from testing (ASTM D4491), and
t_g = geotextile thickness.

Giroud (2010) suggests that an FS_g of 10 to 20 is appropriate to maintain adequate filter permeability. Others (e.g., Loudiere et al. 1983, Christopher and Fischer 1991) recommend that the FS_g value be between 10 and 100.

Over the past several decades geotextile filter fabrics have been developed to provide filtration between base soil and coarse-grained drain materials. While these fabrics are inexpensive compared to mineral filters, they are considered by many to be far less reliable than mineral filters due to their propensity to clog and the potential to be damaged during construction. For this reason, all major dam owning and regulating agencies in the U.S. (U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, FEMA, and FERC) do not allow the use of filter fabrics within critical areas of dam embankments or in high-hazard structures.

6-5.3.3 Surface and Subsurface Drainage.

Pavements and other surface treatments can be destabilized by water ponded at the ground surface or shallow phreatic surfaces. Near-surface groundwater may be collected by intercepting drains prior or collected in the pavement base material as it exits the subgrade. Accumulation of surface water in wide flat areas, due to rainfall or other surface sources, can be mitigated using trench drains connected to deeper drainage systems.

6-5.3.3.1 Intercepting Drains.

Intercepting drains (a.k.a., stability trenches or stability drains) can be used in locations where water seeping from a hillside has a detrimental effect on slope stability or the performance of roadways. These drains consist of shallow trenches with collector pipes surrounded by drainage material, placed to intercept seepage moving horizontally in an upper pervious stratum as illustrated in Figure 6-19. The trench backfill can consist of a filter material compatible with the surrounding soil as shown in Figure 6-20 or a drainage aggregate wrapped in filter fabric (Figure 6-17). The type of trench backfill and filtering mechanism used will depend on the criticality of the drain. Drain designs should aim to be as simple and constructible as possible while still providing suitable filtering.

The effect of intercepting drains on seepage patterns can be evaluated using flow nets or modeled by finite element analyses. Such analyses should also assess the volumetric flow rate into the drains so that the drain pipes and outlets can be properly designed.

6-5.3.3.2 Surface Blanket Drains.

Surface blanket drains are used to intercept ground water beneath pavements and structures to mitigate the buildup of water pressure or destabilization of subgrades. In many cases, the aggregate base layer of pavements may be assessed for its effectiveness as a blanket drain. Design of surface blanket drains should consist of: (1) assessment of the flow rate of drainage into the blanket to calculate the needed spacing for outlets and (2) assessment of the tolerable uplift pressure in the blanket to prevent damage to the overlying pavement, embankment, or structure.

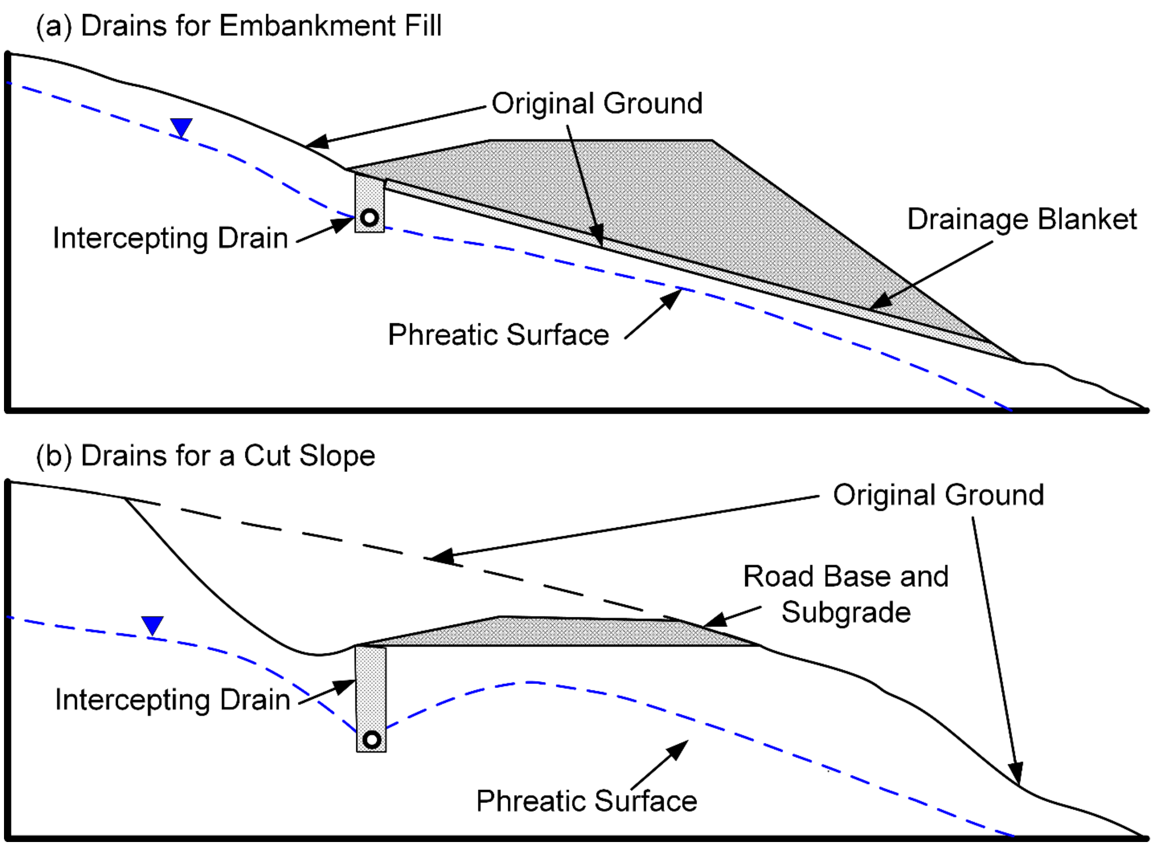


Figure 6-19 Use of Subsurface Interceptor Drains and Blanket Drains for Roadway Drainage

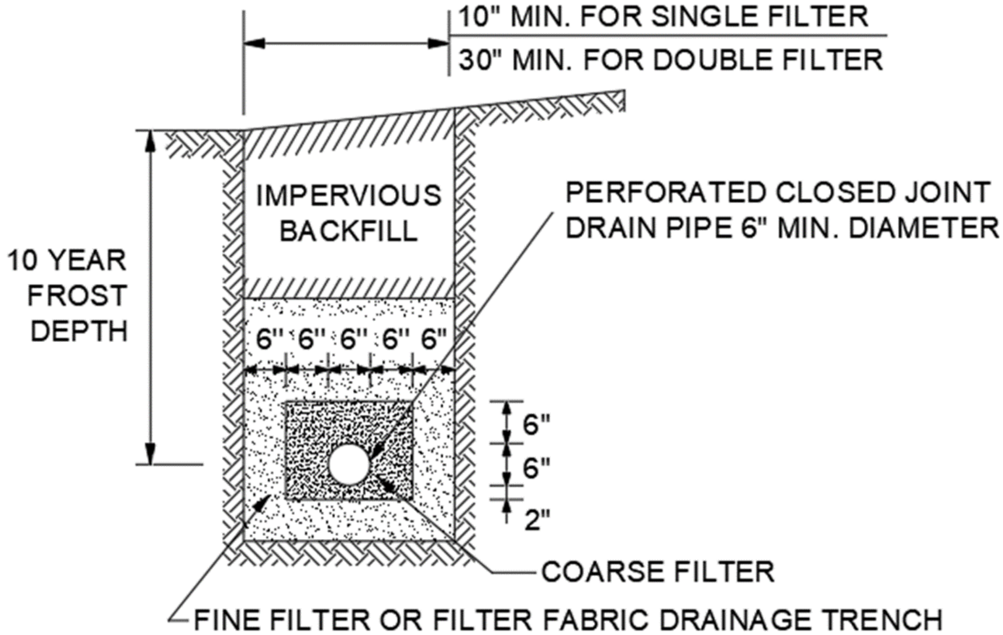
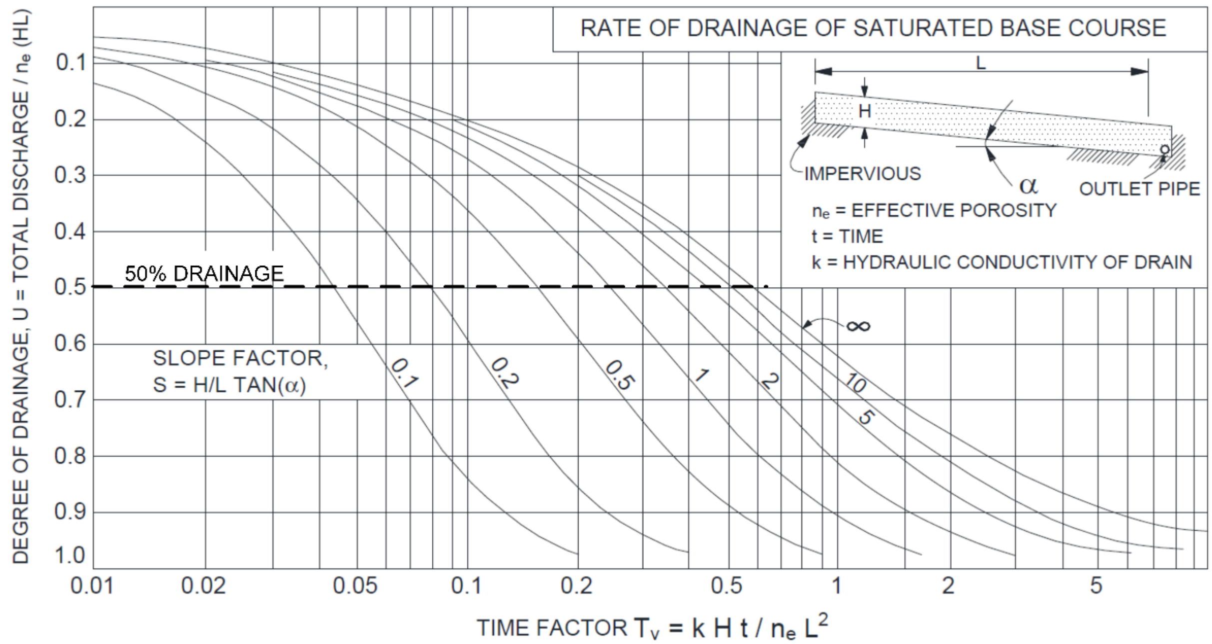


Figure 6-20 Subsurface Drain with a Two-Stage Filter and a Slotted Pipe

The thickness of aggregate base course needed to provide effective drainage can be calculated using Figure 6-21. For a range of slopes, the degree of drainage is related to the porosity and hydraulic conductivity of the aggregate base, the thickness of the base layer, the subgrade slope, the drain spacing, and the time allowed for drainage. Figure 6-21 can be used to select drain spacing or evaluate suitability of base material. *Effective porosity* (also called *specific yield*) is the quantity of water per unit volume that is not retained in the soil by capillarity during discharge (Barber 1959). It ranges from 25 percent for a uniform material, such as medium to coarse sand, to 15 percent for a well-graded sand-gravel mixture.



<u>Required Drain Spacing and Discharge Estimate</u>

1. Select the desired maximum time for 50% drainage (t_{50}) and the slope factor (S).
2. Enter the graph horizontally at the U = 0.5 line and read the time factor (T_V) corresponding to S.
3. Solve the time factor equation for L to determine the required drain spacing:

$$L = \sqrt{\frac{kHt_{50}}{n_e T_V}}$$

4. Estimate the flowrate at time = t_{50}:

$$q = kH\frac{H + L\tan\alpha}{2L}$$

Figure 6-21 Drainage of an Aggregate Base Course (after Barber 1959)

6-5.3.3.3 Drainage of Ponded Areas.

During times of heavy rainfall or runoff from adjacent areas, vertical drainage trenches can be used to mitigate ponding water in level areas or enclosed basins. The flow rate of seepage into parallel trenches can be estimated using Figure 6-23 for an underlying zone that is either completely pervious or completely impervious in comparison to the surface layer. The trench spacing ($2\times S$) can be designed such that the calculated flow rate into the trenches meets or exceeds the required surface infiltration for an area of $1\times2\times S$. The trench must also be designed to sustain the required flow rate and may include collector pipes. If sufficient drainage capacity cannot be provided using trenches, surface drainage facilities are required to prevent ponding.

6-5.3.1 Retaining Wall Drainage.

Water imposes additional destabilizing forces on retaining and basement walls that can lead structural distress or collapse. Drainage systems should be designed to prevent the buildup of water behind walls. Figure 6-22 presents several alternatives for providing retaining wall drainage.

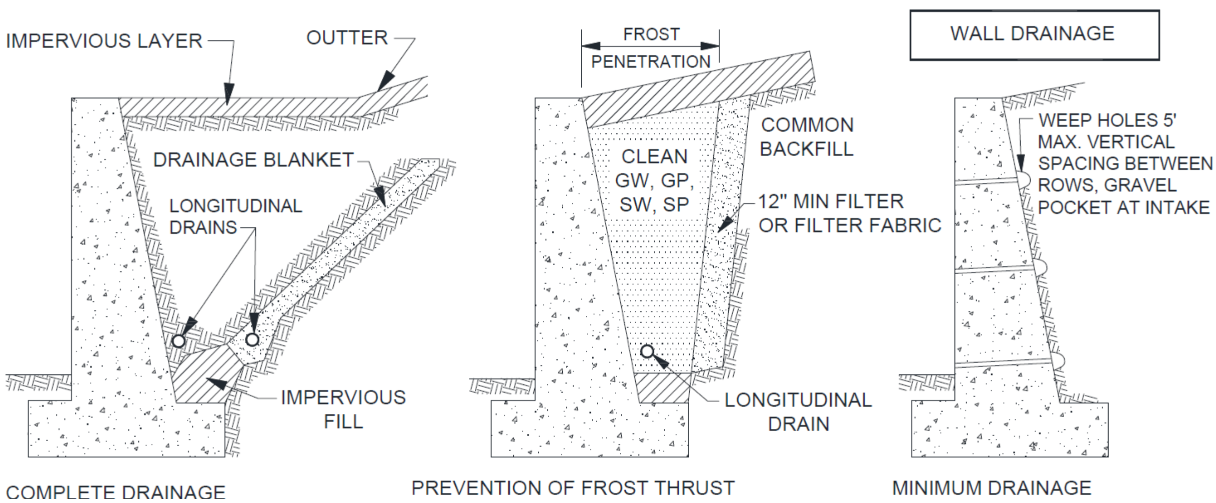
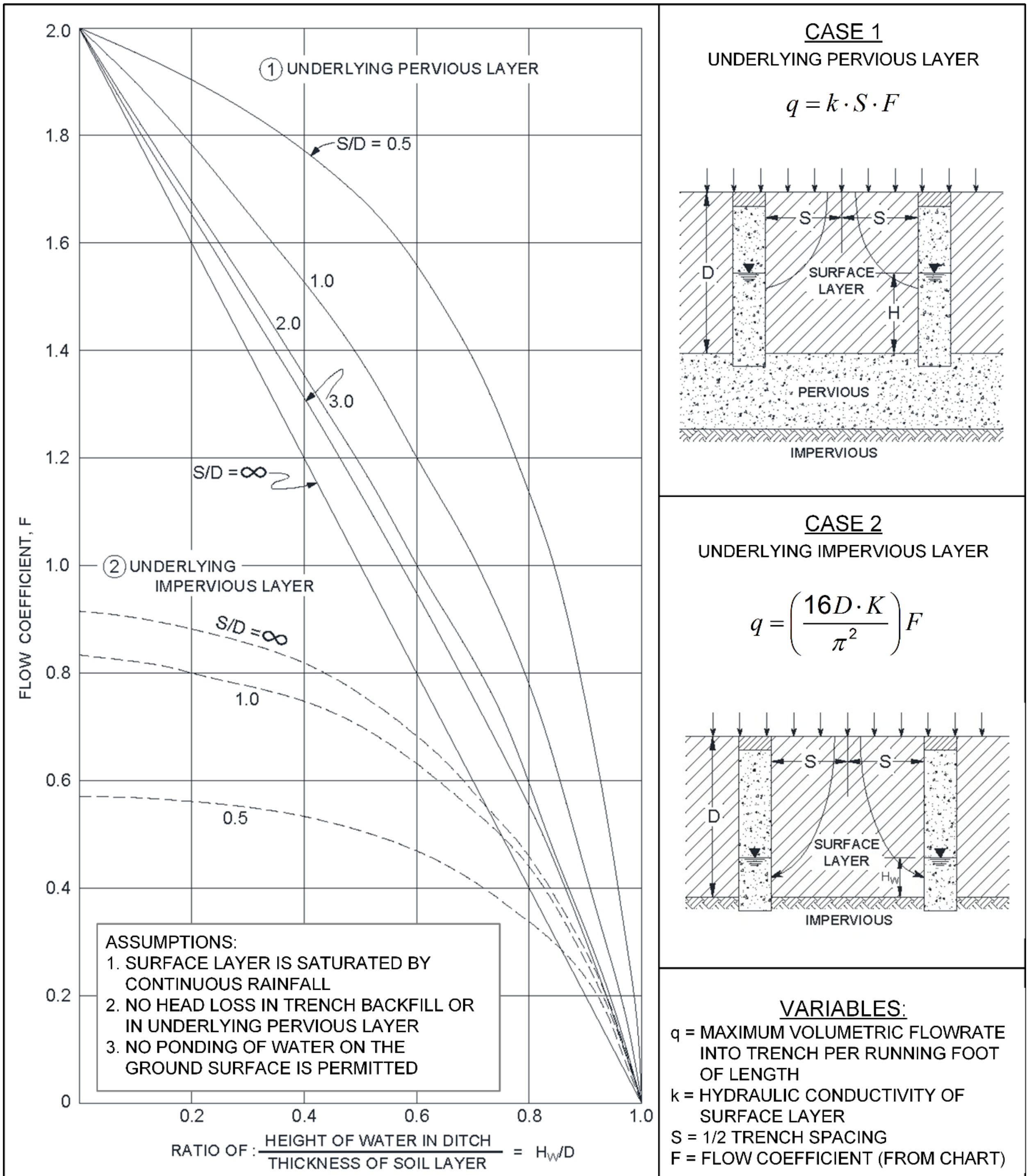


Figure 6-22 Retaining Wall Drainage Alternatives



NOTE: TO PREVENT PONDING OF WATER ON THE GROUND SURFACE, DESIGN DRAINAGE TRENCH SO THAT FLOW INTO THE TRENCH IS EQUAL TO OR GREATER THAN THE INTENSITY OF RAINFALL ON AN AREA OF 1 X 2S. OTHERWISE SURFACE DRAINAGE MUST BE PROVIDED IN ADDITION TO THE TRENCHES.

Figure 6-23 Seepage into Drainage Trenches Used for Draining Ponded Areas (after Kirkham 1950 and 1960)

6-5.3.2 Filters and Drains for Embankments.

Drains and filters are constructed within dams, levees, and other embankments or slopes to drain excess pressures and intercept pathways for internal erosion. The following paragraphs discuss the different types of embankment drains and their applications. In general, embankment drains act to lower the phreatic surface and piezometric pressures in an embankment or slope, resulting in increased slope stability and decreased internal erosion potential. All drain systems should be designed to filter the base soil and provide adequate drainage capacity for the designed purpose.

Embankment subdrains are located below embankment fills to intercept seepage from native soil and bedrock and reduce seepage into the embankment as illustrated in Figure 6-24. Subdrains consist of filter soil or drainage aggregate wrapped in filter fabric. The drains often contain a slotted or perforated collection or outlet pipe.

The other major types of embankment drains are used for intercepting and controlling seepage through or below water retaining structures.

Toe drains consist of a filter and drain located at or near the toe of a dam to collect exiting seepage through the embankment (Figure 6-25a). Toe drains are common in small homogenous dams and levee embankments as well as below the toe of small zoned earth dams. Toe drains do not effectively intercept cracks or defects in dam or levee embankments or shells.

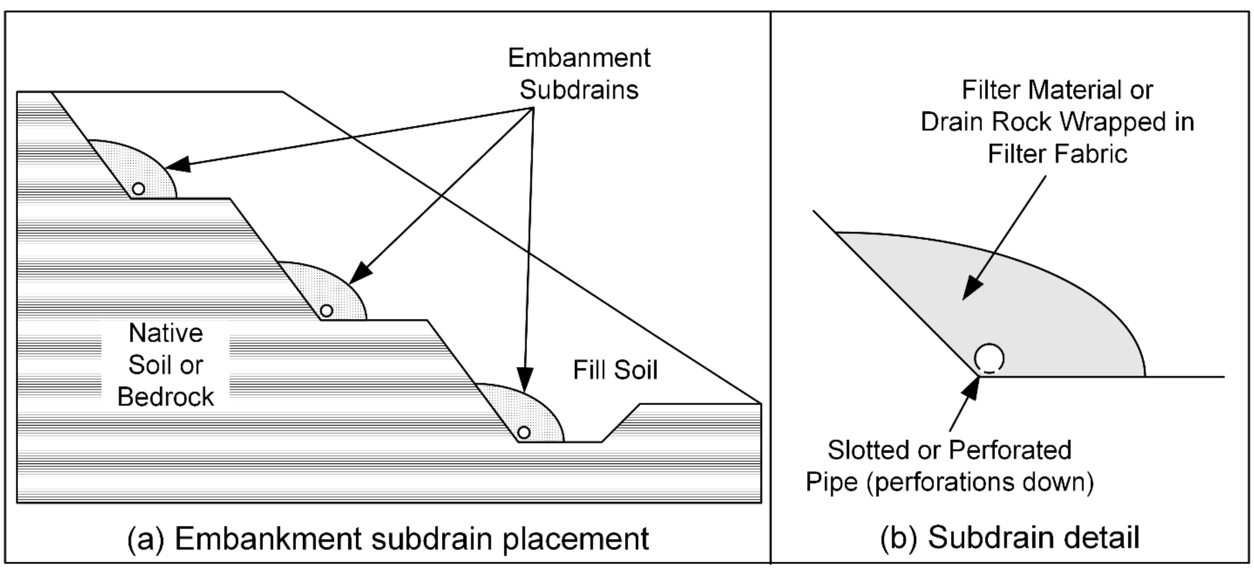


Figure 6-24 Embankment Fill Subdrains

Blanket drains are located at the downstream base of a dam or levee and are designed to collect seepage exiting the embankment (Figure 6-25b). Blanket drains are common in small to moderate sized dam and levee embankments. They are not an effective means of intercepting cracks or defects in dam or levee embankments or shells.

Chimney drains are usually located near the centerline of a dam or levee and are designed collect seepage through the embankment (Figure 6-25c). Chimney drains are a standard component of all modern, large embankment dams. Chimney drains are designed to intercept cracks, defects, or permeable layers in dam or levee embankments or cores. They typically are connected to a blanket drain below the downstream or landside portion of the embankment.

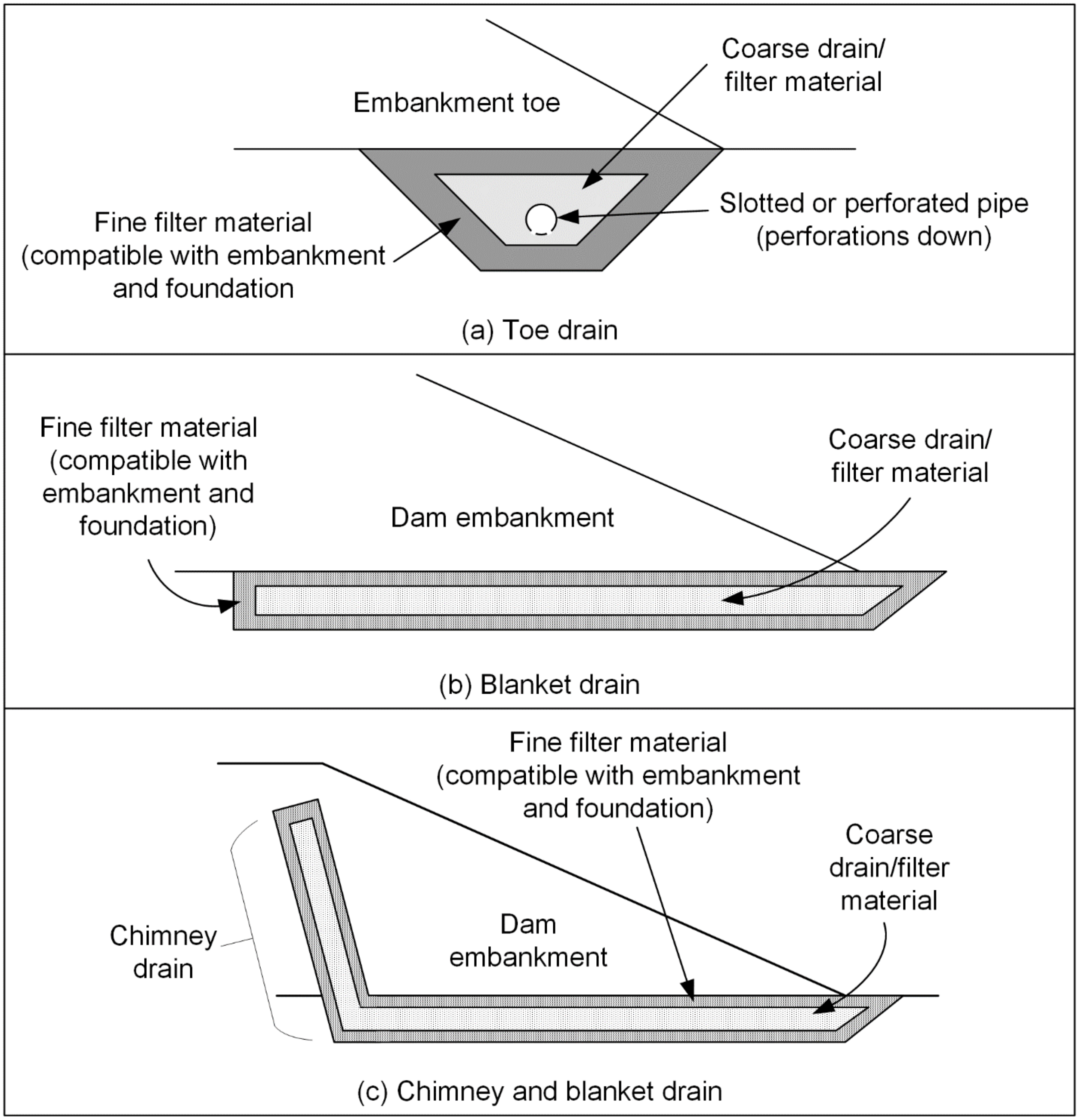


Figure 6-25 Toe, Blanket, and Chimney Drains

An *outlet filter collar* is a zone of filter material located along an outlet or other penetration through an embankment as shown in Figure 6-26. The outlet filter collar prevents concentrated leak erosion along the penetration. These filters are generally not connected to a drain.

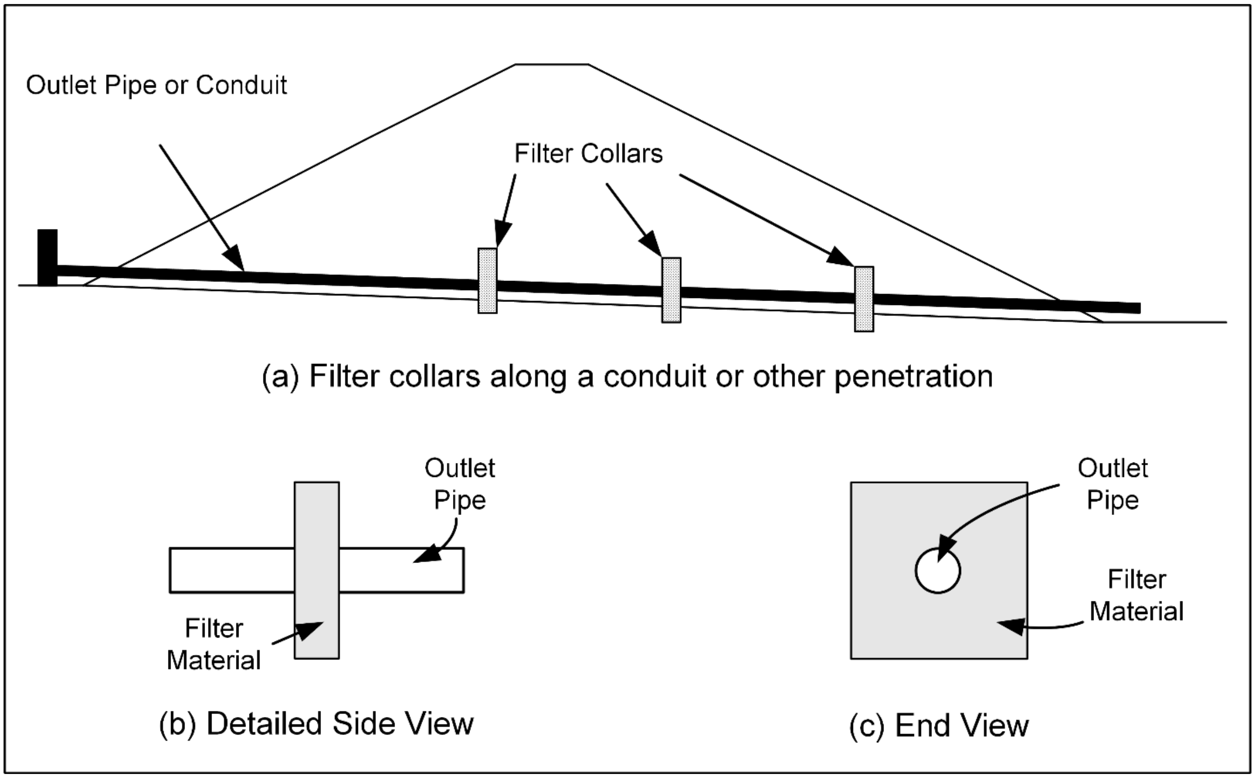


Figure 6-26 Outlet Filter Collars

6-5.3.3 Foundation Drainage.

Under certain conditions, excessive water pressure is present in the soil or rock below or adjacent to a dam or levee. High water pressures can lead to risk of heave, internal erosion, or instability of slopes or structures. These conditions often occur when a low hydraulic conductivity layer prevents drainage from an underlying layer with higher k. Drainage methods for mitigating such pressures include relief trenches and wells.

6-5.3.3.1 Relief Trenches.

A *relief trench* penetrates the upper layer and allows high pressures in the deeper pervious layer to dissipate by upward seepage as shown in Figure 6-27. The relief trench is filled with an appropriate filter material. The width of the trench should be sufficient to reduce the upward pressures beneath the low hydraulic conductivity layer while limiting upward hydraulic gradients in the relief trench to 0.4. Commonly, relief trench design is performed using two-dimensional finite element analysis.

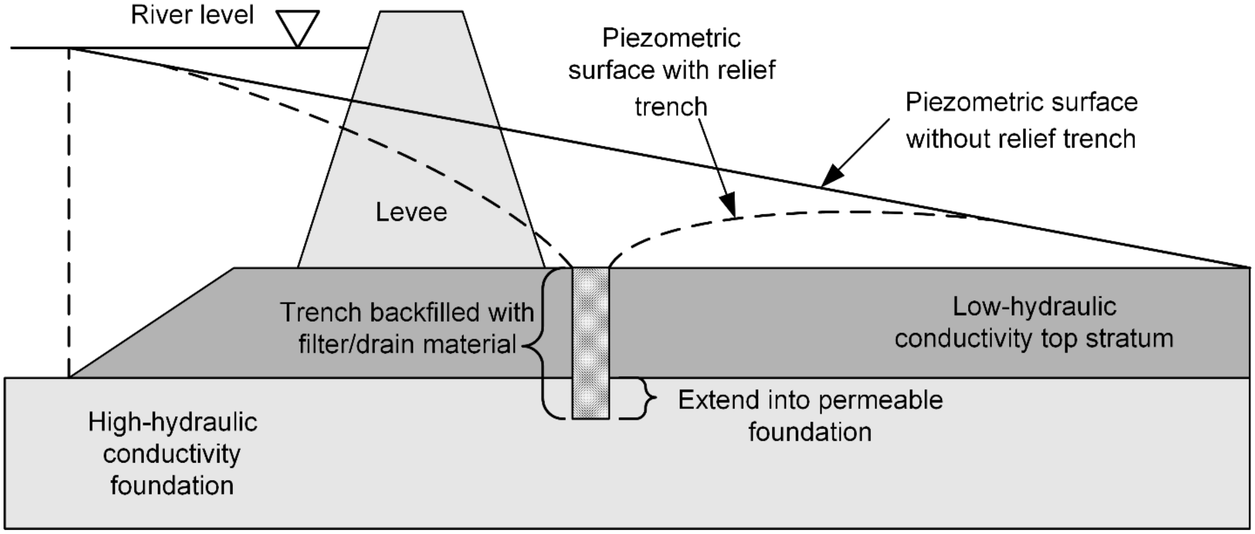


Figure 6-27 Relief Trench Used to Relieve Pressure from Beneath a Blanket Layer with Low Hydraulic Conductivity (not to scale)

Relief trenches reduce the drainage path and increase the flow rate below a hydraulic structure. Seepage at the ground surface must be managed when relief trenches are used. A typical seepage water management system includes collection trenches leading to a sump where the water can be pumped away.

6-5.3.3.2 Relief Wells.

A *relief well* is a large diameter well that extends into a layer of high hydraulic conductivity. Rows of relief wells are installed in areas of excess foundation pressure, often along the downstream side of a levee or dam. Similar to trenches, relief wells reduce water pressure by providing a vertical seepage pathway and reducing the length of the flow path as indicated in Figure 6-28.

Relief wells are constructed in large diameter shafts, often 0.5 to 1.0 meters in diameter, cased with a 15 to 30 cm diameter casing. Details of a typical relief well installation are presented in Figure 6-29. The portion of the relief well that extends into the pervious foundation soil is cased with slotted or screened casing and packed with a filter material designed to filter the surrounding base soil. Most modern casings consist of PVC solid pipes with either slotted PVC or stainless steel screens. However, some wood-stave screen wells are still in operation. The upper portion of the well consists of a solid casing with an annular space sealed with concrete and bentonite to prevent flow and erosion of the upper blanket material.

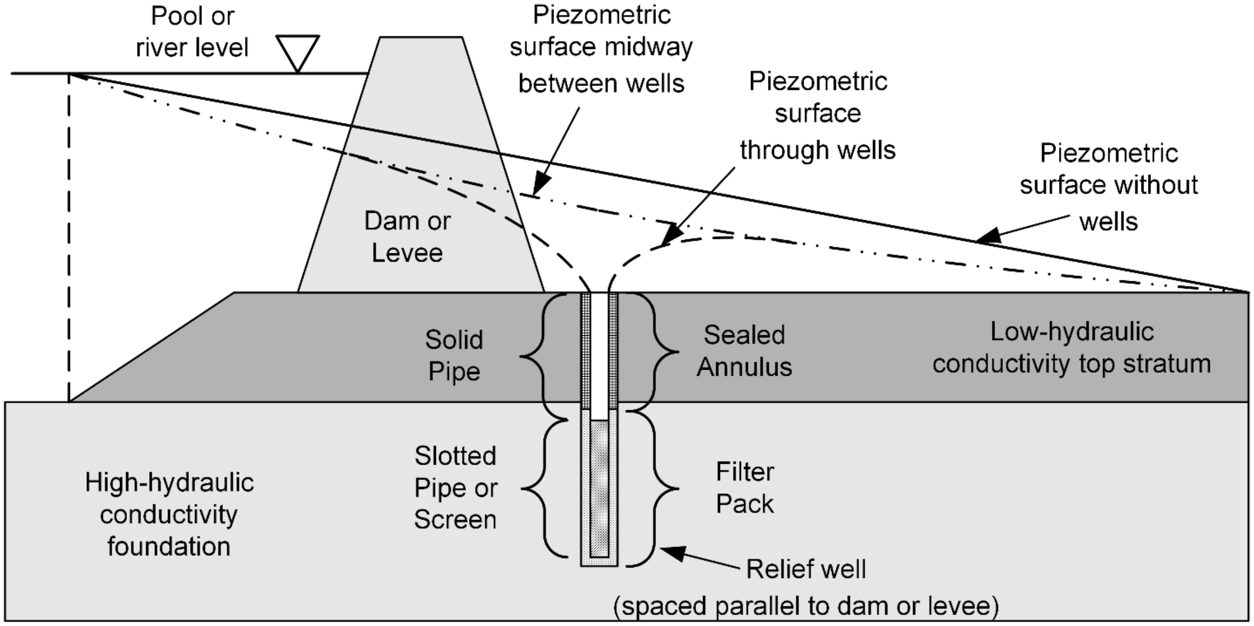


Figure 6-28 Relief Well Used to Relieve Pressure from Beneath a Blanket Layer with Low Hydraulic Conductivity (not to scale)

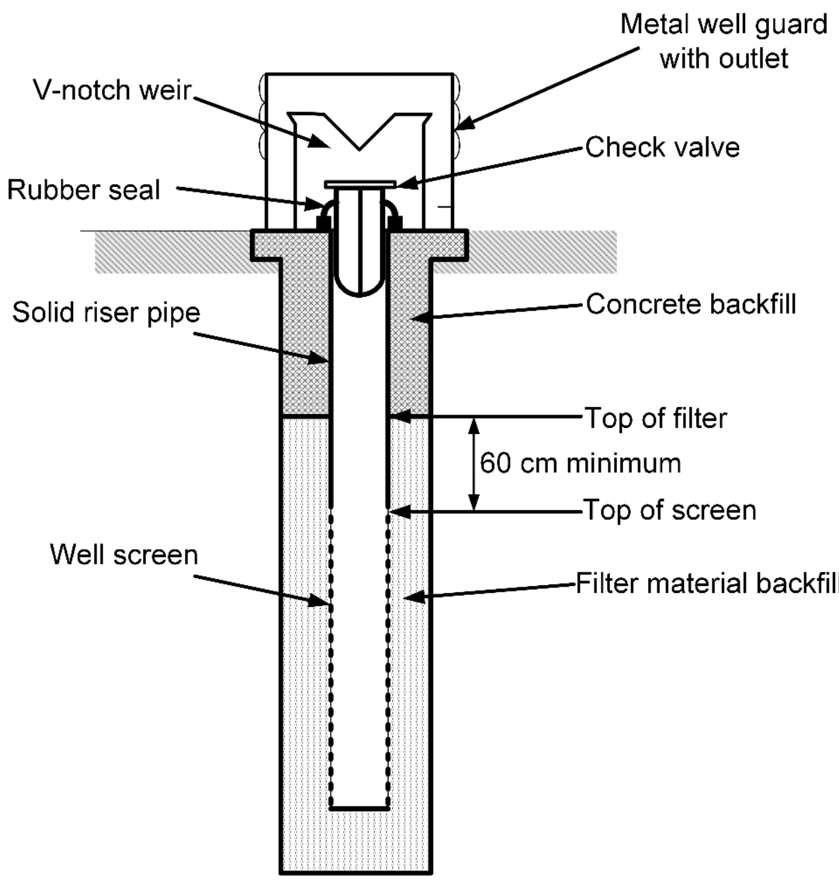


Figure 6-29 Typical Relief Well Construction

The design of relief wells is a three-dimensional problem and can be visualized in terms of the lowering of the piezometric surface that occurs at the wells. The piezometric surface is lowered the most at the well locations as shown in Figure 6-30. Along the line of the wells, the piezometric surface is typically highest at the midpoint between any two wells. Figure 6-30 can be used to estimate the relief well discharge in terms of the well spacing, the well radius, geometric variables, and an extra length factor that empirically accounts for well resistance. The appropriate extra length factor can be determined for wells that penetrate 25, 50, and 100 percent of the pervious foundation layer thickness using the lower diagrams. Alternatively, relief wells can be designed using three-dimensional finite element analyses.

Relief wells require a periodic program of well cleaning and maintenance to prevent clogging of the well screen and filter. Relief well flows should be documented throughout their life span and flows compared with river or reservoir levels to monitor any changes that may be occurring in well efficiency.

6-6 DEWATERING.

Sometimes it is necessary to lower the groundwater level to allow for subsurface construction or to prevent flooding of existing facilities. Dewatering options include: (1) a collection system at the base of the excavation leading to a sump, (2) a well point system, and (3) deep extraction wells. The selection of a dewatering system depends on the expected inflows into the excavation, the potential for heave (see Section 6-4.1), and the required depth of groundwater lowering. There are engineering firms and consultants that specialize in dewatering.

6-6.1 Collection and Sump.

When the volume of inflow into an excavation is low (i.e., excavation into low hydraulic conductivity soils) and the potential for heave is not a concern, a collection and sump system may be sufficient. The collection system may consist of a series of trenches on the bottom of the excavation or a system of relief trenches (see Section 6-5.3.3.1) at the base of the excavation. In some temporary cases, a layer of poorly-graded gravel can be placed over the bottom of the excavation that allows water to flow toward the sump. The collection system leads to a sump with a pump to remove the inflow. Sump pumps can be either electric or gasoline-powered (i.e., “trash” pumps).

6-6.2 Wellpoint Systems.

Wellpoints are 1-1/2- or 2-inch diameter pipes that are connected to a suction system to remove the groundwater. The lower section of each wellpoint is slotted or perforated and screened to prevent removal of the surrounding soil into the pipe. The pipes are pushed or jetted in place, or installed in predrilled holes. The wellpoints are each connected to a header leading to suction pumps.

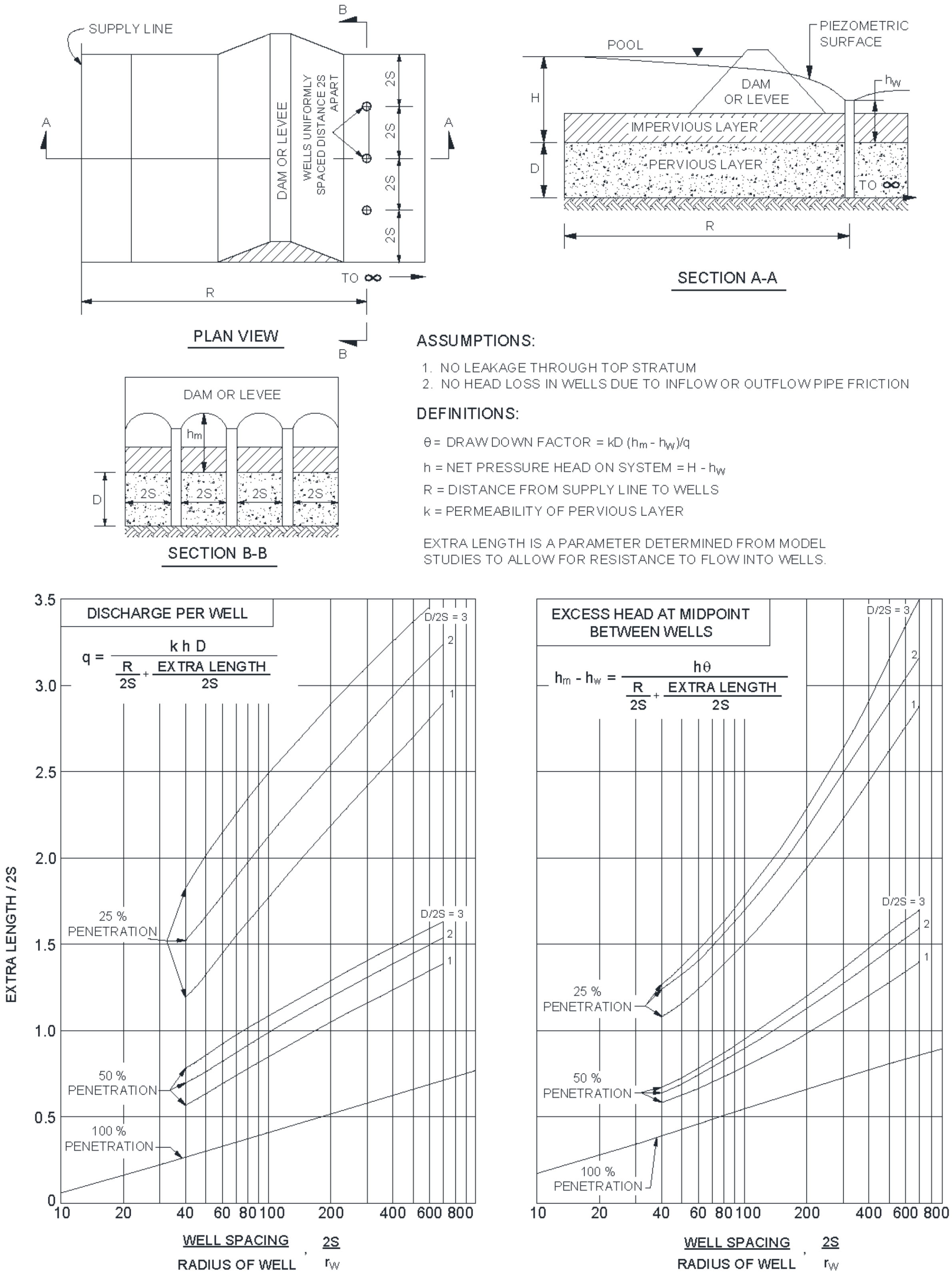


Figure 6-30 Calculation of Relief Well Discharge and Spacing (after USACE 1952)

Wellpoints are generally effective when the soil has D_{10} greater than 0.05 mm or if the soil has a structure, such as varves or laminations, for conducting groundwater horizontally. The maximum differential pressure that can be developed in wellpoints is limited by atmospheric pressure. Thus, the drawdown of the groundwater level using wellpoints is ordinarily limited to 15 to 18 feet below the center of the suction header. If a greater amount of drawdown is required, wellpoints can be installed in successive tiers or stages as excavation proceeds as illustrated in Figure 6-31.

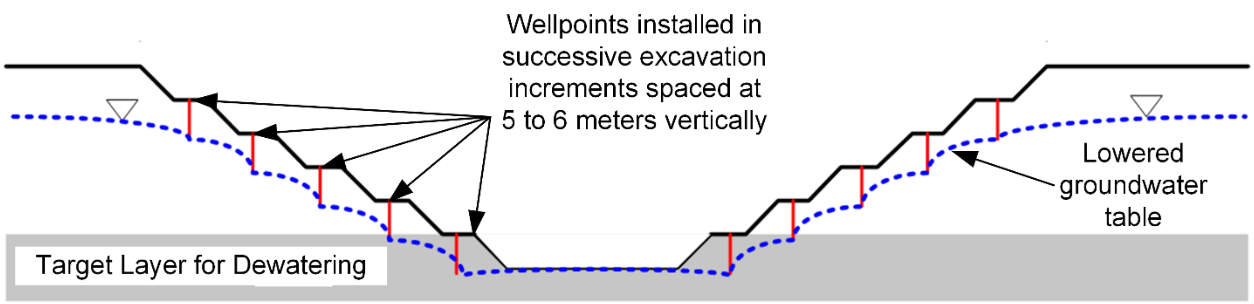


Figure 6-31 Staged Installation of Wellpoints to Lower the Groundwater Table for a Deep Excavation

The discharge capacity for each wellpoint is generally 15 to 30 gpm (3 to 6 m^3/hour). Wellpoint spacing is typically between 3 and 10 feet (1 and 3 m). Closer spacing should be used for soils with lower hydraulic conductivity. In such soils, the effectiveness of wellpoints can be increased by predrilling the locations and backfilling with sand around the wellpoint.

Due to the close spacing of wellpoints, a two-dimensional analysis is generally sufficient. The drawdown and flow into the line of wellpoints can be analyzed either with a flow net or two-dimensional finite element analysis. For soil with high k (clean fine sand or coarser), the quantity of water to be removed controls wellpoint layout. For silty soils, the flow rate is relatively small, and the number and spacing of wellpoints will be influenced by the time available to accomplish dewatering.

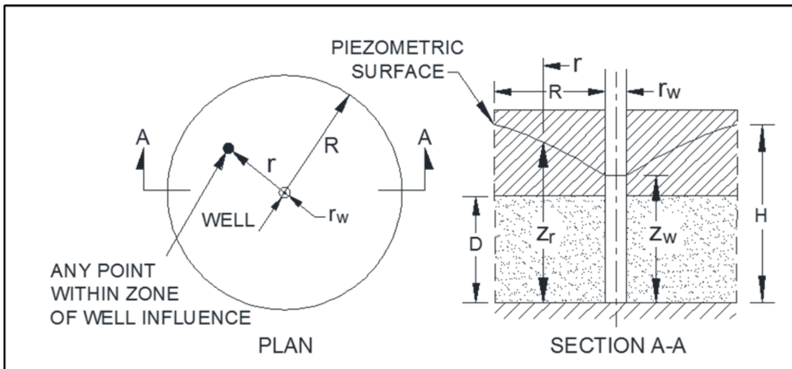
6-6.3 Extraction Wells.

Extraction wells consist of a bored hole containing a well casing with a screened section in the aquifer, a filter pack, and a pipe column. A turbine-type pump with a motor at the surface can be used, or a submersible pump may be placed within the well casing. Extraction wells are used if (a) the dewatering system must be kept outside the excavation area, (b) large quantities of water must be pumped for a long period of time, (c) pumping must commence before excavation to obtain the necessary time for drawdown, or (d) pressures must be lowered in a confined aquifer that is below a low-permeability layer underlying an excavation. Extraction wells may be used for soils with classifications ranging from gravel to silty fine sand, and for water bearing rocks.

Bored shallow wells with suction pumps can be used to replace wellpoints where pumping is required for several months or in silty soils where correct filtering is critical. Ejector or eductor pumps may be utilized within wellpoints for lifts up to about 60 feet. The ejector pump has a nozzle arrangement at the bottom of two small diameter riser pipes which remove water by the Venturi principle. They are used in lieu of a multistage wellpoint system and if the large pumping capacity provided by extraction wells is not required. Their primary application is for sands, but with proper control they can also be used in silty sands and sandy silts.

Figure 6-32 presents equations for analysis of drawdown and pumping quantities for single wells or a group of wells in a circular pattern. The *radius of influence* (R) is often defined as the radius beyond which the well has no influence. R is a function of the discharge (q) and thus changes depending on the rate of pumping. The equations presented allow the calculation of R from data in a single observation well. Once R is known, drawdown at other locations can be calculated.

(a) Single well penetrating artesian stratum

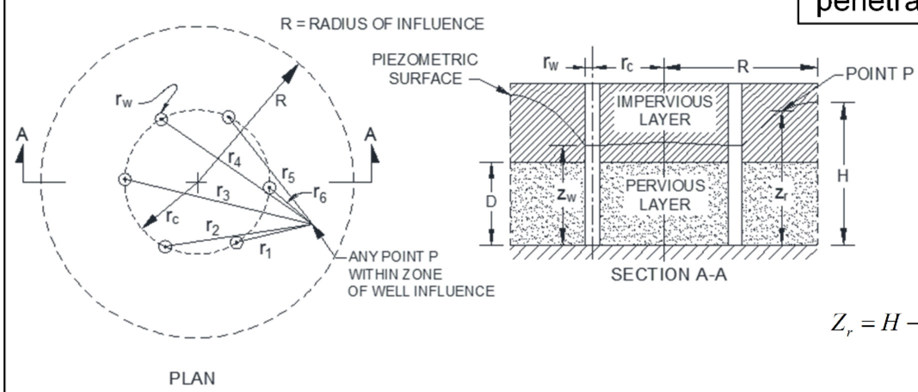


$$Z_r = \frac{H - Z_w}{\ln\left(R/r_w\right)} \ln\left(\frac{r}{r_w}\right) + Z_w$$

$$q = \frac{2\pi k D}{\ln\left(R/r_w\right)}\left(H - Z_w\right)$$

$H =$ head at radius of influence, R

(b) Circle of wells penetrating artesian stratum

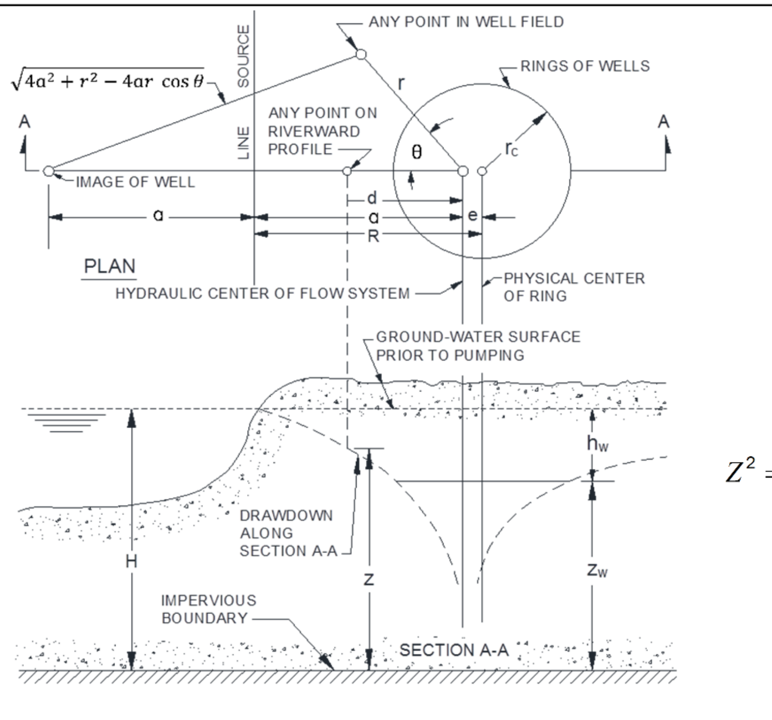


For n wells, discharge per well:

$$q = \frac{2\pi k D\left(H - Z_w\right)}{\ln\left(\dfrac{R^n}{n r_w r_c^{n-1}}\right)}$$

$$Z_r = H - \left(H - Z_w\right)\left[\frac{n \ln R - \sum_{1}^{n} \ln r}{\ln\left(\dfrac{R^n}{n r_w r_c^{n-1}}\right)}\right]$$

(c) Circle of wells adjacent to open water



Eccentricity (e) of hydraulic center

$$e = R - \sqrt{R^2 - r_c^2}$$

Distance from line source to hydraulic center of wells (α)

$$\alpha = \sqrt{R^2 - r_c^2}$$

For any point within the zone of a well's influence:

$$Z^2 = H^2 - \frac{q}{\pi k} \ln \frac{\sqrt{4\alpha^2 + r^2 - 4\alpha r \cos\theta}}{r}$$

Total discharge from the system:

$$q = \frac{\pi k\left(2H h_w - h_w^2\right)}{\log_{10} \dfrac{R^2 \sqrt{R^2 - r_c^2}}{r_c}}$$

Figure 6-32 Drawdown and Pumping Quantities for Single Extraction Wells and Groups of Extraction Wells (after USACE 1952)

6-7 SUGGESTED READING.

Topic	Reference
Groundwater Flow	Cedergren, H. R. 1977. *Seepage, Drainage, and Flow Nets,* John Wiley and Sons, Inc., New York.
	Freeze, R. A. and Cherry, J.A.1979. *Groundwater* Prentice-Hall, Englewood Cliffs, NJ.
Filter Design	Federal Emergency Management Agency (FEMA), 2011. *Filters for Embankment Dams, Best Practices for Design and Construction*.
Numerical Seepage Analysis	Bradley, N. and VandenBerge, D. R. 2015. *Beginner's Guide for Geotechnical Finite Element Analyses*, Center for Geotechnical Practice and Research, Virginia Tech.
	Potts, D. M. and Zdravkovic, L. 2001. *Finite Element Analysis in Geotechnical Engineering: Theory and Application* ICE Publishing.

6-8 NOTATION.

Symbol	Description
a	Isotropic transformation factor for flow nets
A	Cross sectional area of the flow region perpendicular to the flow direction
C'_u	Linear coefficient of uniformity (geotextile design)
D_{li}	Particle size of the coarser sieve (Kozeny-Carman equation)
D_{si}	Particle size of the finer sieve (cm)
D_α	Effective grain size - α is the percent of soil particles smaller than the stated size, values of 5, 10, 15, and 20 are commonly used for α
D_x	Particle size for which X% of the soil is finer
D'_x	Particle size for which X% of the soil is finer for linearized particle distribution (geotextile design)
D_xB	Particle size for which X% of the soil is finer for a base soil
D_xF	Particle size for which X% of the soil is finer for a filter material
e	Void ratio of the soil
f_i	Fraction of particles between two adjacent sieve sizes (Kozeny-Carman equation)
FS_g	Factor of safety for geotextile permeability
h_L	Head loss across flow region
h_p	Pressure head
h_t	Total hydraulic head

Symbol	Description
h_v	Velocity head
h_z	Elevation head
i	Hydraulic gradient
k	Hydraulic conductivity of soil (various subscripts)
k_g	Hydraulic conductivity of geotextile across plane of fabric
L	Length of flow path
n	Porosity of the soil
N_d	Number of equipotential (head) drops in the flow net
N_f	Number of flow channels in the flow net
O_{95}	Geotextile apparent opening size
q	Volumetric flow rate
R	Radius of influence in well design
S	Surface area factor for grain shape (Kozeny-Carman equation)
t_g	Geotextile thickness
u	Water pressure at the point of interest
v_d	Discharge velocity
v_s	Seepage velocity
x	Exponent on effective grain size for hydraulic conductivity correlations
Y	Height of the flow region
Z	Elevation of a point of interest above the elevation datum
β_α	Empirical or semi-empirical coefficient relating k to D_α
γ_w	Unit weight of water
Δh_l	Total head loss for one equipotential drop on a flow net
ψ_g	Geotextile permittivity, provided by manufacturers or from testing (ASTM D4491)

This Page Intentionally Left Blank

CHAPTER 7 SLOPE STABILITY

7-1 INTRODUCTION.

Slope stability analysis is a common category of analyses in geotechnical engineering practice. The analysis contains elements of statics, rock or soil mechanics, and numerical methods. The techniques used range from simple chart solutions to complicated numerical computer solutions. Regardless of the solution method employed, the most important element in slope stability analysis is the shear strength of the soil or rock.

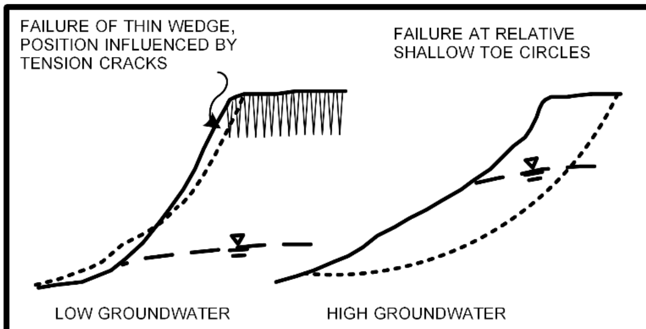
Although rock slope stability and soil slope stability rely on the same basic mechanics, the modes of failure can be very different. In this chapter, rock slope stability will be discussed in a separate stand-alone section.

7-2 TYPES OF SLOPES AND MODES OF FAILURE.

There are many different categories of slopes. *Natural slopes* are those that are ungraded and the slope geometry is controlled by nature. Figure 7-1 shows some general cross-sections and failure conditions for natural slopes. If the slope is steepened by grading or excavation, it is called a *cut*, a *cut slope* or an *excavated slope*. Dam abutments can be natural slopes or cut slopes.

Embankments constructed of compacted soil form another category of slopes. These embankments can be *highway embankments*, *dams* and *levees*, *fill slopes*, *Mechanically Stabilized Earth* (*MSE*) *slopes*, and others. Figure 7-2 shows cross-sections through example embankment slopes and details about the failure conditions.

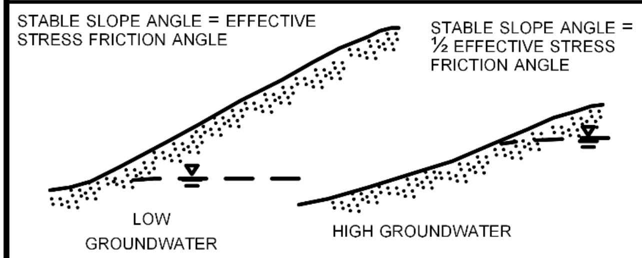
Principal modes of failure in soil or rock are (i) rotation on a curved slip surface approximated by a circular arc, (ii) translation on a planar surface whose length is large compared to depth below ground, and (iii) displacement of a wedge-shaped mass along one or more planes of weakness. Other modes of failure include toppling of rock slopes, falls, block slides, lateral spreading, earth and mud flow in clayey and silty soils, and debris flows in coarse-grained soils. Figure 7-1 and 7-2 show examples of potential slope failure problems in both natural and man-made slopes.



(1) SLOPE IN COARSE-GRAINED SOIL WITH SOME COHESION

WITH LOW GROUNDWATER, FAILURE OCCURS ON SHALLOW STRAIGHT OR SLIGHTLY CURVED SURFACE. PRESENCE OF A TENSION CRACK AT THE TOP OF THE SLOPE INFLUENCES THE FAILURE PLANE LOCATION. WITH HIGH GROUNDWATER, FAILURE OCCURS ON THE RELATIVELY SHALLOW TOE CIRCLE, WHOSE POSITION IS DETERMINED PRIMARILY BY GROUND ELEVATION.

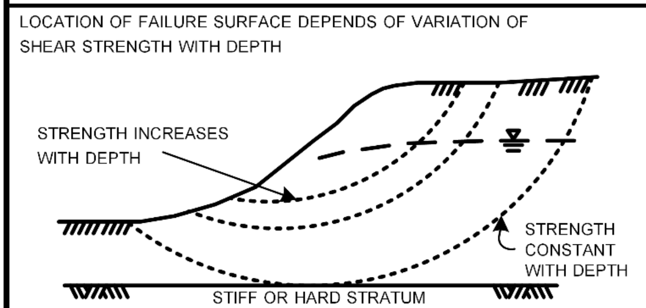
ANALYZE WITH EFFECTIVE STRESS STRENGTH PARAMETERS. PORE PRESSURE IS GOVERNED BY SEEPAGE CONDITION. INTERNAL AND EXTERNAL PORE WATER PRESSURES MUST BE INCLUDED.



(2) SLOPE IN COARSE-GRAINED COHESIONLESS SOIL

STABILITY DEPENDS PRIMARILY ON GROUNDWATER CONDITIONS. WITH LOW GROUNDWATER, FAILURES OCCUR AS SURFACE SLOUGHING UNTIL SLOPE ANGLE FLATTENS TO FRICTION ANGLE. WITH HIGH GROUNDWATER, STABLE SLOPE IS APPROXIMATELY ONE-HALF OF THE EFFECTIVE STRESS FRICTION ANGLE.

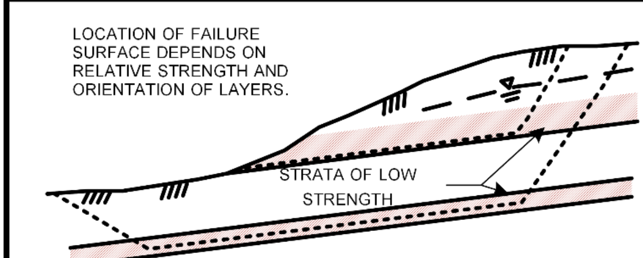
ANALYZED WITH EFFECTIVE STRESSES. INFINITE SLOPE ANALYSIS MIGHT BE APPROPRIATE. SPECIAL CONSIDERATION SHOULD BE GIVEN TO POSSIBLE FLOW SLIDES IN LOOSE, SATURATED FINE SANDS.



(3) SLOPE IN NORMALLY CONSOLIDATED OR SLIGHTLY PRECONSOLIDATED CLAY

FAILURE CAN OCCUR ON CIRCULAR ARCS OR NON-CIRCULAR SURFACES. FOR UNDRAINED ANALYSIS, THE POSITION OF THE WATER TABLE DOES NOT INFLUENCE THE STABILITY, UNLESS ITS POSITION CHANGES THE STRENGTH OF THE CLAY OR ACTS IN THE TENSION CRACKS.

CAN ANALYZE WITH TOTAL STRESSES, USING AN ANALYSIS TECHNIQUE WHICH CAN ACCURATELY ACCOMMODATE VARIATIONS IN SHEAR STRENGTH. DETERMINE SHEAR STRENGTH FROM UNCONSOLIDATED-UNDRAINED TRIAXIAL TESTS, DIRECT SIMPLE SHEAR TESTS, OR VANE SHEAR TESTS.

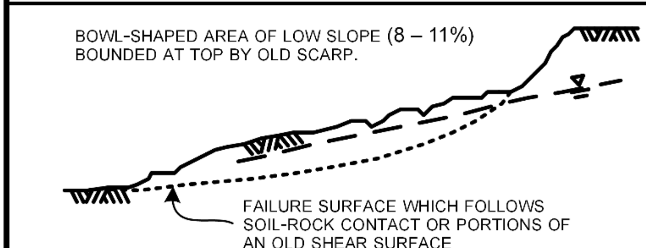


(4) SLOPE IN STRATIFIED SOIL PROFILE

LOCATION OF THE FAILURE PLANE IS CONTROLLED BY THE RELATIVE STRENGTH AND ORIENTATION OF STRATA. THE FAILURE SURFACE IS A COMBINATION OF ACTIVE AND PASSIVE WEDGES WITH A CENTRAL SLIDE BLOCK CHOSE TO CONFORM TO STRATIFICATION.

COMPUTER PROGRAMS OFFER A NON-CIRCULAR FAILURE SURFACE OR A TRUNCATED CIRCULAR FAILURE SURFACE WHICH ARE USEFUL FOR THIS TYPE OF CROSS-SECTION.

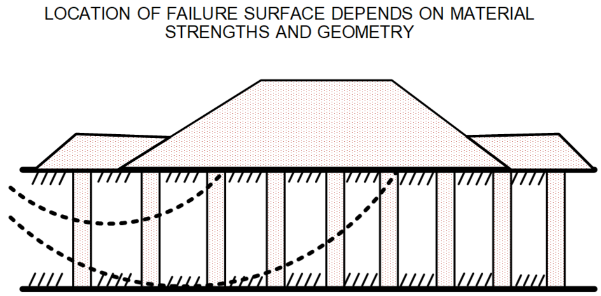
ANALYZE WITH EFFECTIVE STRESS STRENGTH PARAMETERS AND PORE PRESSURES DETERMINED FROM POSITION OF THE PHREATIC SURFACE.



(5) DEEP CREEP MOVEMENTS IN OLD SLIDE MASS

THE STRENGTH OF THE OLD SLIDE MASS DECREASES WITH MAGNITUDE OF MOVEMENT THAT HAS OCCURRED PREVIOUSLY. LARGE MOVEMENTS CAN RESULT IN DEVELOPMENT OF THE RESIDUAL SHEAR STRENGTH OF THE FAILURE SURFACE. SLIDING IS OFTEN AT THE CONTACT OF THE SOIL MASS WITH THE BEDROCK, ESPECIALLY IF THE BEDROCK IS A CLAY SHALE. PERFORM EFFECTIVE STRESS ANALYSIS WITH RESIDUAL FRICTION ANGLE AND PORE PRESSURE DETERMINED FROM POSITION OF THE PHREATIC SURFACE.

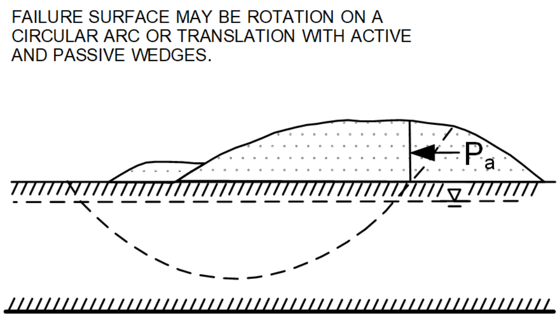
Figure 7-1 Failure Conditions for Cross-sections through Natural Slopes



(1) FAILURE FOR FILL ON SOFT COHESIVE FOUNDATION WITH DRAINS

MINIMUM STABILITY USUALLY OCCURS DURING PLACING OF FILL. IF THE RATE OF CONSTRUCTION IS CONTROLLED, CAN ALLOW FOR GAIN IN STRENGTH WITH CONSOLIDATION FROM DRAINAGE. UNDRAINED ANALYSES CAN BE PERFORMED USING STRENGTHS OBTAINED FROM UU TRIAXIAL TESTS, DSS TESTS, OR VANE SHEAR TESTS. IN ORDER TO INVESTIGATE THE INCREASE IN STRENGTH WITH CONSOLIDATION, CAN USE DSS TESTS.

EFFECTIVE STRESS ANALYSIS CAN BE PERFORMED USING DRAINED STRENGTH PARAMETERS OBTAINED FROM CU TRIAXIAL TESTS OR DIRECT SHEAR TESTS ALONG WITH THE PORE PRESSURES CALCULATED FORM CONSOLIDATION THEORY.

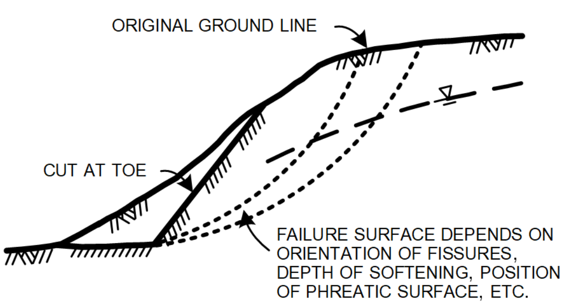


(2) FAILURE OF STIFF COMPACTED FILL ON SOFT CLAY FOUNDATION.

USUALLY, MINIMUM FACTOR OF SAFETY OBTAINED AT END OF CONSTRUCTION. FAILURE MAY BE IN THE FORM OF ROTATION OR TRANSLATION, AND BOTH SHOULD BE CONSIDERED.

FOR RAPID CONSTRUCTION, IGNORE CONSOLIDATION IN THE CLAY LAYER AND USE UNDRAINED STRENGTH OBTAINED FROM UU TRIAXIAL TESTS, DSS TESTS, OR VANE SHEAR TESTS, AND PERFORM AN UNDRAINED ANALYSIS.

ANALYZE LONG-TERM STABILITY USING EFFECTIVE STRESS STRENGTH PARAMETERS FOR CU TRIAXIAL TESTS OR DIRECT SHEAR TESTS. USE PORE PRESSURES FROM STATIC PHREATIC SURFACE.



(3) FAILURE SURFACE FOLLOWING CUT IN STIFF FISSURED CLAY

CUTS IN STIFF FISSURED CLAYS MAY RESULT IN FAILURES MANY YEARS AFTER THE CUT IS MADE. RELEASE OF HORIZONTAL STRESSES BY EXCAVATION CAUSES EXPANSION OF THE CLAY AND OPENING OF FISSURES, ALLOWING SOFTENING AND REDUCTION OF STRENGTH.

PERFORM AN EFFECTIVE STRESS ANALYSIS USING THE FULLY SOFTENED SHEAR STRENGTH ENVELOPE AND PORE PRESSURES CALCULATED FROM THE POSITION OF THE PHREATIC SURFACE.

Figure 7-2 Failure Conditions in Embankment Foundations and Cut Slopes

7-3 DEFINITION OF FACTOR OF SAFETY.

The stability of slopes is characterized by the *factor of safety*, F. Although there have been various methods of defining the factor of safety found in the engineering literature, the most common is shown below:

$$F = \frac{s}{\tau} \quad \textbf{(7-1)}$$

where:
s = shear strength,
τ = shear stress required for equilibrium.

If the factor of safety is equal to unity, the slope is in a condition of barely stable equilibrium, right at the point of failure. As the factor of safety increases above unity, the stability of the slope increases. Slopes having a factor of safety less than one are considered unstable.

The value of s used in the calculation of factor of safety depends on the strength model used to characterize the soil, which is often associated with the drainage conditions assumed as well as the soil type. Table 7-1 shows different strength models that can be used in the analyses for different soil types and drainage conditions.

The shear stress required for equilibrium (τ) is calculated by statics along with assumptions regarding the conditions for equilibrium and other factors. The number of unknowns exceeds the number of equilibrium equations in most forms of slope stability analysis, so assumptions must be made. A major difference in the various methods used to perform slope stability analyses is the conditions of equilibrium that are satisfied.

7-4 METHODS OF ANALYSIS OF SOIL SLOPES.

Slope stability analysis in geotechnical engineering practice has evolved over the past 100 years. Initial methods of assessing the stability of slopes involved mapping areas of instability and determining slope angles from surveys to create *landslide hazard maps*. These types of maps are still produced and can be useful in screening potential stability issues with natural slopes and examining regional landslide risk. Beginning in the 1920s, assessment procedures were developed that provided a more quantitative basis for determining the stability of slopes.

Three numerical procedures are used, with varying degrees of popularity, to assess the stability of slopes: (1) limit equilibrium analysis, (2) finite element and finite difference analysis, and (3) plasticity analysis.

Table 7-1 Strength Models for Different Soil Types and Drainage Conditions

Soil type	Drainage conditions	s, strength	Comments
Coarse-grained soils	Drained	$s = \sigma'_{ff} \cdot tan(\phi')$	Drained conditions are often assumed for coarse-grained soils, such as sands and gravels under static loading conditions. Non-linear envelopes can be used as well.
Coarse-grained soils	Undrained	$s = s_{su}$	Used for dynamic loading and certain conditions of static loading. Can be used for clays and silts as well for dynamic or cyclic loading. For normal undrained analysis, the effective stress strength parameters should be used for coarse-grained soils.
Overconsolidated fine-grained soils	Drained	$s = c' + \sigma'_{ff} \cdot tan(\phi')$	A non-linear envelope can be used for this case as well. Some engineers do not like to use effective stress cohesion for any soil.
Normally consolidated fine-grained soils	Drained	$s = \sigma'_{ff} \cdot tan(\phi')$	The effective stress friction angle should correspond to the soil in a normally consolidated state. This is equal to the fully softened friction angle.
Fine-grained soils (saturated)	Undrained	$s = s_u$	The undrained shear strength can be determined using a variety of laboratory or *in situ* tests. The magnitude of s_u can vary with depth.
Fine-grained soils (partially saturated)	Undrained	$s = c + \sigma_{ff} \cdot tan(\phi)$	This strength model is used for partially saturated soils like compacted clays. The shear strength parameters should be measured using Unconsolidated Undrained triaxial tests. Only use a linear envelope for the range of stress where it appears to be appropriate.

Note: σ'_{ff} = effective stress on failure plane, ϕ' = effective stress friction angle, c' = effective cohesion,
σ_{ff} = total normal stress on failure plane, ϕ = total stress friction angle, c = total stress cohesion,
s_{su} = undrained steady state shear strength, and s_u = undrained shear strength

7-4.1 Limit Equilibrium Analysis.

Limit Equilibrium Analysis is the most popular method of analysis to quantify the stability of soil slopes. The procedure involves dividing the sliding mass into one or more *free bodies*, and determining the forces acting on the free bodies using equations for force and/or moment equilibrium. The shear stress required for a condition of barely-stable equilibrium (τ) is determined for each free body from the analysis of the system of free bodies. These shear stresses are used with Equation 7-1 to calculate the factor of safety of the slope.

Figure 7-3 shows the division of slopes into one, three, and multiple free bodies for analysis using the limit equilibrium method. For these analyses, the failure surface can be linear, circular, or a combination of linear and arc segments. For most limit equilibrium analyses, assumptions must be made so that the equilibrium equations can be satisfied. In many cases, iteration must be performed to obtain a solution, and it takes a computer program to efficiently apply the analysis method.

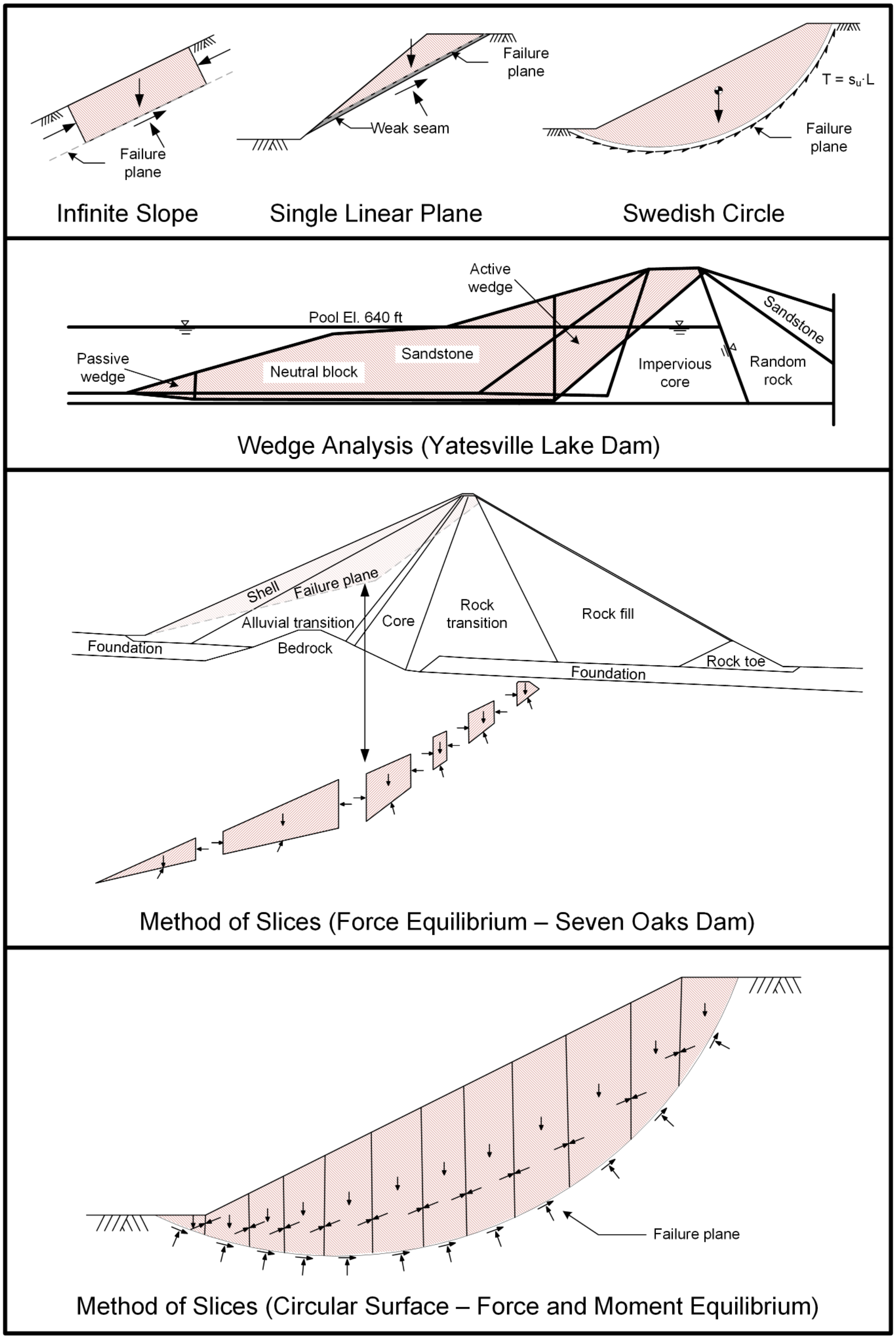


Figure 7-3 Examples of Limit Equilibrium Analysis

In general, the most common methods used in practice assume that the failure surface is circular or a surface comprised of many line segments. The methods that solve for all conditions of equilibrium (force and moment) provide the most accurate answers. These include Spencer's Method (Spencer 1967) and the Morgenstern and Price Method (Morgenstern and Price 1963). Most of the commercially available computer programs can perform these two methods.

In some cases, the potential critical failure surface may be easily identified by a feature such as a thin weak seam. In most other cases, it is necessary to search for the critical failure surface. The common slope stability programs have very robust search routines for circular and noncircular failure surfaces.

Figure 7-4 shows the formulas and calculations for a slope stability analysis using Bishop's Simplified Method. In this method, the soil mass is divided into vertical slices. The free body diagram for a slice is shown on the figure. This method uses circular failure surfaces, and the side forces are assumed to be horizontal. Moment equilibrium is satisfied, but only equations for vertical force equilibrium are used. Horizontal force equilibrium is not satisfied.

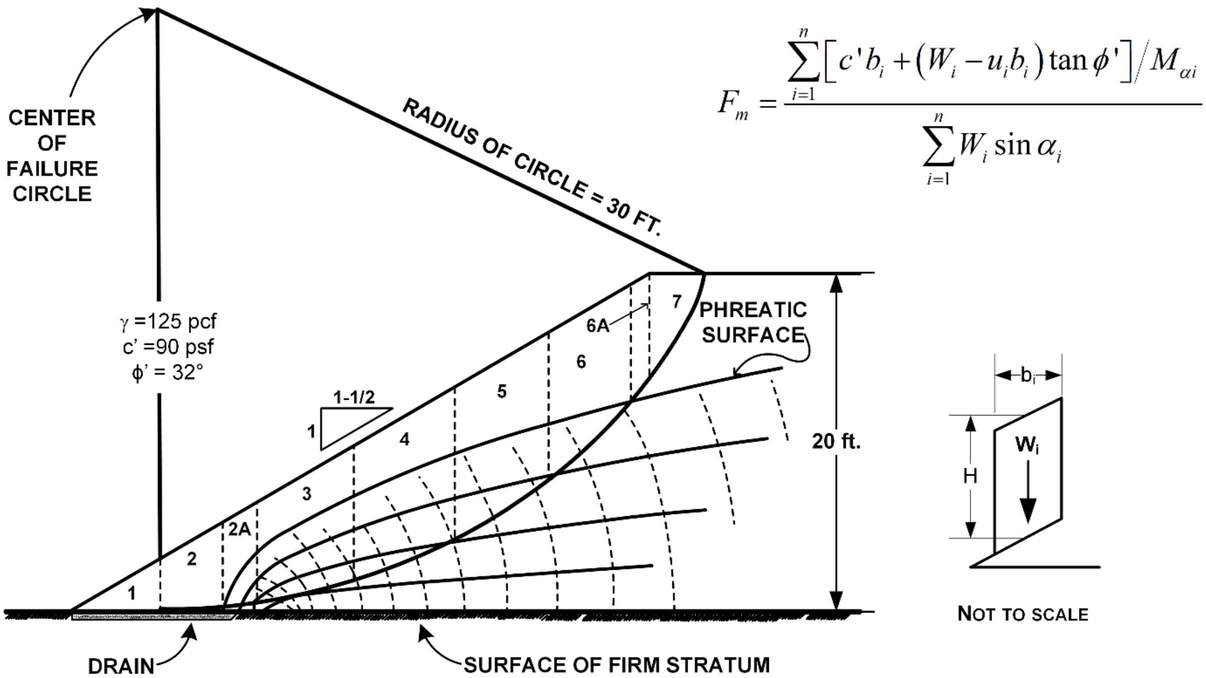
7-4.2 Finite Element Analysis of Slopes.

Use of finite element analysis to analyze slope stability is becoming more popular in geotechnical practice. A thorough assessment of the use of the finite element method is presented by Griffiths and Lane (1999). The finite difference method is an alternative to the finite element method, and both of these assess the slope in a similar fashion. Instead of calculating a factor of safety as defined by Equation 7-1, the finite element and finite difference solutions use a *strength reduction factor* (SRF). The SRF is a factor by which the cohesion (c) and the tangent of the friction angle (ϕ) are reduced to a point where the solution no longer converges. At the critical SRF, the displacements increase rapidly and the equations for equilibrium can no longer be solved.

The finite element method has a few advantages over the more common limit equilibrium method. The failure surface does not have to be identified prior to the analysis. The FE method actively seeks out the critical failure surface automatically as part of the analysis procedure. In addition, the equations for equilibrium are satisfied.

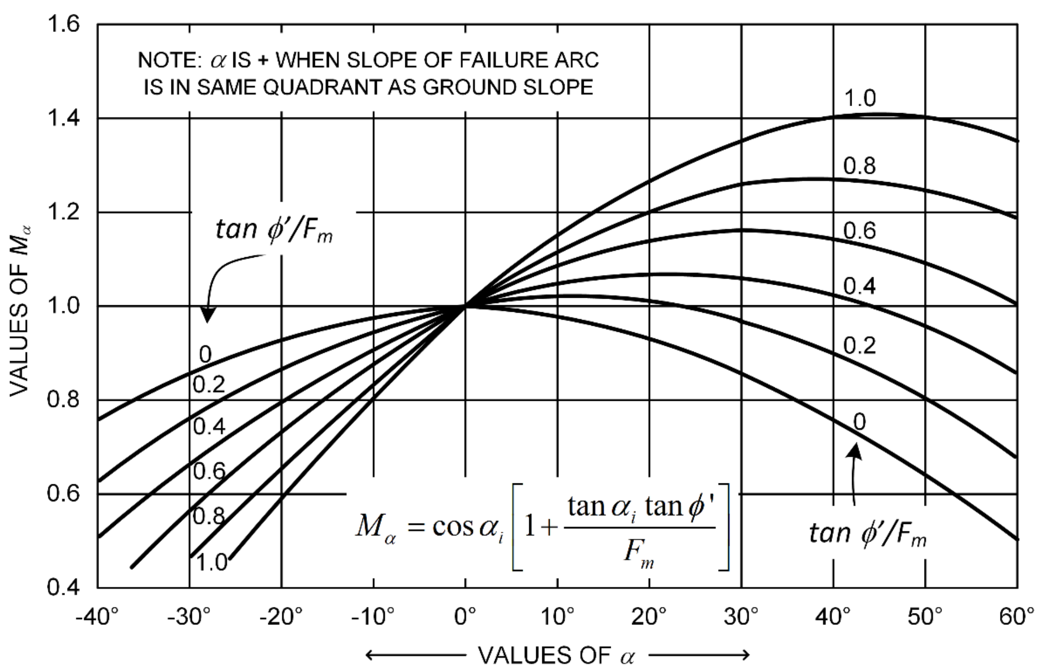
7-4.3 Limit Analysis.

Limit analysis is based on the upper and lower bound theorems for the theory of plasticity. The process involves section of a potential failure surface, and analyzing the failure mass based on a kinematically admissible velocity field and a statically admissible stress field. The use of limit analysis for slope stability calculations has been around for over 40 years, but it has found limited use in geotechnical engineering practice. Commercially available programs that use limit analysis have recently become available, and the popularity may increase.



$$F_m = \frac{\sum_{i=1}^{n}\left[c' b_i + \left(W_i - u_i b_i\right)\tan\phi'\right] / M_{\alpha i}}{\sum_{i=1}^{n} W_i \sin\alpha_i}$$

Considering the equilibrium of forces in the vertical direction, but neglecting the shearing forces between slices, the factor of safety for moment equilibrium can be calculated as indicated above. This equation can be solved by iteration using a spreadsheet. Values of $M_{\alpha i}$ can be obtained from the chart below.



$$M_\alpha = \cos\alpha_i\left[1 + \frac{\tan\alpha_i \tan\phi'}{F_m}\right]$$

Figure 7-4 Example Slope Stability Analysis using Bishop's Simplified Method for an Effective Stress Analysis

Example Calculations

Find F_m for the trial slip circle shown. Strength properties are c'= 90 psf, ϕ'= 32°, and γ_t = 125 pcf. Slope is 1.5H:1V. Flow conditions are shown.

Procedure (Numbers in parentheses correspond to column in example):

1. Divide cross section into vertical slices. (1)
2. Calculate the weight of each slice (W_i) using total unit weights, where is the width of the slice and H_i is the average height of the slice. (2) (3) (4)
3. Calculate $W_i \sin\alpha_i$ for each slice where α_i is equal to the angle between the tangent to the failure surface and the horizontal. (5) (6)
4. Multiply the effective stress cohesion (c') times the width of each slice () (7)
5. Multiply the average pore water pressure along the failure surface of each slice by the width of each slice. (8).
6. Calculate $(W_i - u_i b_i)\tan(\phi')$ for each slice (9).
7. Add $c' b_i$ to (9) for each slice. (10)
8. Select two factors of safety (F_m) and find $M_{\alpha i}$ for each slice using the graph or equation on the previous page (11).
9. Divide column (10) by $M_{\alpha i}$ for each slice and sum the resultants (12).
10. Divide $\sum_{i=1}^{n}[c' b_i + (W_i - u_i b_i)\tan(\phi')]/M_{\alpha i}$ by $\sum_{i=1}^{n} W_i \sin(\alpha_i)$ to calculate F_m.
11. Compare calculated F_m to assumed F_m in Step 8. Reiterate Steps 8, 9, and 10 until assumed F_m of Step 8 equals calculated F_m of Step 10.
12. Repeat above analysis for different failure surfaces to obtain the surface with the smallest factor of safety.

Slice (1)	b_i ft (2)	H_i ft (3)	W_i kips (4)	$\sin\alpha_i$ (5)	$W_i \sin\alpha$ kips (6)	$c' b_i$ kips (7)	$u_i b_i$ kips (8)	(4-8) $\tan\phi'$ kips (9)	(7+9) kips (10)	$M_{\alpha i}$ F_m =1.25 (11)	$M_{\alpha i}$ F_m =1.35 (11)	10÷11 F_m =1.25 (12)	10÷11 F_m =1.35 (12)
1	4.5	1.6	0.9	0.03	0.0	0.40	0.00	0.55	0.95	0.97	0.97	1.00	1.00
2	3.2	4.2	1.7	0.05	0.1	0.29	0.00	1.05	1.35	1.02	1.05	1.30	1.30
2A	1.8	5.8	1.3	0.14	0.2	0.16	0.05	0.80	0.95	1.06	1.05	0.90	0.90
3	5.0	7.4	4.6	0.25	1.2	0.45	1.05	2.25	2.70	1.09	1.08	2.50	2.50
4	5.0	9.0	5.6	0.42	2.3	0.45	1.45	2.55	3.00	1.12	1.10	2.70	2.75
5	5.0	9.3	5.8	0.58	3.4	0.45	1.25	2.70	3.15	1.10	1.08	2.85	2.90
6	4.4	8.4	4.6	0.74	3.4	0.40	0.50	2.65	3.05	1.05	1.02	2.90	2.95
6A	0.6	6.7	0.5	0.82	0.4	0.05	0.00	0.30	0.35	0.98	0.95	0.35	0.40
7	3.2	3.8	1.5	0.87	1.3	0.29	0.00	0.95	1.25	0.93	0.92	1.30	1.35
					12.3							15.80	16.05

For an assumed F_m= 1.25, calculated F_m = 15.8/12.3 = 1.29

For an assumed F_m= 1.35, calculated F_m = 16.05/12.3 = 1.31

A trial assuming F_m= 1.3 would yield F_m= 1.3

Figure 7-4 (cont.) Example Slope Stability Analysis using Bishop's Simplified Method for an Effective Stress Analysis

7-5 WATER PRESSURE EFFECTS.

Water pressures have a profound effect on the stability of slopes. As an example, many failures that occur in natural and constructed slopes occur during periods of heavy precipitation. There are two categories of water pressures in slope stability analysis: (1) *internal water pressures* and (2) *external water pressures*. Examples of these are shown in Figure 7-5.

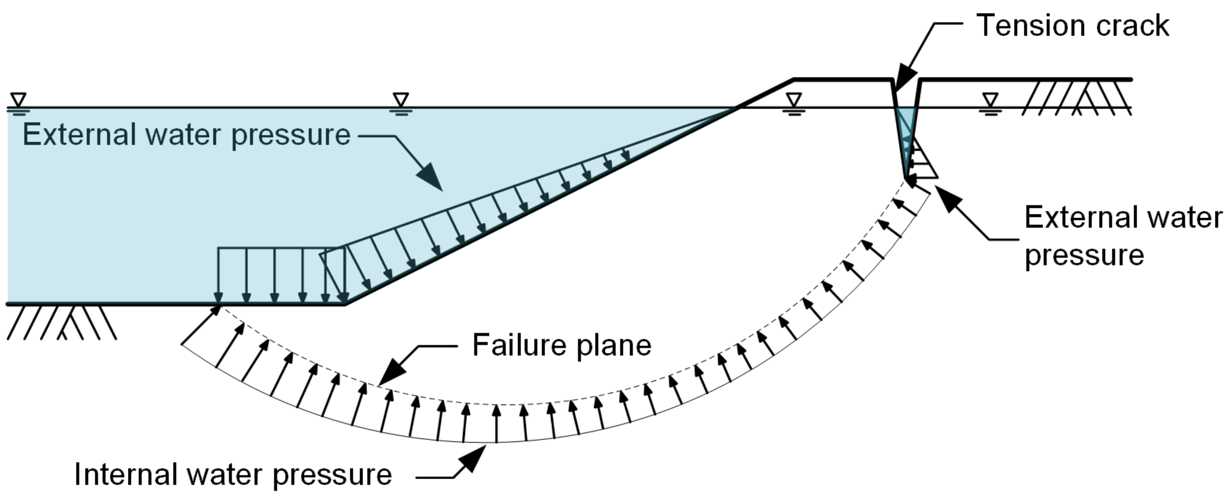


Figure 7-5 Examples of Internal and External Water Pressures in Slope Stability Analyses

Internal water pressures are the same as pore water pressures. These are the static or dynamic water pressures that act on the failure plane within the soil mass. Internal water pressures must be included in slope stability analyses where the soil is characterized by effective stress or drained shear strength parameters (c' and ϕ'). Internal water pressures are not included in the analysis where the soil is characterized by total stress or undrained shear strength parameters (s_u or c and ϕ).

External water pressures are the pressures applied to the free body where standing water is in contact with the soil mass at locations other than the failure surface. Examples of external water pressures are the pressures applied by the reservoir on the upstream slope of a dam or water-filled tension cracks. External water pressures are included in both effective stress and total stress slope stability analyses.

7-5.1 Incorporating Water Pressures in Computer Analyses.

It is important that the engineer fully understand the way that water pressures are specified in computer programs that they use, and how to verify that the correct water pressures are being used. The nomenclature for inputting water pressures is not consistent between the many different programs available for slope stability analysis.

The *water table* or *groundwater table* is normally defined as a line that connects points where the pore water pressure (u) is equal to zero. Water table is often used synonymously with *phreatic surface*. The *piezometric surface* is a surface connecting the height or elevation that water would rise in a series of standpipe piezometers. For hydrostatic conditions with a horizontal water table, the water table, phreatic surface, and piezometric surface are the same. For hydrodynamic cases where water is flowing, the piezometric surface can be at a higher elevation than the water table (upward flow of water) or at a lower elevation than the water table (downward flow of water). An example of this is shown in Figure 7-6. At Point A, the vertical distance to the phreatic surface is indicated on the drawing. However, the pore water pressure is controlled by the distance to the piezometric line, which is also shown on the figure.

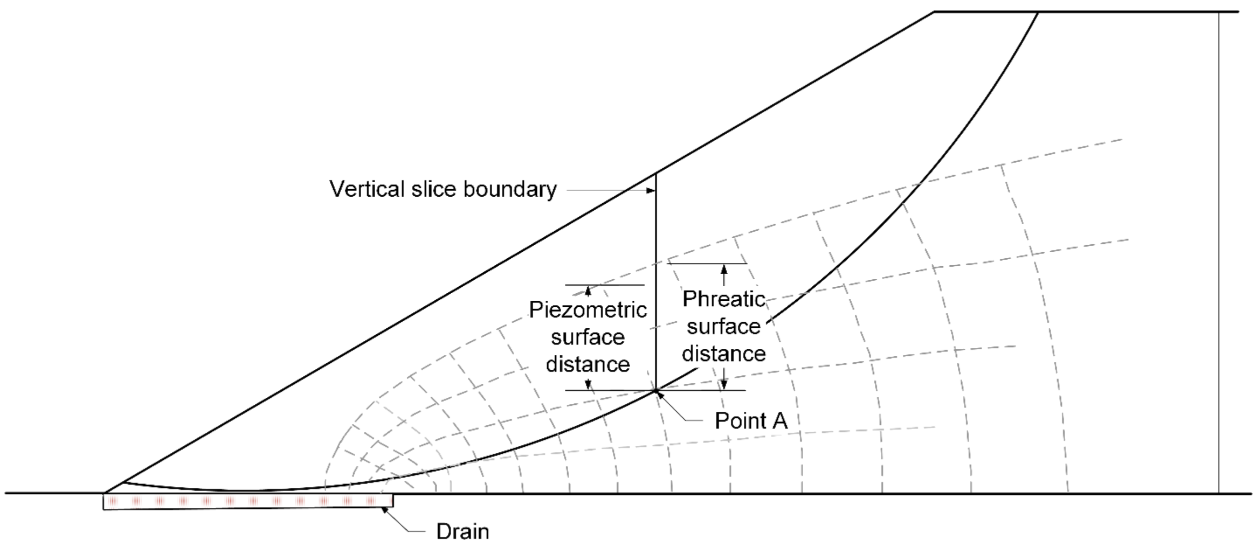


Figure 7-6 Approximate Flow Net for Seepage into a Drain Showing the Difference between the Piezometric Surface and the Phreatic Surface

Internal water pressures can be accommodated in slope stability software in one or more of the following methods:

(1) Water table or phreatic surface – can be corrected to approximate the piezometric surface based on the slope of the surface above the specific point,
(2) Piezometric surface,
(3) Finite element seepage analysis,
(4) Point-by-point entry in x-y coordinates with subsequent interpolation between points, and
(5) Pore pressure coefficient, r_u.

Of these different methods, the finite element seepage analysis is probably the best. It allows a large density of pore water pressure points to be calculated and interpolation between these points is sufficiently accurate with most interpolation methods. Use of the pore pressure coefficient is perhaps the least accurate of the methods listed and is normally only used to verify results from historic analyses.

External water pressures can be automatically applied by most programs by the use of the water table or phreatic surface. As an alternative, external water pressures can be applied by the use of triangular and rectangular distributed loads. A third method is to assign the water properties of a soil material, having the unit weight of water but no shear strength. External water pressures in tension cracks are normally handled automatically by the computer program, but triangular distributed loads can also be used to model water-filled tension cracks.

7-5.2 Seepage Forces.

The flow of water through a slope can serve to destabilize slopes. As indicated in Figure 7-1, the flow of water parallel to the surface of a slope can reduce the factor of safety to about half of the factor of safety without flowing water. As water flows through a soil, a seepage force (S) is imparted to the soil from the viscous resistance to the flow of water. The seepage force can be calculated from:

$$S = i \cdot \gamma_w \quad \textbf{(7-2)}$$

where:
i = hydraulic gradient, and
γ_w = unit weight of water.

The seepage force equation provides a force per volume for the volume where the hydraulic gradient or head loss occurs. For slope stability analyses, the effect of flowing water can be handled by (1) calculating the seepage forces for each slice or free-body and (2) using the buoyant unit weight of the soil below the phreatic surface. Unfortunately, using this method requires that the calculations be largely done by hand. The computer programs that are commercially available do not perform these calculations automatically. The alternative method, which is accommodated by current computer programs, correctly calculates the factor of safety of slopes where flow is occurring by using total unit weights of soils below the water table along with boundary water pressures as discussed above. This method is currently used in geotechnical engineering practice.

7-6 STRENGTH MODELS AND ANALYSIS CASES.

Slope stability analysis cases are often categorized as undrained (or total stress) or drained (effective stress) analyses. These are often called short-term and long-term analyses because their respective use is related to the amount of time required for the soil to consolidate under the changed loading. For this reason, both effective stress and undrained (total stress) strength parameters can be assigned to the different soils in a cross section depending on their drainage condition during the duration of loading.

The general analysis cases are listed below with guidance on strength models to be employed with each.

7-6.1 End of Construction (Short Term).

End of construction or *post-construction* analyses are performed to examine the stability after construction is completed and prior to any dissipation of pore water pressures in fine-grained soils. An example of a valid end of construction analysis is construction of a compacted clay embankment over saturated fine-grained soils. A cross section of this is shown in Figure 7-7a. For this case, the compacted clay embankment would be partially saturated, and the strength would be represented as a c-ϕ soil, with the strength parameters determined from UU triaxial tests. The *in situ* fine-grained soils would be essentially saturated, and the strength would be characterized as $\phi = 0$, $s_u = c$. The shear strength of the *in situ* soils could be measured by UU triaxial tests, DSS tests, laboratory miniature vane shear tests, field vane shear tests, and under some conditions, cone penetration tests.

7-6.2 Cut Slope in Clay.

The cross section of a cut slope in a stiff clay is shown in Figure 7-7b. The critical time in the performance of the cut slope occurs long after the cut is made, when the phreatic surface has reached a steady-state condition. For this type of scenario, effective stress or drained shear strengths should be used for the clay. If the clay has a relatively low plasticity (LL < 40 and PI < 20), it would be appropriate to use the peak drained strength parameters (c' and ϕ') determined from CU triaxial tests or CD direct shear tests. The use of a non-linear effective stress envelope for the clay would also be appropriate (Duncan et al. 2014). If the clay has a high plasticity, contains fissures, and/or is heavily overconsolidated, then the fully softened shear strength should be used to account for changes in shear strength that will likely occur over time. The fully softened shear strength can be measured using remolded test specimens in a direct shear apparatus. Again, the use of a non-linear envelope would be appropriate.

7-6.3 Steady State Seepage in Dams.

One of the stability analyses required for earth and rockfill dams is the evaluation of the factor of safety for the condition of steady state seepage (Figure 7-7c). This case assumes that the reservoir has been at a relatively constant elevation for long enough that a steady-state seepage pattern has developed. The pore water pressures in the dam and foundation can be calculated using finite element analysis. The pore pressures above the phreatic surface are normally assumed to be equal to zero. Effective stress strength parameters (c' and ϕ') are used in the dam and foundation soils. The effect stress strength parameters for the dam materials can be measured with CD direct shear, CD triaxial, or CU triaxial tests on compacted test specimens. In the example, the strength parameters for the silty sand can be determined using *in situ* tests.

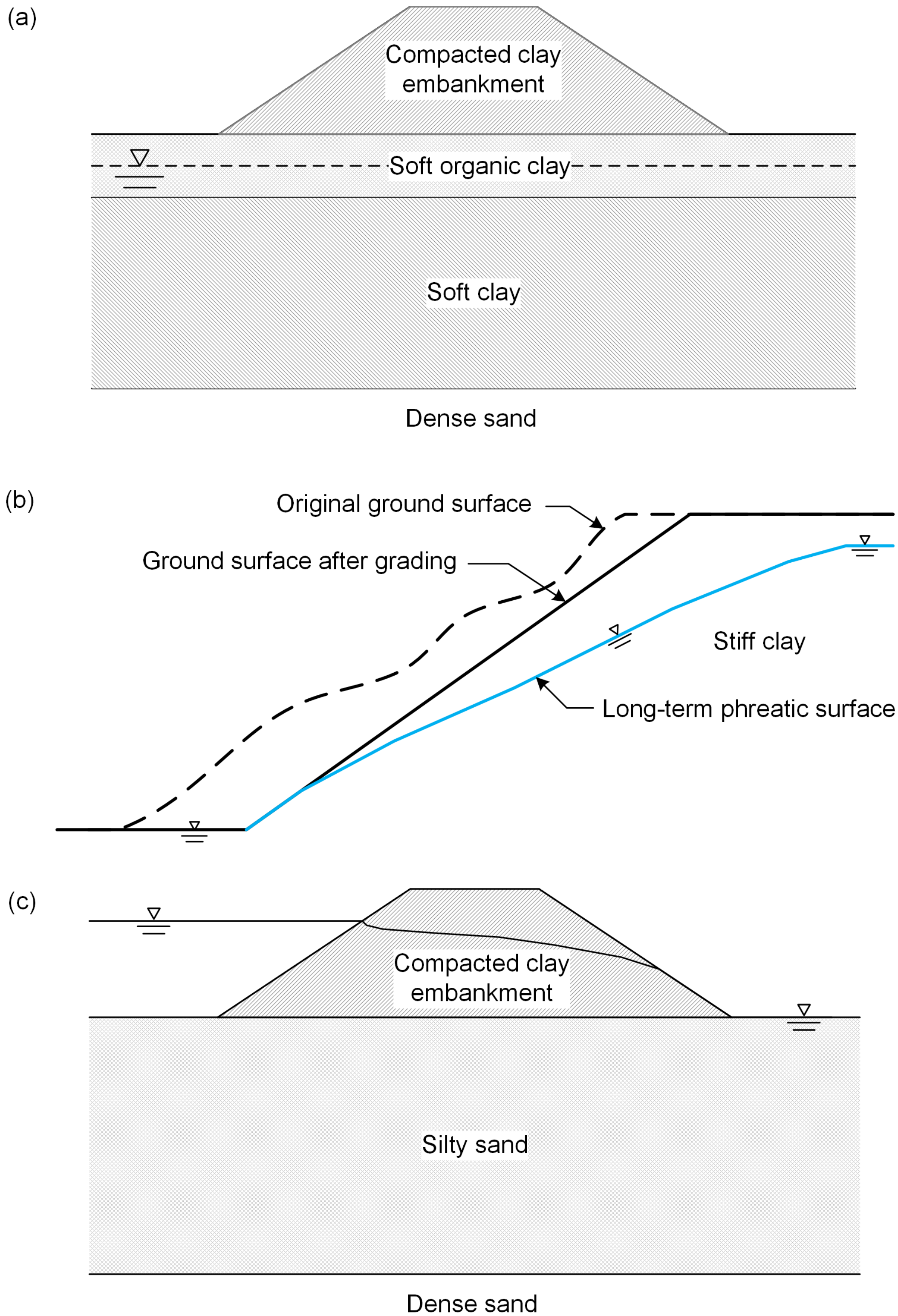


Figure 7-7 Analysis Cases for (a) End of Construction for Embankment on Clay, (b) Cut Slope in Clay, and (c) Levee or Dam in a Condition of Steady State Seepage

7-6.4 Stabilizing Berm for Failed Slope.

Berms are often used to stabilize failed slopes. For example, Figure 7-8 is a cross section of a slope that failed in a fat clay. A stability berm has been constructed at the toe of the slope to increase the factor of safety. It is presumed that the failure surface is known based on inclinometer readings or borings. If sufficient displacement has occurred on the failure surface, then the appropriate shear strength to use is the residual shear strength. The residual friction angle (ϕ'_r) or a nonlinear residual effective stress envelope is best determined by ring shear tests conducted on remolded test specimens of the fat clay. This should be an effective stress analysis with the appropriate phreatic surface used in the analysis.

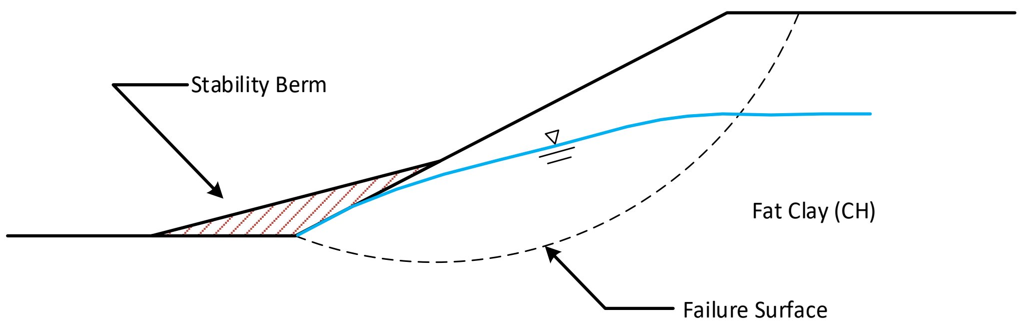


Figure 7-8 Stabilizing Berm Used to Increase the Factor of Safety of a Failed Slope

7-6.5 Other Analysis Cases.

Many other analysis cases are analyzed in geotechnical engineering practice that can be significantly more complex than the simple examples provided. For earth and rockfill dams, a critical case for the upstream slope is *rapid drawdown*. This occurs when the steady state seepage condition is changed by lowering the reservoir. If the reservoir is lowered rapidly (meaning days or weeks), the upstream slope no longer has the stabilizing support of the external water pressure. The shear strengths in the dam are based on the effective stresses prior to drawdown, and the lowering of the reservoir can cause an undrained failure. This is normally performed as a three-stage analysis, and it uses a strength model that is more complex than those used in the other cases described above (Duncan et al. 2014). These types of require considerable technical ability and they should be performed by engineers who have experience with rapid drawdown analysis. Effective stress rapid drawdown methods, such as those based on uncoupled transient seepage analyses, should be avoided.

The stability of slopes is also analyzed for cases of earthquake loading. These analyses can range from simple pseudostatic methods, where a horizontal force is applied to the free body of the limit equilibrium analysis, to very complex numerical analyses. Earthquake analyses are another category that require considerable judgment and experience to obtain meaningful results and should be conducted by engineers skilled in this branch of geotechnical engineering.

7-6.6 Back-Analysis of Slopes.

Failed slopes offer a unique opportunity to develop a model of the shear strengths and ground water conditions at the time of failure. This type of model can be very useful in designing slope stabilization or in analyzing nearby slopes. When performing a forward analysis, the most important unknown is the factor of safety for a specific failure surface. When conducting a back-analysis of a slope, the factor of safety is known ($F = 1$), so a different unknown can be calculated. Normally, the shear strength of a soil layer is the desired property to be determined from back-analysis. If the back-analysis is performed on a slope that failed in an undrained condition, then the average undrained shear strength of a soil layer can be determined from the analysis. If the back-analysis is performed on a slope that failed in a drained condition, then only one of the effective stress strength parameters (c' or ϕ') can be determined. Often, the effective stress cohesion is assumed to be equal to zero, and the friction angle is calculated.

It is important that the other parameters used in a forward analysis be known with confidence for back-analysis. These include the slope geometry, soil stratigraphy, shear strength parameters for layers where strengths are not back-calculated, unit weights, etc. For back-analysis of drained failures, it is important that the pore pressure conditions *at the time of failure* be known. The location of the failure surface should also be known to obtain the most accurate results. Often, the failure surface location may be known from the results of inclinometer readings. In other cases, the location of the failure plane can be determined by careful drilling and sampling. If only the head scarp and toe exit of the failure plane is known, then the failure surface can be determined from the computer program's search routine by only searching for surfaces which go through those two points. If the position of the failure surface is not known, it is important to search for the critical surface and not to assume the location. If the location of the failure surface is assumed, then the resulting shear strength back-calculated will be too low.

7-6.7 Evaluation of Slope Stability Results.

Limit equilibrium slope stability calculations involve thousands of calculations. Since the adoption of computer programs to perform these calculations, project specifications often required that hand calculations be used to verify the results of the computer analyses. While this was possible when simpler methods of slope stability were used, such as Bishop's Simplified Method and the Ordinary Method of Slices, this requirement became impractical for more complex methods, like's Spencer's Method and Morgenstern and Price's Method. The time required to perform the calculations by hand for one failure surface for a cross section containing many slices and an advanced shear strength model has become excessive. In recognition of this, Wright (2013) suggested that new project specifications should require that two different slope stability computer programs should be used to verify analyses. After the minimum factor of safety for the critical failure surface is determined using one program, a different program should be used to analyze the same failure surface using the same method. If the analyses are correct, the factors of safety calculated should be within about 1% of each other.

It is important for the engineer to be able to examine the forces acting on each slice. In particular, the forces at the boundary between slices should be in compression, and the normal force at the base of the slice should be in compression. Many computer programs allow the *line of thrust* to be plotted on the cross section. The line of thrust is a line that is plotted at the point of application of each of the side forces. Ideally, the line of thrust should be located within the soil mass defined by the slices. If portions of the line of thrust plot outside of the free body being analyzed, it often indicates tensile forces between slices or tensile forces at the base of slices. The addition of tension cracks to the cross section can be used to prevent tensile forces between slices, and these can be readily accommodated in commercial computer programs. Further information regarding the utility of the line of thrust can be found in Whitman and Bailey (1967).

The search routines for common commercial slope stability computer programs analyze thousands to tens of thousands of failure surfaces. The stability methods that solve for all conditions of equilibrium have iterative solutions, and the solutions do not always converge. There can be various reasons why the solutions do not converge, including geometry issues with invalid failure surfaces, problems with interpolation of advanced strength models, numerical issues with the solution procedure, etc. Critical failure surfaces can be missed as a result of non-convergence. The engineer should be able to identify when convergence issues are present. The location of this information varies depending on the program that is used, and is sometimes difficult to find. Prior to performing any analyses for record, the engineer should find this information and assess the validity of their results.

7-6.8 Slope Stability Charts.

Chart solutions for slope stability analyses have been available since the 1930s. Prior to the introduction of computers into geotechnical engineering practice, slope stability charts allowed an approximate solution to be quickly obtained. The charts are also useful in estimating the critical failure circle, showing the mode of failure (toe circle vs. deep circle), and other valuable information.

Charts have been developed for many different categories of slope stability analysis, including drained analyses, undrained analyses, rapid drawdown analyses, infinite slope analyses, surcharge loading at the crest, tension cracks, and other specialty cases. A comprehensive set of chart solutions can be found in Duncan et al. (2014). An example of a chart for infinite slope analysis is shown in Figure 7-9. Infinite slope analysis is useful for explaining sloughing failures for slopes having an effective stress cohesion equal to zero, and to examine the effects of seepage on the factor of safety of slopes.

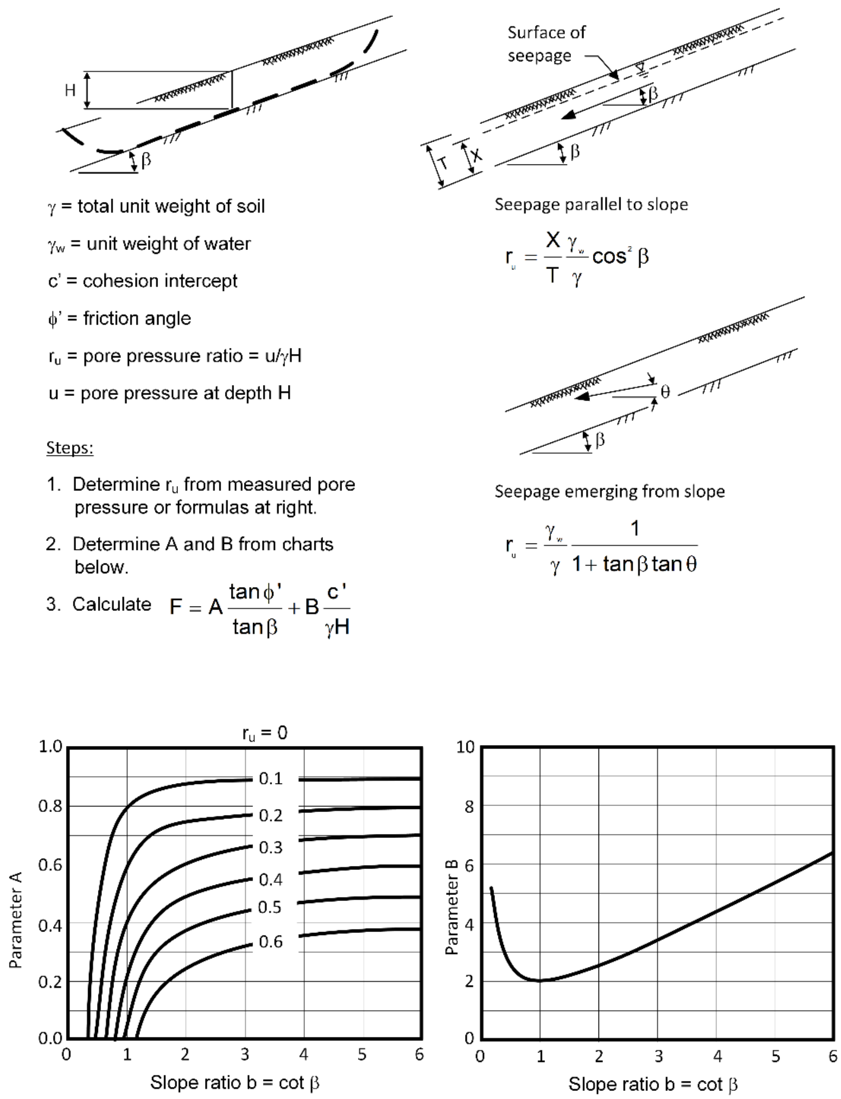


Figure 7-9 Chart Solution for Infinite Slope Analysis (after Duncan et al. 2014)

Charts have historically been used to obtain a quick solution to slope stability problems. Even with the advent of computer-based slope stability analyses, chart solutions still provided an approximate factor of safety in less time than required to run a computer analysis. However, the modern computer programs allow slope stability problems to be defined and solved very quickly, and the speed advantage of chart solutions has been diminished. Chart solutions are best suited for slope stability problems that have simple soil profiles and straightforward strength interpretations. As the soil profiles and strength interpretations become more complex, the accuracy of chart solutions decreases. Even so, chart solutions still offer a viable complementary analysis method to computer solutions.

7-7 SLOPE STABILIZATION.

It is often necessary to increase the factor of safety of existing slopes or to repair slopes that are moving or have failed. Figure 7-10 shows different methods of stabilizing slopes.

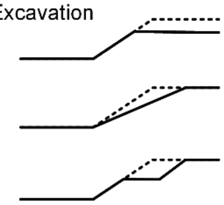
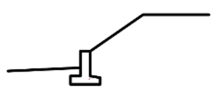
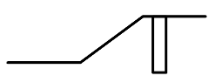
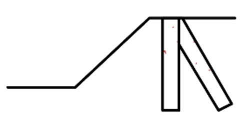
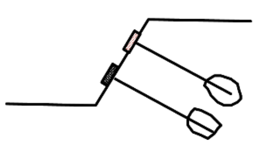
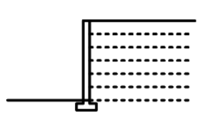
Scheme	Applicable Methods	Comments
1. Changing Geometry - Excavation 	1. Reduce slope height by excavation at the top of slope. 2. Flatten the slope. 3. Excavate a bench in the top of the slope.	1. Area has to be accessible to construction equipment. Disposal site needed for excavated soil. Drainage sometimes incorporated into this method.
2. Toe Berm Fill 	1. Compared earth or rock berm placed at the toe. Drainage may be required behind berm.	1. Sufficient width and thickness of berm required so failure will not occur below or through berm. Borrow soils required.
3. Retaining Structure     	1. Retaining structure – Crib, Cantilever, or MSE. 2. Drilled, cast-in-place vertical piles founded well below the slide plane. Generally, 18 to 30 inches in diameter at 4 to 8 foot spacing. Larger diameter piles at closer spacing may be required in some cases to mitigate failures of cuts in highly fissured clays. 3. Drilled, cast-in-place vertical piles tied back with battered piles or a deadman. Piles founded well below the slide plane. Generally, 12 to 30 inches in diameter at 4 to 8 foot spacing. Larger diameter piles at closer spacing may be required in some cases to mitigate failures of cuts in highly fissured clays. 4. Earth and rock anchors and rock bolts with anchor plates. 5. MSE Wall	1. Usually expensive. Cantilever walls may have to be tied back. 2. Spacing should be such that soil can arch between piles. Grade beam can be used to tie piles together. Very large diameter piles (6+ feet) have been used for deep slides. 3. Space close enough so soil will arch between piles. Piles can be tied together with grade beam. 4. Can be used for high slopes in restricted areas. Conservative design should be used, especially for permanent support. Use may be essential for slopes in rocks where joints dip toward excavation and daylight in the slope. 5. Various types of geosynthetics and wall facings are available.
4. Other Methods	See DM 7.2.	

Figure 7-10 Methods of Stabilizing Slopes

7-8 REQUIRED FACTOR OF SAFETY FOR SOIL SLOPES.

There are many different sources that specify the minimum factor of safety. Often, the design values are determined by municipal or government organizations. For earth dams, the U.S. Army Corps of Engineers' EM 1110-2-1902 (2003) recommends the values listed in Table 7-2. Other organizations dealing with earth dams, such as the U.S. Bureau of Reclamation (USBR), have specified their own values. The values recommended by USBR are given in Table 7-3.

Table 7-2 Factors of Safety for New Earth and Rockfill Dams (USACE 2003)

Analysis Condition	Required F_{min}	Slope
End of Construction	1.3	Upstream and downstream
Steady state seepage (Long term)	1.5	Downstream
Maximum pool level	1.4	Downstream
Rapid drawdown	1.1 to 1.3	Upstream

Table 7-3 Factor of Safety for Dams using Spencer's Method for Dams (USBR 2011)

Loading Condition	Shear Strength Parameters	Pore Pressure Characteristics	Minimum factor of safety
End of construction	Effective	Generation of excess pore pressures in embankment and foundation materials with laboratory determination of pore pressure and monitoring during construction.	1.3
		Generation of excess pore pressures in embankment and foundation materials and no field monitoring during construction and no laboratory determination	1.4
		Generation of excess pore pressures in embankment only with or without field monitoring during construction and no laboratory determination	1.3
	Undrained Strength		1.3
Steady-state seepage	Effective	Steady-state seepage under active conservation pool	1.5
Operational conditions	Effective or undrained	Steady-state seepage under maximum reservoir level (during a probably maximum flood)	1.2
	Effective or undrained	Rapid drawdown from normal water surface to inactive water surface	1.3
		Rapid drawdown from maximum water surface to active water surface (following a probable maximum flood)	1.2
Other	Effective or undrained	Drawdown at maximum outlet capacity (inoperable internal drainage; unusual drawdown)	1.2
	Effective or undrained	Construction modifications (applies only to temporary excavation slopes and the resulting overall stability during construction).	1.3

The required minimum factor of safety is dependent on many different factors, including: (1) type of structure, (2) type of analysis, (3) consequences of failure, (4) uncertainty involved with design parameters, (5) frequency of specific loading event, and many others. An important concept in arriving at a minimum factor of safety involves the degree of uncertainty associated with the design parameters. Sometimes, the minimum factor of safety depends on if the analysis has “well-defined conditions” or “poorly-defined conditions.” Engineering judgment is required to classify a particular site or project into one of these two categories. In some cases, the designation of “well-defined conditions” can only be applied for sites that have already been built upon.

In general, well-defined conditions means that the site exploration and field or laboratory testing program was thorough enough for the engineer to have confidence in the soil stratigraphy and shear strength interpretation. A poorly-defined condition can occur when the borings are spread far apart, few laboratory tests have been conducted, and/or the soil stratigraphy is highly variable. An example of this is the geotechnical guidelines for a large Washington DC suburb. The requirements for factors of safety for two different soil formations are given as follows[13]:

> “For long-term stability, a minimum Factor of Safety (FS) of 1.25 is required when supported with sufficient field and laboratory characterization of the slope’s soils. Otherwise, a minimum FS of 1.5 is required. In case of Critical slope or structure, a minimum FS of 1.5 is required unless a laboratory measured residual strength test is obtained and used in the analysis. In this case, a minimum FS of 1.25 is required when supported with sufficient field and laboratory characterization of the soils.”

> “For long-term stability of the soil formations other than Potomac Formation clay if slope stability analysis is deemed necessary by the engineer or if it is required by the County, a minimum Factor of Safety (FS) of 1.25 is only acceptable when the slope is not critical and the analysis is supported with sufficient site-specific *in situ* or laboratory strength tests of the encountered soils. Otherwise, a minimum factor of safety of 1.5 must be used in the analysis.”

7-9 MECHANICALLY STABILIZED EARTH SLOPES.

Mechanically stabilized earth (MSE) is a term that refers to soil retention structures that include both retaining walls and earth slopes. This section discusses the application of MSE technology to slopes. The design of MSE retaining walls is discussed in DM 7.2.

[13] This example is intentionally left uncited to maintain anonymity of the source.

Design and analysis of MSE slopes is a specialty area in geotechnical engineering. There are engineering consultants who specialize in MSE walls and slopes. In this manual, the rudiments of design and analysis are presented in order that outside designs can be evaluated and not for the purpose of completing a full MSE design.

7-9.1 Applications of MSE.

Reinforced earth slopes are fill structures in which discrete layers of geosynthetic or steel elements are installed during construction at specified locations. A typical cross section of an MSE slope is shown in Figure 7-11.

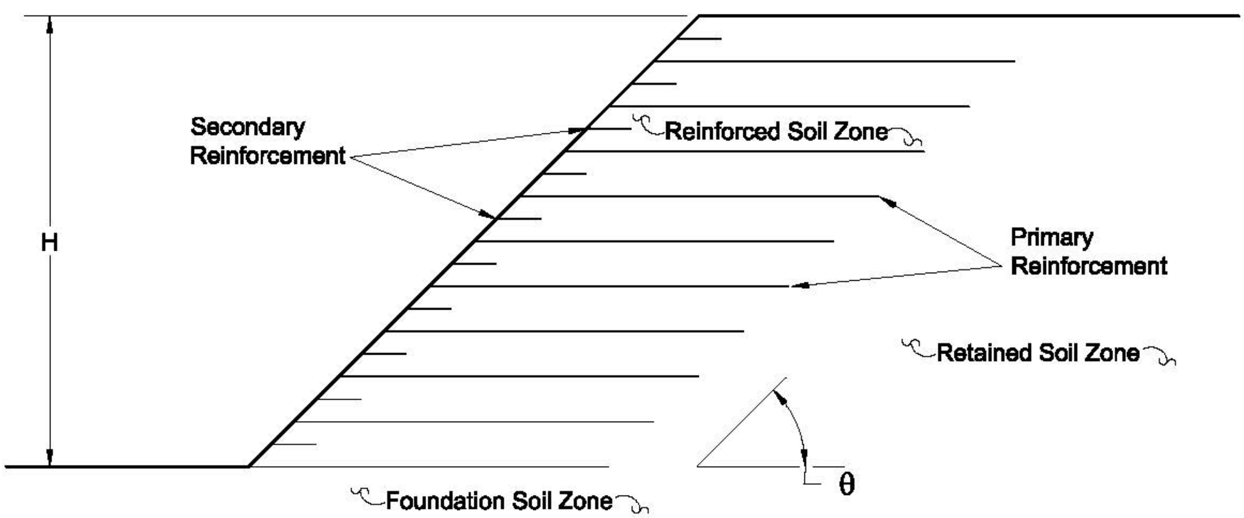


Figure 7-11 Typical Cross-Section of an MSE Slope

The *reinforced soil zone* is that portion of the slope in which layers reinforcement are installed. The *retained soil zone* and *foundation soil zone* are located behind and below the reinforced soil zone, respectively. The layers of primary reinforcement shown in Figure 7-11 resist the development of failure planes through the reinforced soil zone. The layers of secondary reinforcement prevent surficial failure at the slope face.

The primary limitations on the use of MSE slopes relate to constructability and utilities. Constructability is not typically an issue if the slope is part of a larger fill area but may be a concern when an existing hillside must be excavated to build the slope. Utilities can be significant factors in the poor performance of MSE structures, particularly if the utility is *wet* such as a storm sewer or water main. The malfunction of wet utilities may contribute to about one-third of the failures of MSE retaining walls (Valentine 2013).

The distinction between an MSE retaining wall and an MSE slope has been defined by the Federal Highway Administration (FHWA) based on the face angle, θ (FHWA 2009b). If $\theta < 70°$, then the structure is a slope. If $\theta \geq 70°$ or greater, then the structure is a wall. The distinction between an MSE retaining wall and slope has important implications for land use efficiency as illustrated in Figure 7-12. However, the increased land use efficiency of MSE walls and slopes is accompanied by complications related to facing requirements and structural deformations, as well as increased cost.

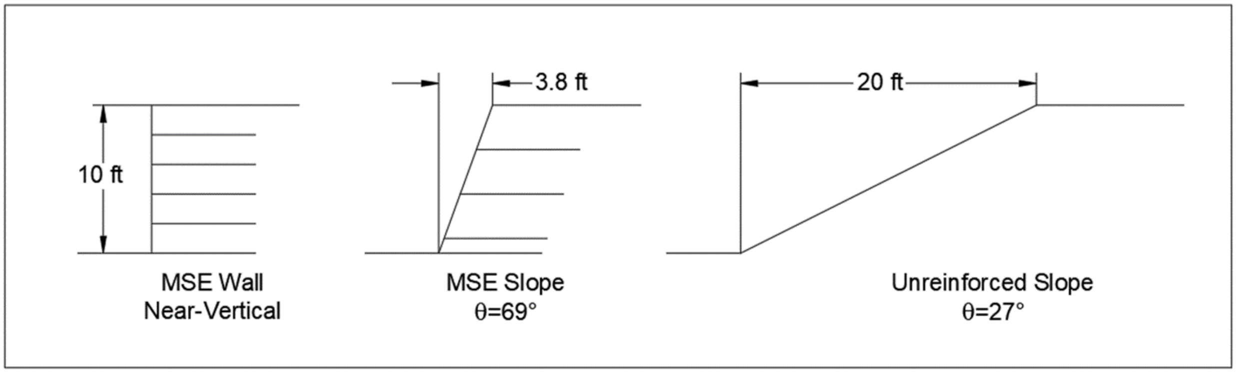


Figure 7-12 Difference in Usable Land for Walls and Slopes

7-9.2 Reinforced Slope Materials.

The soil that is installed in the reinforced zone of an MSE slope is an important structural component of the slope. The properties that are required of reinforced soil should be based on the geometry of the slope and the structures that may depend on the slope for support. FHWA's recommendations for the properties of fill soil in the reinforced zone of MSE slopes permit up to 50% fines that have a $PI \leq 20$ (FHWA 2009b). The fill properties shown in Table 7-4 are recommended for relatively tall or steep slopes; however, the recommendations are only applicable to slopes with a height less than 70 feet.

Table 7-4 Recommendations for Reinforced Fill Soil in MSE Slopes Based on Geometry

<table>
<tr><th>Slope Geometry</th><th colspan="3">Recommended Properties for Reinforced Fill</th></tr>
<tr><td rowspan="6">Slope < 1.2H:1V
($\theta < 40°$)
and
$H < 70$ ft</td><td rowspan="5">Gradation
ASTM D6913</td><td>Sieve Size</td><td>Percent Passing</td></tr>
<tr><td>4 in</td><td>100</td></tr>
<tr><td>No. 4</td><td>20-100</td></tr>
<tr><td>No. 40</td><td>0-60</td></tr>
<tr><td>No. 200</td><td>0-50</td></tr>
<tr><td>Plasticity Index
ASTM D4318</td><td colspan="2">$PI \leq 20$</td></tr>
<tr><td rowspan="6">1.2H:1V ≤ Slope < 0.36H:1V
($40° \leq \theta \leq 70°$)
and
$H < 70$ ft</td><td rowspan="5">Gradation
ASTM D6913</td><td>U. S. Standard Sieve</td><td>Percent Passing</td></tr>
<tr><td>4 in</td><td>100</td></tr>
<tr><td>No. 4</td><td>20-100</td></tr>
<tr><td>No. 40</td><td>0-60</td></tr>
<tr><td>No. 200</td><td>0-35</td></tr>
<tr><td>Plasticity Index
ASTM D4318</td><td colspan="2">$PI \leq 10$</td></tr>
</table>

Other important components of MSE walls and slopes include internal and external drains, filters, separators and erosion control. The use of geosynthetics for these applications is summarized in Table 7-5.

Table 7-5 Summary of Applications and Materials for Reinforced Soil Slopes

Application	Component	Material	Purpose	Comments
Reinforcement	Primary and Secondary Reinforcement	Polyester (PET) and Polypropylene (PP) Geotextile; PET, PP and High-Density Polyethylene (HDPE) Geogrid	Provide tensile strength and confinement to fill soil.	PET and HDPE are usually used for primary reinforcement. PET, HDPE and PP can be used for secondary reinforcement.
Facing	Soft Armor Face ($\theta < 40°$)	Rolled Erosion Control Product (RECP)	Prevent erosion caused by surface water runoff	Consult manufacturers for recommendations of RECP specifications based on θ and service period.
	Hard Armor Face ($\theta \geq 40°$)	Welded Wire Fabric (WWF)		Typically, galvanized WWF 4x4-W4.0xW4.0 should be used. Hardware cloth required behind WWF to prevent spilling of retained gravel fill.
		Nonwoven PP Geotextile	Separation and filtration	Separate gravel fill at slope face from finer reinforced soil.
		Gravel	Fill soil immediately behind WWF	GP or GW with 1.0 in minimum particle size.
Internal Drainage	Blanket Drain	Gravel	Drainage medium	Typically, ASTM C33 No. 57 or No. 67 stone.
		Nonwoven PP Geotextile	Separation and filtration	Install above and below drainage gravel to separate from adjacent finer grain soil.
	Chimney Drain	Gravel	Drainage medium	Typically, ASTM C33 No. 57 or No. 67 stone. Can be replaced by drainage composite.
		Drainage Composite	Drainage medium	Use drainage composite with geonet core to replace drainage gravel. Space drainage composite to typically provide 33% to 75% coverage.
External Drainage	Drainage Swale	RECP in form of Turf Reinforcement Mat (TRM)	Divert and control surface water runoff	Line swale with TRM. Consult manufacturer for specifications. Locate swale 5 ft. to 10 ft. behind slope crest. Size swale based on hydraulic analyses. Use bench with swale at mid-slope for H over 25 to 30 ft.

7-9.3 Geosynthetic Reinforcement Strength.

Geosynthetics that are used in soil reinforcement applications are typically designed to exhibit their maximum tensile strength in one direction. In this respect, such geosynthetics are said to be *uniaxial* and the design strength direction usually corresponds to the material's MD or *roll-direction*. Geosynthetics that exhibit significant tensile strength in both the MD and cross machine direction (XMD) are said to be *biaxial*.

The tensile strength of a geosynthetic that is used for the design of an MSE slope is based on a *minimum average roll value* ($MARV$) that is reported by the manufacturer. In the United States, the industry practice is to reduce the average value by two standard deviations and to define the result as the minimum average roll value ($MARV$). Reduction factors are then applied to the strength $MARV$ to account for potential degradation of strength as a result of creep, environmental conditions and installation damage.

7-9.3.1 Long-Term Design Strength.

The assessment of a geosynthetic's long-term tensile strength (T_{al}) for use in the design of an MSE slope follows current FHWA procedures (FHWA 2009b):

$$T_{al} = \frac{T_{ULT}}{RF_{CR} \times RF_D \times RF_{ID}} \qquad \textbf{(7-3)}$$

where:
T_{ULT} = ultimate tensile strength of the geosynthetic based on the MARV,
RF_{CR} = reduction factor applied to account for creep under sustained tensile loading,
RF_D = reduction factor applied to account for the degradation due to environment, and
RF_{ID} = reduction factor applied to account for damage during installation.

The reduction factors are discussed briefly in the following sections. Details regarding the determination of RF_{CR}, RF_D, and RF_{ID} for a geosynthetic can be found at Appendix B of FHWA (2009b).

7-9.3.2 Reduction Factor for Creep (RF_{CR}).

The tendency of a geosynthetic to elongate under sustained tensile loading is called *creep* and it is a property of materials that are manufactured using PET, HDPE, PP and other polymers. If the magnitude of the load is sufficiently great and if it is maintained for a sufficient period of time, the creep can induce rupture or result in such elongation that the material's performance is compromised.

In the United States, the standard of practice to determine a *reduction factor for creep* (RF_{CR}) that is based on the sustained load that will induce creep rupture at the end of the design service period. For permanent MSE slopes the design service period should be no less than 75 years. A longer service period may be appropriate for structures that support critical infrastructure.

7-9.3.3 Reduction Factor for Durability (RF_D).

Geosynthetics may degrade depending on their base polymer and if they are exposed to certain environmental conditions. Polyester geosynthetics may degrade as a result of hydrolysis. Geosynthetics manufactured with HDPE and PP are subject to degradation by their reaction with oxygen, particularly in the presence of elevated temperatures. Oxidation can also be initiated by exposure to UV light (i.e., UV-oxidation). The resistance of these polymers to oxidation can be significantly increased by the addition of antioxidants during the manufacturing process. Polyester is also susceptible UV-oxidation but to a lesser degree than HDPE and PP (FHWA 2009a). Protection of PET yarns is typically provided in the form of coatings. In the case of all geosynthetics, the protective roll wraps should not be removed until the material is installed to minimize UV light exposure.

The FHWA recommends a default *reduction factor for durability* (RF_D) of 1.3 for PET, HDPE, and PP geosynthetics provided certain criteria are satisfied. Also, a lower RF_D may be used if it is indicated by product specific testing. Further details are given in FHWA (2009b).

7-9.3.4 Reduction Factor for Installation Damage (RF_{ID}).

The standard of practice in the United States is for the manufacturers of geosynthetic reinforcement to assess the potential for installation damage through the performance of full-scale tests. Such testing programs typically evaluate the damage induced by compaction of coarse gravel, sandy gravel and silty or clayey sand.

The geosynthetic manufacturer should be consulted to obtain its recommendation for the *reduction factor for installation damage* (RF_{ID}). The manufacturer should also be consulted for its recommendations regarding measures to reduce installation damage. Typical measures include the following:

- Tracked vehicles should not traffic directly on panels of geosynthetic reinforcement. There should be no less than 8 inches of fill soil between the tracks and the geosynthetic. Sharp turns by tracked vehicles on fill soil should be avoided.
- Rubber tire vehicles may operate directly on the geosynthetic reinforcement at speeds less than 10 miles per hour. Sudden braking and turning should be avoided.

- Fill soil should not be dumped directly onto geosynthetic reinforcement. Rather, it should be dumped onto fill soil that has already been spread and then bladed onto the geosynthetic by a dozer.

7-9.4 Soil-Geosynthetic Interaction.

The determination of geosynthetic reinforcement length in the design of an MSE slope is based in part on the resistance of the reinforcement to pullout from between layers of confining soil. In FHWA (2009b) the FHWA defines a geosynthetic's resistance to pullout as:

$$P_r = F^* \cdot \alpha \cdot \sigma'_v \cdot L_e \cdot C \quad \textbf{(7-4)}$$

where:
P_r = geosynthetic reinforcement's resistance to pullout,
F^* = pullout resistance factor,
α = scale correction factor to account for nonlinear stress reduction,
σ'_v = effective vertical stress at the soil-reinforcement interface,
L_e = length of reinforcement embedded behind the trial failure surface, and
C = number of surfaces on which pullout resistance is mobilized (i.e. 2 for geosynthetics).

The critical failure surface used to calculate L_e should be that surface that exhibits the minimum F deemed acceptable. Also, L_e should be no less than 3 feet to assure adequate pullout resistance.

Some manufacturers of geosynthetic reinforcement have characterized soil-geosynthetic interaction in terms of a *coefficient of interaction* (C_i) based on pullout tests with C_i defined as:

$$C_i = \frac{\tan \delta}{\tan \phi'} \quad \textbf{(7-5)}$$

where:
ϕ' = the effective stress internal angle of friction, and
δ = the effective soil-geosynthetic interface friction angle.

The values of F^* and C_i are related by:

$$F^* = C_i \tan(\phi') \quad \textbf{(7-6)}$$

7-9.5 Analysis and Design of Reinforced Slopes.

The most technically challenging aspect of the design of an MSE slope is deciding the required strength, length and vertical spacing of the layers of reinforcement. The critical failure surface for a slope with layers of horizontally-oriented geosynthetic reinforcement is frequently a combination of circular and linear segments, particularly if the critical failure surface is entirely outside of the reinforced soil zone (i.e., a global failure surface rather than a compound failure surface).

Most of the software packages that are used for soil slopes can also be used for MSE slopes. There are some software packages specifically written for MSE slopes, and these are listed in Appendix B. Spencer's Method (Spencer 1967) and the Morgenstern and Price Method (Morgenstern and Price 1963) both lend themselves to the analyses of noncircular failure surfaces, solve for all conditions of equilibrium (i.e. moment and force), and provide the most accurate solutions. Either of these two methods is preferred for the analysis of MSE slopes.

One of the most important considerations in the modeling of an MSE slope in a limit equilibrium slope stability computer program is the definition of F given in Equation 7-1. However, the presence of geosynthetic reinforcement requires that its strength be applied to the right side of the equation in the numerator or the denominator (Duncan et al. 2014). Two options are available as summarized in Table 7-6. The method used by slope stability software can be determined using the simple approach suggested by Duncan et al. (2014).

Table 7-6 Methods of Incorporating Geosynthetic Reinforcement Strength in Factor of Safety Equation

Method of Including Reinforcement Strength	Factor of Safety Equation
Method A (Active)	$F = \dfrac{\text{shear strength}}{\text{shear stress required for equilibrum} - \text{reinforcement resistance}}$
Method B (Passive)	$F = \dfrac{\text{soil strength+reinforcement resistance}}{\text{shear stress required for equilibrium}}$

If Method A is used to define F, then the strength of the geosynthetic used to calculate F is T_d. To account for potential uncertainties in the geosynthetic T_d should be divided by a factor of safety for geosynthetic strength (F_R) of at least 1.3. If Method B is used, then T_d will be reduced by F and the application of F_R is not necessary.

The reinforcement force orientation assumed by limit equilibrium analysis can vary from one that is parallel to the reinforcement to one that is tangent to the slip surface. Setting the orientation parallel to the reinforcement in a slope stability computer program is common practice and tends to result in a lower F compared to setting the orientation tangent to the slip surface.

A detailed discussion of the procedure to determine the reinforcement requirements of MSE slopes is provided by the FHWA (2009), particularly for the case in which Bishop's simplified method is used. The FHWA manual also considers the mechanics of internal sliding failure and locally soft foundation soil at the slope toe. The steps provided in Table 7-7 are intended to help an engineer to construct a computer model for in MSE slope design.

Table 7-7 Steps for Designing an MSE Slope

Step	Procedure
1	Draw a scaled cross section of the slope that reflects the existing and proposed grades as well as external water conditions, and permanent and temporary loads. Use high quality site plans to locate these features as accurately as possible.
2	Use the available geotechnical information to determine and draw the boundaries of soil and rock strata as well as groundwater.
3	Use the results of Steps 1 and 2 it to construct the cross section in a computer program model.
4	Assign physical, strength and hydraulic properties to the sections of the model as indicated by the available geotechnical information.
5	Select either Spencer's method or the Morgenstern and Price method to analyses failure surfaces.
6	Select one to three values of geosynthetic reinforcement strength (T_{al}) based on manufacturer information, or assume typical values.
7	Determine whether the computer program used Method A or B to defined F. If the program provides an option, select Method A and then reduce the geogrid strength by $F_R = 1.3$ or more.
8	Set the reinforcement force orientation parallel to the reinforcement.
9	Assign the F* or C_i parameter based on recommendations by the manufacturer of the geosynthetic reinforcement. If recommendations are not available or if they are not supported by test data, assume that $C_i = 0.67$. This will be conservative for the soil parameters shown in Table 7-4.
10	If the computer program provides an option, select 100% reinforcement coverage as opposed to partial coverage.
11	Assign layers of geosynthetic reinforcement to the cross section. Vertical spacing of 3 ft. is a good initial starting point. In general, the vertical spacing of reinforcement should not exceed 3 ft.
12	Set the length (L) of each layer of reinforcement to about $0.7 \cdot H$. The required L will increase if there is a slope below (i.e. a toe slope) or behind (i.e. a crest slope) the MSE structure.
13	Perform preliminary analysis by setting the search limits to evaluate only those surfaces which exit through the face of the slope. Evaluate both circular and noncircular failure surfaces. If the resulting F is too low, then change the layers in the vicinity of the bottom of the failure surface to types with higher strengths.
14	After designing for failure surfaces that exit through the slope face, change the search limits to evaluate compound and global surfaces that pass below the toe of the structure.
15	If a compound failure surface is indicated that has an unacceptably low F, then increase the strength of the lower reinforcement layers or decrease their vertical spacing. If a global failure surface is indicated that has an unacceptably low F, then increase the length of the reinforcement layers.

Using the process in Table 7-7, the modifications required to obtain a satisfactory F that is balanced with geosynthetic efficiency is an iterative process in which geosynthetic strengths and lengths are adjusted. Once the optimum design is determined, the parameters that may have significant uncertainty should be considered. For example, if rock is thought to be present below the toe of the MSE slope, changing the elevation of the top of rock by a few feet in the computer model can have a profound effect that makes the difference between a stable slope and slope failure. Similarly, there is frequently significant uncertainty regarding the location of groundwater and soil shear strength. The effect of these uncertainties should be investigated through parametric analyses coupled with engineering judgment.

The designer is cautioned to avoid making the design over-complicated. Small savings in material obtained from optimized lengths or spacings are often offset by potential for error in construction or an increased difficulty in constructability.

7-9.6 Required Factor of Safety for MSE Slopes.

An MSE slope should be designed to a target F that is based on considerations of the uncertainties regarding site conditions, material properties and the consequences of slope failure. In general, the standard of practice is to provide a F in the range of 1.3 to 1.5. If the site conditions and material properties are understood well and if the consequences of failure are relatively low, then a minimum F of 1.3 may be appropriate. However, if site conditions are subject to unforeseeable changes and if soil types, strengths and locations are poorly understood, then F of 1.5 or higher may be necessary. Similarly, if the proper performance of the MSE slope is required for the operation of important structures, then F of 1.5 or higher may be indicated. For MSE slopes designed in accordance with FHWA guidance, a minimum factor of safety of 1.5 is required.

7-10 ROCK SLOPE STABILITY.

The stability of rock slopes may become a concern during the excavation for the construction of roads, buildings and infrastructure components. Often a stability issue cannot be identified until the excavation is underway and information that is needed to assess the potential for various modes of failure becomes available. Analyses of rock slope stability may need to be performed expeditiously to avoid project delays. The potential for delays can be exacerbated by a need to design stabilization measures. In other cases, rock slope instability does not occur until well after the initial excavation and rock weathering has taken its toll.

This section provides an overview of some of the aspects of rock slopes and a more in-depth discussion of others. The fundamental mechanics of rock slope failure are covered by a discussion of sliding blocks, plane failure, wedge failure, and toppling failure. Stabilization measures for rock slopes and mitigation of rock falls are also addressed. More in-depth discussion can be found in FWHA (1998), Hoek and Bray (1981), and Rowland et al. (2007).

7-10.1 Modes of Rock Slope Failure.

Fortunately, the stresses in most rock slopes are much less than the rock strength, and for this reason most rock slopes are relatively stable. The potential for rock slope failure becomes a concern under two general conditions. First, discontinuities in the rock mass propagate and the rock separates as blocks, wedges, columns, or other types of sections. Second, rock that has already separated in the form of cobbles and boulders can translate downslope under the influence of gravity as a rock fall. In both cases, the separated rock may pose a hazard to both property and lives.

There are six typical configuration of rock slopes, some of which may pose risks of instability. Four possible configurations of rock discontinuities are shown in Figure 7-13 while rock slopes with weak and weathered rock are depicted in Figure 7-14.

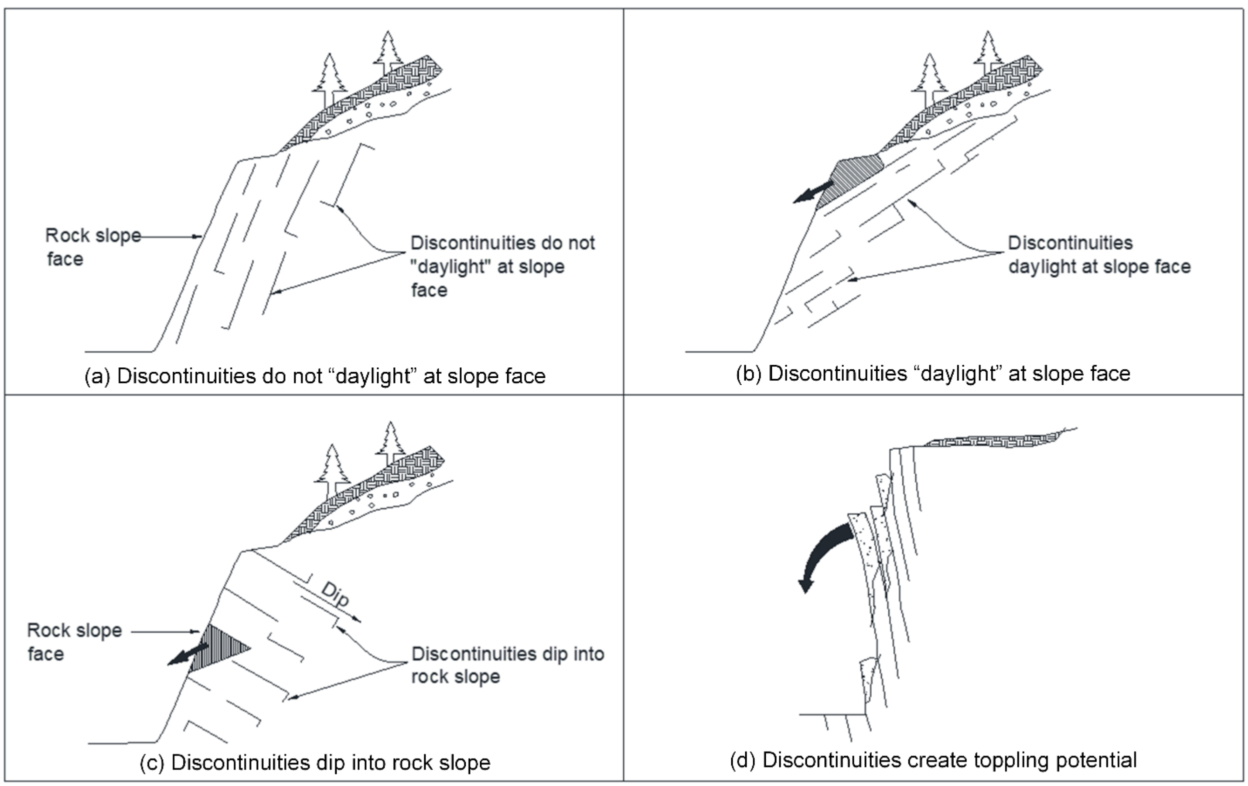


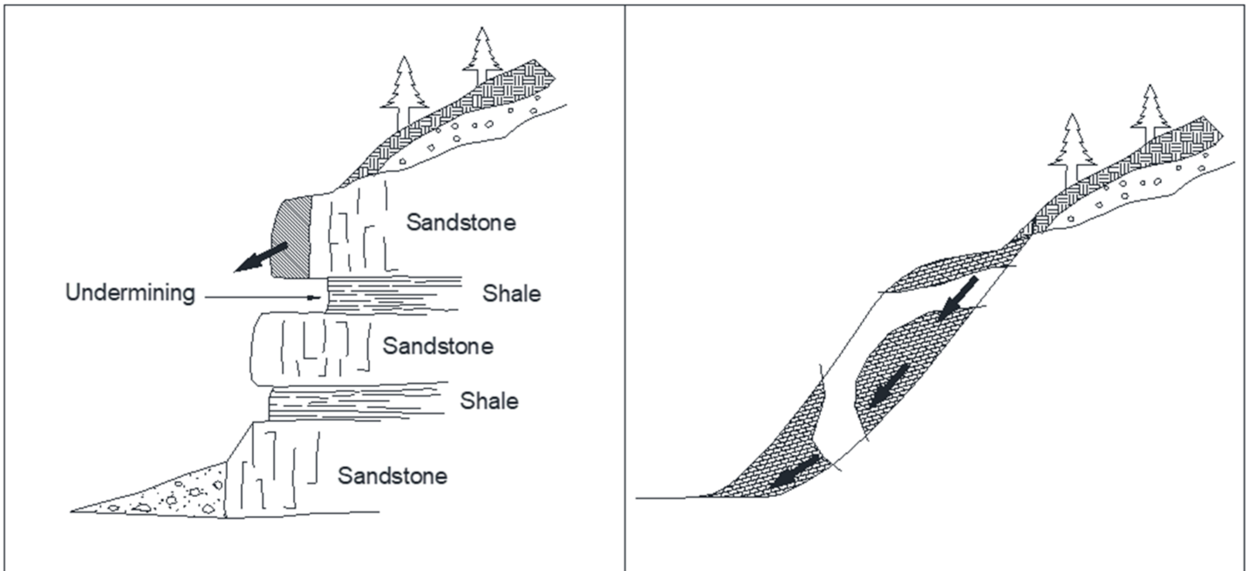
Figure 7-13 Rock Discontinuity Conditions (after FHWA 1998)

The term *discontinuity* refers to faults, joints, bedding planes, or any other surface upon which rock may move. The pattern of discontinuities shown in Figure 7-13a is typical for sedimentary rock, such as limestone, sandstone, and shale, that has been deposited in bedded layers and later uplifted by geologic processes. The orientation of the discontinuities in Figure 7-13a is roughly parallel to the rock slope face, but they do not *daylight* at the slope face. That is, the discontinuities do not extend to and intersect the exposed surface of rock at the slope face. In such a configuration the rock slope face is expected to remain stable. In contrast, Figure 7-13b shows a rock slope with discontinuities that daylight at the slope face. With such orientation of discontinuities, a potential for rock slope failures exists.

Figure 7-13c shows a rock slope with generally favorable bedding in that the discontinuities *dip* into the rock slope (dip is discussed later in this section) and there is little potential for rock to slide out of the slope face. However, blocks of rock at the slope face may become instable when discontinuities daylight at the slope face. The potential for the development of such conditions are increased if blasting was performed during slope excavation.

A rock slope configuration that illustrates the conditions for the toppling of rock columns is shown in Figure 7-13d. Toppling becomes a risk for rock with relatively thin bedding with steeply dipping discontinuities. The stability of rock columns can degrade relatively quickly if water seeps readily into the discontinuities from surface water runoff and increases the rate of weathering. In regions with frequent freeze-thaw cycles the rate of degradation may accelerate further because the frozen water can cause the rock columns to separate.

Sandstone and shale are often found with near-horizontal bedding. Excavation of such a bedding sequence generally results in a shale layers that weather faster than sandstone. In such conditions layers of sandstone may be undermined and form ledges that are prone to fracturing and failure. Such a condition is illustrated in Figure 7-14a. Weak rock slopes with closely spaced impersistent joints may fail along a circular or noncircular surface much like a soil slope as shown in Figure 7-14b.



(a) Weathering in sedimentary rock sequences

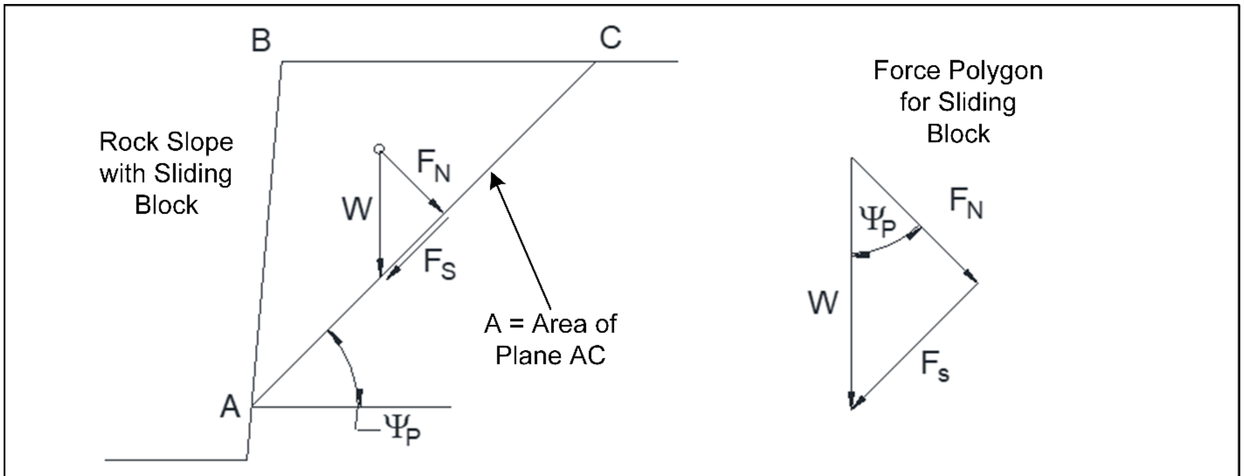
(b) Slope failure in closely fractured weak rock

Figure 7-14 Weathering and Weak Rock Conditions (after FHWA 1998)

An assessment of the potential for one of the above modes of failure to develop often requires a geologic investigation, field mapping of discontinuities, stereographic projection of geologic data, and an evaluation of rock strength. Each of these tasks represent significant sections in comprehensive publications on the topic of rock slope engineering.

7-10.2 Mechanics of a Sliding Block.

The mechanics of a sliding block are central to two types of rock slope stability analyses. Considering the rock slope depicted in Figure 7-15, the weight of the block ABC is represented by force W, which acts through the block's centroid. The component of W that acts perpendicular to the sliding plane AC is F_N. The component of W that acts parallel to the sliding plane AC is F_S. The relationship of these three forces is defined by the angle, or *dip*, of the sliding plane (Ψ_P) with respect to the horizontal plane.



Stability Equations

Block Forces	Stresses on Plane AC	Block Stability
$F_N = W\cos\Psi_P$	$\sigma = \dfrac{F_N}{A} = \dfrac{W\cos\Psi_P}{A}$	Shear strength, $s = c' + \sigma' \tan\phi'$
$F_S = W\sin\Psi_P$	$\tau = \dfrac{F_S}{A} = \dfrac{W\sin\Psi_P}{A}$	$F = \dfrac{s}{\tau} = \dfrac{c'A + W\cos\Psi_P\tan\phi'}{W\sin\Psi_P}$

Notes: This solution assumes no pore pressure on the sliding plane. Pore pressure will reduce the factor of safety. The shear strength (s) can be defined with any failure envelope appropriate for the rock conditions.

Figure 7-15 Rock Slope with Sliding Block

The factor of safety against sliding on plane AC is calculated as shown Figure 7-15. This solution assumes no pore pressure is acting on the sliding plane. Positive pore pressure will reduce the effective normal stress, shear strength, and the factor of safety.

7-10.3 Plane Failure.

The rock slope with a sliding block shown in Figure 7-15 is a simple version of a plane failure. It is not a type of failure that is often encountered because the conditions for its development rarely occur. However, the mechanics of a plane failure also apply to the more frequently encountered wedge failure. For this reason, it is instructive to further consider plane failures.

7-10.3.1 Sloped Surface Orientation Terms.

A discussion of plane failure requires the definition of three terms that are used to describe the orientation of sloped planes such as a slope face or a potential failure surface. The dip (Ψ) of a sloped plane is the inclination of that surface as measured from a horizontal plane, as shown in Figure 7-16. The *dip direction* or *dip azimuth* (α) is the direction of the horizontal trace of the line of dip measured clockwise from north. Often the term *strike* is used to describe the orientation of a sloped plane. It is the direction of a line that is formed by an intersection of the sloped plane with an imaginary horizontal plane. The orientation of the strike of a sloped surface is perpendicular to the dip direction of the sloped surface.

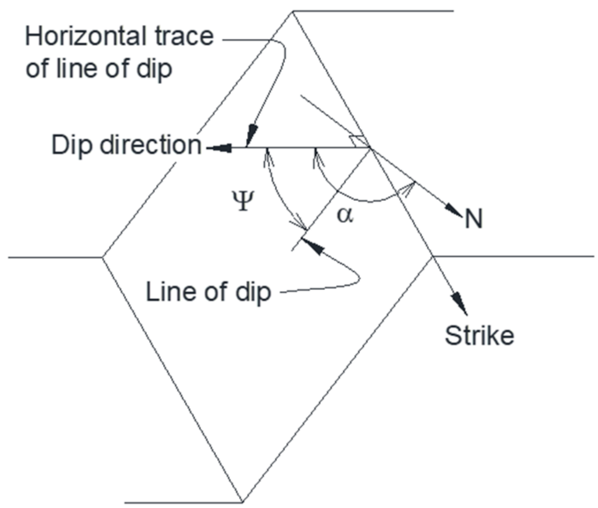


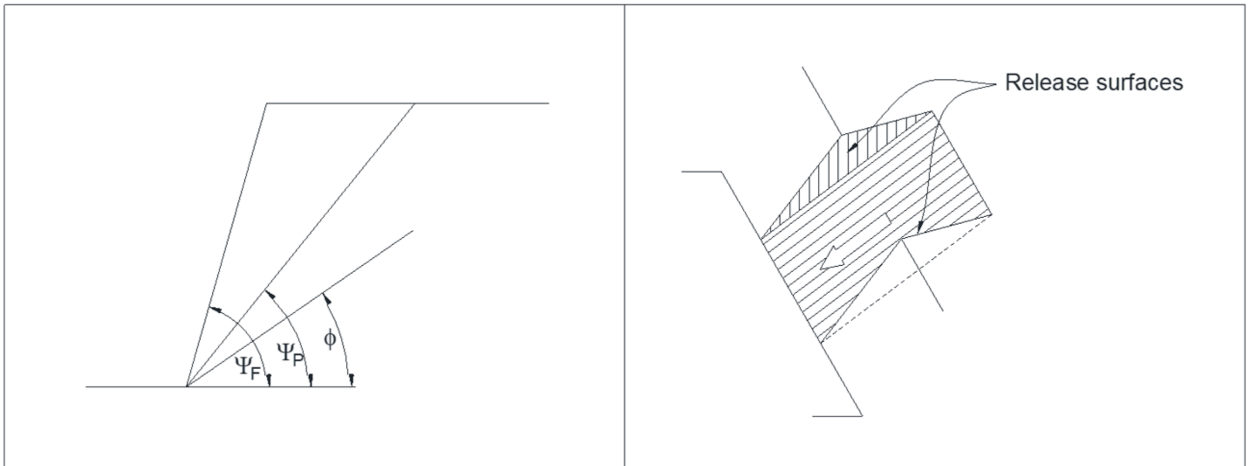
Figure 7-16 Definition of Sloped Surface Orientation Terms

7-10.3.2 General Conditions for Plane Failure.

For sliding to occur on a single plane the four conditions must be satisfied (Hoek and Bray 1981):

1. The plane on which sliding occurs must strike nearly parallel (i.e., within about 20º) to the slope face.
2. The failure plane must daylight in the slope face (i.e., intersect the slope face). Therefore, the dip of the failure plane (Ψ_P) must be less than the dip of the slope face, Ψ_F. That is, $\Psi_P < \Psi_F$.
3. The dip of the failure plane must be greater than the angle of friction at the failure plane. That is, $\phi' < \Psi_F$.
4. Release surfaces that provide negligible resistance to sliding must be present in the rock mass to define the lateral boundaries of the slide.

The relative positions of the planes defined by Ψ_F, Ψ_P, and ϕ' are shown in Figure 7-17a. The release surfaces associated with a sliding plane are shown in Figure 7-17b.

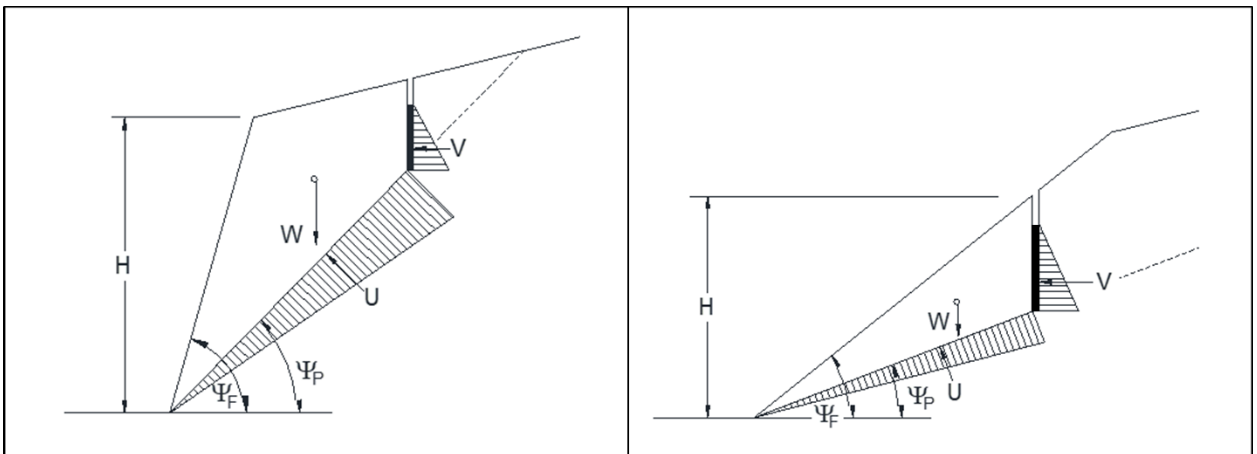


(a) Planes defined by Ψ_F, Ψ_P and ϕ' (b) Release surfaces for a sliding plane

Figure 7-17 Geometry for Plane Failure (after Hoek and Bray 1981)

7-10.4 Plane Failure Analyses.

Rock slopes analyzed for plane failure can also consider the presence of a tension crack, which may contain water. The crack may be located either above or below the slope crest as shown in Figure 7-18. The uplift force applied by water at the failure plane is designated as U. The force applied by water in the tension crack is designated as V. The factor of safety for such conditions can be calculated using the equation presented in Figure 7-18.



(a) Tension Crack in Upper Section (Above Crest) (b) Tension Crack in Lower Section (Below Crest)

$$F = \frac{s}{\tau} = \frac{c'A + \left(W\cos\Psi_P - U - V\sin\Psi_P\right)\tan\phi'}{W\sin\Psi_P + V\cos\Psi_P}$$

Figure 7-18 Rock Slopes with Tension Cracks (after Hoek and Bray 1981)

Further details regarding the stability analyses of sliding planes are described in the FHWA (1998) and by Hoek and Bray (1981). While such analyses can be practically performed using hand calculations, analytical efficiency can be significantly improved by use of computer programs.

7-10.5 Wedge Failure.

The rock slope with a sliding wedge shown in Figure 7-19 is similar to a sliding plane, but the presence of Plane A and Plane B make it possible to model a geometry that is encountered in the field more frequently.

The convention adopted in the FHWA (1998) and by Hoek and Bray (1981) is that the release surface designated as Plane A is the flatter of the two release surfaces. The steeper release surface is designated as Plane B. These two surfaces intersect along the *line of intersection*.

As with a plane failure, there are certain geometrical requirements for wedge failure to occur. Specifically, $\Psi_{Fi} > \Psi_{Fi} > \phi'$, where Ψ_{Fi} is the inclination of the slope face as measured at right angles to the line of intersection, Ψ_i is the dip of the line of intersection and ϕ' is the average friction angle of Plane A and Plane B. Note that Ψ_{Fi} is not the same as Ψ_F unless the dip direction of the line of intersection is the same as the dip direction of the slope face (Hoek and Bray 1981).

The factor of safety of the wedge in Figure 7-19 may be determined by assuming that sliding is resisted only by friction at the surface of Plane A and Plane B. With this simplifying assumption, the resisting forces on these planes can be determined by calculation of the normal forces R_A and R_B on each plane, as illustrated in Figure 7-20a. The component forces of the weight of the wedge perpendicular and parallel to the line of intersection are shown in Figure 7-20b.

Hoek and Bray (1981) relate the factor of safety against wedge failure (F_W) to that for a slope with a face that is inclined at Ψ_{Fi} and a failure plane that is inclined at Ψ_i by a wedge factor K. This wedge factor can be graphically determined using a figure provided in both the FHWA (1998) and Hoek and Bray (1981).

The analysis of a wedge failure for which cohesion or water are present is more complicated than for a wedge failure in which only the friction angle at the failure planes is considered. Both the FHWA (1998) and by Hoek and Bray (1981) discuss this analytical process in detail. Such an analysis can also be performed efficiently using the computer programs.

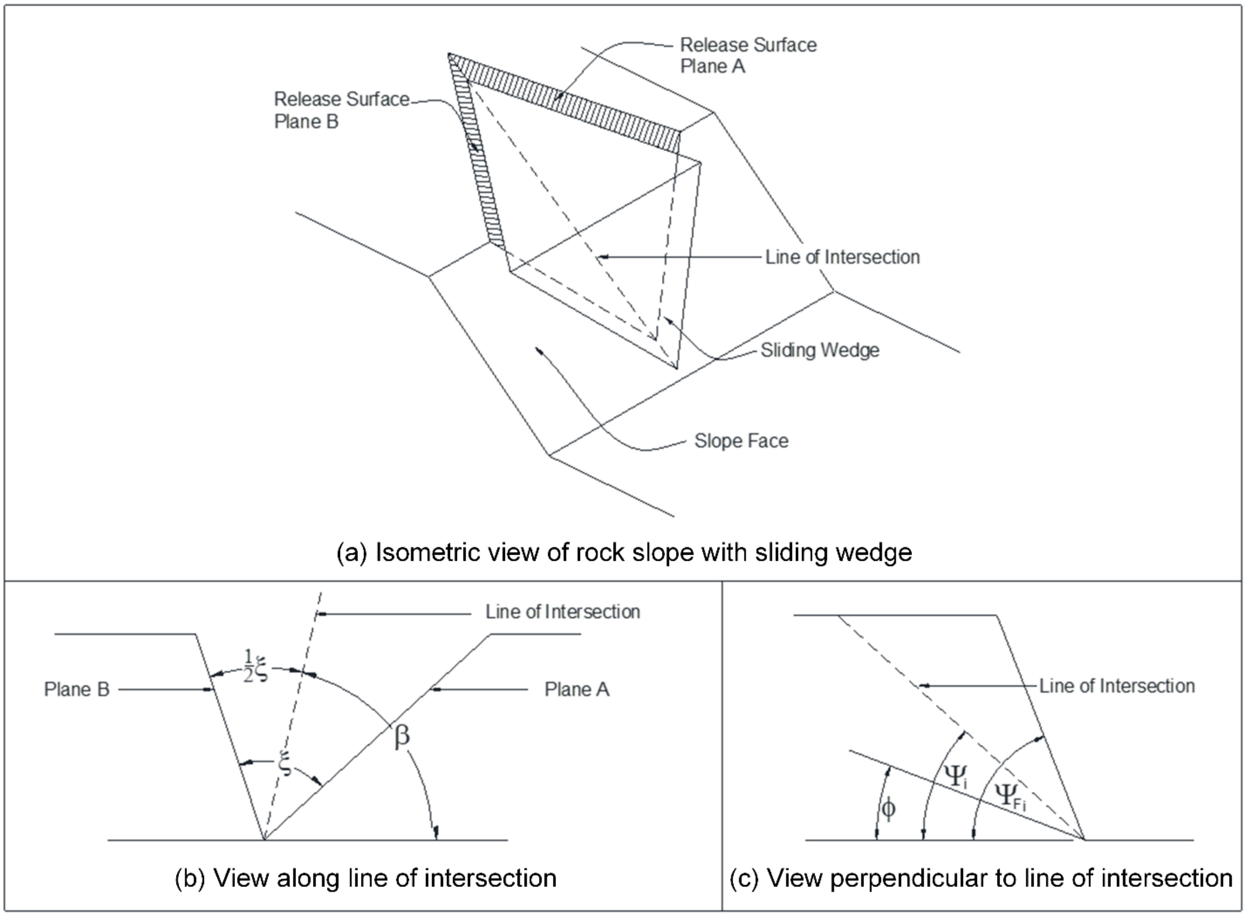
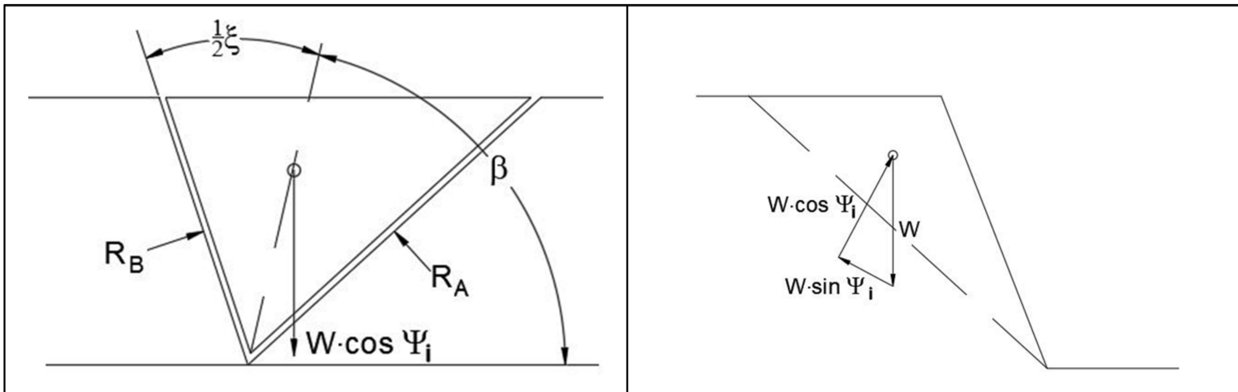


Figure 7-19 Rock Slope with Sliding Wedge (after Hoek and Bray 1981)



(a) Along Line of Intersection

(b) Perpendicular to Line of Intersection

Resolve forces horizontally and vertically

$$R_A \sin\left(\beta - \frac{1}{2}\xi\right) = R_B \sin\left(\beta + \frac{1}{2}\xi\right)$$

$$R_A \cos\left(\beta - \frac{1}{2}\xi\right) - R_B \cos\left(\beta + \frac{1}{2}\xi\right) = W \cos \Psi_i$$

Factor of Safety

$$R_A + R_B = W \cos \Psi_i \sin \beta \Big/ \sin\left(\frac{1}{2}\xi\right)$$

$$F_W = \frac{s}{\tau} = \frac{\sin \beta}{\sin\left(\xi / 2\right)} \frac{\tan \phi'}{\tan \Psi_i}$$

Figure 7-20 View of Wedge Geometry (after Hoek and Bray 1981)

7-10.6 Toppling Failure.

For a column of rock to be subject to toppling failure, the center of gravity of the column must be located on the side of the column at the slope face. In this way, the column is loaded eccentrically. Such loading creates tensile stress on the side of the column away from the slope face, as shown in Figure 7-21. If the tensile capacity of the column is exceeded, failure can ensue.

Analyses of rock toppling can be significantly more complicated than those for plane failure or block failure. A method for hand calculations is described in FHWA (1998) but such a procedure may have limited applicability to actual field conditions.

7-10.7 Circular Failure.

As described in section 7-10.1, if a rock slope consists of weak material with closely spaced, impersistent joints, then the slope may fail along a circular or noncircular surface much as a soil slope. Analyses of these types of failures can be performed using the methods previously discussed for the stability of soil slopes. However, it should be noted that even weak intact rock can exhibit significant cohesive strength. An accurate assessment of the actual cohesive strength may be difficult to make. It is also important to realize that zones of relatively strong rock may exist behind zones of relatively weak rock. The presence of the strong rock zones may significantly affect the location of the critical failure surface.

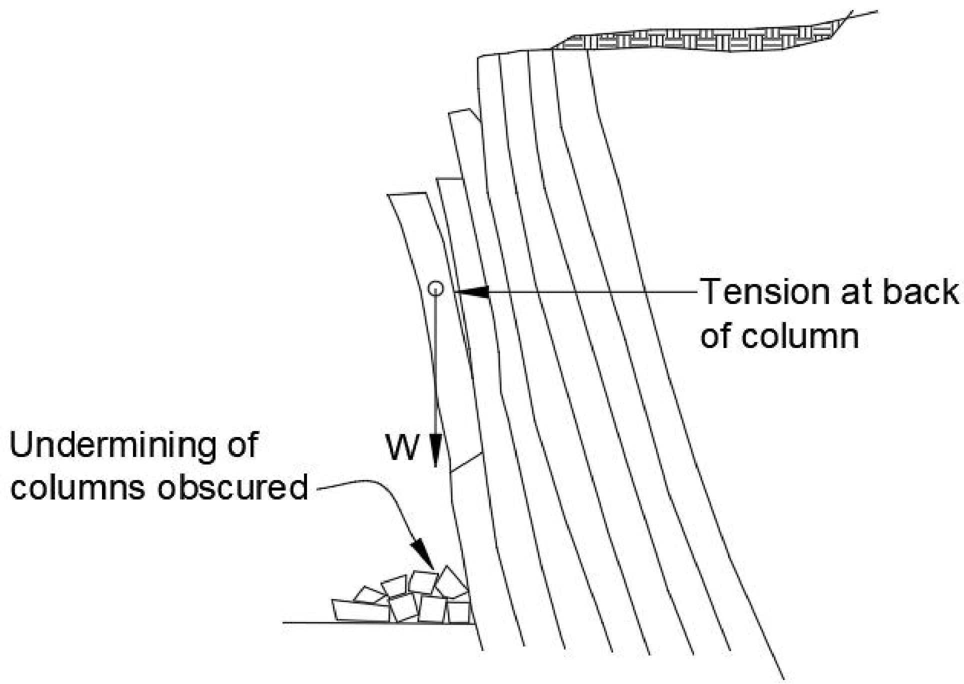


Figure 7-21 Rock Slope Subject to Toppling Failure

7-10.8 Rock Slope Stabilization and Protection.

Several measures can be taken to mitigate the hazards presented by unstable rock slopes. These measures vary from the relatively simple to those which require considerable analytical expertise, construction skill, and expense.

7-10.8.1 Stabilization and Protection Options.

The range of stabilization measures that are typically available include rock reinforcement, rock removal and protective barriers. A range of options is available under each of these categories as shown in Figure 7-22.

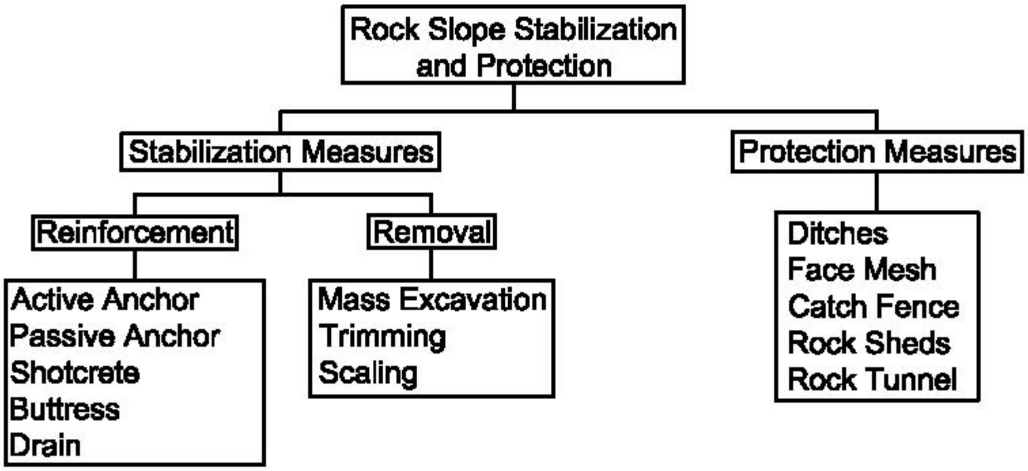


Figure 7-22 Rock Slope Stabilization and Protection Measures (after FHWA 1998)

7-10.8.2 Reinforcement

Anchors have been used for many years to stabilize both soil and rock slopes. In general, anchors can be classified as passive or active. A *passive anchor* that is frequently used for top-down excavation stabilization is the soil nail. For rock slope stabilization it may be referred to as a *rock bolt* or *dowel*. It typically comprises a steel tendon in the form of an all-thread bar that is centered within a drill hole. A cement grout is installed in the drill hole to bond the tendon to the adjacent soil or rock. Grout is usually placed by tremie from the distal end to the anchor head. Typically, such holes are drilled at a declination of about 15° or more below the horizontal plane to prevent spilling of the grout at the excavated face.

The steel bars used for these applications typically exhibit a tensile capacity of at least 75 ksi. Higher capacity bars are readily available. Typical bar diameters correspond to standard reinforcement steel sizes of #8 (i.e. 1.0-inch nominal diameter) to #11 (i.e. 1.41-inch nominal diameter). Resistance to bar corrosion is typically provided by an epoxy coating or galvanization. The grout that surrounds the bar can also provide some protection against corrosion, but the grout is subject to cracking and may not provide complete coverage.

Different types of liquid resins are manufactured for use with rock anchors as an alternative to cement grout. Resin cartridges include a hardener that can be selected to provide a range of hardening times. The cartridges are inserted into the drill hole and then followed by insertion of the steel bar tendon. The tendon is then spun at a prescribed rate to mix the resin and hardening agent and to distribute the mixture to both bar and rock surfaces. Unfortunately, there is some skepticism within the ground anchor contracting industry that resins can be consistently distributed to rock and tendon surfaces and can reliably provide requisite bond capacities. Also, resins do not provide the same level of corrosion protection as does cement grout.

The FHWA has published several manuals on the design of soil nail structures. The current version is *Geotechnical Engineering Circular No. 7* (FHWA 2015). This manual should be consulted in the design of passive anchors for rock stabilization applications.

A passive anchor does not impart a stabilization force to the adjacent rock or soil until the rock or soil tends to displace. At that point the passive anchor provides a resisting force. In contrast, an *active anchor* is stressed as part of its installation process. Such anchors may comprise steel bars like a soil nail. However, if a particularly long anchor or one with high tensile capacity is required, then steel strand tendons may be indicated. The installation of such an active anchor is similar to that of a passive anchor. First, a hole for the anchor is drilled and then the strand is inserted and centered within the hole. Next, the strand is grouted, but only for a certain length of the strand starting from the distal end. A length between the top of the grouted section and the anchor head is left *unbonded*. The reason for the unbonded section is that this portion of the tendon must be left to strain under a design stressing load to provide an active force at the anchor head. This force is transferred to a loading plate or block that is secured against the rock slope face. In this way the active force can be used to stabilize a large rock plane, wedge or unstable columns. This is perhaps the most important distinction between an active anchor and a passive anchor. Unlike a passive anchor, an active anchor does not depend on soil or rock movement to mobilize its strength.

The *bonded* length of the tendon is that portion which is grouted. The length of the bonded section is based on analyses that consider the load in the anchor and the bond strength between the grout and the adjacent soil or rock.

Steel strand tendons are typically available in configurations that provide a working tensile capacity of about 35 to 500 kips. Tendons with considerably higher capacities can be fabricated.

The design of active anchor systems is discussed in the FHWA's *Geotechnical Engineering Circular No. 4* (FHWA 1999). This manual should be consulted in the design of active anchors for rock stabilization applications.

When anchors are designed for the stabilization of rock slopes, some consideration should be given to the potential for conditions that may cause steel corrosion. Such conditions often prevail in areas where coal and acidic runoff are present or where sodic and pyritic soils are found. The FHWA provides the electrochemical parameters in Table 7-8 as limits for the use of steel reinforcement in MSE structures. These limits should be considered when designing the corrosion protection for active and passive anchors.

Table 7-8 Recommended Limits of Electrochemical Properties for Reinforced Fill with Steel Reinforcement (after FHWA 2009b)

Property	Criteria	Test Method
Resistivity	>3000 ohm-cm	AASHTO T-288
pH	>5 and <10	AASHTO T-289
Chlorides	<100 ppm	ASTM D4327
Sulfates	<200 ppm	ASTM D4327

7-10.8.3 Shotcrete.

Shotcrete is essentially concrete that has little to no gravel-size particles (i.e. larger than the No. 4 sieve) that can be sprayed onto vertical and near-vertical surfaces. It is usually applied in layers to build up the total coating to a specified thickness. Both steel welded wire fabric (WWF) and bars may be used within the shotcrete to provide reinforcement.

Shotcrete can be used to stabilize rock slopes that are subject to raveling and dislodgement of gravel, cobble and boulders. It will tend to adhere to such unstable faces but it should be secured with relatively short passive anchors (i.e. soil nails, rock bolts or dowels). Otherwise, the shotcrete may delaminate from the rock slope in a short period of time. The length of the anchors can be 10 feet or less if they are not actually needed for stabilization of rock planes and wedges. If the rock slope surface is mostly unstable then the anchors should be spaced at intervals no greater than about 6 feet.

A common cause for separation of shotcrete from the face of a rock slope is the presence of water behind the shotcrete. Water frequently seeps from rock slopes, and it should be drained using a drainage composite. Drainage is especially important in climates where the water can freeze. Drainage composites can be successfully used behind shotcrete. The composites typically are available in a width of 4 feet. They should be installed with a coverage of 50%. A drainage grate should be installed at the base of each drainage composite strip and daylighted by a weep hole through the shotcrete.

7-10.8.4 Buttress.

Buttresses have been used for more than 1,000 years to stabilize slopes, walls and buildings. In general, a buttress is a gravity structure that provides passive resistance to displacement. For rock slope stabilization a buttress may comprise piled soil or rock, or it may be an engineered reinforced concrete structure or an MSE structure. The engineering analyses of the mass requirements of a buttress are relatively straightforward and similar to those of a gravity retaining wall.

7-10.8.5 Drains.

Drains are often used in conjunction with rock slope reinforcement measures to counter the destabilizing effects of water that is retained behind a slope face. In general, relief drains are drilled using equipment similar to that used for anchors. However, instead of being angle below the horizontal plane relief drains are typically angle 2° or more above the horizontal plane.

An unfortunate reality of relief drains is that they often become clogged by the accumulation of organic material. Removal of the organic obstructions is generally not practical.

7-10.8.6 Rock Removal.

The stability of rock slopes can often be improved by the removal of material. On a large scale, such removal may take the form of *mass excavation* using drilling and blasting measures followed by dozers, track hoes and haul trucks.

On a smaller scale *trimming* may be used to more selectively remove problematic formations such as overhangs (see Figure 7-14), planes, wedges and columns. Trimming may also employ drilling and blasting and may be preferable to mass excavation in terms of cost and also in terms of potential disruption of adjacent transportation or commercial operations.

If the rock slope includes loose cobbles and boulders that may present a rock fall hazard, then *scaling* may be the most appropriate method of rock removal. In a scaling operation, personnel traverse the slope face while secured by ropes and harnesses. They use hand tools to dislodge rock and may even remove soil deposits and vegetation

7-10.8.7 Rock Fall Protection Measures.

Measures to protect against rock falls may include the installation of surface restraints, barriers or ditches. However, the design of any of these measures usually requires an assessment of the risk posed by rock falls.

Rock fall analyses are generally beyond the capabilities of hand calculations, although some graphical aids have been developed for this purpose (FHWA 1998). When the FHWA (1998) was published, the computer-supported analysis of rock falls was at a relatively early stage. The complexity of the problem was such that computer modeling had to be paired with videography and surveying to render solutions with meaningful accuracy.

After a rock fall analysis has been performed and a reasonable estimate of the final location of fallen rocks can be obtained, ditches can be designed to capture errant cobbles and boulders. Guidelines for the dimensioning of capture ditches are provided in FHWA (1998).

Steel face mesh can be installed over rock slope surfaces to restrain material that might otherwise dislodge. The mesh may be relatively fine twisted wire or it may comprise larger diameter elements depending on strength requirements. If the mesh is placed directly on the slope face, it must be secured by anchors that are installed in a regular pattern. In a separate application, the top of the mesh can be secured to a stable section of rock slope and left suspended to drape in front of the slope at lower elevations. Rocks that dislodge from the slope and would otherwise represent a rock fall hazard are intercepted by the mesh curtain. In such applications, a ditch is usually installed below the mesh to capture fallen material. As with reinforcement anchors, steel mesh is subject to corrosion in aggressive electrochemical environments. Both the mesh and its anchor components should be designed with corrosion protection.

Catch fences have become a common feature along highways that pass through mountainous terrain. In general, they are a practical and cost-effective measure to protect against rock falls. However, an assessment of rock fall trajectories is essential to determine both the proper location, height, and structural capacities of such barriers.

7-10.8.8 Rock Sheds and Tunnels.

Rock sheds are an effective method of protecting vehicular traffic from rock falls, but their use is rarely justified unless the cost of other mitigation measures is especially high. They are typically needed on roadways that have been cut into hillsides. They are designed with a roof that slopes downhill. On the uphill side of the roof, the roof support beams are secured onto benches. On the downhill side of the roof, the roof support beams can be supported by columns.

In locations where it is not practical to construct a rock shed it may be necessary to construct a tunnel. FHWA (1998) describe such an example for a railway in Canada.

7-11 SUGGESTED READING.

Topic	Reference
Stability Analysis - General	Bishop, A. W. and Bjerrum, L. (1960). The relevance of the triaxial test to the solution of stability problems, *Proceedings of the ASCE Research Conference on the Shear Strength of Cohesive Soils*, Boulder, CO.
	Skempton, A. W. (1948). The Φ = 0 analysis of stability and its theoretical basis, *Proceedings of the 2nd International Conference on Soil Mechanics and Foundation Engineering,* Rotterdam, Vol. 1, pp. 72–78.
	Terzaghi, K. Peck, R. B., and Mesri, G. (1996). *Soil Mechanics in Engineering Practice,* 3rd ed., Wiley, Hoboken, NJ, 549 pages.
Limit Equilibrium Methods	Bishop, A. W. (1955). The use of slip circles in the stability analysis of earth slopes, *Geotechnique*, 5(1), 7–17.
	Bromhead, E. N. (1992). *The Stability of Slopes*, 2nd ed., Blackie, New York.
	Janbu, N. (1954a). Application of composite slip surface for stability analysis, *Proceedings of the European Conference on Stability of Earth Slopes,* Stockholm, Vol. 3, pp. 43–49.
	Janbu, N. (1954b). *Stability Analysis of Slopes with Dimensionless Parameters,* Harvard Soil Mechanics Series 46, Harvard University Press, Cambridge MA.
	Janbu, N. (1968). Slope stability computations, *Soil Mechanics and Foundation Engineering Report,* The Technical University of Norway, Trondheim.
Progressive Failure	Bjerrum, L. (1967). Progressive failure in slopes of overconsolidated plastic clay and clay shales, *ASCE, Journal of the Soil Mechanics and Foundation Division*, 93(5), 1–49.
Back Analysis	Chandler, R. J. (1977). Back analysis techniques for slope stabilization works: a case record, *Geotechnique*, 27(4), 479–495.
	Filz, G. M., Brandon, T. L., and Duncan, J. M. (1992). *Back Analysis of Olmsted Landslide Using Anistropic Strengths,* Transportation Research Record 1343, Transportation Research Board, National Research Council, National Academy Press, Washington, DC, pp. 72–78.
Geosynthetic Reinforcement	Koerner, R. M. (1998). *Designing with Geosynthetics,* 4th ed., Prentice Hall, Upper Saddle River, NJ.
Seismic Slope Stability	Makdisi, F. I., and Seed, H. B. (1978). A simplified procedure for estimating dam and embankment earthquake–induced deformations, *ASCE, Journal of the Geotechnical Engineering Division,* 104(7), 849–867.
	Seed, H. B. (1979). Considerations in the earthquake–resistant design of earth and rockfill dams, Nineteenth Rankine Lecture, *Geotechnique*, 29(3), 215–263.
Staged Construction of Slopes	Ladd, C. C. (1991). Stability evaluation during staged construction, *ASCE, Journal of Geotechnical Engineering,* 117, 540–615.
Residual and Fully-Softened Conditions	Skempton, A. W. (1977). Slope stability of cuttings in brown London clay, *Proceedings of the 9th International Conference on Soil Mechanics*, Tokyo, Vol. 3, pp. 261–270.
	Skempton, A. W. (1985). Residual strength of clays in landslides, flooded strata and the laboratory, *Geotechnique*, 35(1), 3–18.

7-12 NOTATION.

Symbol	Description
b_i	Width of the slice
c	Total stress cohesion
C	Number of surfaces on which pullout resistance is mobilized
c'	Effective stress cohesion
F	Factor of safety
F_m	Factor of safety for Bishop's Simplified Method in effective stress example.
F_N	Component of W that acts perpendicular to the rock block sliding plane
F_R	Factor of safety for geosynthetic strength
F_S	Component of W that acts parallel to the rock block sliding plane
F_W	Factor of safety against wedge failure
F^*	Pullout resistance factor
H_i	Average height of the slice
i	Hydraulic gradient
K	Wedge factor
L_e	Length of reinforcement embedded behind the trial failure surface
$MARV$	Minimum average roll value
M_α	Denominator in equation for calculating normal force at the base of a slice used for assessing validity of normal force.
P_r	Geosynthetic reinforcement's resistance to pullout
RF_{CR}	Reduction factor for creep
RF_D	Reduction factor for durability
RF_{ID}	Reduction factor for installation damage
r_u	Pore pressure coefficient
s	Shear strength
S	Seepage force
SRF	Strength reduction factor
s_{su}	Undrained steady state shear strength

Symbol	**Description**
s_u	Undrained shear strength
T_{al}	Geosynthetic’s long-term tensile strength
T_{ULT}	Ultimate tensile strength of the geosynthetic based on the $MARV$
u	Pore water pressure
U	Uplift force applied by water at the failure plane
V	Force applied by water in the tension crack
W	Rock block weight
W_i	Weight of each slice
α	Dip direction or dip azimuth
α	Scale correction factor to account for nonlinear stress reduction
α_i	Angle between the tangent to the failure surface and the horizontal
γ	Unit weight
γ_w	Unit weight of water
δ	Effective soil-geosynthetic interface friction angle
θ	Face angle
σ	Total stress
σ'	Effective stress
σ'_v	Effective vertical stress
τ	Shear stress required for equilibrium
ϕ'	Effective stress friction angle
ϕ	Total stress friction angle
ϕ'_r	Residual friction angle
Ψ	Dip
Ψ_{Fi}	Inclination of the slope face as measured at right angles to the line of intersection in a wedge failure analysis
Ψ_i	Dip of the line of intersection in a wedge failure analysis
Ψ_P	Angle of a sliding block plane with respect to horizontal

CHAPTER 8 CORRELATIONS FOR SOIL AND ROCK

8-1 INTRODUCTION.

Correlations are useful tools for obtaining values of engineering parameters based on index properties or other easily measured soil parameters. Correlations are often used when measured values are not available. The accuracy and applicability of correlations depend on the data source, the statistical approach for determining the correlation, and the causal relationship between the index property and the engineering parameter. For these reasons, engineers should use correlations with caution. It is often prudent to seek out the original source of the correlation to ensure that it is applicable to the engineering problem at hand.

Often, correlations provide an uncertain, empirical prediction of the parameter, which means that there are usually values above and below the proposed trend line. Uncertainty results from both scatter in the measured data and the inability of the chosen mathematical relationship to perfectly predict the observed trends. Because of this uncertainty, correlations are typically most appropriate for preliminary design or as a check that measured values are in general agreement with the behavior of the soils used to develop the correlation. In addition, correlations can provide the basic form of an equation that can be used with experimental data to create site-specific correlations for an individual project or area.

For cases where the required property cannot be measured and correlations are used for final designs, the uncertainty in the parameter should be evaluated by the engineer. Different approaches can be used, including (1) the use of a range of values rather than a single value of a parameter, (2) use of the lowest likely value, (3) application of confidence limits, or (4) explicit consideration of uncertainty in the correlation using formal reliability analysis.

Confidence limits are trend lines that are offset from the mean based on the standard deviation ($S.D.$) of the residuals between the data and the mean. Confidence limit boundaries plotted with mean trends help to illustrate the variability in a data set. Confidence limits or the standard deviation can be used to select appropriately conservative values from correlations. For example, if a correlated parameter is assigned a value that is one standard deviation below the mean, the probability is only 16% that the actual value is lower than the assigned value. This probability reduces to 2% for an assigned value that is two standard deviations below the mean. These probability margins assume that the error in the correlation follows a normal or log-normal distribution and that the selected trend line fits the data well.

The selection of an appropriate confidence limit above or below the mean trend depends on the effect of parameter on the particular analysis. In most cases, it is better to use a confidence below the mean. This will decrease the probability that the correlated parameter is greater than the actual value, which undesirable in many cases (e.g., shear strength, Young's modulus, etc.). In a few cases, the opposite might be the case (e.g., compression index).

8-2 EFFECTIVE STRESS (DRAINED) SHEAR STRENGTH.

8-2.1 Coarse-Grained Soils.

Most of the correlations presented for coarse-grained soils have been developed for relatively clean sands unless otherwise noted. These correlations should not be used in micaceous sands. The presence of mica tends to reduce some index properties (e.g. the SPT N value) significantly but might not affect the drained friction angle when compared to clean sands (Sabatini et al. 2002). These correlations should not be used for gravelly soils unless specified.

8-2.1.1 Correlations with Soil Type.

Carter and Bentley (2016) summarized typical values for the effective stress friction angles of coarse-grained soils as presented in Table 8-1 and Table 8-2. Table 8-1 presents values for the drained friction angle of different types of coarse-grained soils in loose and dense conditions and Table 8-2 presents the values of effective stress friction angle for coarse-grained soils compacted to the maximum dry density based on ASTM D698.

Table 8-1 Typical Values of the Effective Stress Friction Angle for Coarse-grained Soils (Carter and Bentley 2016)

Soil Description	ϕ' (in degrees)	
	Loose	Dense
Uniform sand, round grains	27	34
Well-graded sand, angular grains	33	45
Sandy gravel	35	50
Silty sand	27-33	30-34
Inorganic silt	27-30	30-35

Table 8-2 Typical Values of the Effective Stress Friction Angle for Compacted Coarse-grained Soils (Carter and Bentley 2016)

Soil Description	USCS	ϕ' (in degrees)
Well-graded sand-gravel mixtures	GW	>38
Poorly-graded sand-gravel mixtures	GP	>37
Silty gravels, poorly-graded gravel-sand-silt	GM	>34
Clayey gravels, poorly-graded gravel-sand-clay	GC	>31
Well-graded clean sand, gravelly sand	SW	38
Poorly-graded clean sand, gravelly sand	SP	37

A correlation for the drained friction angle as a function of relative density, dry unit weight and soil type is presented in Figure 8-1.

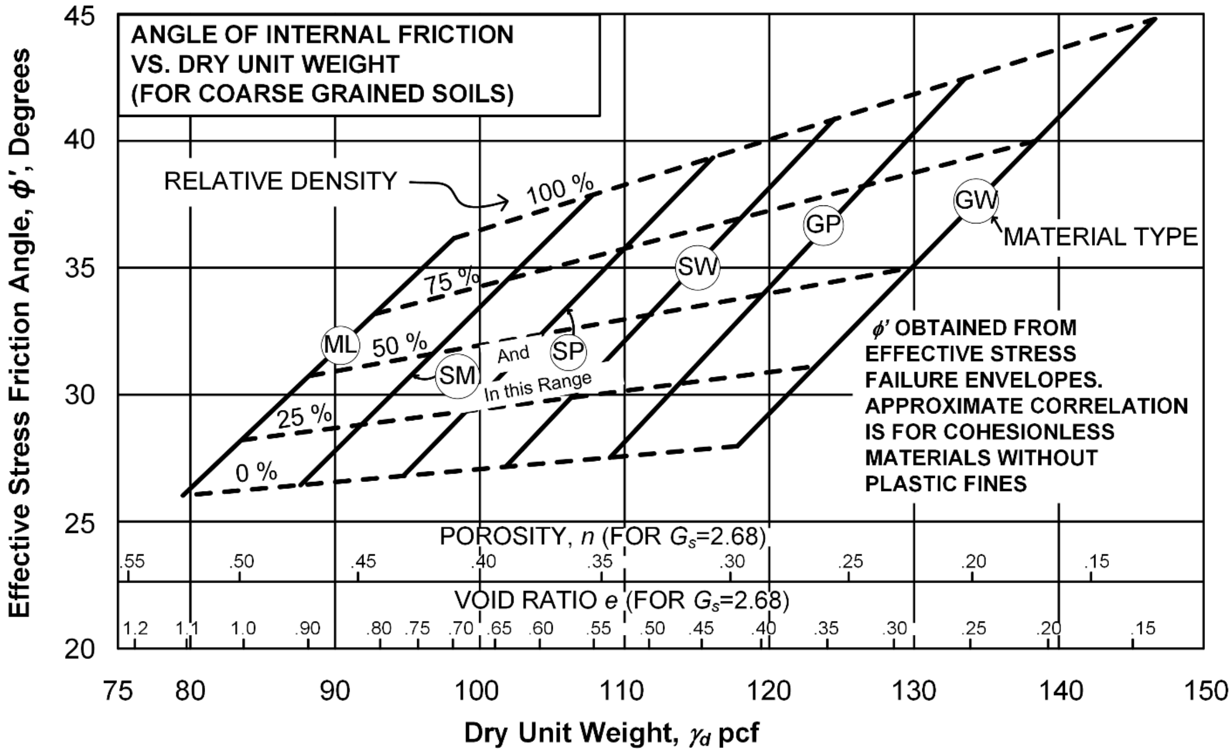


Figure 8-1 Approximate Relationship between the Effective Stress Friction Angle and Dry Unit Weight for Various Relative Densities and Types of Soil

8-2.1.2 Correlations with Standard Penetration Test.

Many relationships have been presented in the literature to estimate drained shear strength parameters of coarse-grained soils using results from the standard penetration test. In older correlations where no energy correction for the SPT N value was used, it was assumed that the reported N values were equal to N_{60}.

Relationships between SPT N values and static cone tip resistance presented by Duncan et al. (1989) summarizing the work presented by Meyerhof (1956) and Mitchell (1981) are shown in Table 8-3 and Table 8-4, respectively.

Table 8-3 Relationship between SPT N Value, Relative Density and Effective Stress Friction Angle (Meyerhof 1956)

State of Packing	Relative Density (%)	N_{60} (blows/ft)	Static Cone Tip Resistance, q_c (tsf)	Effective Stress Friction Angle (degrees)
Very Loose	< 20	< 4	< 20	< 30
Loose	20 - 40	4 - 10	20 - 40	30 - 35
Compact (Medium)	40 - 60	10 - 30	40 - 120	35 - 40
Dense	60 - 80	30 - 50	120 - 200	40 - 45
Very Dense	> 80	> 50	> 200	> 45

The effective stress friction angles presented in Table 8-3 are for clean sands and should be decreased by 5° for clayey sands and increased by 5° for gravelly sands. To use Table 8-3 on saturated very fine or silty sand, the measured SPT N should be corrected using the equation below:

$$N' = \begin{cases} N_{60} & \text{for } N_{60} \leq 15 \\ 15 + 0.5\left(N_{60} - 15\right) & \text{for } N_{60} > 15 \end{cases} \tag{8-1}$$

where:
N' = blow count corrected for dynamic pore pressure effects, and
N_{60} = measured blow count corrected for 60% energy.

Table 8-4 Relationship between SPT N Value, Relative Density, and Angle of Internal Resistance (after Mitchell 1981)

State of Packing	Relative Density[1] (%)	Standard Penetration Resistance, $N_{1,60}$ (blows/ft)[2]	Static Cone Resistance, q_c (tsf)	Effective Stress Friction Angle (degrees)	Dry Unit Weight (kN/m^3)
V. Loose	< 15	< 4	< 50	< 30	< 14
Loose	15 - 35	4 - 10	50 - 100	30 - 32	14 - 16
M. Dense	35 - 65	10 - 30	100 - 150	32 - 35	16 - 18
Dense	65 - 85	30 - 50	150 - 200	35 - 38	18 - 20
V. Dense	85 - 100	> 50	> 200	> 38	> 20

[1] Freshly deposited, normally consolidated sand
[2] Corrected to an effective vertical overburden pressure of 1 atm.

Sowers (1979) related the effective stress friction angle to SPT N values for depths less than 5 feet and greater than 20 feet as presented in Figure 8-2. Interpolation can be used for depths between 5 and 20 feet. Shioi and Fukui (1982) also correlated the effective stress friction angle to N_{60} using (also shown in Figure 8-2):

$$\phi' = \sqrt{15 \cdot N_{60}} + 15 \text{ (For roads and bridges)} \quad \textbf{(8-2)}$$

$$\phi' = 0.3 \cdot N_{60} + 27 \text{ (For buildings)} \quad \textbf{(8-3)}$$

where:
N_{60} = SPT N value corrected for 60% energy.

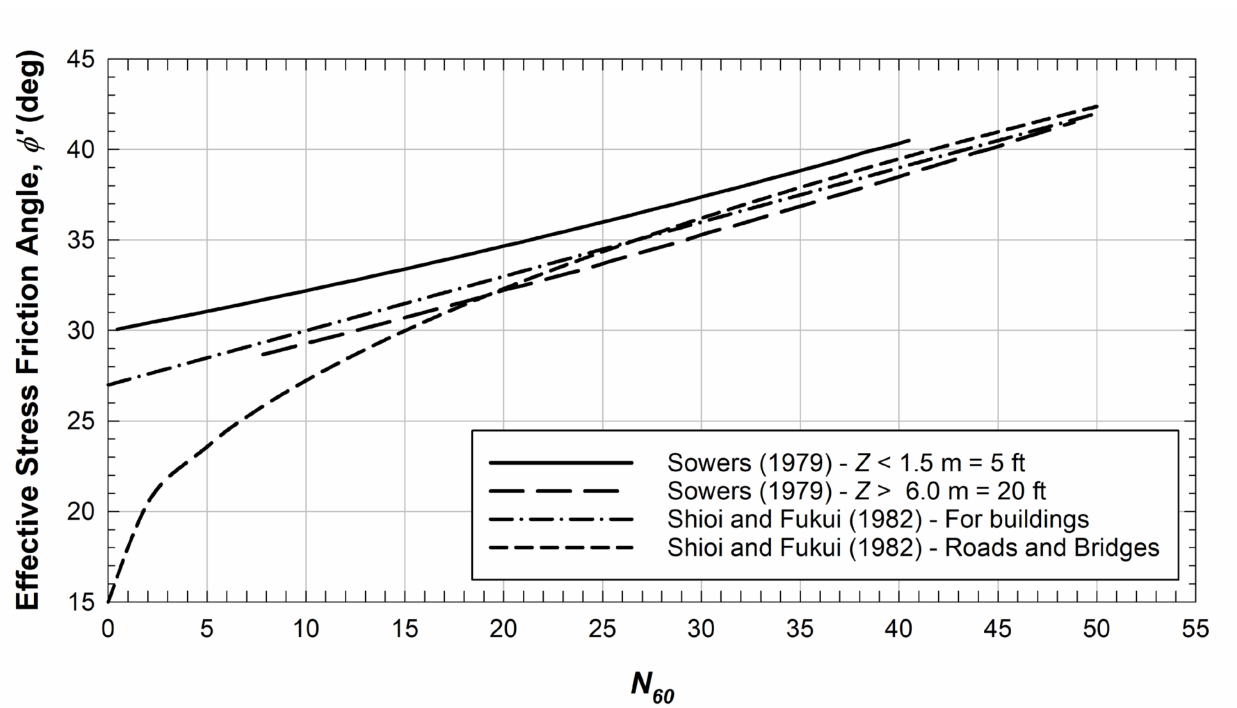


Figure 8-2 Relationship between Effective Stress Friction Angle of Coarse-Grained Soils and SPT N_{60} Value

Parry (1977) and Schmertmann (1975) considered the effects of overburden pressure on the relationship between the effective stress friction angle and SPT N, resulting in the correlations shown in Figure 8-3.

Kulhawy and Mayne (1990) approximated the trends in Figure 8-3(bottom) as:

$$\phi' = \tan^{-1}\left[\frac{N_{60}}{12.2 + 20.3\left(\sigma'_v / P_a\right)}\right]^{0.34} \tag{8-4}$$

where:
ϕ' = effective stress friction angle,
N_{60} = SPT N value corrected for 60% energy,
σ'_v = vertical effective stress, and
P_a = atmospheric pressure.

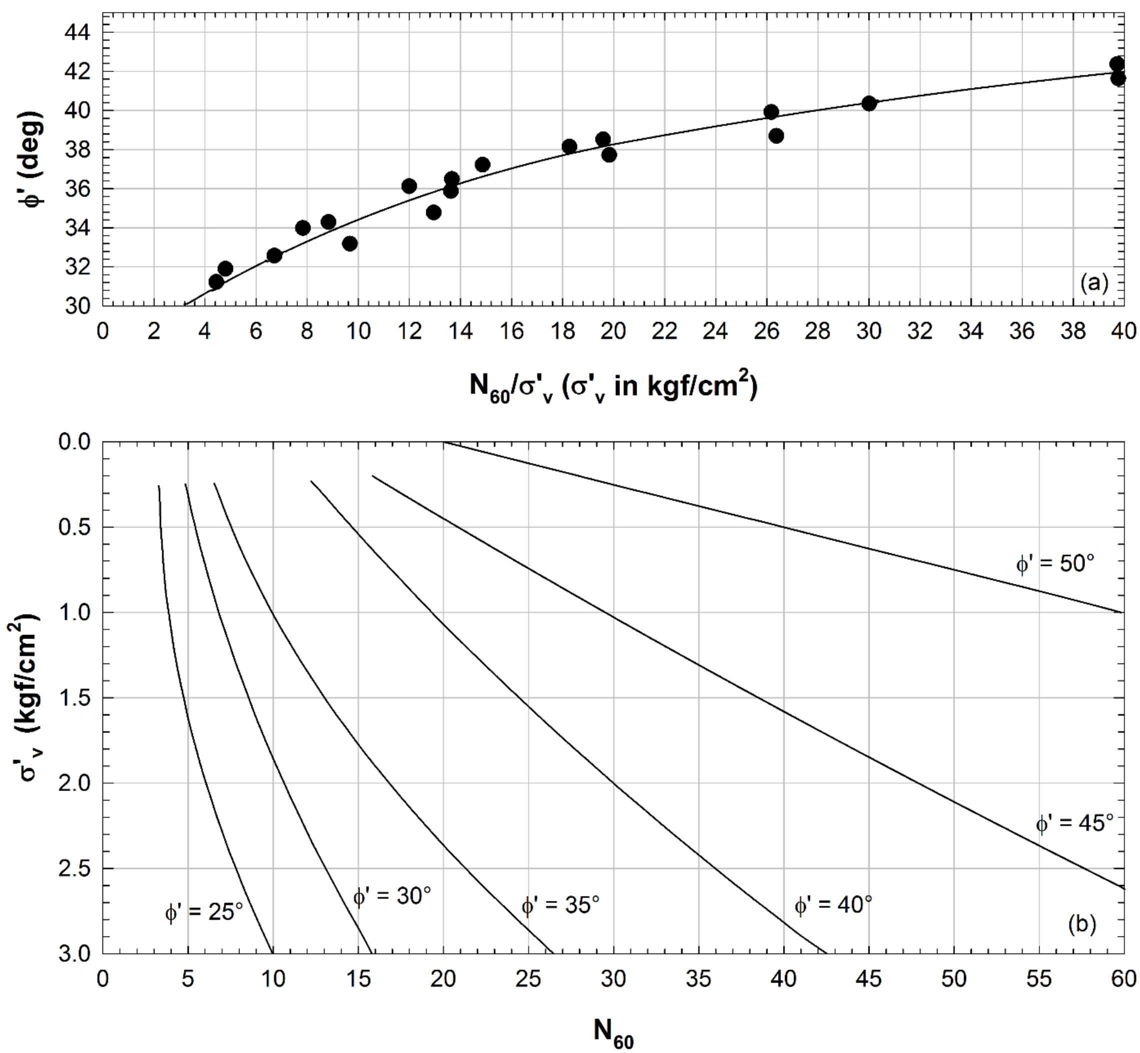


Figure 8-3 Relationship between Peak Effective Stress Friction Angle, Overburden Pressure, and SPT Blow Count for Sands (top) after Parry (1977) and (bottom) after DeMello (1971) and Schmertmann (1975)

Peck et al. (1974) developed the correlation for the effective stress friction angle based on SPT N values shown in Figure 8-4. According to Ameratunga et al. (2016), this correlation is conservative. Wolff (1989) approximated this relationship as:

$$\phi' = 27.1 + 0.3N_{1,60} - 0.00054\left(N_{1,60}\right)^2 \qquad \textbf{(8-5)}$$

where:
$N_{1,60}$ = SPT N value corrected for 60% energy and 1 atm overburden pressure.

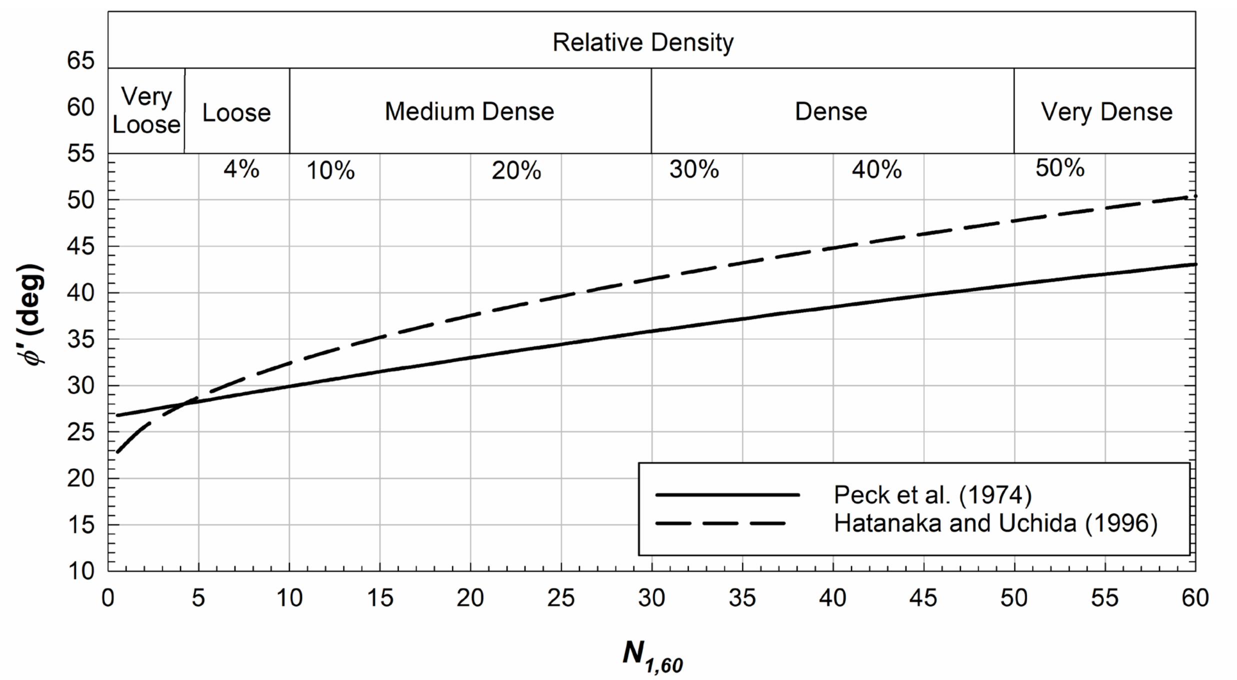


Figure 8-4 Variation of Effective Stress Friction Angle with $N_{1,60}$ (after Peck at al. 1974, and Hatanaka and Uchida 1996)

Hatanaka and Uchida (1996) also correlated the effective stress friction angle of sands to $N_{1,60}$ as shown in Figure 8-4. This equation was developed using the results of triaxial tests from high-quality intact frozen samples of natural sands. Using an SPT hammer with an efficiency of 78%, the relationship was found to be:

$$\phi' = \sqrt{15.4N_{1,60}} + 20 \qquad \textbf{(8-6)}$$

8-2.1.3 Correlations with Cone Penetration Test.

Two relationships between CPT results and effective stress friction angle were already presented in Table 8-3 and Table 8-4. Table 8-5 presents a similar relationship developed by Bergdahl et al. (1993), according to Ameratunga et al. (2016).

Table 8-5 Relationship between Relative Density, Cone Tip Resistance, and Effective Stress Friction Angle (after Bergdahl et al. 1993, and Ameratunga et al. 2016)

Relative Density	q_c (tsf)	ϕ' (degrees)
Very loose	0 – 26.1	29 – 32
Loose	26.1 – 52.2	32 – 35
Medium	52.2 – 104.4	35 – 37
Dense	104.4 – 208.8	37 – 40
Very dense	> 208.8	40 – 42

Mayne (2007) used the results of calibration chamber tests to estimate the effective stress friction of coarse-grained soils for CPT results as

$$\phi' = 17.6 + 11 \cdot \log\left(\frac{q_t / P_a}{\sqrt{\sigma'_v / P_a}}\right) \quad \textbf{(8-7)}$$

where:
ϕ' = drained friction angle,
q_t = corrected tip resistance= $q_c + u \cdot (1+a)$,
u = pore pressure measured behind the cone tip, often named the u_2 position,
a = cone net area ratio = ratio of the face area to shoulder area,
σ'_v = effective vertical stress, and
P_a = atmospheric pressure in same units as vertical stress and q_c.

Figure 8-5 correlates the effective stress friction angle with CPT tip resistance as summarized by Meyerhof (1976).

In cases where the tip resistance increases with depth, the method outlined in Figure 8-6 can be used to obtain the bearing capacity factor (N_q). The correlation presented in Figure 8-7 can be used to obtain the effective stress friction angle from N_q.

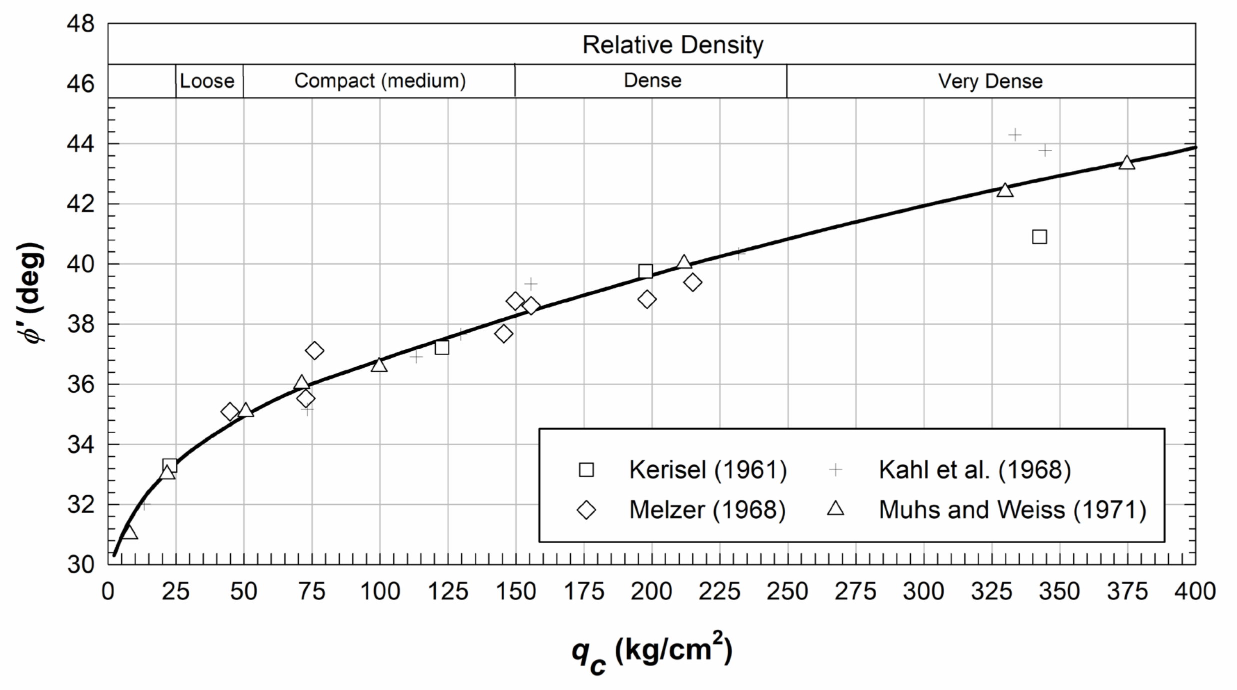
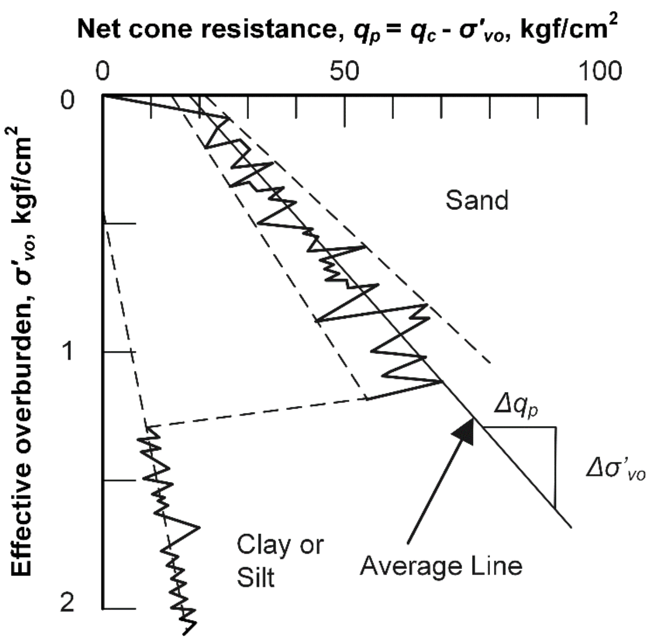


Figure 8-5 Relationship between Effective Stress Friction Angle and Cone Tip Resistance (after Kerisel 1961, Kahl et al. 1968, Melzer 1968, Muhs and Weiss 1971, and Meyerhof 1976)



1. Plot the net cone resistance vs. effective overburden stress.
2. Draw an average line to represent the variation of q_p with σ'_{vo} as shown above
3. The slope of the line is N_p:

$$N_p = (\Delta q_p / \Delta \sigma'_{vo})$$

4. Calculate $N_q = N_p + 1$
5. Determine ϕ' using the correlation between N_q and ϕ' shown in Fig.8-7
6. For the example shown above:
   $N_p = 47$, $N_q = 48$, $\phi' = 37°$

Figure 8-6 Estimation of ϕ' from a Cone Resistance Profile (after Duncan et al. 1989)

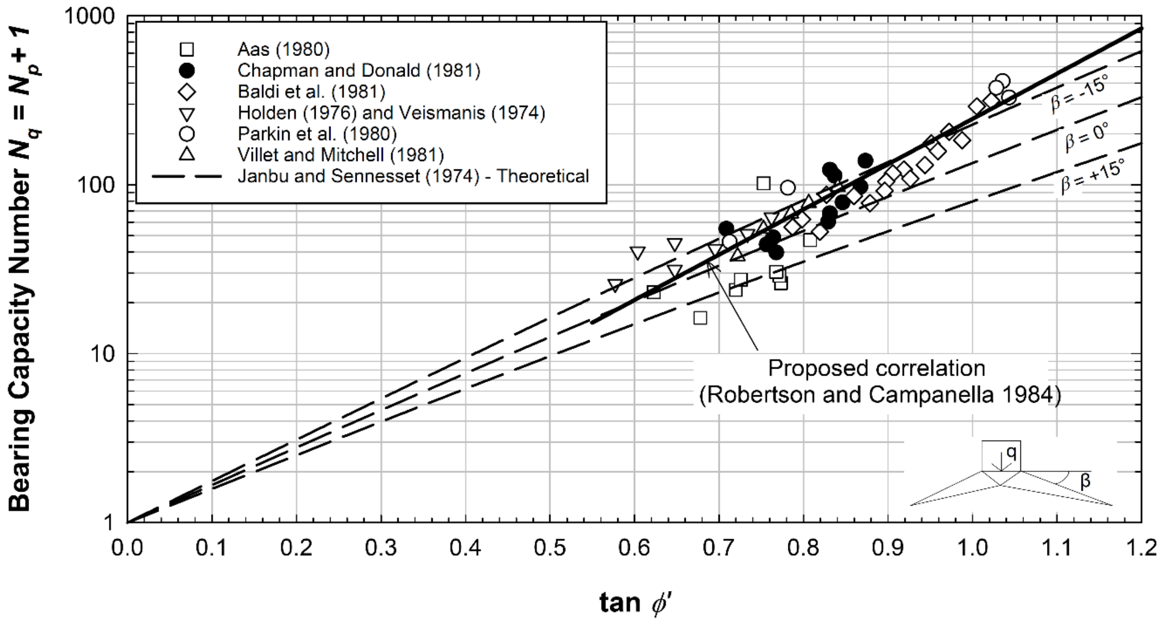


Figure 8-7 Relationship between Bearing Capacity Number N_q and Peak Effective Stress Friction Angle from Large Calibration Tests (after Duncan et al. 1989)

Robertson and Campanella (1983) correlated the effective stress friction angle to the measured CPT tip resistance (electric cone) from tests performed in a calibration chamber. The correlation used drained triaxial tests on uncemented, unaged, moderately compressible quartz sands and considers the effect of overburden pressure as shown in Figure 8-8. The relationship presented in Figure 8-8(a) was approximated by Robertson and Cabal (2014) using the relationship:

$$\tan\phi' = \frac{1}{2.68}\left[\log\left(\frac{q_c}{\sigma'_v}\right) + 0.29\right] \quad \textbf{(8-8)}$$

where:
ϕ' = drained friction angle,
q_c = cone tip resistance, and
σ'_v = effective vertical stress in same units as q_c.

Schmertmann (1975) presented a correlation to determine the effective stress friction angle based on the CPT tip resistance. To use this correlation, the relative density first needs to be determined using Figure 8-9. Using the correlated value of relative density, the effective stress friction angle can be determined from Figure 8-10.

For this purpose, Schmertmann (1978) developed a correction factor (R) such that:

$$R = 1 + 0.75\left(OCR^{\beta} - 1\right) = \frac{q_{c,OC}}{q_{c,NC}} \quad \textbf{(8-9)}$$

where:
OCR = overconsolidation ratio,
β = exponent,
$q_{c,OC}$ = CPT tip resistance in overconsolidated sand, and
$q_{c,NC}$ = CPT tip resistance in normally consolidated sand.

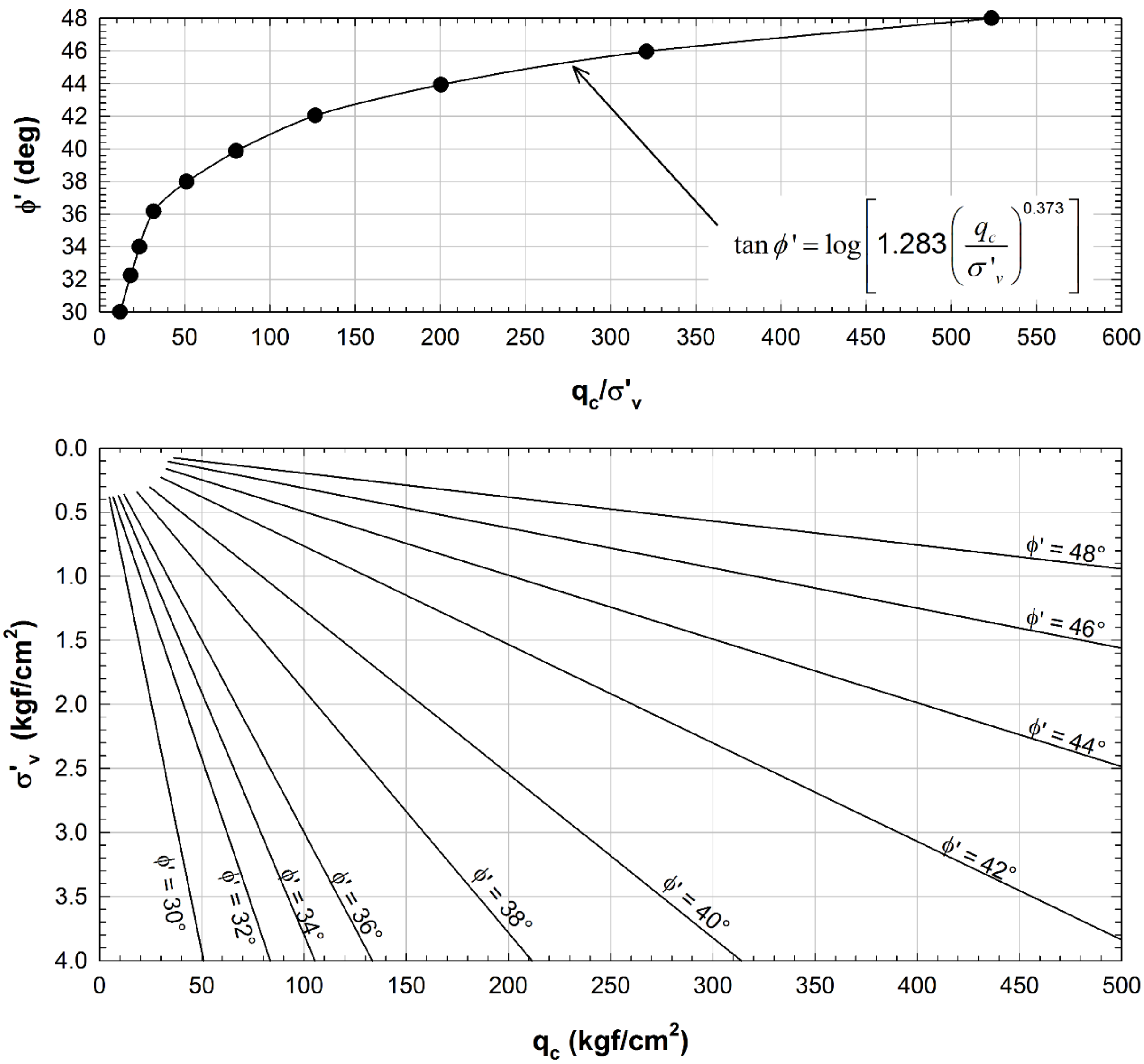


Figure 8-8 Variation of Peak Effective Stress Friction Angle with σ'_v and Cone Resistance for Normally Consolidated, Uncemented, Quartz Sands (after Robertson and Campanella 1983)

For overconsolidated sands, the effect of overconsolidation on the measured tip resistance needs to be considered before using correlations proposed for normally consolidated sands.

An example of using this approach is shown in Figure 8-11. According to Lunne and Christoffersen (1985), β can be assumed as 0.45 for all practical purposes.

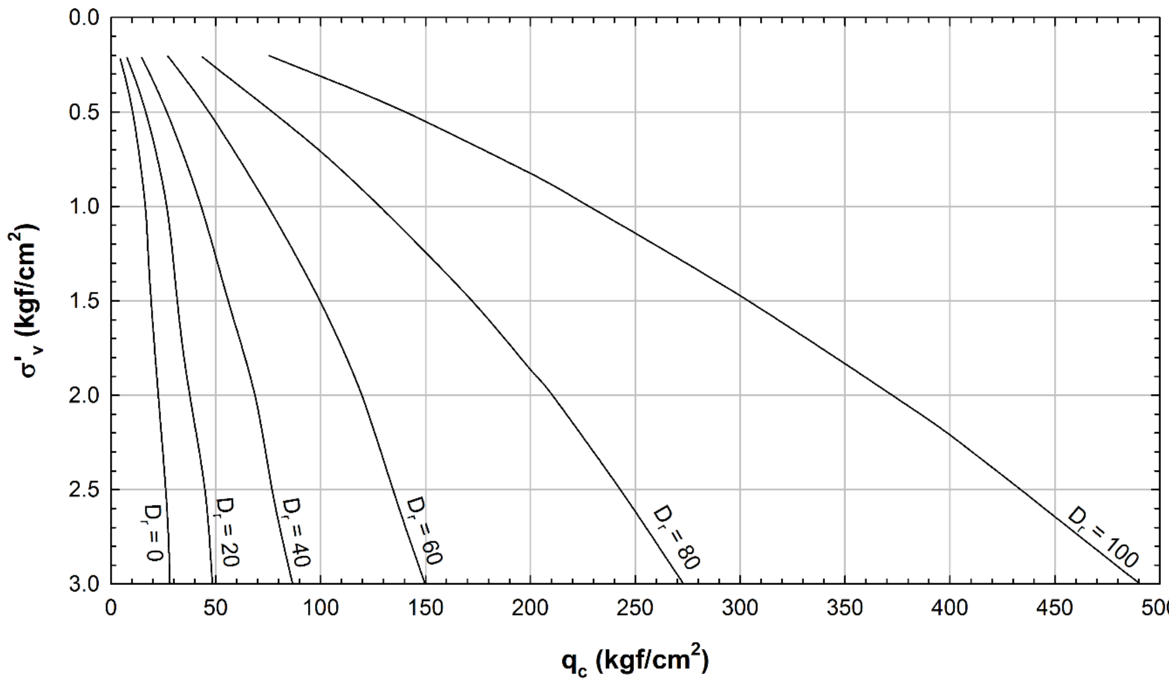


Figure 8-9 Estimation of Relative Density for Normally Consolidated Sands from Cone Penetration Resistance (after Schmertmann 1978)

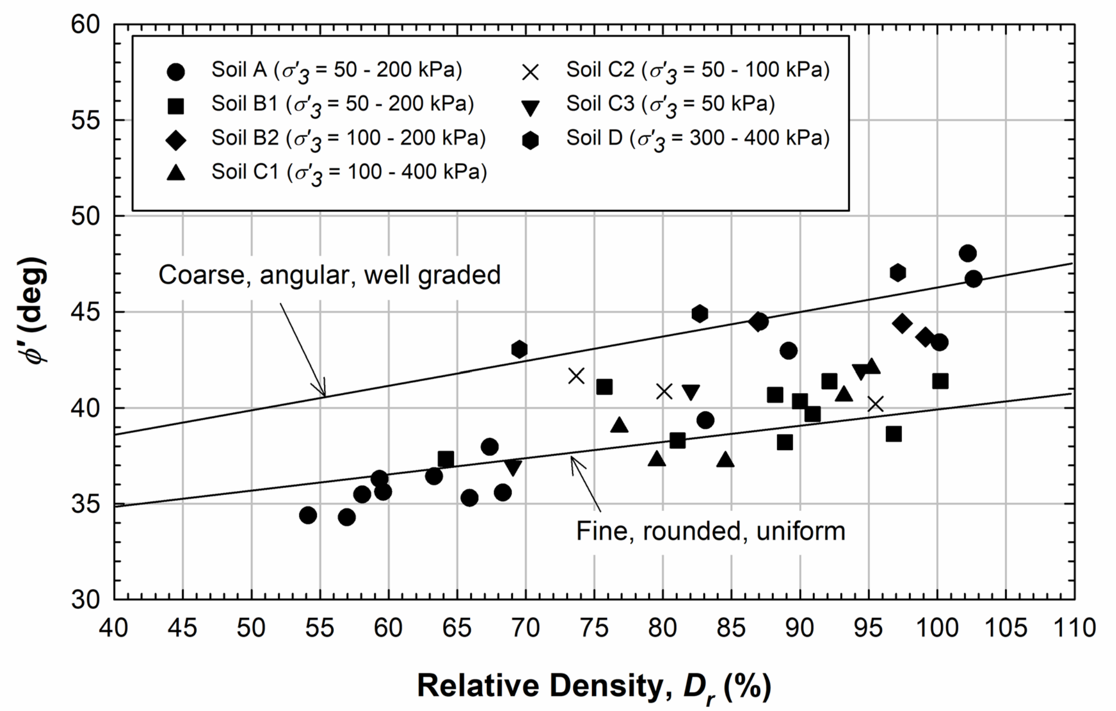


Figure 8-10 Relationship between Friction Angle and Relative Density based on Triaxial Compression Tests on North Sea Sands (after Schmertmann 1975, and Lunne and Kleven 1982)

Example:

Given σ'_v = 0.5 kgf/cm^2, $q_{c,OC}$ = 200 kgf/cm^2, and OCR = 7
For β = 0.45, R = 1.95 from plot below.
Normally consolidated $q_c = q_{c,OC} / R$ = 200 / 1.95 = 103 kgf/cm^2
From Figure 8.10: ϕ' = 44° From Figure 8.9: D_r = 90%

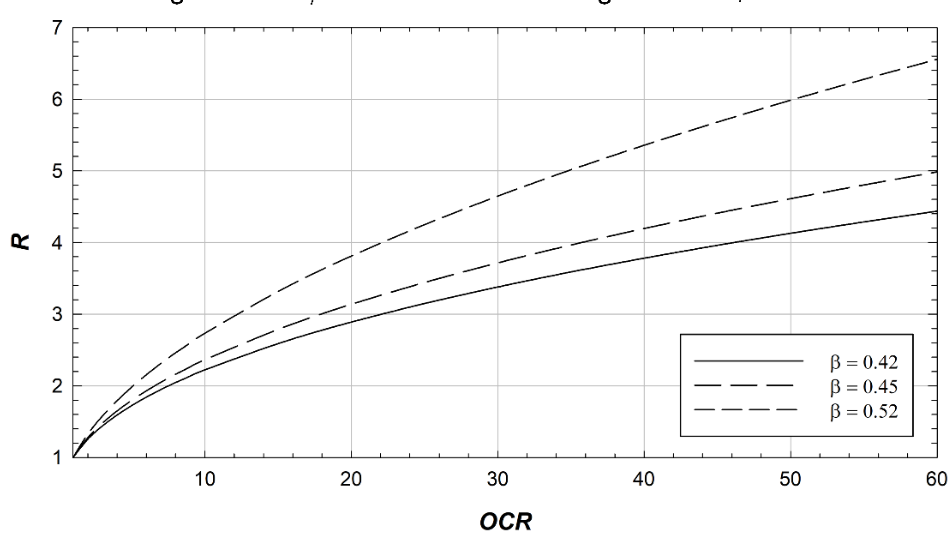


Figure 8-11 Correction for Effects of Overconsolidation on Cone Penetration Tip Resistance in Sand (after Lunne and Christoffersen 1985, and Duncan et al. 1989)

8-2.1.4 Correlations with Dilatometer.

Marchetti (1997) proposed correlations to relate the effective stress friction angle for clean sands to the horizontal stress index (K_D) from the dilatometer test in which:

$$K_D = \frac{p_0 - u_0}{\sigma'_v} \quad \textbf{(8-10)}$$

where:
p_0 = corrected pressure required to initiate movement of the membrane against the soil,
u_0 = hydrostatic pore pressure, and
σ'_v = effective vertical stress.

Ricceri et al. (2002) proposed that the upper bound estimate of effective stress friction angle from dilatometer tests is:

$$\phi' = 31 + \frac{K_D}{0.236 + 0.066 K_D} \quad \textbf{(8-11)}$$

and Marchetti (1997) proposed that the lower bound estimate is:

$$\phi' = 28 + 14.6 \cdot \log K_D - 2.1\left(\log K_D\right)^2 \quad \textbf{(8-12)}$$

where:
ϕ' = effective stress friction angle and
K_D = horizontal stress index.

According to Marchetti, the lower bound solution can underestimate the *in situ* friction angle by 2° to 4°. The upper and lower bound equations are plotted in Figure 8-12.

8-2.2 Fine-Grained Soils.

The effects of overconsolidation on the shear strength preclude the development of accurate correlations for the effective shear parameters of fine-grained soils. However, multiple correlations have been developed for the fully softened (ϕ'_{FS}) and residual (ϕ'_r) friction angles of clays, where the fully softened friction angle is taken to be equal to the normally consolidated peak value.

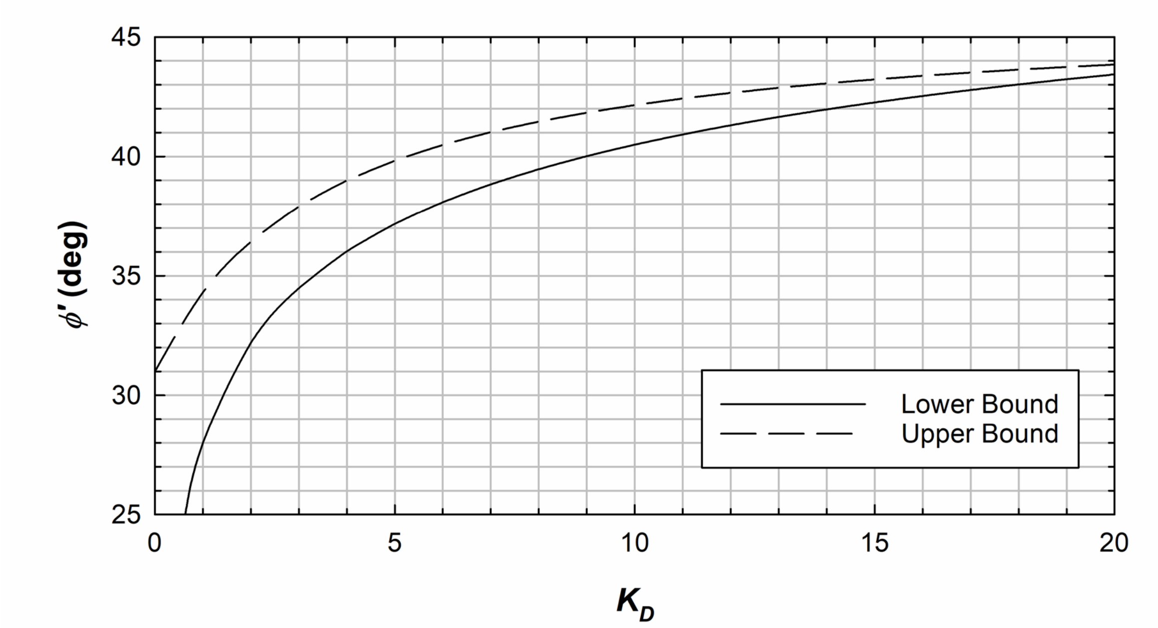


Figure 8-12 Range of Effective Stress Friction Angle for Clean Sands based on the Horizontal Stress Index from the Dilatometer Test (after Marchetti 1997, and Ricceri et al. 2002)

8-2.2.1 Correlations for Fully Softened Shear Strength.

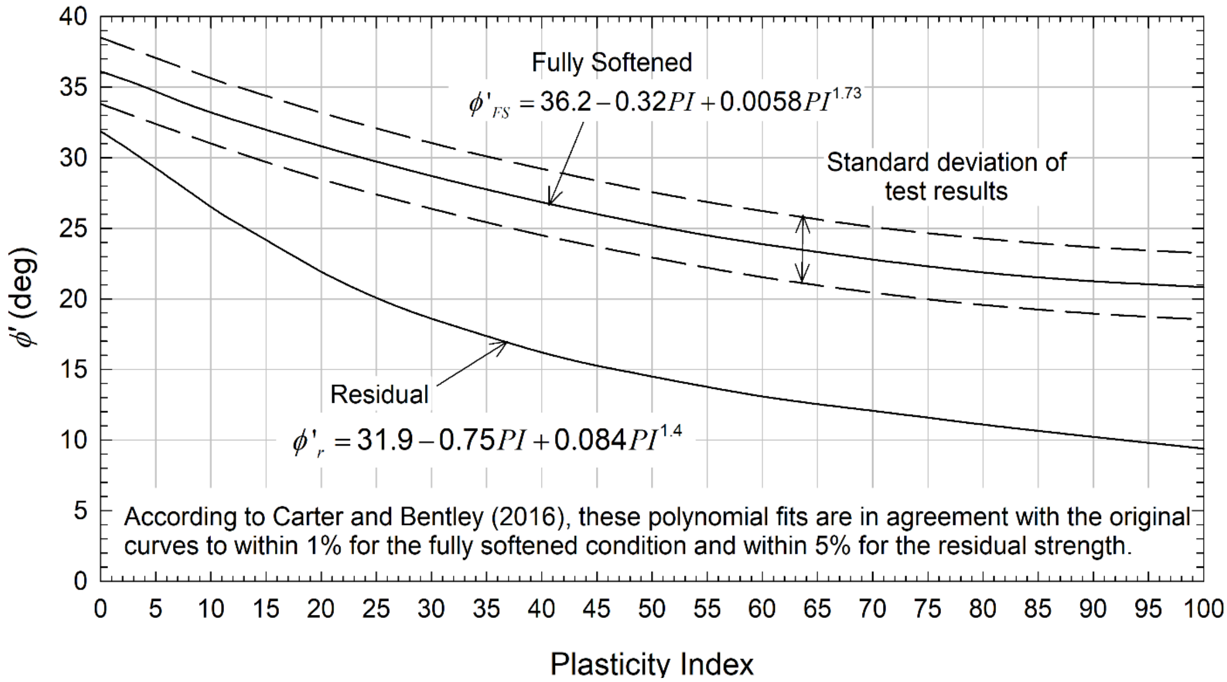
Gibson (1953) presented a relationship for ϕ'_{FS}, which is plotted in Figure 8-13. The standard deviation of the data about the trend is plotted as confidence limits. The mean trend line can be approximated by the equation below according to Carter and Bentley (2016):

$$\phi'_{FS} = 0.0058PI^{1.73} - 0.32PI + 36.2 \tag{8-13}$$

where:
PI = plasticity index.

According to Carter and Bentley (2016) the polynomial fit is in agreement with the original curve to within 1% for the fully softened condition.

A similar correlation was presented by Ladd et al. (1977) based on triaxial tests on intact normally consolidated clays as shown in Figure 8-14. The confidence limits in this figure are plotted at one standard deviation above and below the mean trend. **1**\\



/1/ Figure 8-13 Relationship between the Effective Stress Friction Angle of Fine-Grained Soil and Plasticity Index (after Gibson 1953, Carter and Bentley 2016)

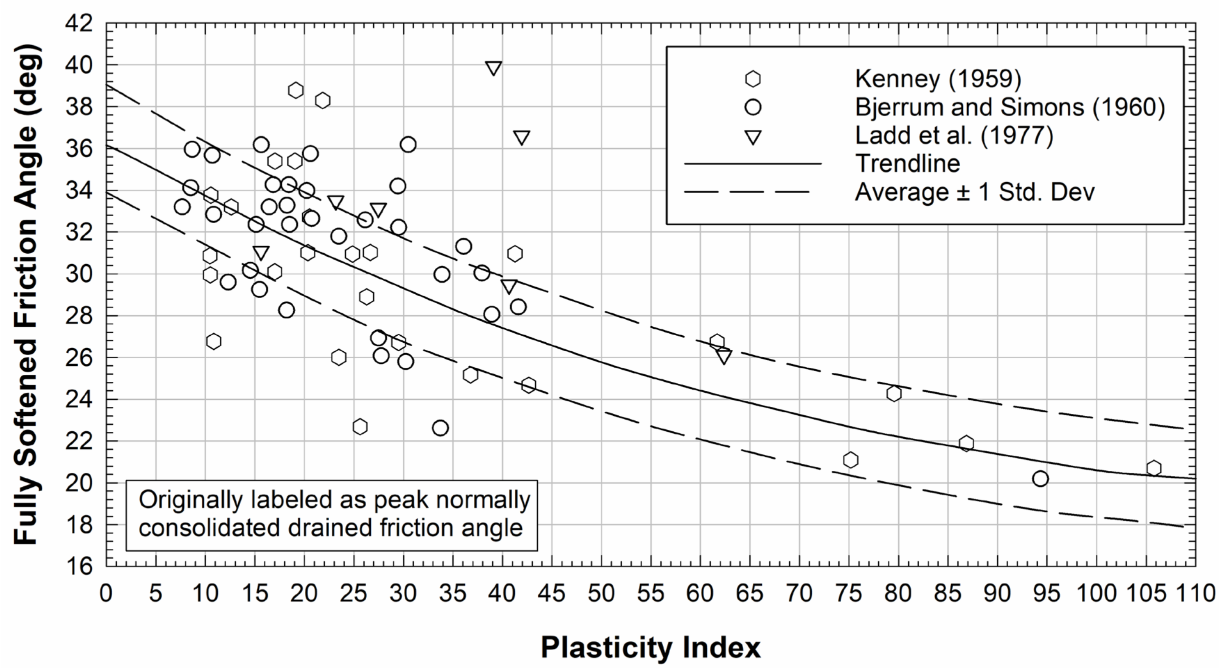


Figure 8-14 Correlation between ϕ'_{FS} and *PI* based on Triaxial Tests on NC Clays (after Kenney 1959, Bjerrum and Simons 1960, Ladd et al. 1977)

A similar relationship between ϕ'_{FS} and PI was proposed by Terzaghi et al. (1996) as shown in Figure 8-15. This relationship was developed from the results of tests on normally consolidated specimens with most of them being remolded.

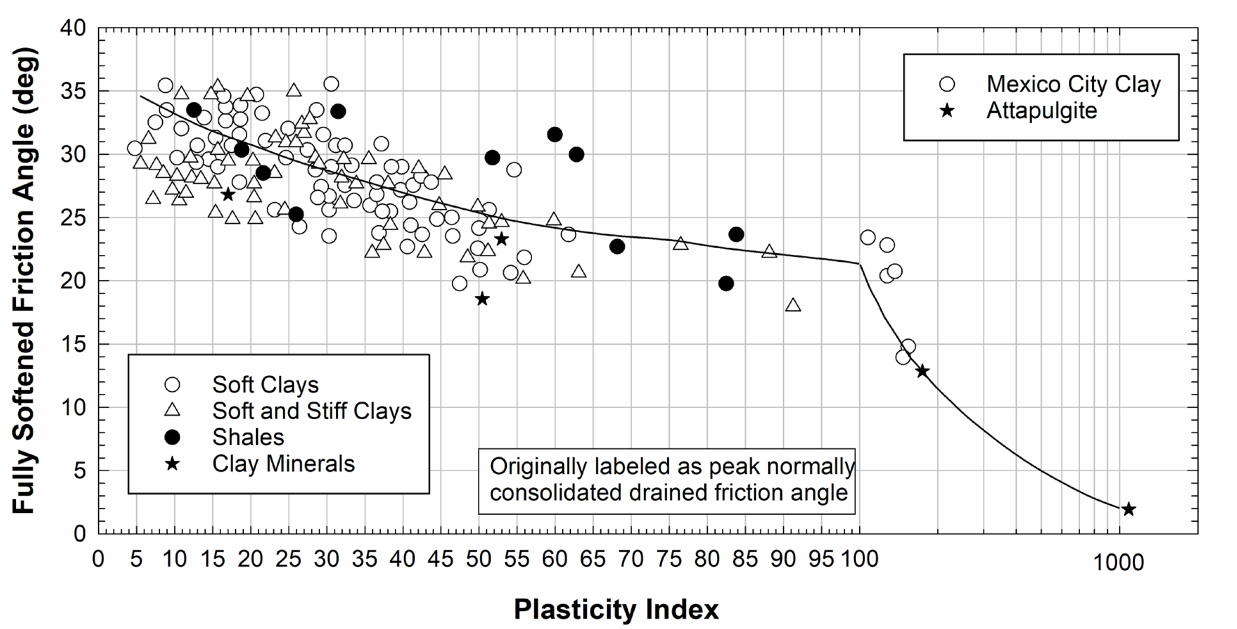


Figure 8-15 Relationship between ϕ'_{FS} and PI (after Terzaghi et al. 1996)

Tiwari and Ajmera (2011) presented the correlations shown in Figure 8-16 and Figure 8-17 for the fully softened friction angle. These correlations were based on direct shear tests performed on 36 artificially created soils. Tiwari and Ajmera (2011) created the artificial soils for this study by mixing different proportions of quartz, kaolinite and montmorillonite.

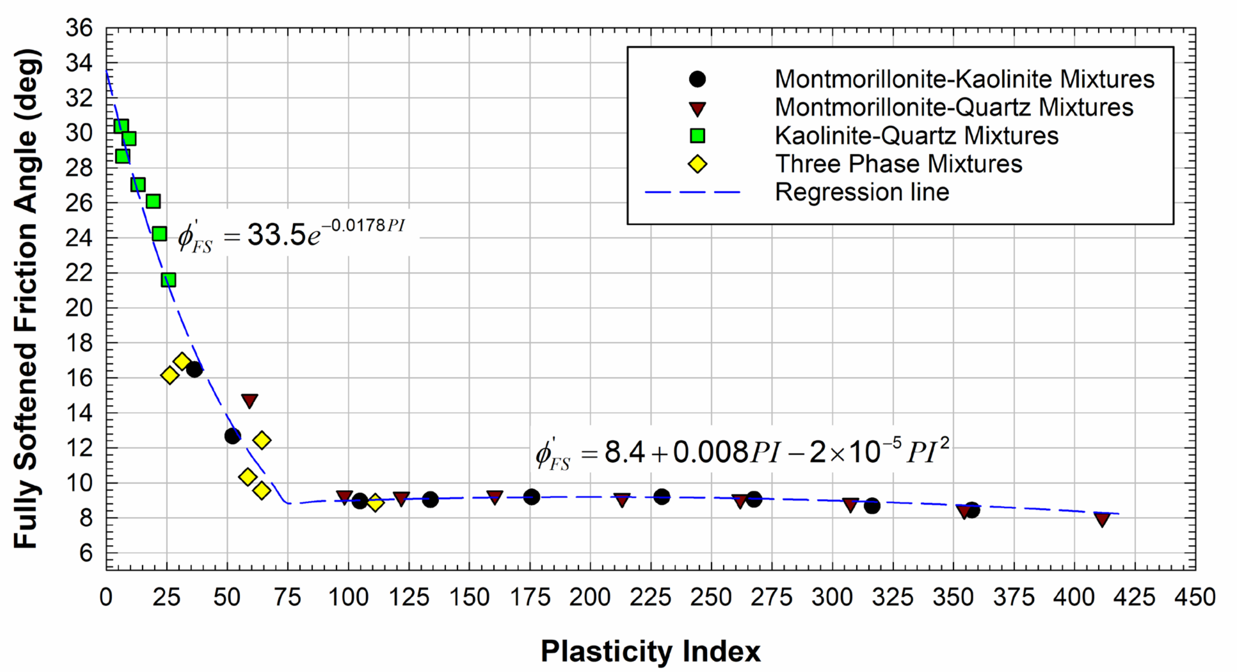


Figure 8-16 Variation of the Fully Softened Friction Angle with Plasticity Index (after Tiwari and Ajmera 2011)

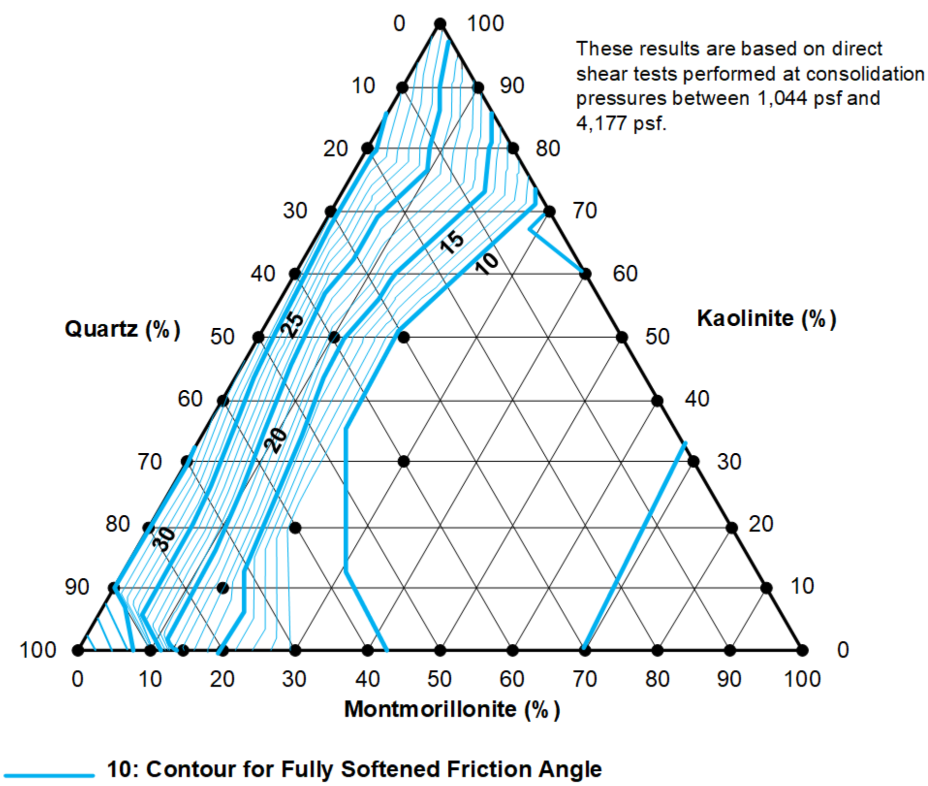


Figure 8-17 Fully Softened Friction Angle based on Mineral Composition (after Tiwari and Ajmera 2011)

The preceding relationships only consider linear failure envelopes (i.e., constant friction angle) while real soils often exhibit a nonlinear failure envelope. Nonlinear failure envelopes have been described by multiple mathematical forms, including normal stress dependent secant friction angle and two-parameter power function with parameters a and b. Shear strength is calculated using a secant friction angle as:

$$s = \sigma'_{ff} \tan \phi'_{\sec} \quad \textbf{(8-14)}$$

where:
s = effective stress shear strength,
σ'_{ff} = effective normal stress on the failure plane, and
ϕ'_{sec} = stress dependent secant friction angle.

The two-parameter power function describes shear strength nonlinearly as:

$$s = aP_a \left(\frac{\sigma'_{ff}}{P_a} \right)^b \quad \textbf{(8-15)}$$

where:
s = effective stress shear strength,
a = empirical coefficient related to the steepness of the power function,
σ'_{ff} = effective normal stress,
P_a = atmospheric pressure in same units as stress, and
b = empirical coefficient related to the curvature of the power function.

Castellanos et al. (2021) presented the correlations for nonlinear fully softened shear strength parameters shown in Figure 8-18 and Figure 8-19. These correlations were developed based on over 400 direct shear tests on 97 soils (Castellanos et al. 2021). The equations and standard deviations provided on the plots allow uncertainty in the correlations to be explicitly considered. Castellanos et al. (2021) also provide statistical measures of the covariance of the correlations for a_{FS} and b_{FS}.

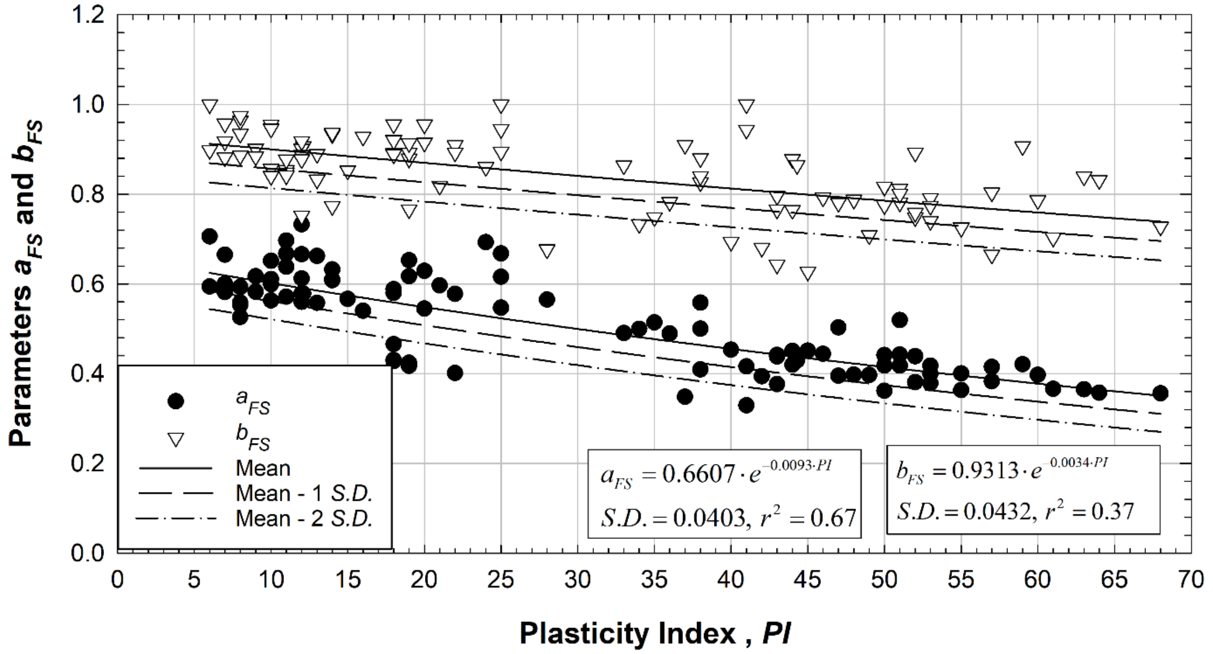


Figure 8-18 Correlation between Power Function Parameters a_{FS} and b_{FS} and Plasticity Index (after Castellanos et al. 2021)

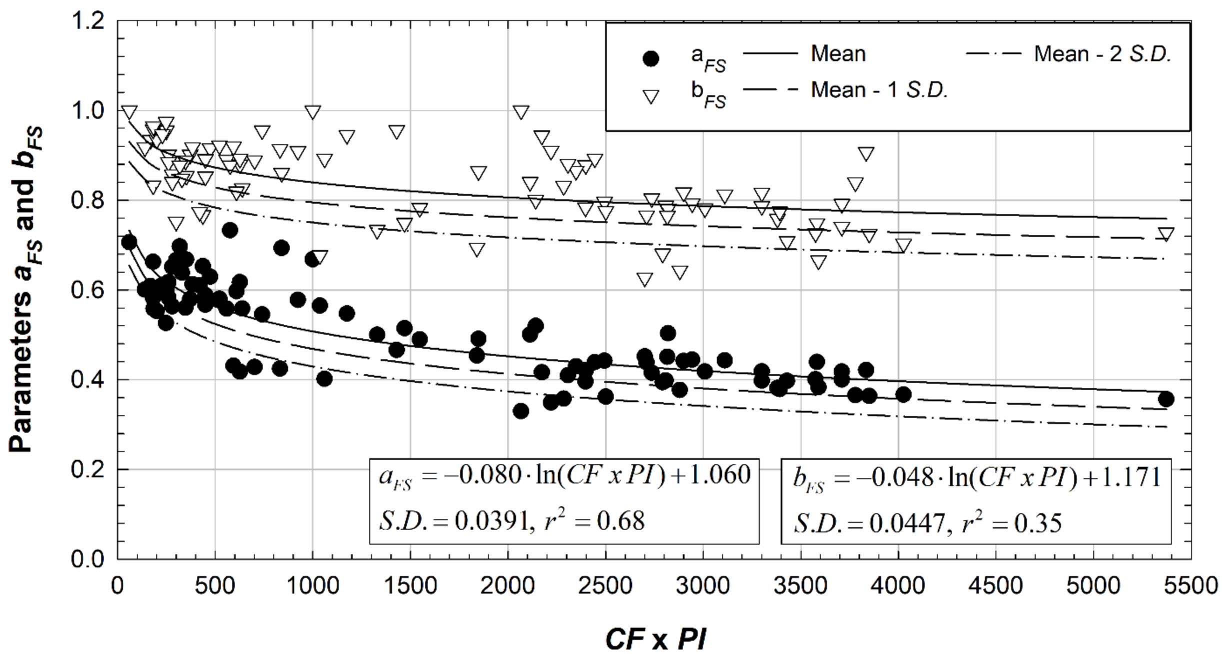


Figure 8-19 Correlation between Power Function Parameters a_{FS} and b_{FS} and $CF \times PI$ (after Castellanos et al. 2021)

8-2.2.2 Correlations for Residual Shear Strength.

Gibson (1953) also presented a relationship for ϕ'_r as plotted in Figure 8-13. The residual friction angle trend line can be approximated by the equation below, according to Carter and Bentley (2016):

$$\phi'_r = 0.084 \cdot PI^{1.4} - 0.75 \cdot PI + 31.9 \quad \textbf{(8-16)}$$

where:
PI = plasticity index.

According to Carter and Bentley (2016) this polynomial fit agrees with the original curves to within 5% for the residual friction angle.

Skempton (1964, 1985) related the residual friction angle to the clay-sized fraction as presented in Figure 8-20. The frictions angles were measured using ring shear tests performed on normally consolidated and overconsolidated samples.

Using published results, Voight (1973) developed the correlation presented in Figure 8-21(top) to estimate the residual strength of clays based on the plasticity index. Voight's correlation was later supported by the residual strength measurements performed by Bovis (1985) whose results can be seen in Figure 8-21(bottom).

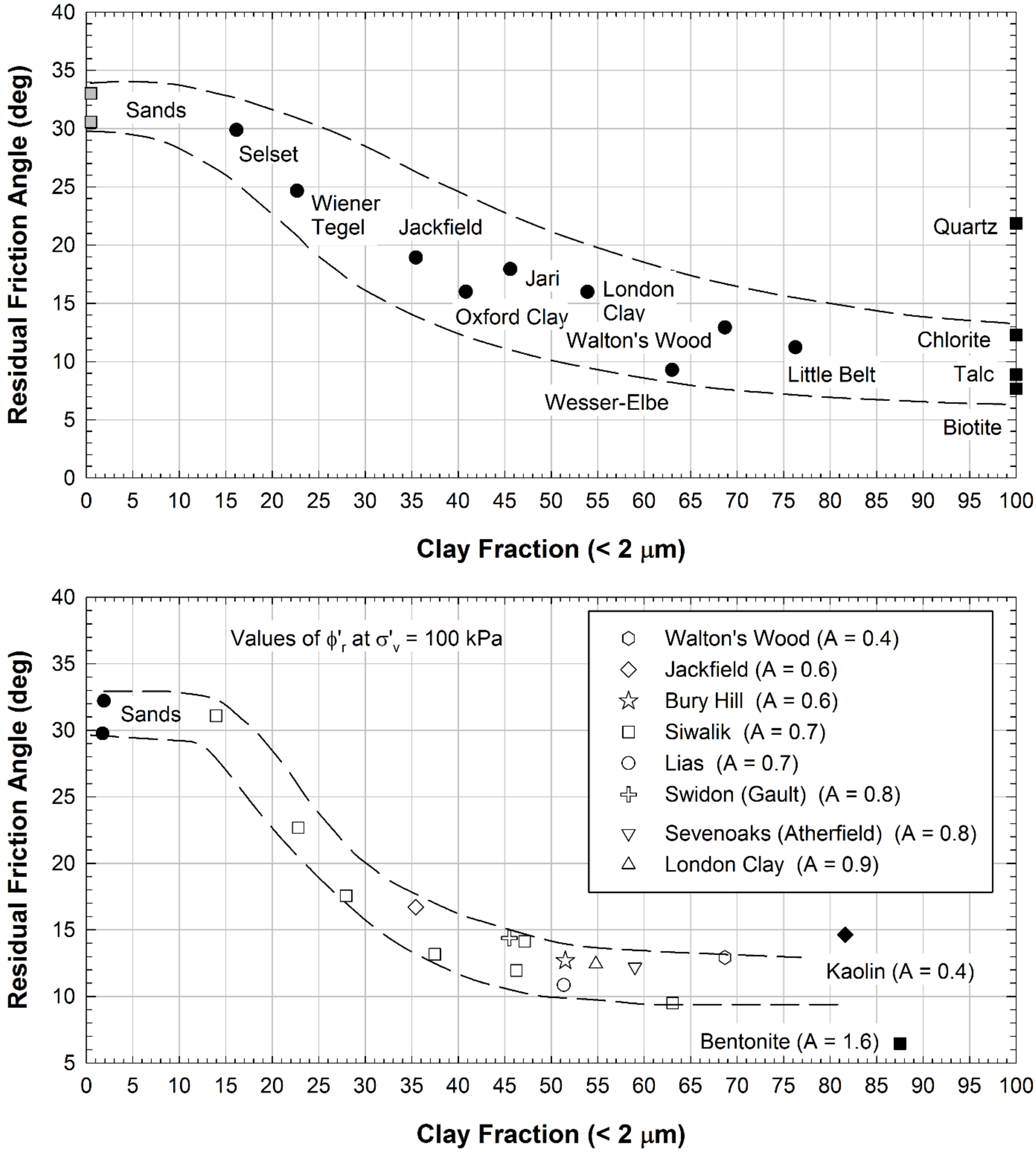


Figure 8-20 Correlation between the Residual Friction Angle and Clay-sized Fraction (after Skempton 1964, 1985)

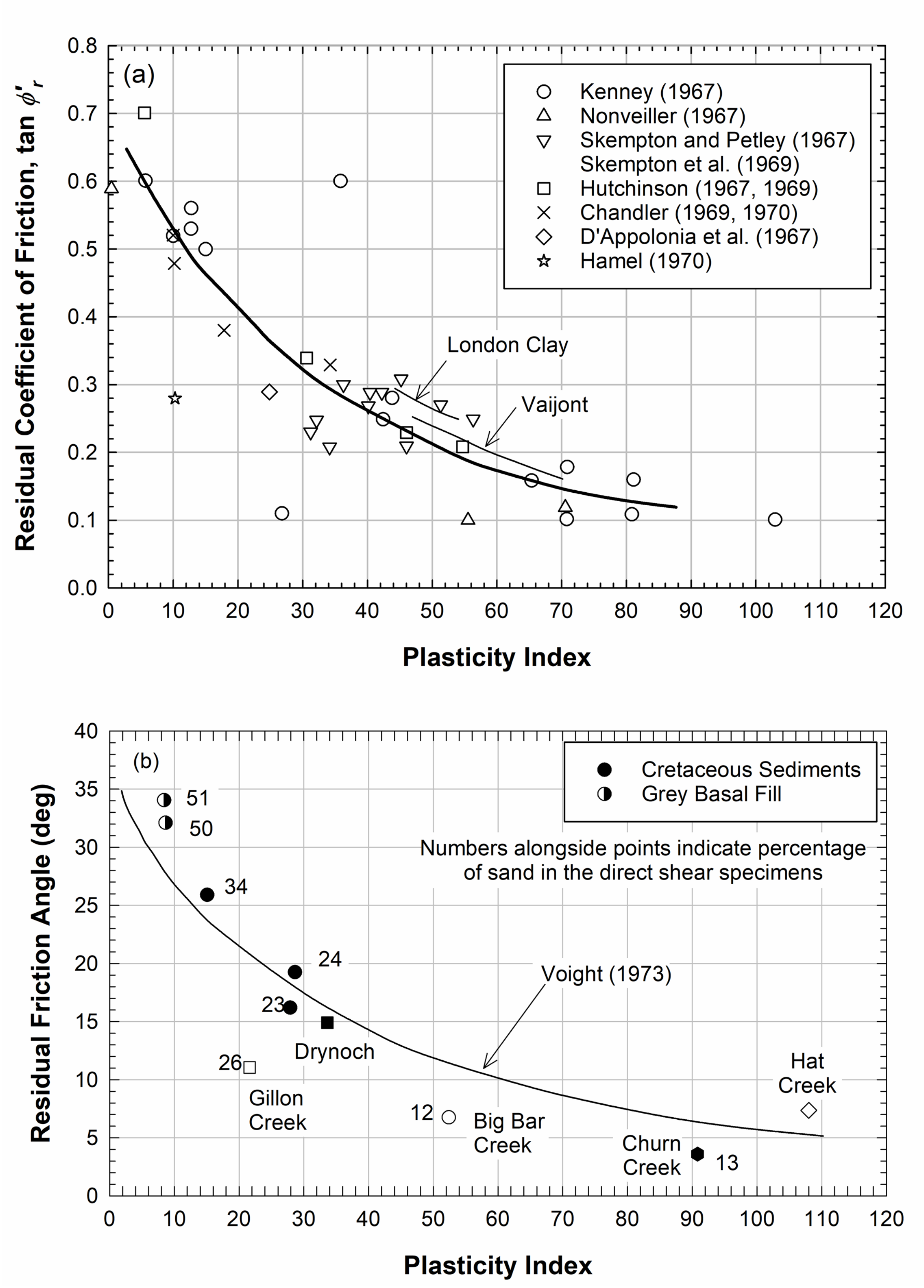


Figure 8-21 Residual Friction Angle vs. Plasticity Index – (top) Data Collected by Voight (1973), and (bottom) Measurements by Bovis (1985)

Stark and Hussain (2013) correlated the residual friction angle of clays to the liquid limit for various ranges of clay sized fraction as shown in Figure 8-22. This correlation needs to be used with care because of the methods that were used to process the soil samples for index property measurements were not consistent. For this correlation, the index properties of clay samples were obtained from specimens sieved through a No. 40 sieve without any other processing. On the other hand, shale samples were ball-milled and sieved through a No. 200 sieve. These differences in the procedures used to process samples for measuring the index properties should be considered when using the correlation.

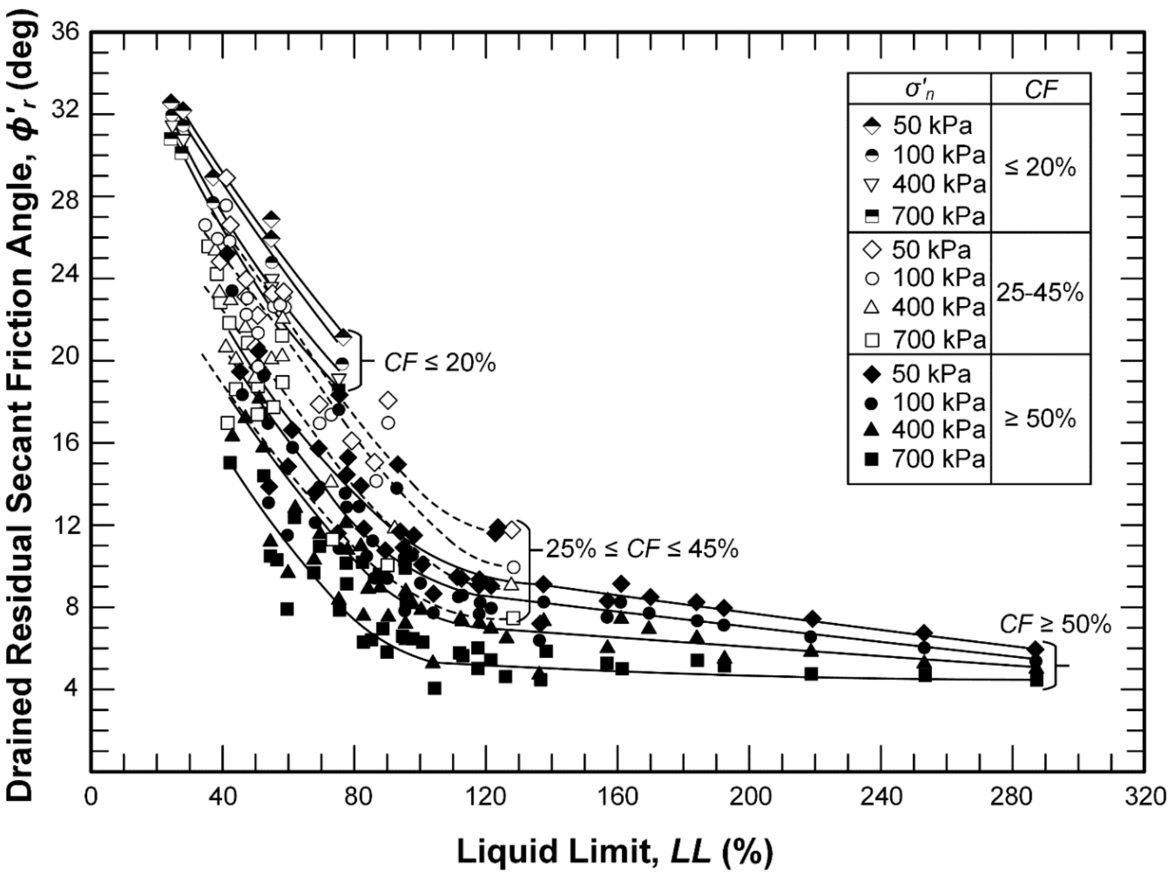


Figure 8-22 Drained Residual Secant Friction Angle as a Function of *LL* and *CF* (after Stark and Hussain 2013)

Stark and Hussain (2013) correlation provides stress-dependent residual secant friction angles for four different value of effective normal stress ranging from 50 to 700 kPa. The trends can be calculated as

$$\phi'_r = C_0 + C_1 \cdot LL + C_2 \cdot LL^2 + C_3 \cdot LL^3 \quad \textbf{(8-17)}$$

where:
LL = liquid limit and
C_0, C_1, C_2, and C_3 = empirical coefficients listed in Table 8-6.

Table 8-6 Coefficients for Stark and Hussain (2013) Residual Friction Angle Correlation

***CF* and *LL* Range**	**Effective normal stress σ' (kPa)**	**Coefficients for Equation 8-17**			
		C_0	C_1	C_2	C_3
CF < 20%	50	39.7	-0.29	6.63E-04	0
	100	39.4	-0.298	6.81E-04	0
	400	40.2	-0.375	1.36E-03	0
	700	40.3	-0.412	1.68E-03	0
25% < CF < 45%	50	31.4	-6.79E-03	-3.62E-03	1.86E-05
	100	29.8	-3.63E-04	-3.58E-03	1.85E-05
	400	28.4	-5.62E-02	-2.95E-03	1.72E-05
	700	28.1	-0.2083	-8.18E-04	9.37E-06
CF > 50% and LL < 120	50	33.5	-0.31	3.90E-04	4.40E-06
	100	30.7	-0.2504	-4.21E-04	8.05E-06
	400	29.4	-0.2621	-4.01E-04	8.72E-06
	700	27.7	-0.3233	2.90E-04	7.11E-06
CF > 50% and 120 < LL < 300	50	12.0	-0.0215	0	0
	100	10.9	-0.0183	0	0
	400	8.3	-0.0114	0	0
	700	5.8	-0.0049	0	0

Laboratory testing at Virginia Tech has produced correlations for residual shear strength based on the results of torsional ring shear tests on 102 clays with plasticity indices between 6 and 112, liquid limits between 22 and 143, and clay fractions ranging from 13 to 90%. Figure 8-23 and Figure 8-24 present the relationship between power function parameters (see Equation 8-15), plasticity index, and clay fraction.

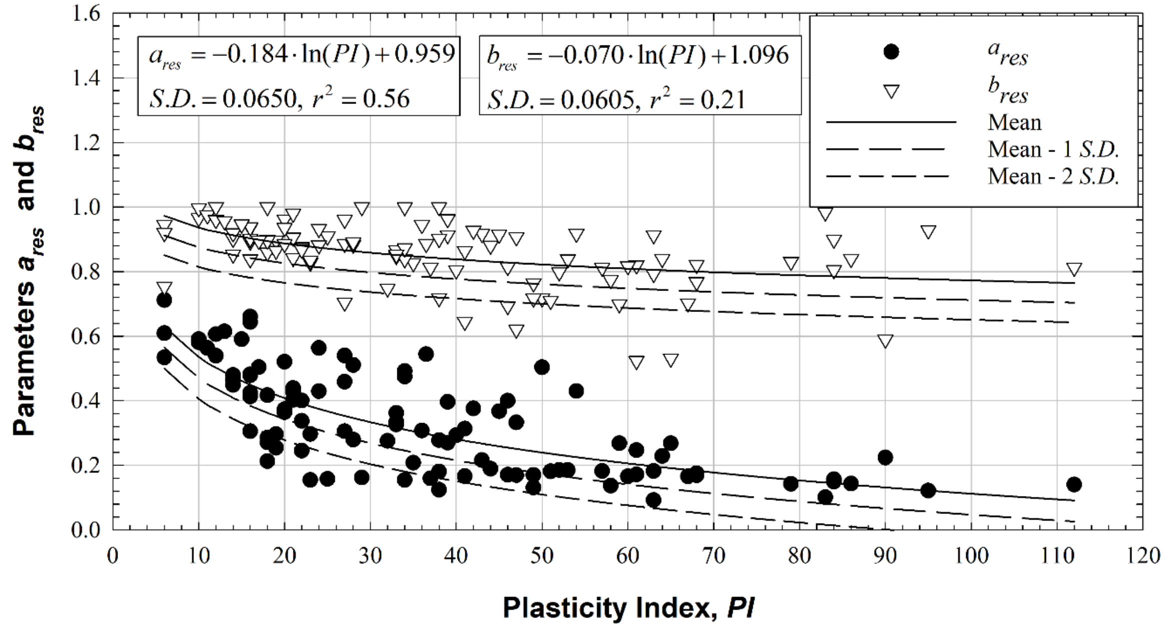


Figure 8-23 Residual Shear Strength Power Function Parameters Related to Plasticity Index (after Castellanos et al. 2021)

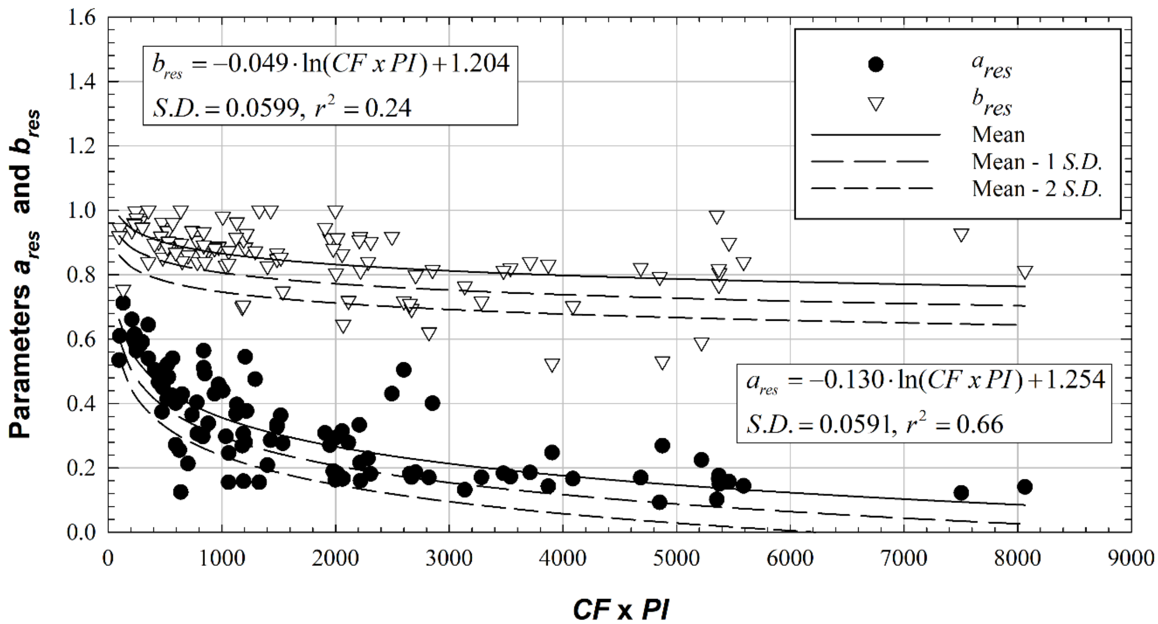


Figure 8-24 Residual Shear Strength Power Function Parameters Related to Plasticity Index and Clay Fraction (after Castellanos et al. 2021)

8-3 UNDRAINED SHEAR STRENGTH.

8-3.1 Correlations with Index Properties.

Skempton and Northey (1952) presented the relationship shown in Figure 8-25 that related the undrained shear strength of normally consolidated clays to the liquidity index. Terzaghi et al. (1996) demonstrated a strong relationship between the undrained shear strength of remolded clays and the liquidity index as shown in Figure 8-26. The results show similar behavior over a wider range of liquidity index to that observed by Skempton and Northey (1952).

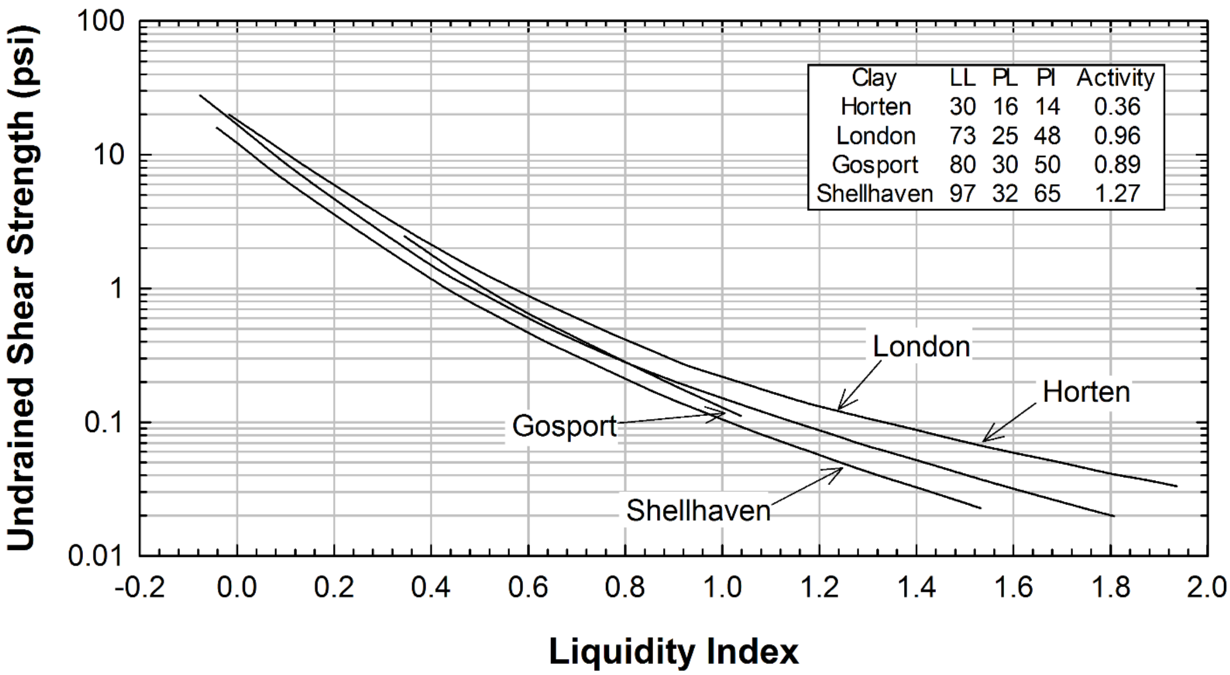


Figure 8-25 Relation between Liquidity Index and Undrained Shear Strength of Remolded Clays (after Skempton and Northey 1952)

Skempton (1957) compiled data from various sources to estimate the undrained shear strength of normally consolidated clay based on plasticity index as:

$$\frac{s_u}{\sigma'_v} = 0.11 + 0.0037PI \qquad \textbf{(8-18)}$$

where:
s_u = undrained shear strength,
σ'_v = vertical effective stress, and
PI = plasticity index (%).

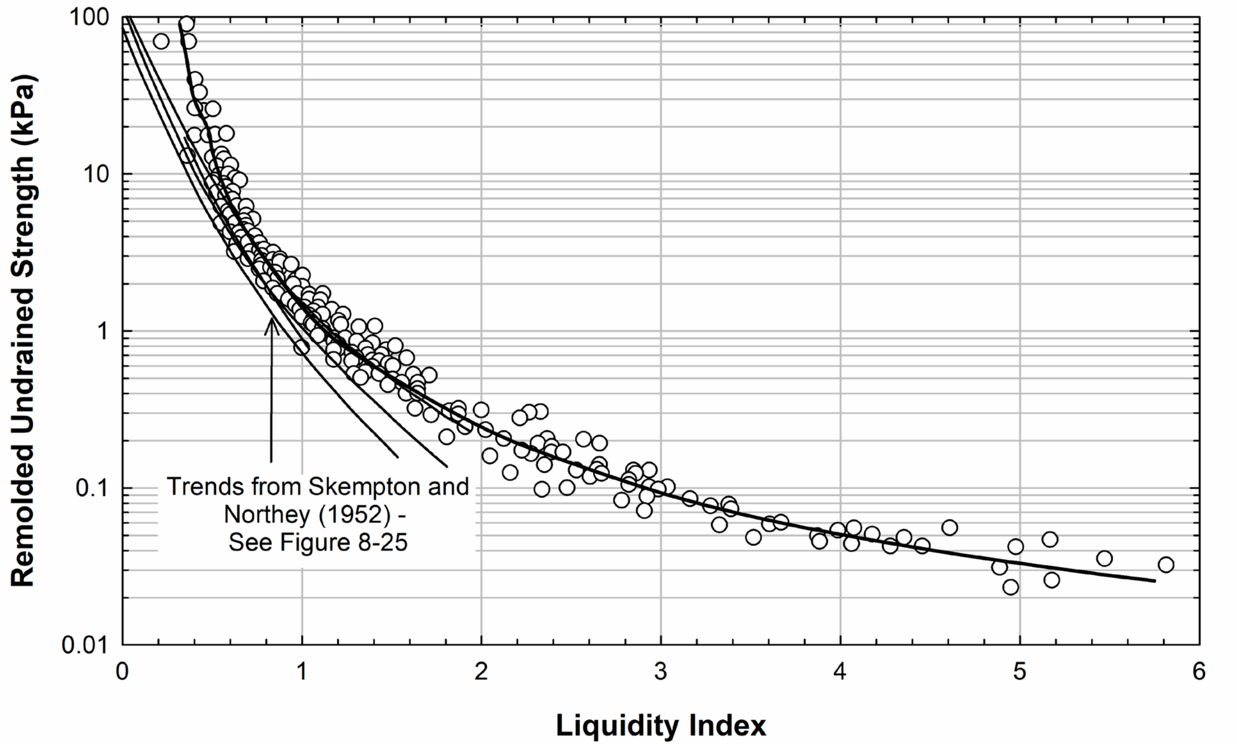


Figure 8-26 Relationship between Remolded Undrained Shear Strength and Liquidity Index (after Terzaghi et al. 1996)

Skempton's (1957) correlation, which is plotted in Figure 8-27, was based primarily on the results of field vane tests. It is unlikely that these shear strengths were corrected as required by ASTM D2573, meaning the values might be too high. The correlation presented by Skempton (1957) was later supported by Robertson and Campanella (1984) using vane shear test results presented by Ladd and Foott (1974).

A similar correlation based on laboratory tests was presented by Ladd and DeGroot (2004) and is shown in Figure 8-28. The correlation presented Ladd and DeGroot (2004) shows the dependency of the undrained shear strength on the laboratory stress path used to obtain the measurement.

Larson (1980) collected the undrained strength ratios and liquid limits of normally consolidated Scandinavian clays from various sources. These data is plotted in Figure 8-29 along with the equation proposed by Hansbo (1957):

$$\left(\frac{s_u}{\sigma'_v}\right)_{NC} = 0.0045LL \quad \textbf{(8-19)}$$

where:
s_u = undrained shear strength (normally consolidated),
σ'_v = vertical effective stress, and
LL = liquid limit (%).

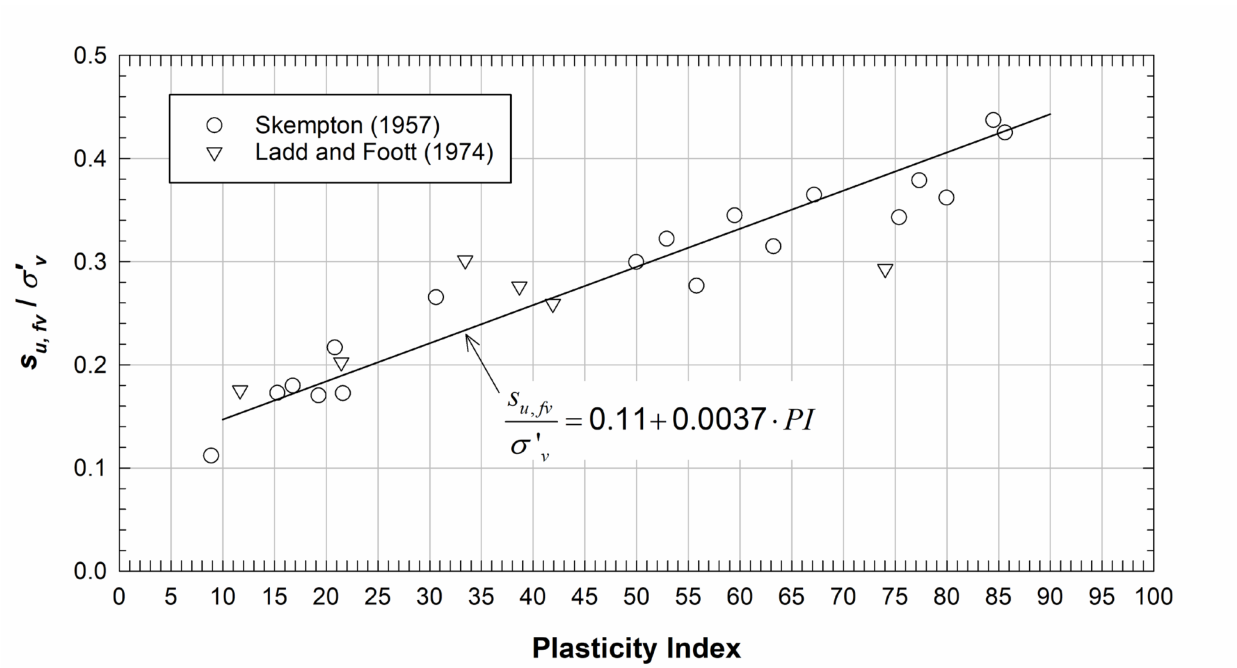


Figure 8-27 Correlation between Undrained Strength Ratio and Plasticity Index – Field Vane (after Robertson and Campanella 1984)

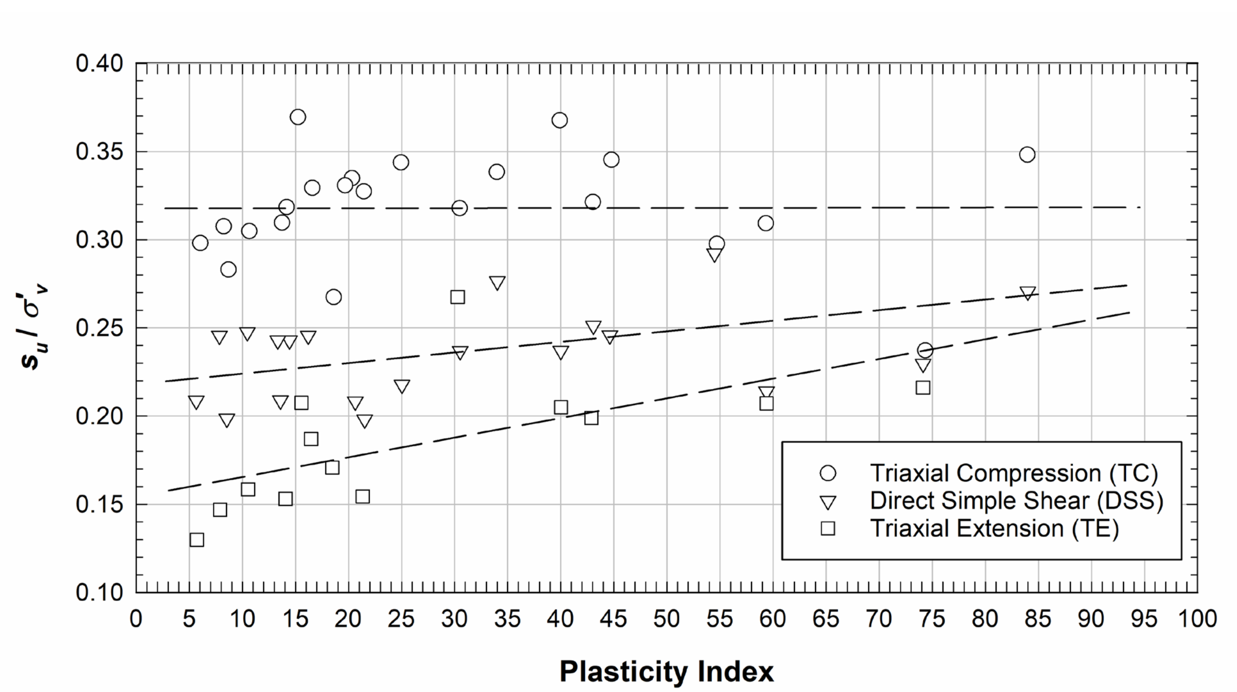


Figure 8-28 Correlation between Undrained Strength Ratio and Plasticity Index – Laboratory Testing (after Ladd and DeGroot 2004)

The data collected by Larson (1980), which is from field vane tests, agrees well with the Equation 8-19. Larson (1980) discusses various methods for correcting undrained strength measured using the vane shear but it is not clear whether or not the data in Figure 8-29 were corrected.

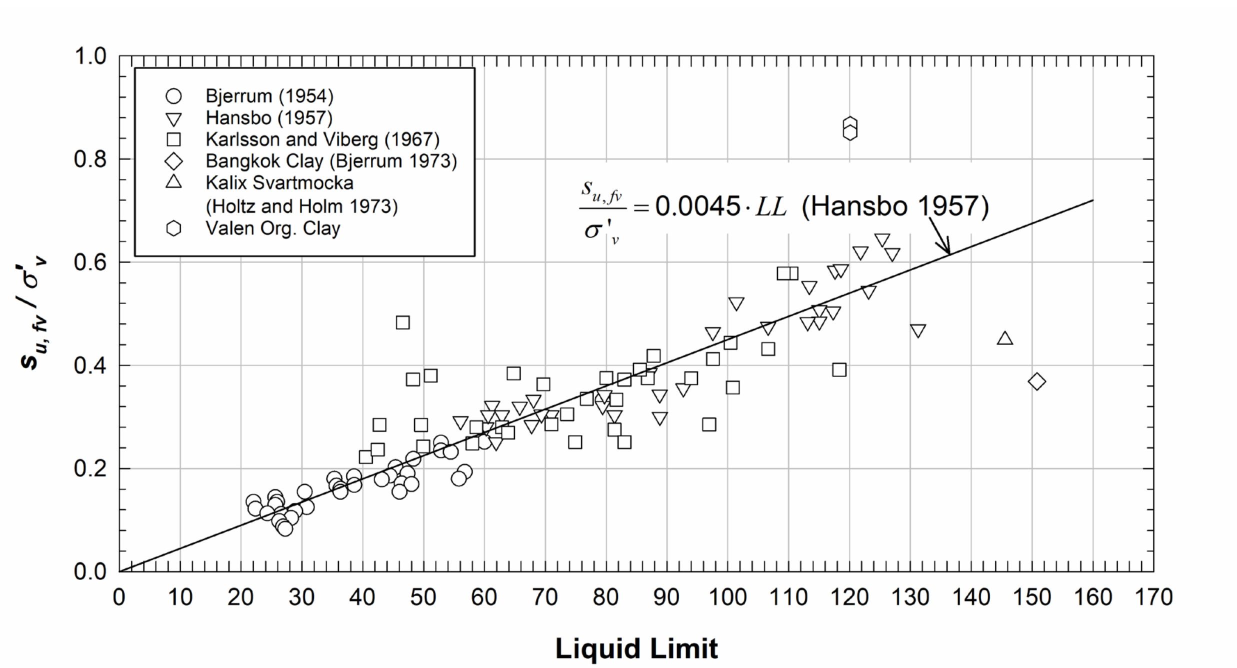


Figure 8-29 Variation of the Undrained Strength Ratio with Liquid Limit (after Larson 1980)

8-3.2 Correlations with Stress History.

Mesri (1975) corrected the results of vane shear tests from the literature with the vane correction factor proposed by Bjerrum (1972) and found that the undrained strength ratio for normally consolidated soil is relatively constant. Similarly, Jamiolkowski et al. (1985) found relatively constant values of normally consolidated undrained strength ratio for clays with PI less than 60. Chandler (1988) and Ladd and DeGroot (2004) also analyzed undrained strength data sets to determine typical values of undrained strength ratio for various types of clay. These trends are summarized in Table 8-7.

Overconsolidation results in an increase in the undrained shear strength. Schmertmann (1978) compared the undrained strength ratio for overconsolidated clays to that for normally consolidated clays as a function of OCR as summarized in Table 8-8 and Figure 8-30.

Table 8-7 Typical Normally Consolidated Undrained Strength Ratios

Source	NC Undrained Strength Ratio	Comments
Mesri (1975)	0.22 ± 0.03	Collection of vane shear test results
Jamiolkowski et al. (1985)	0.23 ± 0.04	Clays with PI less than 60 based on several embankment failures
Chandler (1988)	Range: 0.16 to 0.33 High value: 0.74 Mean (all): 0.28 Mean (discard extreme values): 0.22 ± 0.05	Based on the Mesri (1975) dataset of field vane shear tests on clay
Sabatini et al. (2002)	0.23	Saturated clay
	0.16	Soils with horizontal layering or features
Ladd and DeGroot (2004)	Nominally 0.20 Std. Dev. = 0.015	Sensitive cemented marine clays, Canadian Champlain clays (PI < 30%, LI > 1.5)
	$0.22+0.05\left(\frac{PI}{100}\right)$ Nominally 0.22	Homogeneous CL and CH sedimentary clays of low to moderate sensitivity, no shells or sand lenses layers (PI = 20 to 80%)
	0.16	Northeastern U.S. varved clays, direct simple shear failure mode
	Nominally 0.25 Std. Dev. = 0.05	Sedimentary deposits of silts and organic soils (Atterberg Limits plot below A-line) and clays with shells, excludes peat

Notes: PI = plasticity index, LI = liquid index
Shear strengths presented by Jamiolkowski et al. (1985) and Chandler (1988) were not corrected as required by ASTM D2573 and may be too high.

Table 8-8 Approximate Relation of Undrained Strength Ratio and OCR (after Schmertmann 1978)

OCR	Undrained Strength Ratio
Less than 1	0 – 0.1
1	0.10 – 0.25
1 to 1.5	0.26 – 0.50
3	0.51 – 1.00
6	1.00 – 4.00
Greater than 6	> 4.00

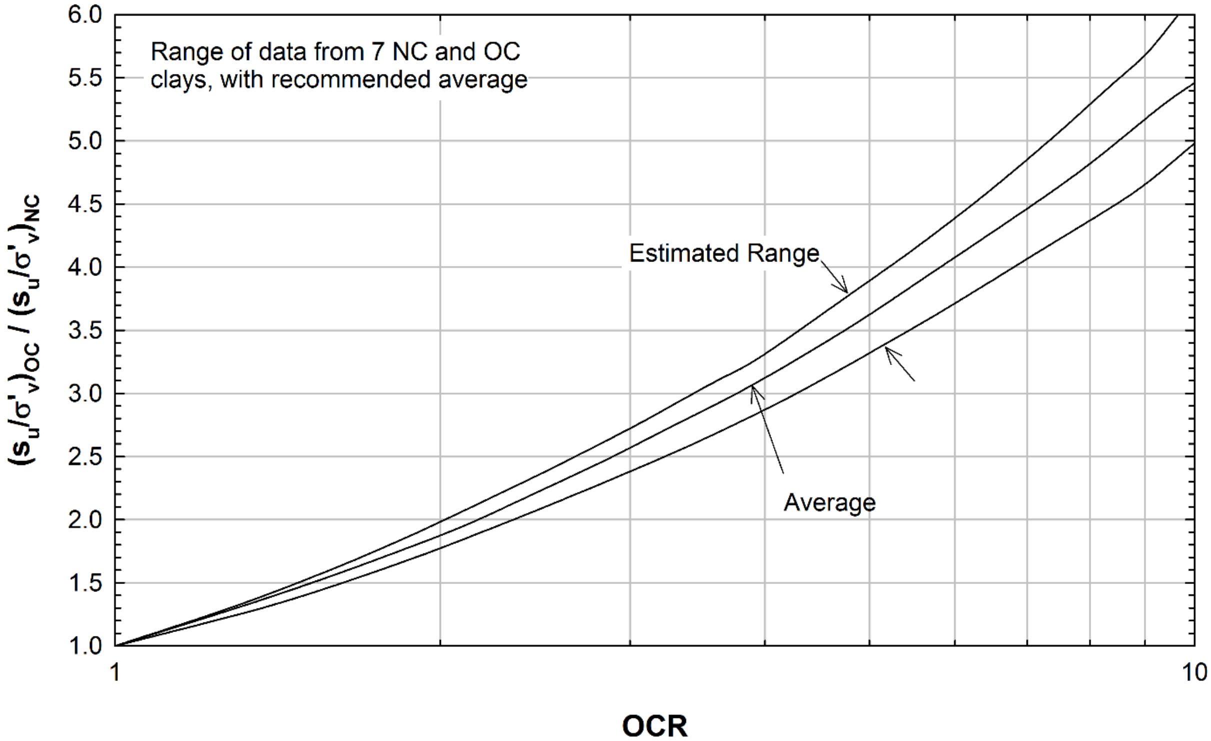


Figure 8-30 Normalized Undrained Strength Ratio vs. *OCR* (after Schmertmann 1978)

For overconsolidated clays, Jamiolkowski et al. (1985) and Ladd and DeGroot (2004) showed that the effects of stress history on the undrained shear strength ratio can be accounted for by:

$$\left(\frac{s_u}{\sigma'_v}\right)_{OC} = \left(\frac{s_u}{\sigma'_v}\right)_{NC} OCR^m \qquad \textbf{(8-20)}$$

where:
s_u = undrained shear strength (NC = normally consolidated, OC = overconsolidated),
σ'_v = vertical effective stress,
OCR = overconsolidation ratio, and
m = semi-empirical fitting parameter.

The value of m is theoretically related to the recompression and compression indices as shown by Roscoe et al. (1958) and Mitachi and Kitago (1976) for ideal or remolded soils.[14] For real soils, undrained laboratory shear strength tests on soil specimens at

[14] For this to be true, ideal or remolded soils must be assumed to follow the tenets of critical state soil mechanics. This assumption breaks down for soils exhibiting post-peak strain softening. This idealization also assumes that C_c and C_r are log-linear for all ranges of stresses and for any rebound pressure.

different values of OCR can be used to determine m. Ladd et al. (1977) observed that m is approximately 0.8 based on direct simple shear tests. Typical values for m are summarized in Table 8-9.

Table 8-9 Typical Values of *m*

Source	m	**Soil Description**
Roscoe et al. (1958), Mitachi and Kitago (1976)	$m \approx 1 - \frac{C_r}{C_c}$	Saturated clay (theoretical)
Jamiolkowski et al. (1985), Chandler (1988)	Range: 0.8 to 1.35 High value: 1.51 Mean (all): 1.03 Mean (discarding extreme values): 0.97	Field vane shear tests on clay
Sabatini et al. (2002)	0.8	Saturated clay
Ladd and DeGroot (2004)	1.00	Sensitive cemented marine clays, Canadian Champlain clays ($PI < 30\%$, $LI > 1.5$)
	$0.88 \cdot \left(1 - \frac{C_r}{C_c}\right) \pm 0.06$ Nominally 0.8	Homogeneous CL and CH sedimentary clays of low to moderate sensitivity, no shells or sand lenses layers (PI = 20 to 80%)
	0.75	Northeastern U.S. varved clays, direct simple shear failure mode
	$0.88 \cdot \left(1 - \frac{C_r}{C_c}\right) \pm 0.06$ Nominally 0.8	Sedimentary deposits of silts and organic soils with Atterberg Limits below the A-line and clays with shells, excludes peat
Note: C_c = compression index and C_r = recompression index		

For very soft clays with overconsolidation ratios less than 2, Sabatini et al. (2002) found that the undrained shear strength could be estimated as (assumes m equals 1):

$$s_u \approx 0.21\sigma'_p \qquad \textbf{(8-21)}$$

where:
s_u = undrained shear strength and
σ'_p = preconsolidation pressure.

The consolidation stress state in triaxial compression tests also influences the undrained shear strength. Based on data from 48 normally consolidated clays, Mayne (1985) found that the ratio was about 0.87 for undrained shear strengths from K_0 consolidated and isotropically consolidated undrained triaxial compression tests.

Kulhawy and Mayne (1990) examined the data and found that the normally consolidated undrained strength ratio for K0-consolidated tests can be related to the isotopically consolidated tests by:

$$\left(\frac{s_u}{\sigma'_v}\right)_{ACU} = 0.15 + 0.49\left(\frac{s_u}{\sigma'_v}\right)_{ICU} \quad \textbf{(8-22)}$$

where:
$(s_u / \sigma'_v)_{ACU}$ = undrained strength ratio in CK_0U triaxial compression, and
$(s_u / \sigma'_v)_{ICU}$ = undrained strength ratio in ICU triaxial compression.

8-3.3 Correlations with Cone Penetration Test.

Undrained shear strength is typically estimated from the cone tip resistance measured in the CPT using methods based on bearing capacity. The three methods are the N_c, N_k, and N_{kt} methods as defined by Lunne et al. (1997). The empirical bearing capacity factors (N_c, N_k, and N_{kt}) should be calibrated on a site- or region-specific basis by relating known values of undrained shear strength measured using the triaxial device (ASTM D2166, ASTM D2850), laboratory miniature vane shear (ASTM D4648), field vane shear (ASTM D2573), or direct simple shear (ASTM D6528) to the predicted values based on Equations 8-23 to 8-25.

The N_c method is the simplest and directly relates the CPT tip resistance to the undrained shear strength as:

$$s_u = \frac{q_c}{N_c} \quad \textbf{(8-23)}$$

where:
q_c = cone tip resistance, and
N_c = empirical bearing capacity factor.

In most cases, the value of N_c is in the range of 17 to 23 for normally consolidated and slightly overconsolidated clays. The N_c method may be less accurate than other methods at depths greater than 15 m because the overburden pressure is not considered.

The N_k method considers the overburden pressure acting at the point of the measurement. Based on this method, the undrained shear strength can be determined from CPT results as:

$$s_u = \frac{q_c - \sigma_v}{N_k} \quad \textbf{(8-24)}$$

where:
q_c = cone tip resistance,
σ_v = total vertical stress, and
N_k = empirical bearing capacity factor.

Data presented by Lunne and Kleven (1982), shows that N_k ranges from about 10 to about 19 with an average of 15. Carter and Bentley (2016) suggest values of 17 or 18 for normally consolidated clays and 20 for overconsolidated clays.

The N_{kt} method is a modification of the N_k method that considers the pore pressure acting at the tip of the cone. The undrained shear strength is calculated as:

$$s_u = \frac{q_t - \sigma_v}{N_{kt}} \quad \textbf{(8-25)}$$

where:
q_c = cone tip resistance,
σ_v = total vertical stress,
N_{kt} = empirical bearing capacity factor,
q_t = corrected tip resistance = $q_c + u \cdot (1+a)$,
u = pore pressure measured behind the cone tip, often called the u_2 position.
a = cone net area ratio = ratio of the face area to shoulder area.

Modern cones have net area ratios above 0.8 and little difference is typically observed in the N_k and N_{kt} methods. Values of N_{kt} are often in the range of 14 to 16.

8-3.4 Correlations with Standard Penetration Test.

Various attempts have been made to correlate the undrained shear strength of clays to SPT N values. Observed ranges of undrained shear strength based on soil consistency and N are summarized in Table 8-10.

Table 8-10 Approximate Undrained Shear Strength for Cohesive Soils Based on SPT N

Soil Consistency	SPT N Value	Undrained Shear Strength (psf)		
		Parcher and Means (1968)	Tschebotarioff (1973)	Terzaghi et al. (1996)
Very soft	< 2	300	-	< 250
Soft	2 – 4	300 – 600	250 – 500	250 – 500
Medium	4 – 8	600 – 1200	500 – 1000	500 – 1000
Stiff	8 – 15	1200 – 2400	1000 – 2000	1000 – 2000
Very stiff	15 – 30	2400	2000 – 4000	2000 – 4000
Hard	> 30	> 4500	> 4000	> 4000

Stroud and Butler (1975) developed a correlation for the undrained shear strength of overconsolidated clays as a function of the SPT N value. As shown in Figure 8-31, the relationship exhibits significant scatter, which reduces the reliability of the correlation. Carter and Bentley (2016) approximated the trendline in Figure 8-31 as:

$$\frac{s_u}{N} = \frac{8910}{PI^3} + 4.36 \quad \textbf{(8-26)}$$

where:
s_u = undrained shear strength (in kPa),
N = SPT-N value, and
PI = plasticity index.

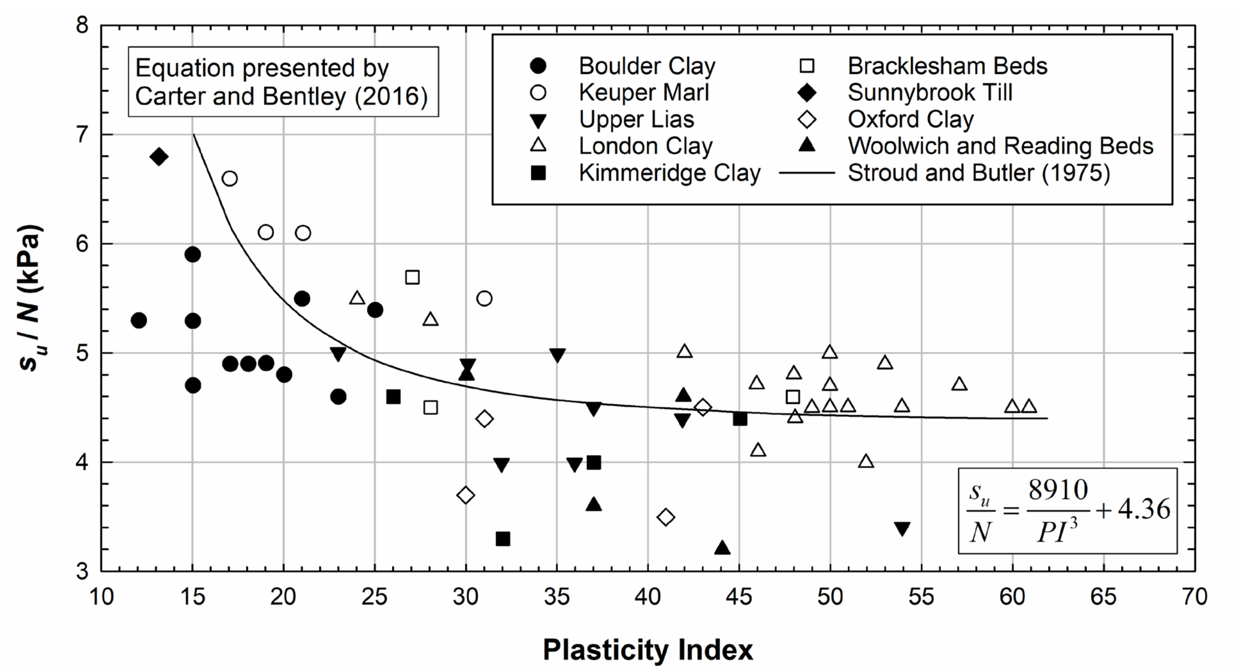


Figure 8-31 Correlation between Undrained Shear Strength, SPT N Value, and Plasticity Index for Overconsolidated Clays (after Stroud and Butler 1975)

Sowers (1979) correlated undrained shear strength to SPT N for different USCS soil classifications as presented in Figure 8-32. Relationships proposed by Hara et al. (1974) and Terzaghi and Peck (1967) are also presented in Figure 8-32. Hara et al.'s correlation is based on undrained shear strengths from triaxial compression tests.

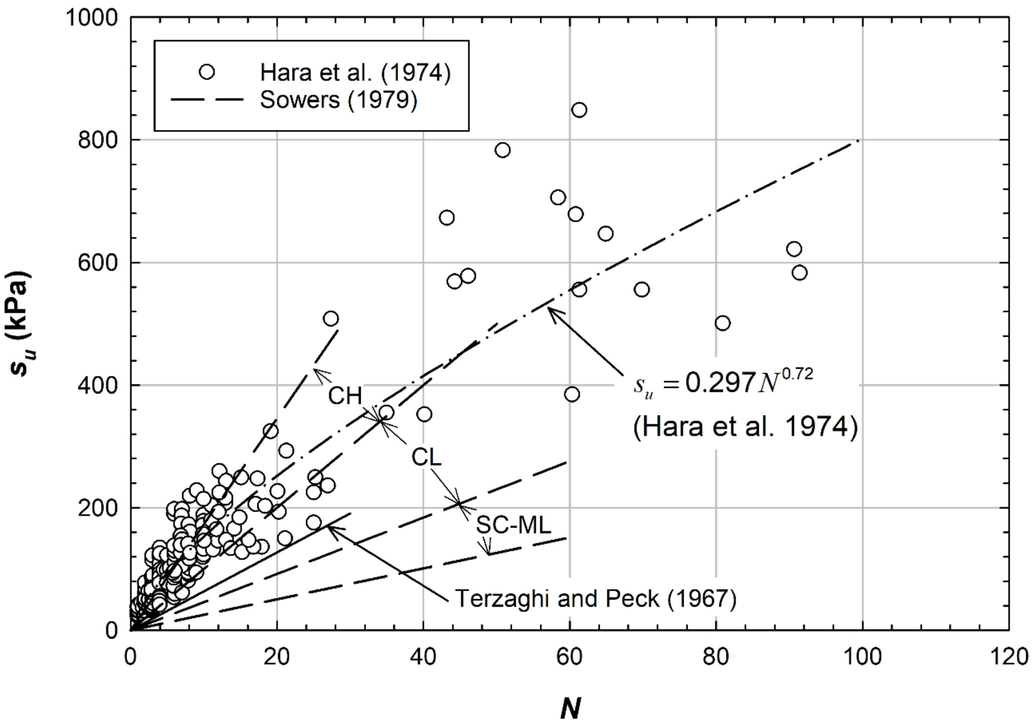


Figure 8-32 Relationship between Undrained Shear Strength and SPT N (after Terzaghi and Peck 1967, Hara et al. 1974, and Sowers 1979)

8-3.5 Correlations with Dilatometer.

The undrained shear strength of overconsolidated clays has been correlated to the horizontal stress index (K_D) and the dilatometer modulus (E_D) as summarized in Table 8-11.

Table 8-11 Undrained Shear Strength Correlations to Dilatometer

Undrained Strength Ratio or Undrained Shear Strength (kPa)	Source
$\left(\frac{s_u}{\sigma'_v}\right)_{OC} = \left(\frac{s_u}{\sigma'_v}\right)_{NC}\left(0.5K_D\right)^{1.25} \approx 0.22\left(0.5K_D\right)^{1.25}$	Marchetti (1980)
$\left(\frac{s_u}{\sigma'_v}\right)_{OC} = 0.35\left(0.47K_D\right)^{1.14}$	Kamei and Iwasaki (1995)
$s_u = 0.018E_D$	Iwasaki and Kamei (1994)
Note: s_u = undrained shear strength in kPa, σ'_v = vertical effective stress in kPa, K_D = horizontal stress index from dilatometer, and E_D = dilatometer modulus in kPa.	

8-4 CONSOLIDATION PARAMETERS.

8-4.1 Compression and Recompression Indices – Fine-Grained.

The *compression index* (C_c) is the slope of the virgin consolidation line of the e vs. log(σ'_v) plot. The *recompression index* (C_r) is the slope of the recompression line of the e vs. log(σ'_v) plot. These parameters are used to calculate the compression of the clay when subjected to an increase in stress in the normally consolidated and overconsolidated ranges (See Section 5-5.2.1). An alternative of the compression and recompression indices are the *modified compression index* ($C_{\varepsilon c}$) and *modified recompression index*, $C_{\varepsilon r}$ (a.k.a., compression and recompression ratio). The modified compression and recompression indices are equal to the compression and recompression indices divided by ($1+e_0$), respectively. These are the slopes of the compression and recompression curves when vertical strain is used instead of void ratio.

8-4.1.1 Typical Values.

Typical values of the compression index for different clays and silts are summarized in Table 8-12.

Table 8-12 Typical Values for C_c for Undisturbed Clays

Soil	C_c	Reference
Boston Blue Clay, undisturbed (CL)	0.35	Lambe and Whitman (1969)
Chicago clay undisturbed (CH)	0.42	
Cincinnati Clay (CL)	0.17	
Louisiana Clay, undisturbed	0.33	
New Orleans Clay, undisturbed (CH)	0.29	
Siburua clay (CH)	0.21	
Kaolinite	0.21 – 0.26	
Na-Montmorillonite (CH)	2.6	
Normally consolidated medium sensitive clays	0.2 – 0.5	Holtz and Kovacs (1981)
Organic silt and clayey silts (ML-MH)	1.5 – 4.0	
Organic clays (OH)	> 4.0	
Peat (Pt)	10 – 15	
Chicago silty clay (CL)	0.15 – 0.30	
Boston Blue Clay (CL)	0.3 – 0.5	
Vicksburg Buckshot Clay (CH)	0.5 – 0.6	
Swedish medium sensitive clays (CL-CH)	1 – 3	
Canadian Leda clays (CL-CH)	1 – 4	
Mexico City Clay	7 – 10	
San Francisco Bay Mud (CL)	0.4 – 1.2	
Bangkok Clays (CH)	0.4	
Uniform sand, loose (SP)	0.05 – 0.06	USACE (1990)
Uniform sand, dense (SP)	0.02 – 0.03	
Uniform silts (ML)	0.2	

8-4.1.2 Correlations with Index Properties.

Many relationships have been developed to estimate the compression and recompression indices based on parameters, such as water content, liquid limit, and void ratio. Some of these correlations are summarized in Table 8-13 and Table 8-14 and plotted in Figure 8-33 thru Figure 8-38. As can be seen from these plots, the presented correlations estimate values of compression and recompression indices that vary significantly. For the compression index, the correlations using the natural water content tend to be in closer agreement compared to those based on other index properties. Prior to use, the soil type(s) used to develop the correlations and the sensitivity of the project to errors in the prediction of settlement should be considered to determine if the intended application matches.

Leroueil et al. (1983) showed that the sensitivity of the clay also affects the value of the compression index, especially for marine deposits. The results presented in Figure 8-39 show a significant effect of the sensitivity on the compression index.

Lambe and Whitman (1969) presented typical ranges of the modified compression index of clays as a function of the natural water content and these are shown in Figure 8-40.

Table 8-13 Compression Index Correlations

Correlation	Comments	References
$C_c = 0.007(LL - 10)$	Remolded clays.	Skempton (1944)
$C_c = 0.0046(LL - 9)$	Clays from Sao Paulo, Brazil	Cozzolino (1961)
$C_c = LL^{1.673} / 2040$	Hong Kong soft marine clay	Lumb and Holt (1968)
$C_c = 0.0083(LL - 9)$	Remolded clays	Schofield and Wroth (1968)
$C_c = 0.003(LL - 10)$	Cohesive soils of the Rhone Alpes and Valley of the Seine River	Gielly et al. (1969)
$C_c = 0.006(LL - 9)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_c = 0.008(LL - 5)$	Dredging material	Salem and Krizek (1976)
$C_c = 0.00797(LL - 8.16)$	Indiana soils	Lo and Lovell (1982)
$C_c = 0.01(LL - 13)$	All clays	USACE (1990)
$C_c = 0.009(LL - 10)$	Undisturbed clay of sensitivity less than 4. Reliability 30%	Terzaghi et al. (1996)
$C_c = 1.15(e_0 - 0.91)$	All clays (Lower limit)	Nishida (1956)
$C_c = 0.30(e_0 - 0.27)$	Inorganic silty clays	Hough (1957)

Table 8 13 (cont.) Compression Index Correlations

Correlation	Comments	References
$C_c = 0.256 + 0.43(e_0 - 0.84)$	Brazilian motley clays	Cozzolino (1961)
$C_c = 1.21 + 1.055(e_0 - 1.87)$	Brazilian soft silty clays	
$C_c = 0.75(e_0 - 0.50)$	Soils of very low plasticity	Sowers (1970)
$C_c = 0.40(e_0 - 0.25)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_c = 0.22 + 0.29e_0$	Weathered and soft Bangkok clays	Adikari (1977)
$C_c = 0.575e_0 - 0.241$	French clays	Vidalie (1977)
$C_c = 0.5363(e_0 - 0.411)$	Indiana soils	Goldberg et al. (1979)
$C_c = 0.5673(e_0 - 0.4422)$	Wabash Lowland	
$C_c = 0.4941(e_0 - 0.3507)$	Crawford Upland	
$C_c = 0.5621(e_0 - 0.4215)$	Outwash and alluvial deposits	
$C_c = 0.496e_0 - 0.195$	Indiana soils	Lo and Lovell (1982)
$C_c = 0.3745e_0$	Saturated clays	Rendon-Herrero (1983)
$C_c = 0.434(e_0 - 0.336)$	Soils from nine states in the USA	
$C_c = 0.85\left(w_n/100\right)^{3/2}$	Finnish muds and clays	Helenelund (1951)
$C_c = 0.01404w_n - 0.189$	All clays	Nishida (1956)
$C_c = 0.01w_n$	Chicago and Canada clays	Koppula (1981)
$C_c = 0.01(w_n - 5)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_c = 0.008w_n + 0.2$	Weathered and soft Bangkok clays	Adikari (1977)
$C_c = 0.0147w_n - 0.213$	French clays	Vidalie (1977)
$C_c = 0.0133w_n - 0.1621$	Crawford Upland	Goldberg et al. (1979)
$C_c = 0.0126w_n - 0.162$	Indiana soils	Lo and Lovell (1982)
$C_c = 0.01w_n - 0.07549$	Soils from nine states in the USA	Rendon-Herrero (1983)
$C_c = 0.0115w_n$	Organic soils, peats	USACE (1990)
$C_c = 0.012w_n$	All Clays	
$C_c = 0.135PI$	Remolded clays	Wroth and Wood (1978)
$C_c = 0.005PI \cdot G_s$		

Table 8 13 (cont.) Compression Index Correlations

Correlation	Comments	References
$C_c = 0.37(e_0 + 0.003LL - 0.34)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_c = 0.009e_0 + 0.008LL + 0.20$	Weathered and soft Bangkok clays	Adikari (1977)
$C_c = 0.0101(e_0 LL - 0.5765LL + 12.665)$	Crawford Upland	Goldberg et al. (1979)
$C_c = 0.40(e_0 + 0.001w_n - 0.25)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_c = 0.009w_n + 0.002LL - 0.1$		
$C_c = 0.0129(w_n + 0.1015LL - 16.1875)$	Indiana soils	Goldberg et al. (1979)
$C_c = 0.0114(w_n + 0.2491LL - 18.8134)$	Crawford Upland	Goldberg et al. (1979)
$C_c = 0.0082w_n + 0.0043CF - 0.1403$	Cohesive soils in Alberta, Canada	Koppula (1981)
$C_c = 0.37(e_0 + 0.003LL + 0.0004w_n - 0.34)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_c = 0.0153(w_n + 0.1022LL - 0.3104PL - 11.623)$	Indiana soils	Goldberg et al. (1979)
$C_c = 0.5684(e_0 + 0.033LL - 0.0082PL + 0.0329\sigma'_p - 0.4322)$		
$C_c = 0.6076(e_0 + 0.003LL - 0.0095PL + 0.43\sigma'_p - 0.4186)$	Outwash and alluvial deposits	
$C_c = 0.0025CF + 0.1165e_0 + 0.0036w_n + 0.0014PI + 0.0009PL - 0.997$	Cohesive soils in Alberta, Canada	Koppula (1981)
$C_c = 0.5\left(\left(1+e_0\right)/G_s\right)^{2.4}$	Saturated clay	Al-Khafaji and Andersland (1992)
$C_c = 0.0121 \cdot w_n \cdot G_s$	Saturated sediment fine-grained soil	Rendon-Herrero (1983)
$C_c = 0.185\left[\left(1+e_0\right)^2/G_s - 0.144\right]$	Soils from nine states in USA	
$C_c = 0.489\left[\ln\left(\frac{\left(1+e_0\right)^2}{G_s}\right) + 0.296\right]$		
$C_c = 0.141G_s^{1.2}\left(\frac{1+e_0}{G_s}\right)^{2.382}$		

Table 8-14 Recompression Index Correlations

Correlation	Comments	References
$C_r = 0.0045LL$	Marine clays of Southeast Asia	Cox (1968)
$C_r = 0.002(LL + 9)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_r = 0.00463LL - 0.013$	Bangkok clays	Balasubramaniam and Brenner (1981)
$C_r = 0.00238LL + 0.0294$	Indiana soils	Lo and Lovell (1982)
$C_r = 0.208e_0 + 0.0083$	Chicago clays	Peck and Reed (1954)
$C_r = 0.156e_0 + 0.0107$	Inorganic and organic clayey and silty soil	Elnaggar and Krizek (1970)
$C_r = 0.14(e_0 + 0.007)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_r = 0.2037(e_0 - 0.2465)$	Indiana soils	Goldberg et al. (1979)
$C_r = 0.221(e_0 - 0.3074)$	Wabash Lowland	
$C_r = 0.152e_0 + 0.0125$	Indiana soils	Lo and Lovell (1982)
$C_r = 0.0043w_n \delta_{Vm}$	Marine clays of Southeast Asia	Cox (1968)
$C_r = 0.003(w_n + 7)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_r = 0.0039w_n + 0.013$ for $w_n < 100\%$	French clays	Vidalie (1977)
$C_r = 0.403\log(w_n) - 0.478$		
$C_r = 0.0065(w_n - 11.6361)$	Wabash Lowland	Goldberg et al. (1979)
$C_r = 0.00566w_n - 0.037$	Bangkok clays	Balasubramaniam and Brenner (1981)
$C_r = 0.003w_n + 0.0249$	Indiana soils	Lo and Lovell (1982)
$C_r = PI/370$	Remolded clays	Wroth and Wood (1978)
$C_r = 0.126(e_0 + 0.003LL - 0.06)$	Clays for Greece and USA	Azzouz et al. (1976)
$C_r = 0.142(e_0 - 0.0009w_n + 0.006)$		
$C_r = 0.0034(e_0 w_n + 8.3647)$	Wabash Lowland	Goldberg et al. (1979)
$C_r = 0.0033(e_0 w_n + 12.5168))$	Crawford Upland	
$C_r = 0.003w_n + 0.0006LL + 0.004$	Clays for Greece and USA	Azzouz et al. (1976)
$C_r = 0.135(e_0 + 0.01LL - 0.002w_n - 0.06)$		

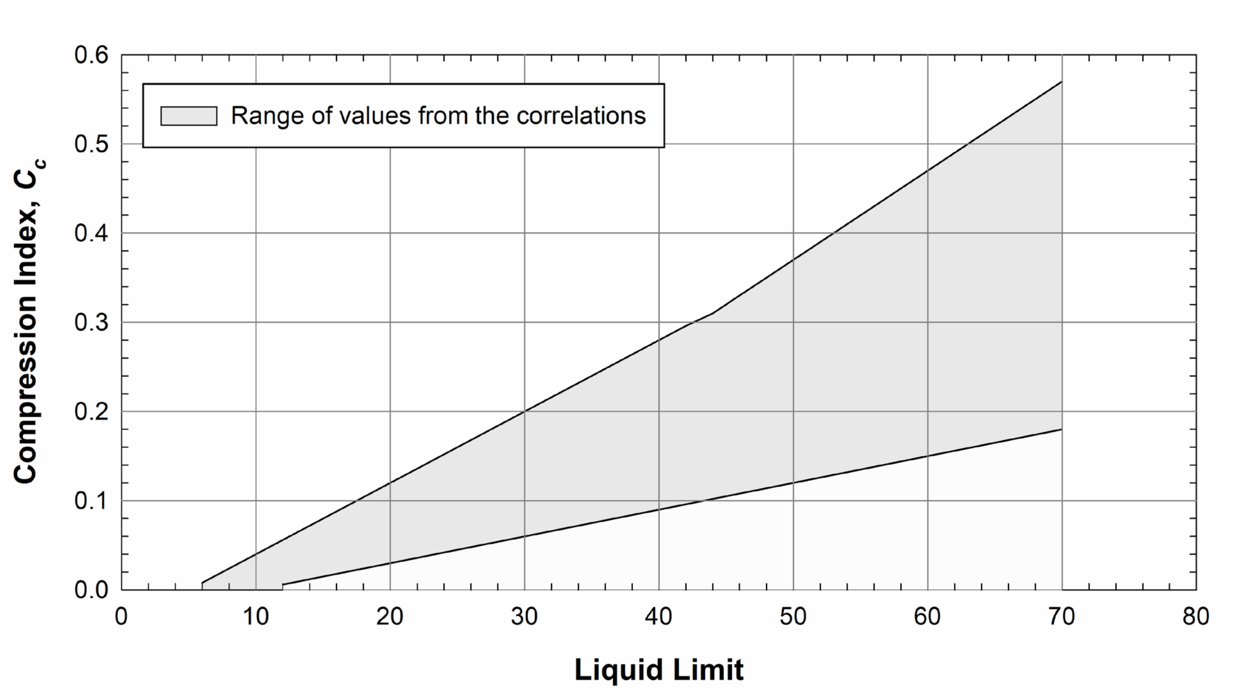


Figure 8-33 Range of Compression Index based on Liquid Limit Predicted by Correlations

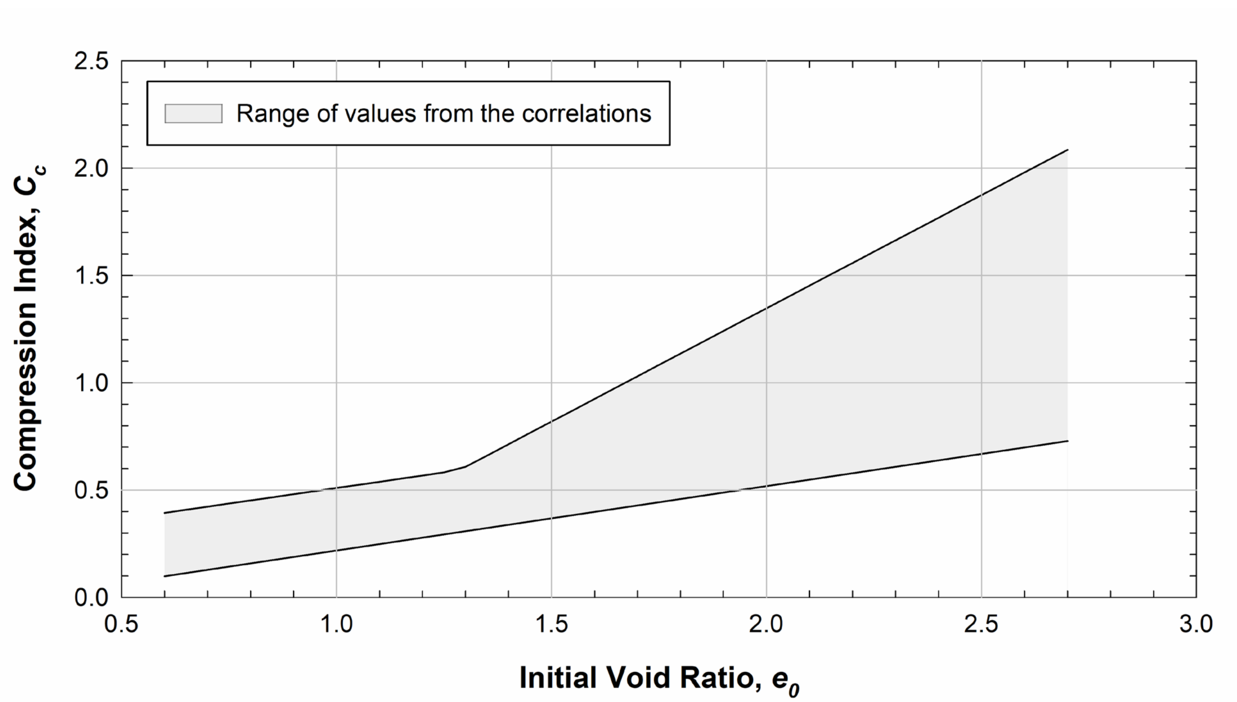


Figure 8-34 Range of Compression Index based on Initial Void Ratio Predicted by Correlations

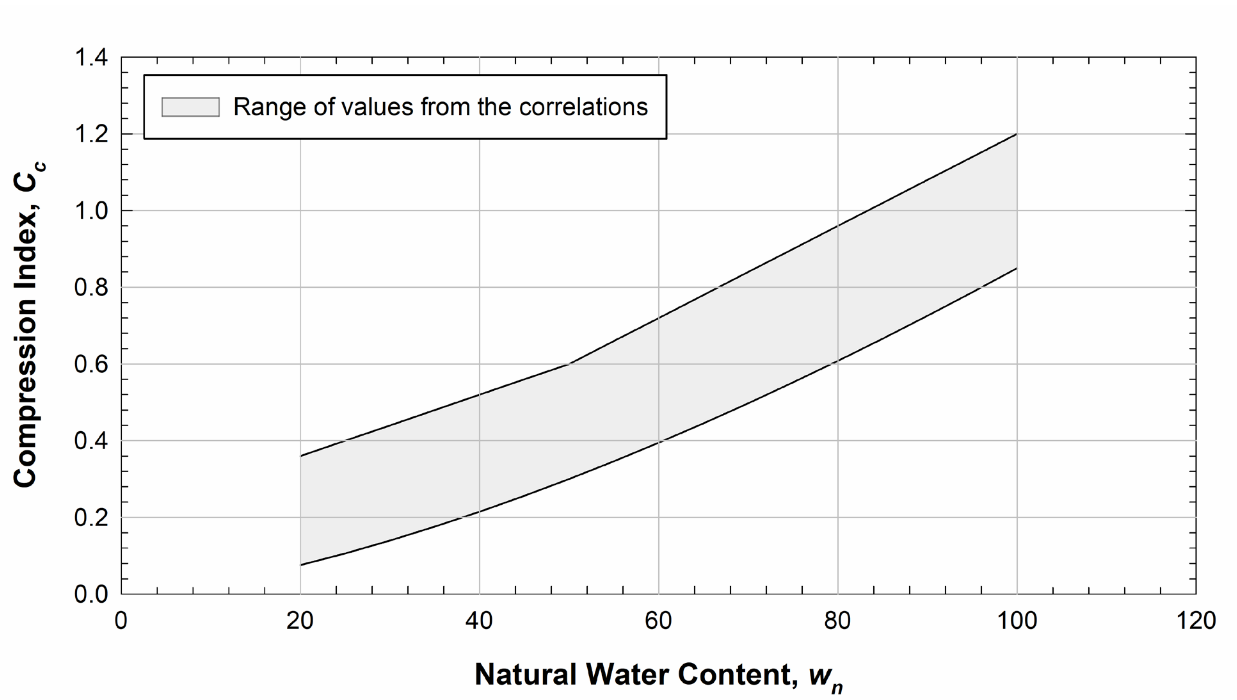


Figure 8-35 Range of Compression Index based on Natural Water Content Predicted by Correlations

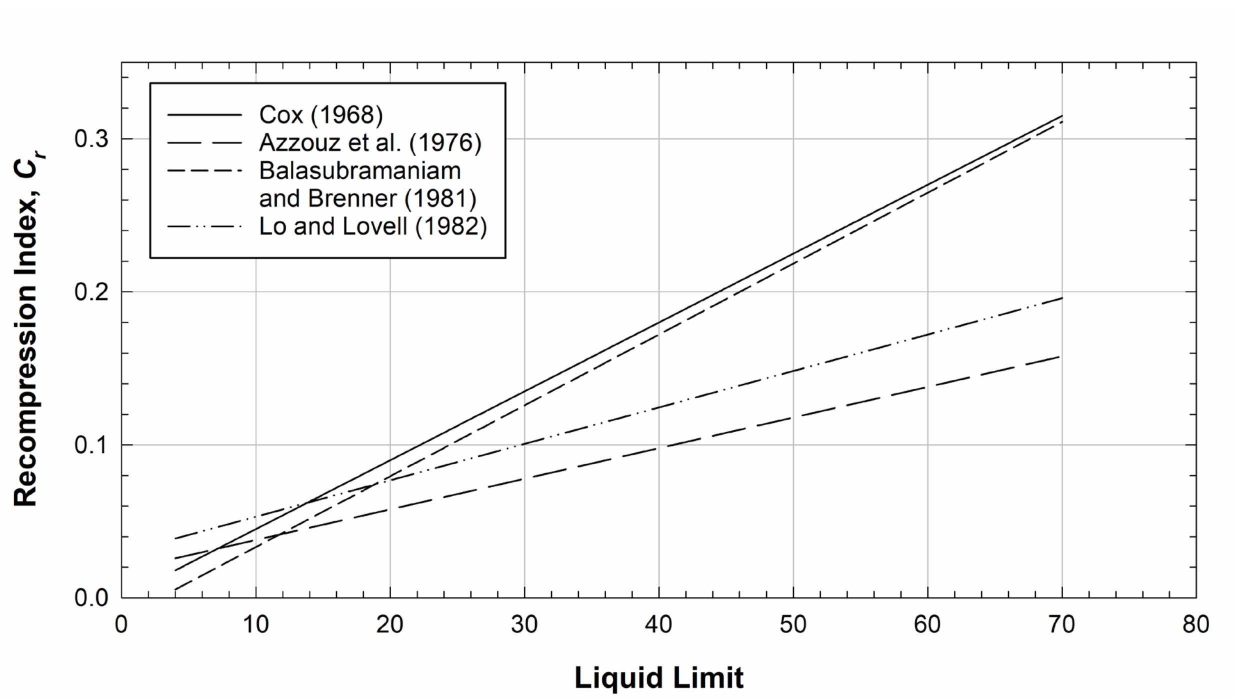


Figure 8-36 Correlations for Recompression Index based on Liquid Limit

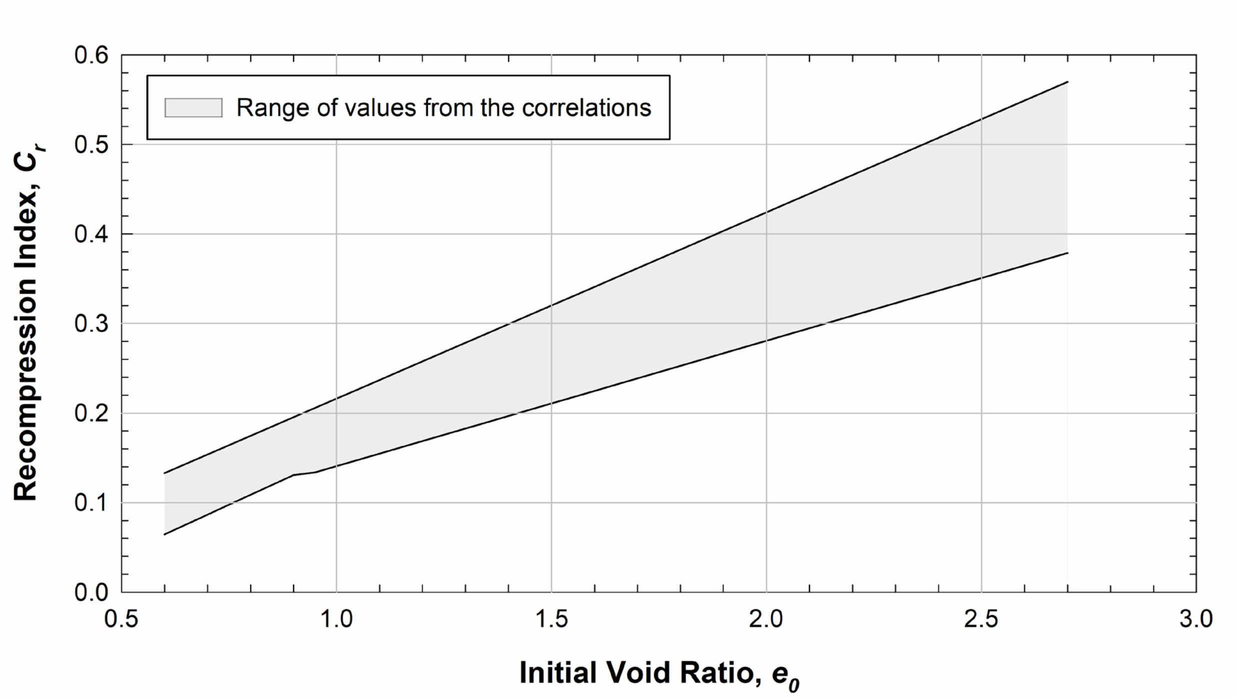


Figure 8-37 Range of Recompression Index based on Initial Void Ratio Predicted by Correlations

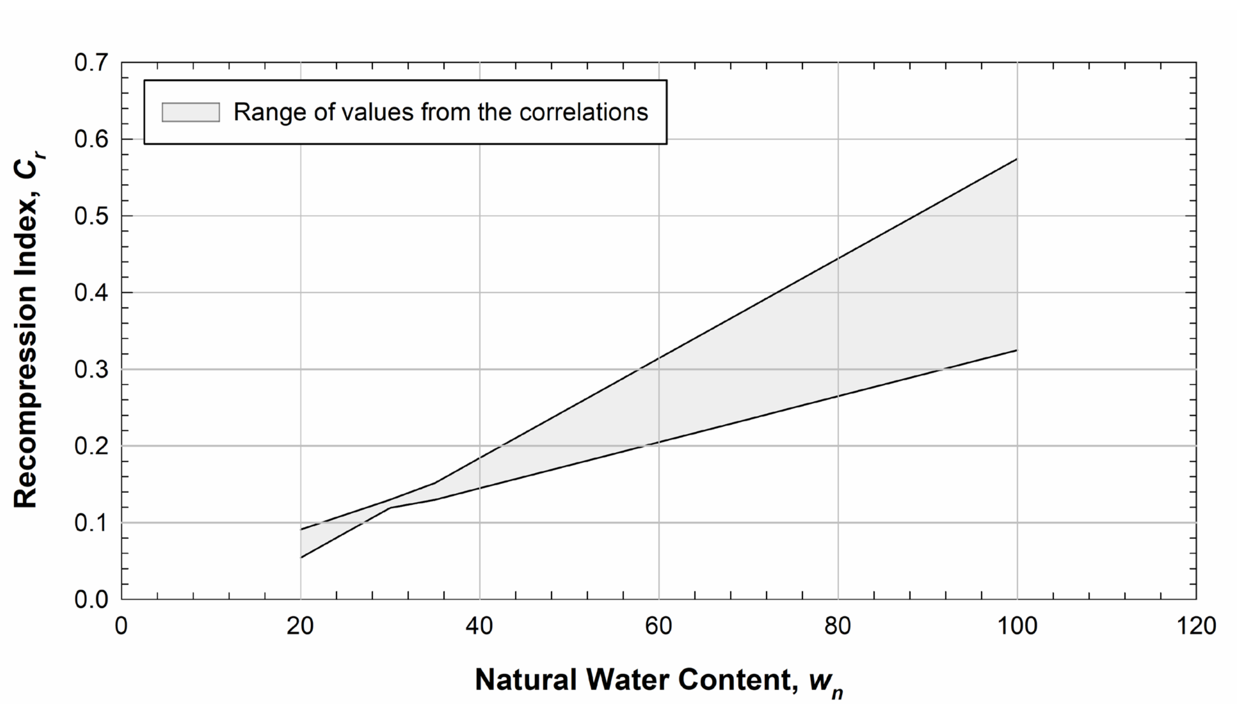


Figure 8-38 Range of Recompression Index based on Natural Water Content Predicted by Correlations

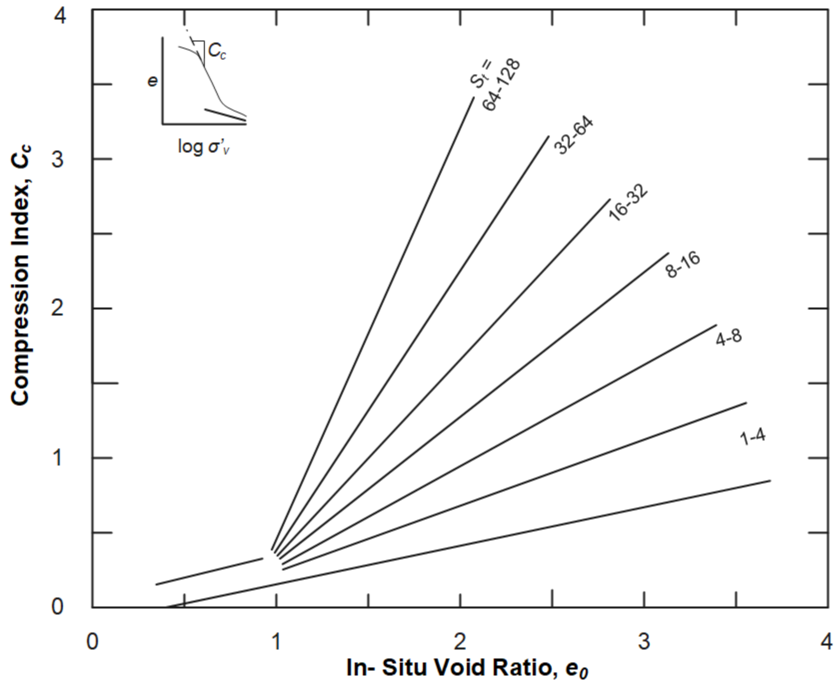


Figure 8-39 Sensitivity (S_t), *In situ* Void Ratio, and Compression Index Relationship (after Leroueil et al. 1983)

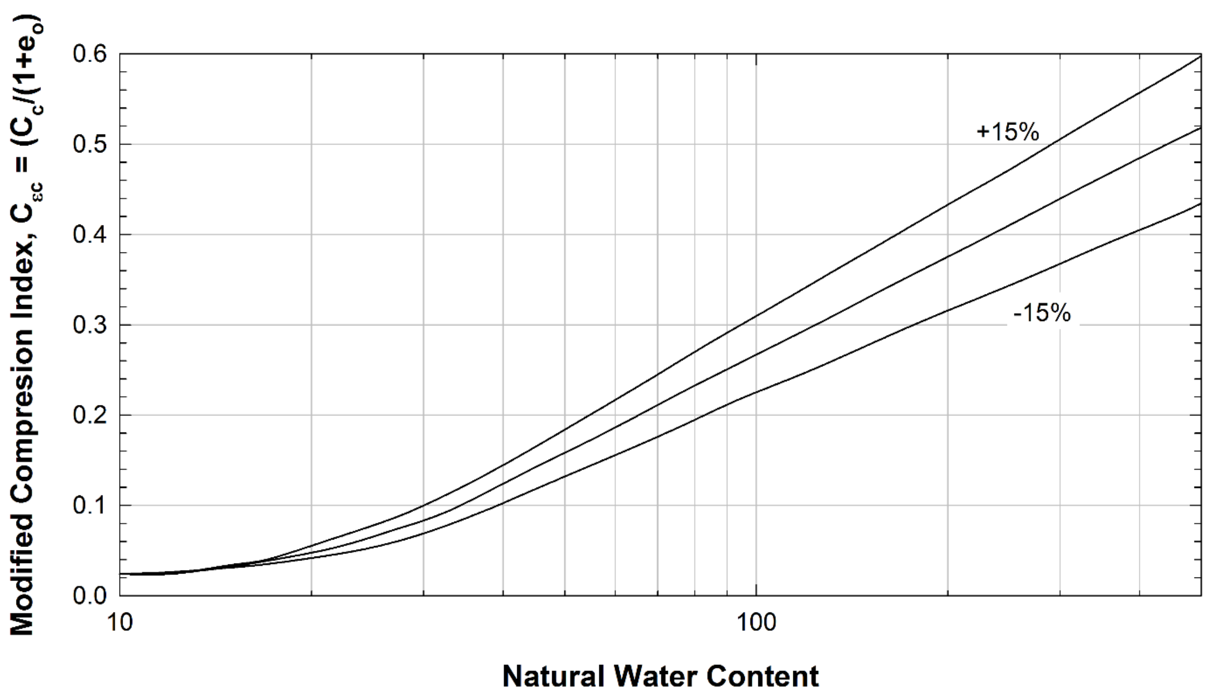


Figure 8-40 Correlation between Modified Compression Index and Water Content (after Lambe and Whitman 1969)

Burland (1990) compiled data from normally consolidated clays, both undisturbed and reconstituted at a liquidity index ranging from 1 to 1.5. Recognizing that vertical stresses between 100 and 1000 kPa control most consolidation calculations, he defined the normally consolidated void ratios at these stresses as e^*_{100} and e^*_{1000}, respectively. From these void ratios, the intrinsic compression index was defined as:

$$C_c^* = e_{100}^* - e_{1000}^* \quad \textbf{(8-27)}$$

where:
C^*_c = intrinsic compression index,
e^*_{100} = intrinsic void ratio at 100 kPa, and
e^*_{1000} = intrinsic void ratio at 1000 kPa.

By normalizing the current void ratio with respect to e^*_{100}, Burland defined the void index as:

$$I_v = \frac{e - e_{100}^*}{C_c^*} \quad \textbf{(8-28)}$$

where:
I_v = void index,
e = void ratio,
e^*_{100} = intrinsic void ratio at 100 kPa, and
C^*_c = intrinsic compression index.

With the data normalized in this way, he defined the *sedimentation compression line* (SCL) and *intrinsic compression line* (ICL), which describe the typical variation of the *in situ void index* (I_{v0}) with effective stress for a wide range of clays. The SCL represents the typical relationship for the compression of naturally sedimented clays. The ICL represents the typical relationship for the compression of remolded clays. Burland's SCL and ICL are plotted in Figure 8-41.

While the values of e^*_{100} and C^*_c are best determined from laboratory tests, Burland (1990) found that these parameters could be estimated from the void ratio at the liquid limit (e_L) by:

$$e_{100}^* = 0.109 + 0.679e_L - 0.089e_L^2 + 0.016e_L^3 \quad \textbf{(8-29)}$$

and

$$C_c^* = 0.256e_L - 0.04 \quad \textbf{(8-30)}$$

where:
e^*_{100} = intrinsic void ratio at 100 kPa,
e_L = void ratio at water content equal to the liquid limit, and
C^*_c = intrinsic compression index.

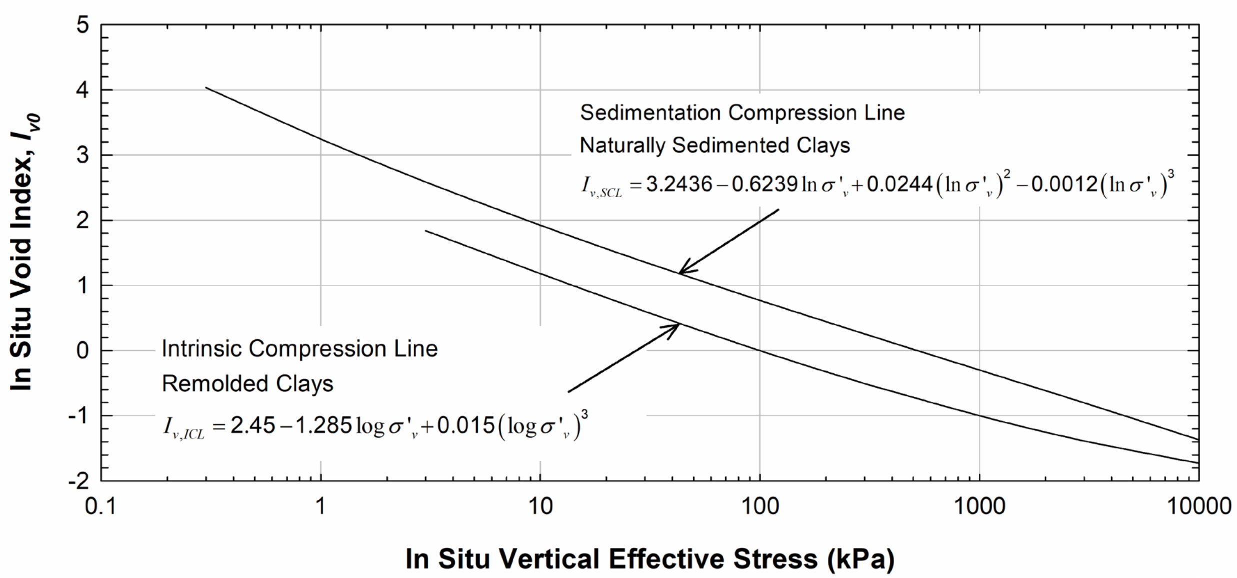


Figure 8-41 Sedimentation and Intrinsic Compression Lines (after Burland 1990)

Using Equations 8-28 through 8-30 and the relationships shown in Figure 8-41, the virgin consolidation line can be approximated solely based on liquid limit for both freshly deposited soils (using ICL) or structured, aged deposits (using SCL). This approach is particularly useful for validation of laboratory consolidation tests. Examples of the ICL and SCL for liquid limits ranging from 25 to 125 are plotted in Figure 8-42.

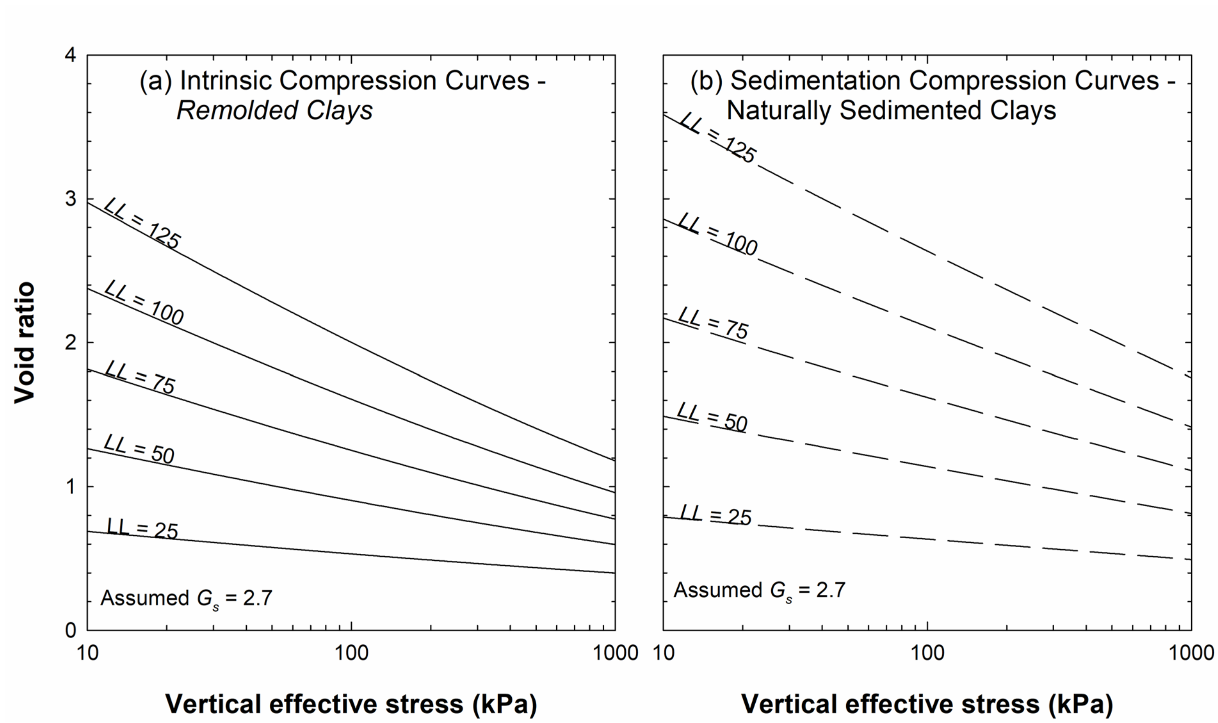


Figure 8-42 \1\ Example *NC* Compression Curves based on a) Intrinsic Compression Line and b) Sedimentation Compression Line /1/

8-4.2 Compression and Recompression Indices – Coarse-Grained.

The compressibility of coarse-grained soils is normally significantly smaller than that from fine-grained soils. The compressibility of coarse-grained soils is not typically defined in terms of the compression and recompression indices. Instead the modulus-based methods presented in Chapter 5 are employed. The constrained modulus for coarse-grained soils is usually stress dependent (Kulhawy and Mayne 1990) and may be estimated using correlations in the following section. If required, typical values for the modified compression index of coarse-grained soils are summarized in Table 8-15 and Table 8-16.

Table 8-15 Modified Compression Indices for Saturated, Normally Consolidated Sands (after Burmister 1962, Coduto et al. 2011)

Soil Type	$C_{\varepsilon c} = C_c / (1+e_0)$					
	$D_r = 0\%$	$D_r = 20\%$	$D_r = 40\%$	$D_r = 60\%$	$D_r = 80\%$	$D_r = 100\%$
Medium to coarse sand (SW & SP)	0.010	0.008	0.006	0.005	0.003	0.002
Fine to coarse sand (SW)	0.011	0.009	0.007	0.005	0.003	0.002
Fine to medium sand (SW & SP)	0.013	0.010	0.008	0.006	0.004	0.003
Fine sand (SP)	0.015	0.013	0.010	0.008	0.005	0.003
Fine sand with little fine to coarse silt (SM)	0.017	0.014	0.012	0.009	0.006	0.003

Table 8-16 Compressibility Data for Six Sands (Been et al. 1987)

Sand	e_0	C_c		C_r
		$\sigma'_v / P_a = 1$ to 3	$\sigma'_v / P_a = 20$ to 30	
Monterrey 0	0.854	0.021	0.085	0.006
	0.782	0.018	0.090	0.007
Ticino	0.917	0.025	0.130	0.007
	0.827	0.026	0.085	0.006
Hokksund	0.870	0.024	0.095	0.005
	0.790	0.018	0.056	0.005
Ottawa	0.760	0.025	0.030	0.007
	0.560	0.005	0.100	0.003
Reid-Bedford	0.900	0.013	0.090	0.005
	0.650	0.005	0.019	0.003
Hilton Mines	0.950	0.038	0.210	0.009
	0.732	0.022	0.100	0.006

8-4.3 Constrained Modulus.

The secant drained constrained modulus (M_{ds}) was found to be a function of the vertical effective stress (σ'_v) and a modulus number (m) by Janbu (1963). The constrained modulus for normally consolidated clays, silts, and sands is related in either a linear or nonlinear fashion to vertical effective stress by:

$$M_{ds} = m \cdot \sigma'_v \qquad \textbf{(8-31)}$$

or

$$M_{ds} = m \cdot P_a \cdot \left(\frac{\sigma'_v}{P_a} \right)^{0.5} \qquad \textbf{(8-32)}$$

where:
M_{ds} = constrained modulus,
m = modulus number,
σ'_v = vertical effective stress, and
P_a = atmospheric pressure (same units as M_{ds} and σ'_v).

Janbu (1963) related the modulus number to the void ratio (or porosity) and the natural water content as shown in Figure 8-43 and Figure 8-44, respectively. In addition, Janbu (1985) presented the relationship for the modulus number of NC silts and sands as a function of the porosity, as presented in Figure 8-45.

8-4.3.1 Correlations with Standard Penetration Test.

Based on results from nine British clays, Stroud (1974) correlated the constrained modulus of clays to the SPT N value as:

$$M_{ds} = f \cdot N \cdot P_a \qquad \textbf{(8-33)}$$

where:
M_{ds} = constrained modulus,
f = empirical coefficient related to plasticity index from Figure 8-46,
P_a = atmospheric pressure, and
N = SPT blow count.

According to Kulhawy and Mayne (1990), Stroud’s correlation is not very reliable and should be used with caution.

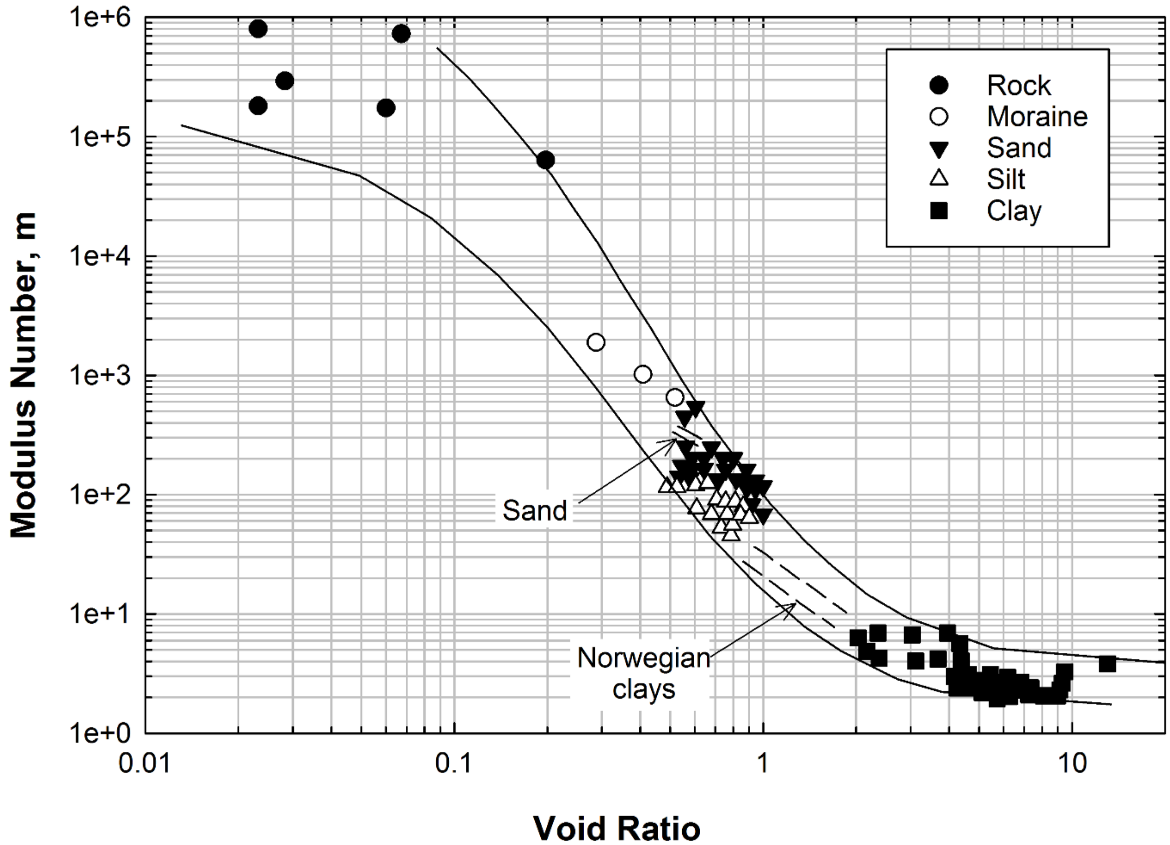


Figure 8-43 Relationship between Modulus Number and Void Ratio for *NC* Soils (after Janbu 1963)

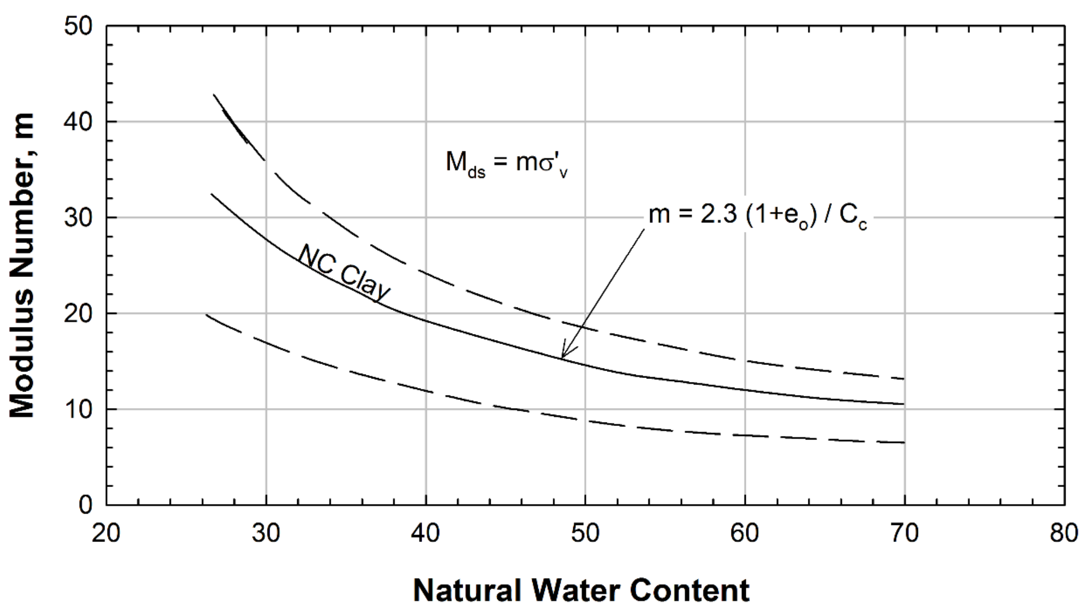


Figure 8-44 Modulus Number for *NC* Clays (after Janbu 1985)

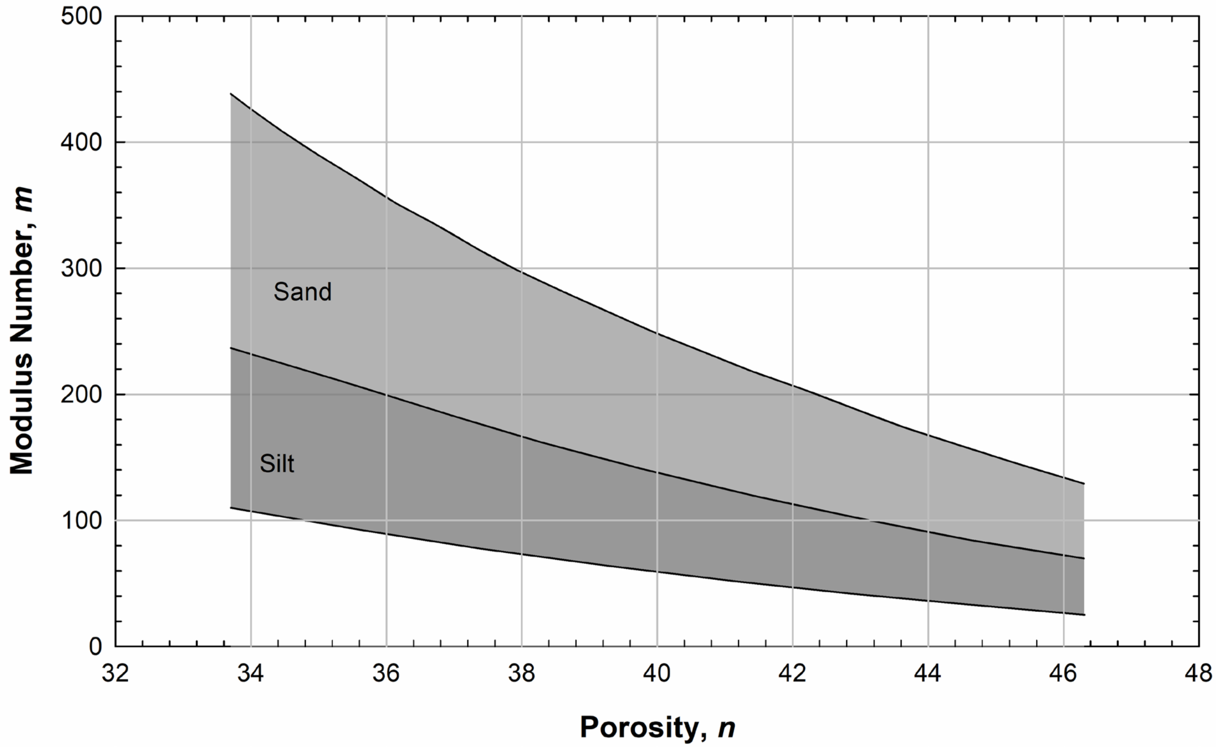


Figure 8-45 Modulus Number for *NC* Silts and Sands (after Janbu 1985)

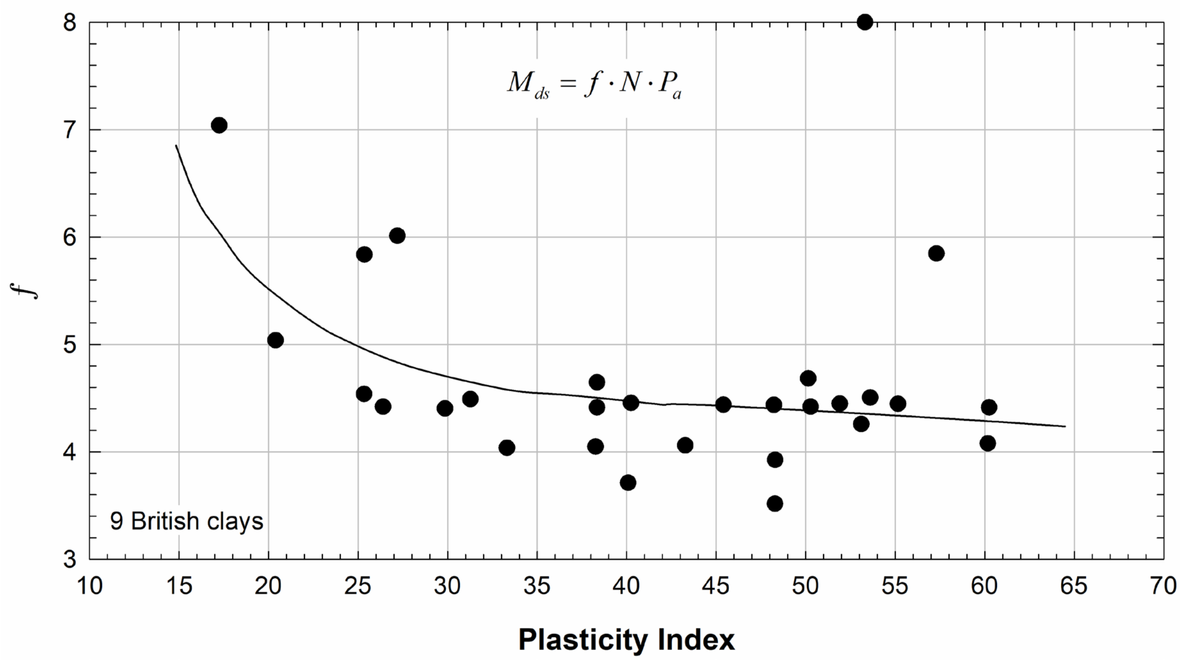


Figure 8-46 Variation of Empirical Coefficient *f* used for Calculating Constrained Modulus with *PI* (after Stroud 1974)

8-4.3.2 Correlations with Cone Penetration Test.

Numerous correlations have been presented to estimate the value of constrained modulus using the results from the cone penetration tests. Most of these correlations use the form of the equation shown below:

$$M_{ds} = \alpha \cdot q_c \tag{8-34}$$

where:
M_{ds} = constrained modulus,
q_c = cone tip resistance, and
α = empirical coefficient.

Mitchell and Gardner (1975) compiled values of α for different soils and showed that α can range from 0.4 to 8. In most cases, α is between 1 and 3. These values were obtained using a variety of cones with different geometries and testing procedures.

Kulhawy and Mayne (1990) presented the correlation shown in Figure 8-47 to obtain the constrained modulus of clays based on CPTu data in the form of tip resistance corrected for pore pressure and overburden stress.

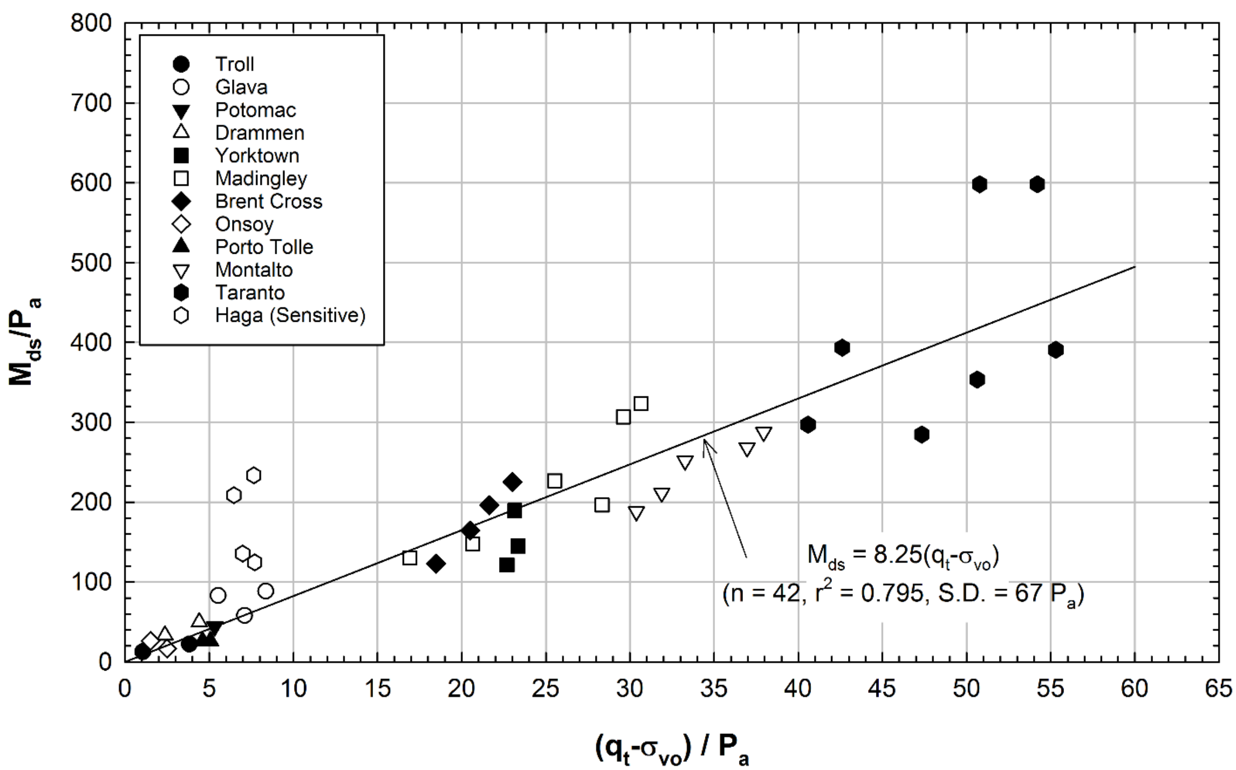


Figure 8-47 Correlation between Normalized Constrained Modulus and Normalized q_t from CPTu for Clays (after Kulhawy and Mayne 1990)

8-4.4 Coefficient of Secondary Compression.

The coefficient of secondary compression defines the settlement as a function of time after primary consolidation is completed. As with the compression ratios, the coefficient of secondary compression can be defined as a function of strain ($C_{\varepsilon\alpha}$) or as a function of the void ratio (C_{α}). See Section 5-5.4 for more details.

Mesri (1973) summarized the data shown in Figure 8-48 to estimate the coefficient of secondary compression of NC clays using the natural water content. Based on that data, the modified coefficient of secondary compression can be estimated as:

$$C_{\varepsilon\alpha} = 0.0001 \cdot w_n \quad \textbf{(8-35)}$$

where:
$C_{\varepsilon\alpha}$ = secondary compression ratio and
w_n = natural water content.

According to Kulhawy and Mayne (1990), $C_{\varepsilon\alpha}$ ranges from 0.0005 and 0.001 for most overconsolidated clays. The ratio of the coefficient of secondary compression to the compression index ($C_{\alpha} / C_c = C_{\varepsilon\alpha} / C_{\varepsilon c}$) is more or less constant for a given soil (Mesri and Godlewski 1977). Values of C_{α} / C_c are summarized in Table 8-17. Another correlation for the coefficient of correlation for silts and clays is presented in Figure 8-49.

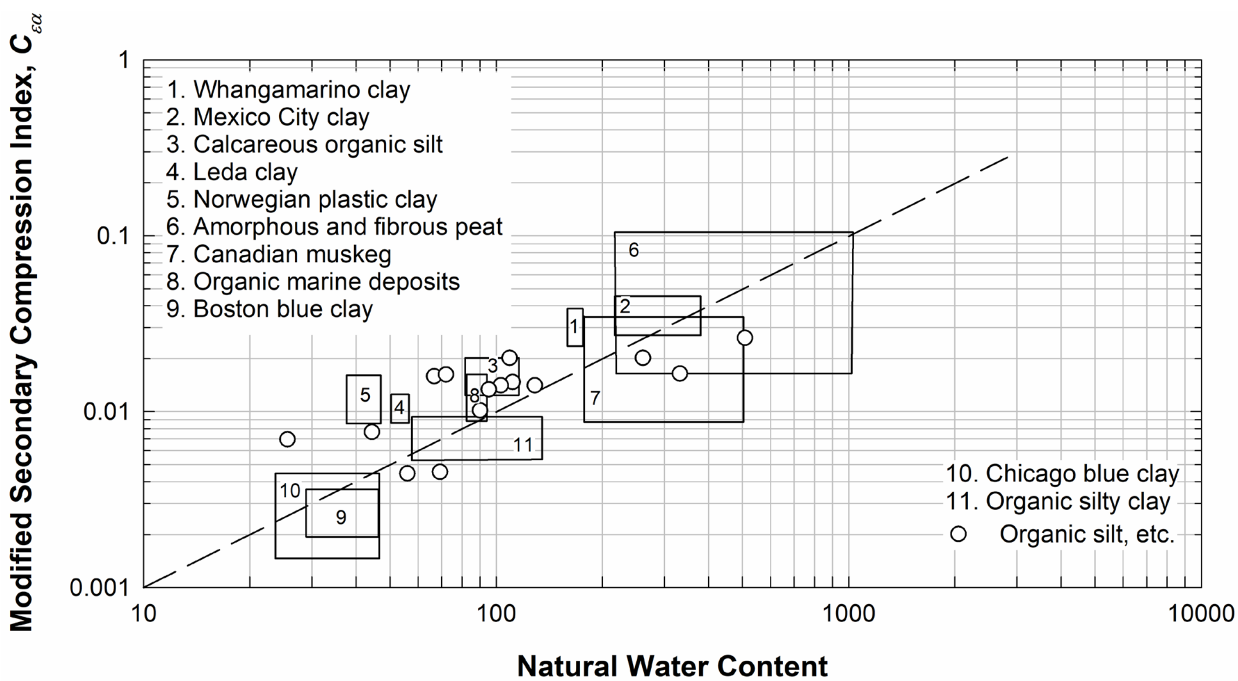


Figure 8-48 Correlation between Modified Secondary Compression Index and Natural Water Content for Normally Consolidated Clays (after Mesri 1973, Holtz and Kovacs 1981)

Table 8-17 Typical Values of C_α / C_c for Natural Soils (after Mesri and Godlewski 1977)

Grouping	Soil Type	C_α / C_c
Inorganic clays and silts	Whangamarino clay	0.03 – 0.04
	Leda clay	0.025 – 0.06
	Soft blue clay	0.026
	Portland sensitive clay	0.025 – 0.055
	San Francisco Bay Mud	0.04 – 0.06
	New Liskeard varved clay	0.03 – 0.06
	Silty clay C	0.032
	Nearshore clays and silts	0.055 – 0.075
	Mexico City clay	0.03 – 0.035
	Hudson River silt	0.03 – 0.06
Organic clays and silts	Norfolk organic silt	0.05
	Calcareous organic silt	0.035 – 0.06
	Post-glacial organic clay	0.05 – 0.07
	Organic clays and silts	0.04 – 0.06
	New Haven organic clay silt	0.04 – 0.075
Peats	Amorphous and fibrous peat	0.035 – 0.083
	Canadian muskeg	0.09 – 0.10
	Peat	0.075 – 0.085
	Peat	0.05 – 0.08
	Fibrous peat	0.06 – 0.085

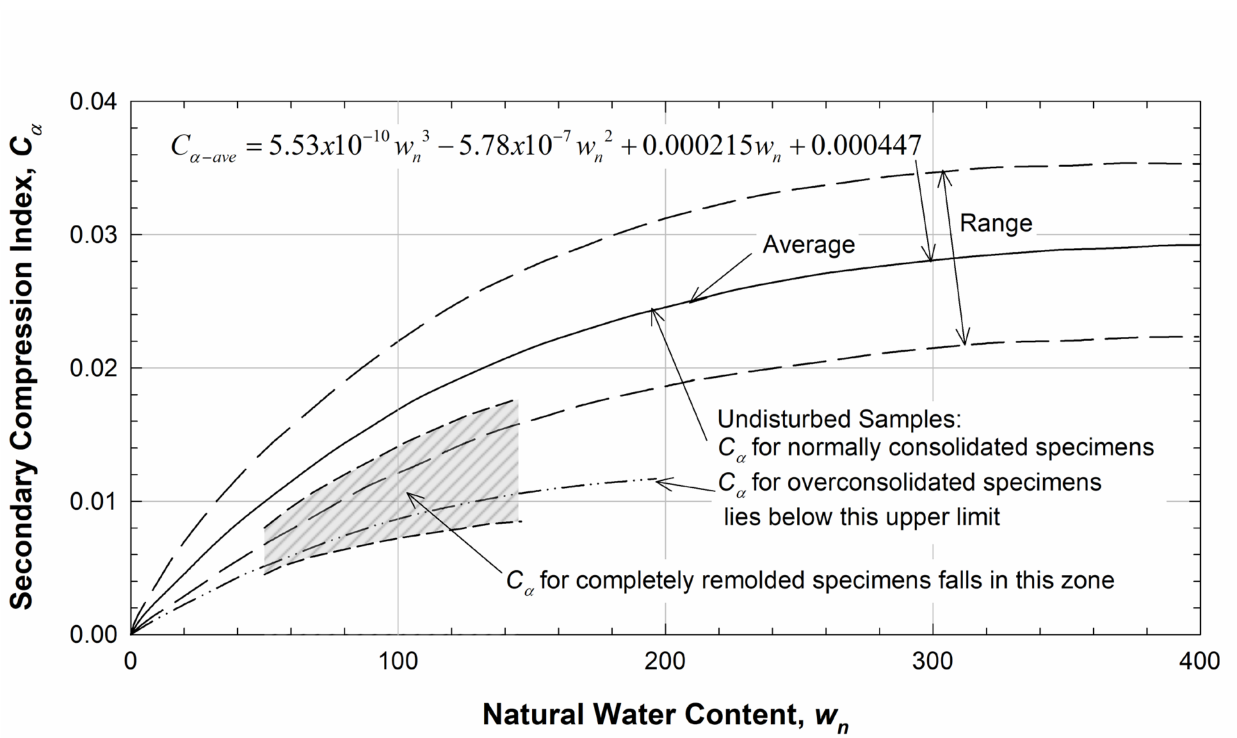


Figure 8-49 Secondary Compression Index for Silts and Clays

8-4.5 Coefficient of Consolidation.

The coefficient of consolidation (c_v) is a difficult parameter to estimate for design use because *in situ* stratigraphy can include sand seams and lenses, varved layers, etc. Small laboratory test specimens may not contain these fabric elements. In addition, the coefficient of consolidation can differ in the vertical and horizontal directions. Laboratory tests normally only measure the coefficient of consolidation in one direction. A first-order approximation for the coefficient of consolidation can be obtained using Figure 8-50.

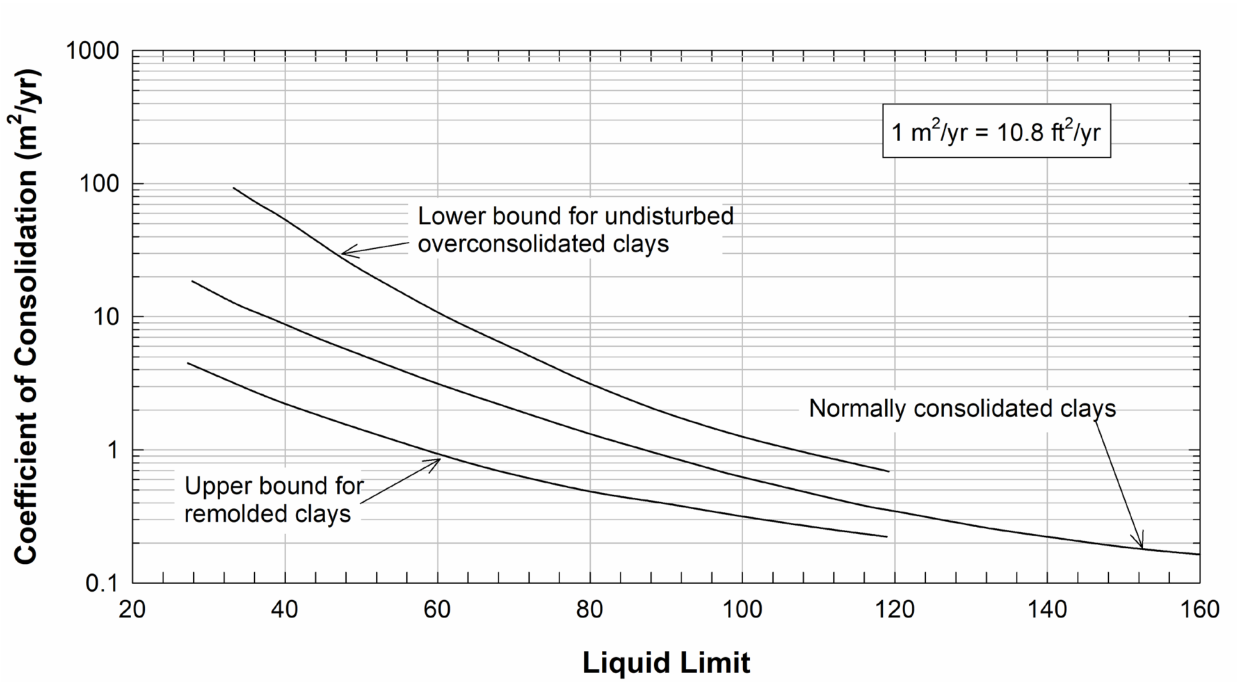


Figure 8-50 Approximate Relationship between Coefficient of Consolidation and Liquid Limit

8-5 ELASTIC PARAMETERS.

8-5.1 Definitions.

Correlations to four elastic parameters will be presented in this section: (1) Young's modulus (E) is the ratio of the change in normal stress in a given direction to the strain in the same direction within the elastic range; (2) bulk modulus (K) is the change in mean stress divided by the corresponding volumetric strain; (3) shear modulus (G) is the ratio of the change shear stress divided by the shear strain caused by that stress; and (4) Poisson's ratio (ν) is the ratio of the lateral strain to the axial strain caused by a change of stress. The relationships between these parameters are summarized in Table 8-18.

Table 8-18 Relationships between Common Elastic Parameters

Parameter	$E =$	$K =$	$G =$	$\nu =$
E & G	---	$\frac{EG}{3(3G-E)}$	---	$\frac{E-2G}{2G}$
E & ν	---	$\frac{E}{3(1-2\nu)}$	$\frac{E}{2(1+\nu)}$	---
E & K	---	---	$\frac{3KE}{9K-E}$	$\frac{3K-E}{6K}$
G & ν	$2G(1+\nu)$	$\frac{2G(1+\nu)}{3(1-2\nu)}$	---	---
G & K	$\frac{9KG}{3K+G}$	---	---	$\frac{3K-2G}{2(3K+G)}$
K & ν	$3K(1-2\nu)$	---	$\frac{3K(1-2\nu)}{2(1+\nu)}$	---

In fine-grained soils, the value of the Young's modulus from field testing is normally derived under undrained conditions (E_u). Assuming a Poisson's ratio for undrained conditions of 0.5, the Young's modulus under drained conditions can be found:

$$E = \frac{2}{3}(1+\nu)E_u \qquad \textbf{(8-36)}$$

where:
E = Young's modulus for drained conditions,
ν = Poisson's ratio for drained conditions, and
E_u = Young's modulus for undrained conditions.

The shear modulus represents the response of the soil skeleton and it is independent of drainage conditions (i.e., $G = G_u$) (Kulhawy and Mayne 1990). Assuming a Poisson's ratio for undrained conditions of 0.5, the relationships in Table 8-18 indicate that E_u is three times greater than the shear modulus. According to Kulhawy and Mayne (1990), the undrained Young's modulus of soils is stress path dependent.

8-5.2 Undrained Young's Modulus of Fine-Grained Soils.

8-5.2.1 Typical Values.

Typical values of undrained Young's modulus are summarized in Table 8-19.

8-5.2.2 Correlations with Undrained Shear Strength.

Duncan and Buchignani (1987) proposed a correlation to obtain the ratio of the undrained shear modulus to the undrained shear strength for fine grained soils as a function of the plasticity index and overconsolidation ratio as shown in Figure 8-51. This correlation is based on results obtained from direct simple shear tests.

Table 8-19 Typical Range of Undrained Young's Modulus for Clays

Clay Consistency	E_u / P_a	
	USACE (1990)	**Kulhawy and Mayne (1990)**
Very soft	5 – 50	
Soft	50 – 200	15 – 40
Medium	200 – 500	40 - 80
Stiff or silty	500 – 1000	80 – 200
Sandy	250 – 2000	
Clay shale	1000 – 2000	

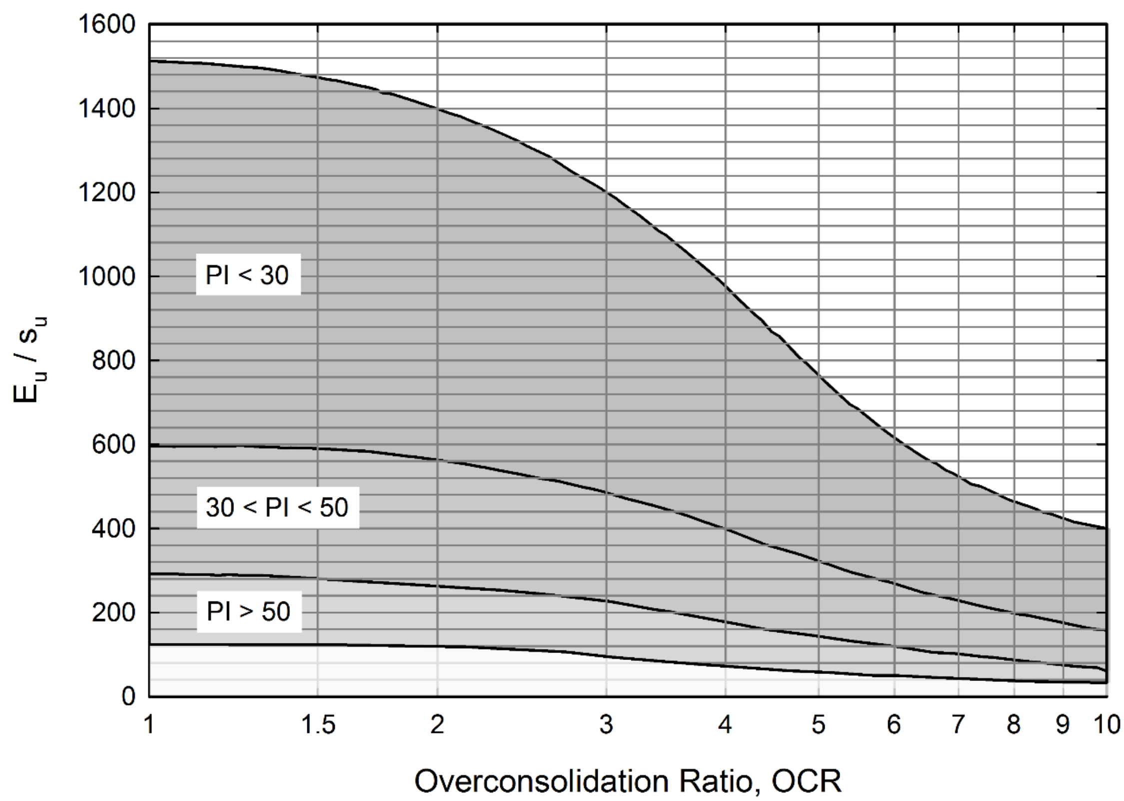


Figure 8-51 Correlation of Undrained Modulus Normalized by Undrained Shear Strength to Overconsolidation Ratio (after Duncan and Buchignani 1987)

8-5.2.3 Correlations with Standard Penetration and Pressuremeter Tests.

The pressuremeter test is used to directly measure a soil modulus in the horizontal direction. According to Kulhawy and Mayne (1990), the horizontal modulus measured in clay using the pressuremeter test is approximately equal to the undrained Young's modulus.

Ohya et al. (1982) presented the relationship for the undrained Young's modulus from the pressuremeter (E_{PMT}) and the SPT N value shown in Figure 8-52. The relationship shown in this figure exhibits a large amount of scatter ($r^2 = 0.39$), and it should be used with caution.

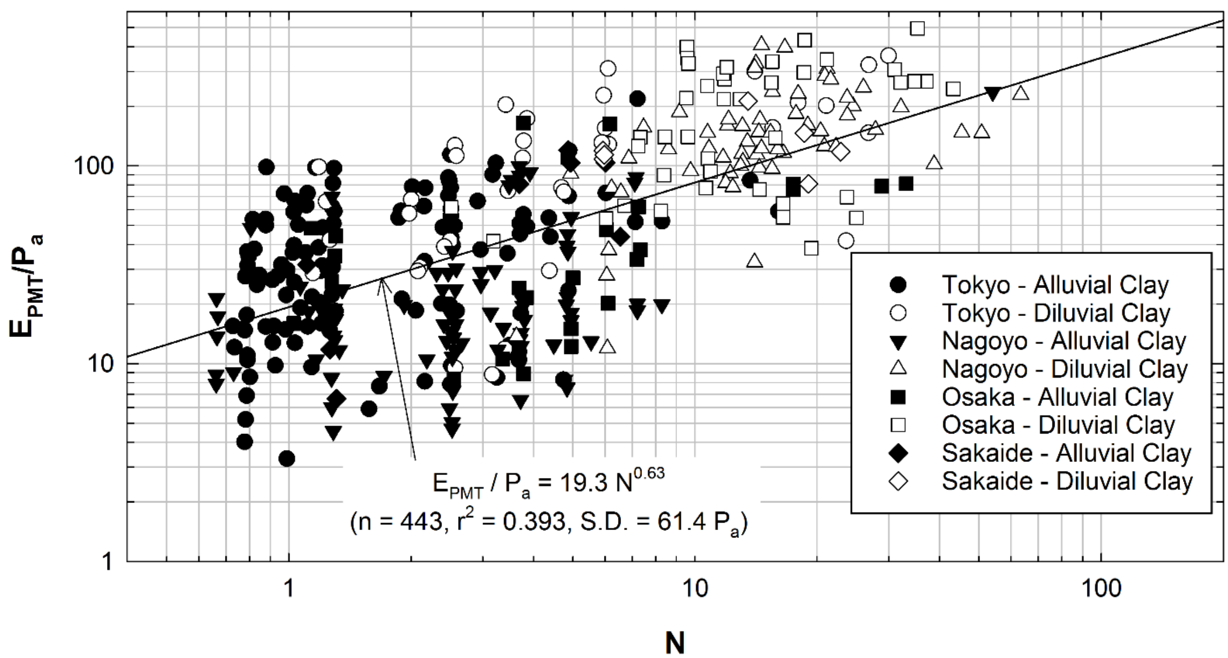


Figure 8-52 Correlation between PMT Modulus for Clays and SPT N (after Ohya et al. 1982)

8-5.2.4 Correlations to Load Tests.

Poulos and Davis (1980) presented the relationship for the undrained Young's modulus calculated from load tests on drilled shafts and driven piles as a function of the undrained shear strength of the clay, as shown in Figure 8-53.

Callanan and Kulhawy (1985) presented the relationship for the undrained Young's modulus of clays back calculated from load tests on drilled shafts and spread foundations presented in Figure 8-54. In the right side of Figure 8-54, σ_{vm} is the mean total vertical stress over the foundation depth.

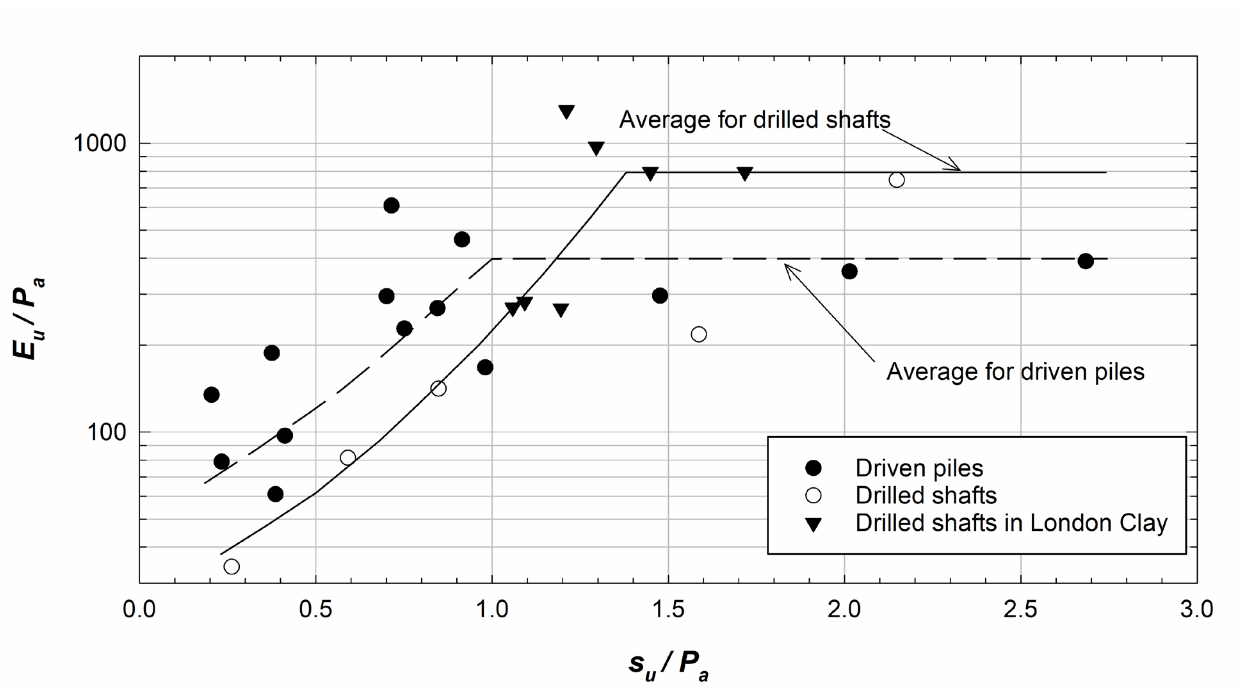


Figure 8-53 Undrained Modulus for Deep Foundations in Compression (after Poulos and Davis 1980)

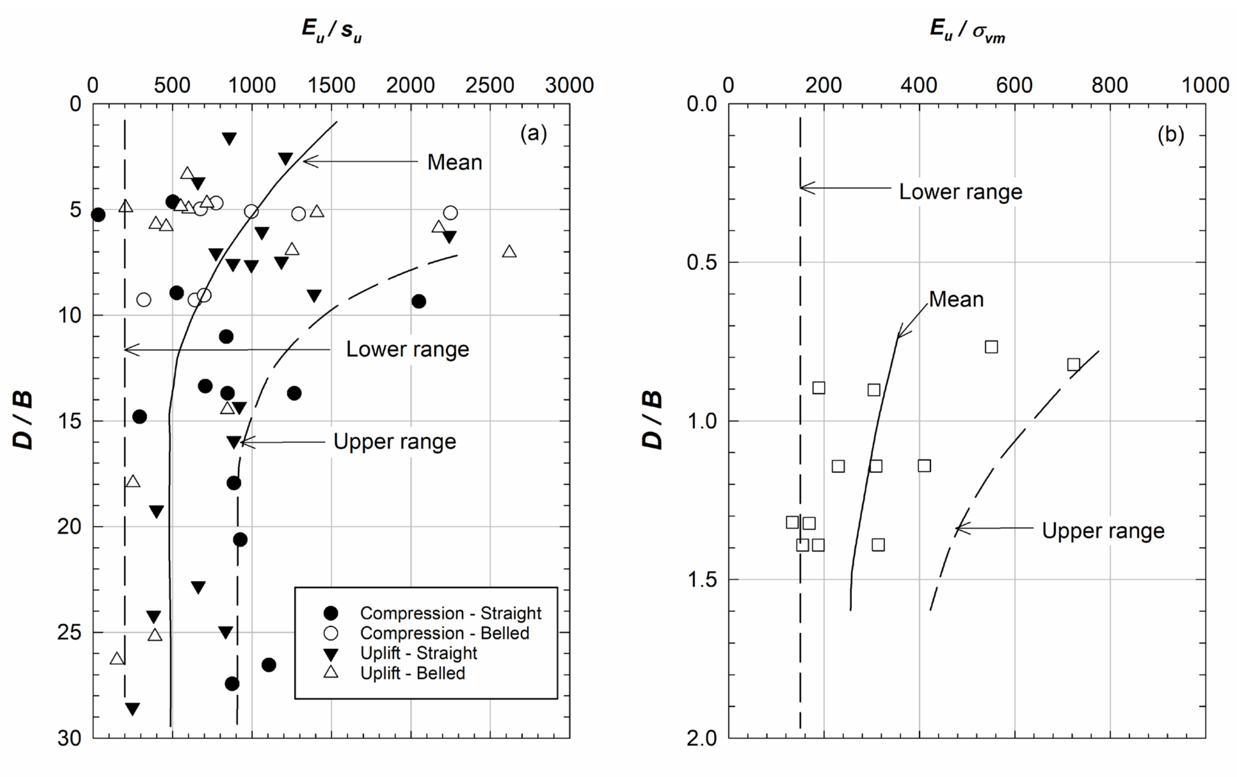


Figure 8-54 Undrained Modulus for (left) Drilled Shafts in Compression and Uplift and (right) Spread Foundations in Uplift (after Callanan and Kulhawy 1985)

8-5.3 Drained Young's Modulus of Coarse-Grained Soils.

Coarse-grained soils only experience undrained conditions for a very short period of time and under special circumstances. For this reason, the Young's modulus is only required for drained conditions in most cases. Typical values of drained Young's modulus (E) based on relative density are summarized in Table 8-20 for coarse-grained soils.

Table 8-20 Typical Ranges of Drained Young's Modulus for Coarse-Grained Soils

Relative Density or Soil Type	Normalized Drained Young's Modulus (E_u / P_a)		
	Poulos (1975)		USACE (1990)
	Typical	Driven Piles	
Loose	100 – 200	275 – 550	100 – 250
Medium	200 – 500	550 – 700	250 – 1000
Dense	500 – 1000	700 – 1100	1000 – 2000
Silty sand	---	---	250 – 2000

8-5.3.1 Correlations with SPT N Values.

Many different correlations have been developed to estimate the drained Young's modulus of coarse-grained soils using SPT N values. Some of these correlations are presented in Table 8-21 and plotted in Figure 8-55.

Table 8-21 Correlations for Drained Young's Modulus of Coarse-Grained Soils using SPT N Values

Equation	Applicable to	Reference
$E/P_a \approx 7.1 \cdot (1-\nu^2) \cdot N$	Sandy soils	After Ferrent (1963)
$E/P_a \approx 4.7(N+15)$	Sands	After Webb (1969)
$E/P_a \approx 3.1(N+5)$	Clayey sands	
$E/P_a \approx C(N+6)$	Silts with sand and gravels with sand with N < 15	Begemann (1974)
$E/P_a \approx 39.5 + C(N-6)$	Silts with sand and gravels with sand with N ≥ 15	
$E/P_a \approx 5N_{60}$	Sands with fines	Kulhawy and Mayne (1990)
$E/P_a \approx 10N_{60}$	NC clean sands	
$E/P_a \approx 15N_{60}$	OC clean sands	
E = drained Young's modulus, P_a = atmospheric pressure (in same units as E), N = SPT blow count value (use N_{60} for modern samplers) ν = Poisson's ratio, and C = empirical coefficient equal to 3 for silts with sand and 12 for gravel with sand		

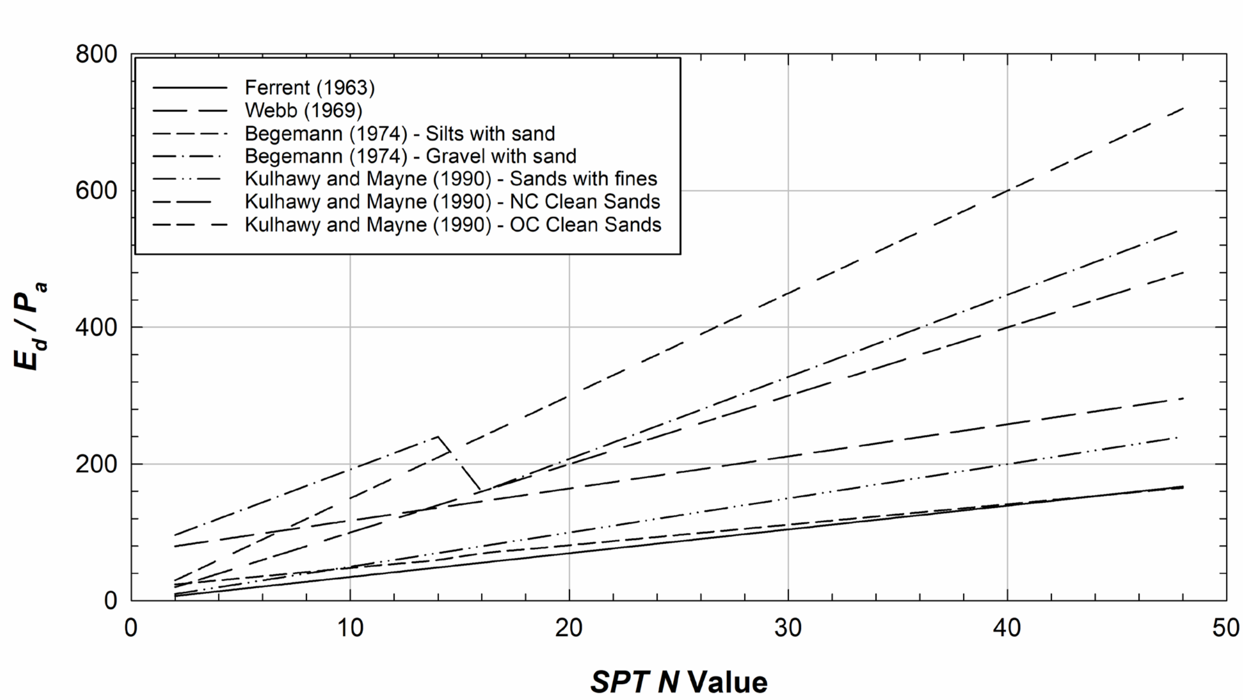


Figure 8-55 Correlations for Drained Young's Modulus of Granular Soils

8-6 CALIFORNIA BEARING RATIO (*CBR*).

The California bearing ratio (*CBR*) is a penetration test developed by the California Department of Transportation to assess the load-bearing capacity of soils used for building roads. This test is described in ASTM D1883. The *CBR* is predominately a laboratory test, but there are methods available to measure *CBR* in the field. *CBR* can be determined for test specimens that have been soaked, or specimens at their compaction water content. Because these correlations apply to specific soil types, the original references should be consulted before using the correlations.

8-6.1 Correlations with Index and Compaction Properties.

Several researchers have presented correlations to estimate the *CBR* using index properties. Correlations to grain size, Atterberg limits, and other index properties are summarized in Table 8-22. Correlations between *CBR* and soil compaction properties are summarized in Table 8-23.

Table 8-22 *CBR* Correlations with Grain Size, Atterberg Limits, and Unit Weight

Equation	Reference / Comment
$CBR = \frac{75}{1 + 0.728\left(FC \times PI\right)}$	NCHRP (2001), $FC \times PI = 0$
$CBR = 28.09 \cdot \left(D_{60}\right)^{0.358}$	NCHRP (2001), $FC \times PI = 0$
$CBR = 95$	NCHRP (2001), $D_{60} \geq 30$ mm
$CBR = 5$	NCHRP (2001), $D_{60} \leq 0.01$ mm
$CBR = 0.24 \cdot GC + 3.1$	Yildirim and Gunaydin (2011)
$CBR = 18.5 - 0.18 \cdot FC$	
$CBR_{unsoaked} = 4.75 - 0.044LL + 0.15PL$	Patel and Desai (2010)
$CBR = 5.18 - 0.028LL - 0.047PL$	
$CBR = 23 + 1.42 \cdot \gamma_d - 0.213 \cdot PI - 0.916 \cdot w - 0.368 \cdot LL$	George et al. (2009)
$CBR = 0.0004 \cdot G_s^{9.7915}$	Yashas et al. (2016)
$CBR = 1.36 \times 10^{-8} \left(\gamma_m\right)^{6.6141}$	
$CBR = 9.27 \times 10^{-10} \left(\gamma_d\right)^{7.4106}$	
$CBR_{soaked} = 1.93\beta - 31$	Al-Hashemi and Bukhary (2016)

FC = fines content = percent passing #200 sieve,
SC = sand content = percent retained between #4 and #200 sieve,
GC = gravel content = percent retained between 75 mm and #4 sieve,
LL = liquid limit, PL = plastic limit, PI = plasticity index,
γ_d = dry unit weight (in kN/m^3), γ_m = moist unit weight (in kN/m^3),
w = water content (in percent), Gs = specific gravity of solids, and
β = angle of repose

Table 8-23 *CBR* Correlations to Index and Compaction Properties (after Singh et al. 2011)

Equation
$CBR = 33\left(\frac{\gamma_d}{\gamma_{d,\max}}\right) - 5.5\left(\frac{w}{w_{opt}}\right) - 1.15PL - 2.21$
$CBR_{unsoaked} = 24\left(\frac{\gamma_d}{\gamma_{d,\max}}\right) - 67\left(\frac{w}{w_{opt}}\right) - 2PL + 104.7$

PL = plastic limit,
γ_d = dry unit weight, $\gamma_{d,max}$ = maximum dry unit weight from Modified Proctor test,
w = water content, and w_{opt} = optimum water content from Modified Proctor test.
Water contents should be either both in decimal or both in percentage form.

8-6.2 Correlations with Dynamic Cone Penetration.

Many correlations have been developed to estimate CBR from the results of dynamic cone penetration tests. Most of these correlations can take the form

$$CBR = A \cdot DCP^{x} \tag{8-37}$$

where:
CBR = California Bearing Ratio,
A = empirical coefficient,
DCP = dynamic cone penetration index (mm/blow), and
x = empirical exponent.

The values of A and x found by various researchers are summarized in Table 8-24. The range of CBR values expected from these correlations is presented in Figure 8-56.

Table 8-24 *CBR* Correlations with *DCP*

Reference / Comment	A	x
Gabr et al. (2000)	25	-0.55
Feleke and Araya (2016), fine-grained soils	47	-0.90
George et al. (2009)	47	-0.79
White et al. (2018), CL with CBR < 10	59	-2.00
Feleke and Araya (2016), coarse-grained soils	90	-1.17
Feleke and Araya (2016), fine-grained soils	104	-0.91
Feleke and Araya (2016), coarse-grained soils	157	-0.85
George and Kumar (2018)	246	-1.35
White et al. (2018), All soils except CL with CBR < 10	292	-1.12
Smith and Pratt (1983)	363	-1.15
Harrison (1986), clay-like soils with DCP < 10 mm/blow	501	-1.12
Harrison (1986), clay-like soils with DCP > 10 mm/blow	363	-1.16
Kleyn and Van Heerden (1983)	425	-1.27

Nazzal (2003) developed a similar correlation to those in Table 8-24 for soils with DCP values between 6.3 and 67 mm/blow:

$$CBR = \frac{2559}{DCP^{1.84} - 7.35} + 1 \tag{8-38}$$

where:
CBR = California Bearing Ratio, and
DCP = dynamic cone penetration index (mm/blow).

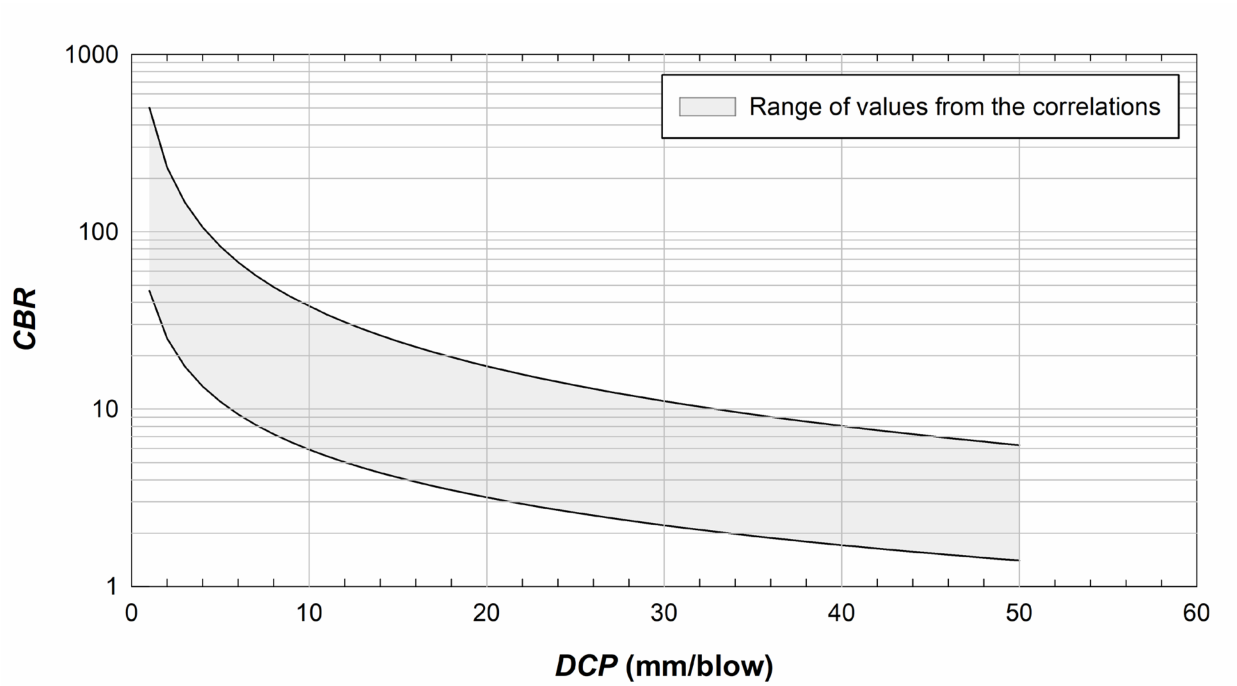


Figure 8-56 Range of *CBR* based on *DCP* Predicted by Correlations

8-6.3 Correlations with Standard Penetration Test.

Livneh (1989) found that the *CBR* could be estimated from the results of the Standard Penetration Test as shown below. The data used to obtain this correlation is presented in Figure 8-57.

$$\log CBR = -5.13 + 6.55\left(\log \frac{300}{N}\right)^{-0.26} \quad \textbf{(8-39)}$$

where:
CBR = California Bearing Ratio, and
N = SPT blow count value (use N_{60} for modern hammers).

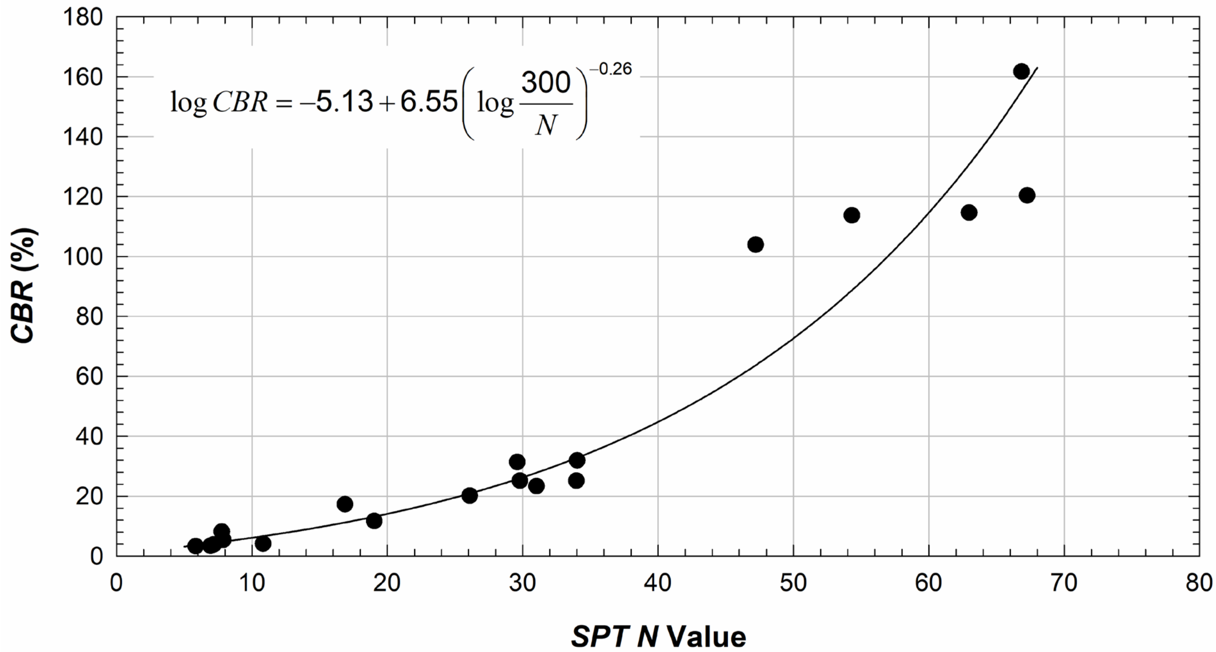


Figure 8-57 Correlation for *CBR* in Terms of SPT *N* Value (Livneh 1989)

8-7 HYDRAULIC CONDUCTIVITY.

The hydraulic conductivity (a.k.a., the coefficient of permeability) governs the flow rate and head loss as water flows through a soil mass. The hydraulic conductivity has one of the widest ranges of any engineering parameter as can be seen in Table 8-25. The wide range of possible values and the influence of variable ground conditions on the hydraulic conductivity make this parameter difficult to evaluate with a high degree of accuracy.

8-7.1 Typical Values.

Typical values of hydraulic conductivity based on soil type are presented in Table 8-25. Other typical values based on soil type can be found in Section 6-3.3.

8-7.2 Correlations for Coarse-Grained Soils.

One of the first correlations to estimate the hydraulic conductivity based on grain size was presented by Hazen (1911). This correlation was developed for saturated clean sands with a fines content less than 5% and D_{10} values ranging from 0.1 mm to 3 mm:

$$k = C \cdot (D_{10})^2 \quad \textbf{(8-40)}$$

Where:
k = hydraulic conductivity (cm/s),
C = empirical coefficient, usually taken to be 1 cm/s/mm^2, and
D_{10} = grain size corresponding to 10% passing on the grain-size distribution (mm).

Table 8-25 Typical Ranges of Hydraulic Conductivity based on Soil Type (after Terzaghi et al. 1996)

Soil	Hydraulic Conductivity (m/sec)	Relative Permeability
Gravel	> 10^{-3}	High
Sandy gravel	10^{-3} to 10^{-5}	Medium
Clean sand		
Fine sand		
Sand	10^{-5} to 10^{-7}	Low
Dirty sand		
Silty sand		
Silt	10^{-7} to 10^{-9}	Very low
Silty clay		
Clay	< 10^{-9}	Practically impermeable

Based on data from the middle and lower Mississippi River Valley, the USACE (1993) correlated the *in situ* horizontal permeability of fine to medium, relatively uniform sands (USCS classifications of SP or SW) as shown in Figure 8-58. This correlation was recommended for use only within the geographic area for which it was developed.

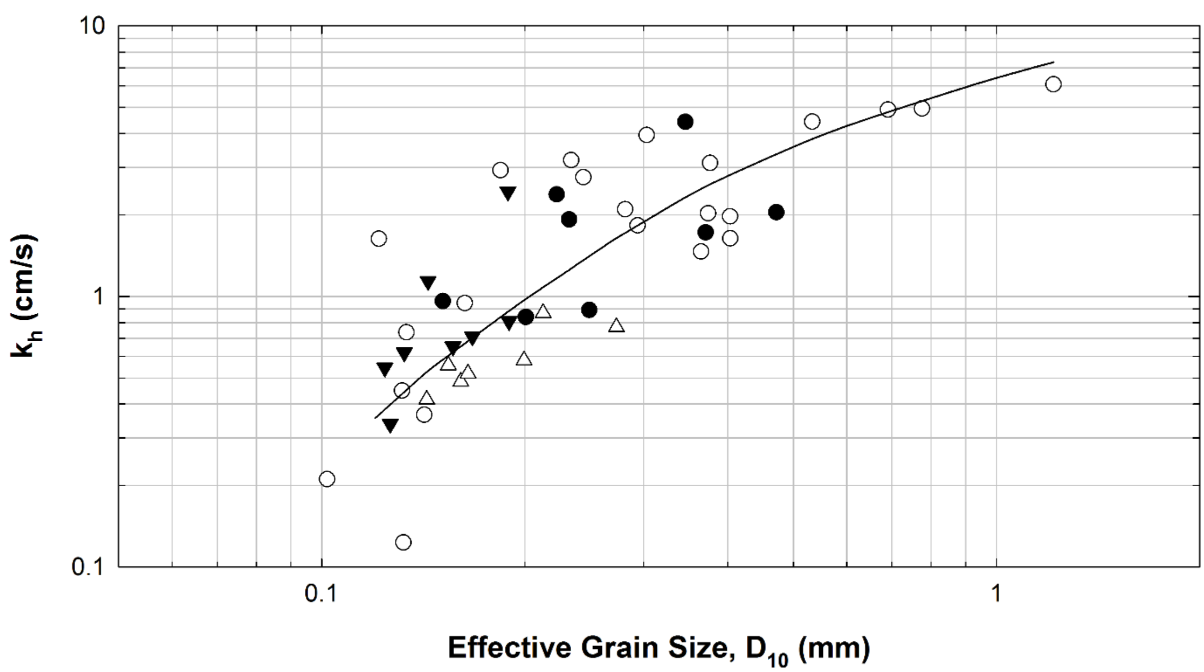


Figure 8-58 Horizontal Hydraulic Conductivity based on D_{10} (after USACE 1993)

As shown in Figure 8-59, Kenney et al. (1984) correlated the hydraulic conductivity of coarse-grained soils to the grain size corresponding to 5% passing on the cumulative grain-size distribution curve (D_5). A similar correlation can be developed between the hydraulic conductivity for clean coarse-grained soils and the D_{10} grain size as shown in Figure 8-60.

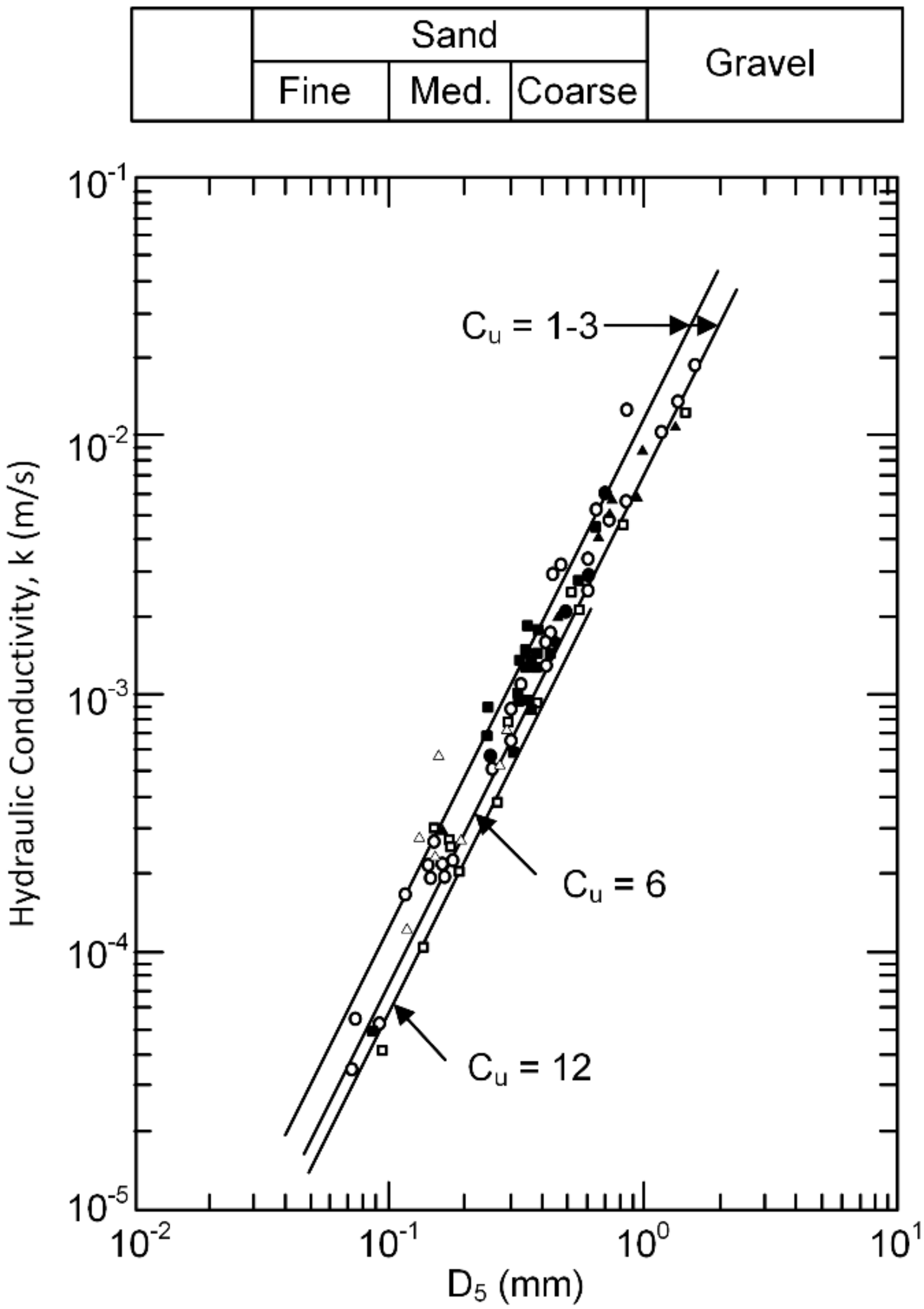


Figure 8-59 Hydraulic Conductivity based on D_5 (after Kenney et al. 1984)

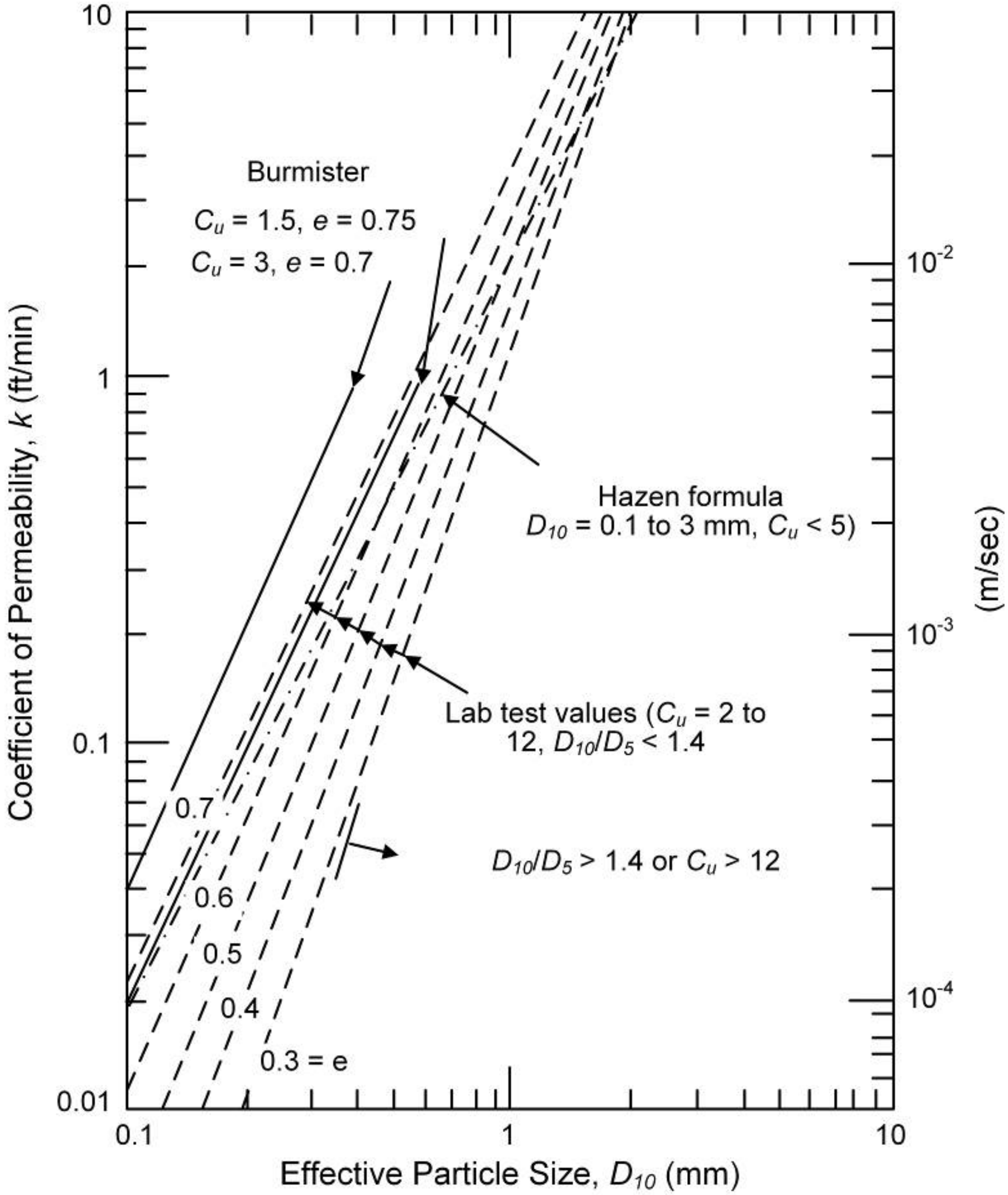


Figure 8-60 Hydraulic Conductivity of Sands and Sand-Gravel Mixtures as a Function of D_5, D_{10}, C_u, and e

Carrier (2003) presented a modified version of the Kozeny-Carman equation (Kozeny 1927; Carman 1938, 1956) to estimate the hydraulic conductivity using the full grain-size distribution of a soil. The modifications introduced by Carrier (2003) to the original equation simplify its use. The hydraulic conductivity can be estimated by:

$$k = 1.99 \times 10^2 \frac{cm}{s \cdot mm^2} \left[\frac{100\%}{\sum \frac{f_i}{D_{li}^{0.404} \times D_{si}^{0.596}}} \right]^2 \left(\frac{1}{S^2} \right) \left(\frac{e^3}{1+e} \right) \quad \textbf{(8-41)}$$

where:
k = hydraulic conductivity (cm/s),
f_i = fraction of particles (by mass) between two adjacent sieve sizes,
D_{li} = the particle size of the coarser sieve (mm),
D_{si} = the particles size of the finer sieve (mm),
S = surface area factor ranging from 6 for spheres to 8.5 for angular particles, and
e = void ratio.

Additional discussion and correlations of k to grain size can be found in Section 6-3.3.

8-7.3 Correlations for Fine-Grained Soils.

Unlike coarse-grained soils, the hydraulic conductivity of fine-grained soils is difficult to estimate from index properties. Hydraulic conductivity correlations for fine-grained soils should be used with caution.

Carrier and Beckman (1984) related the hydraulic conductivity and the Atterberg limits and void ratio of fine-grained soils using:

$$k = 0.0174 \left[\frac{e - 0.027(PL - 0.242PI)}{PI} \right]^{4.29} \left(\frac{1}{1+e} \right) \quad \textbf{(8-42)}$$

where:
k = hydraulic conductivity in m/s,
e = void ratio,
PL = plastic limit, and
PI= plasticity index.

Benson et al. (1994) measured the hydraulic conductivity on intact test specimens obtained from compacted clay liners from 67 landfills in North America. The results of those tests were found to relate to other measured properties of the clays as:

$$\ln k = -18.35 + \frac{894}{W} - 0.08PI - 2.87\left(\frac{w}{\gamma_w/\gamma_d - 1/G_s}\right) + 0.32\sqrt{GC} + 0.02CF \qquad (8\text{-}43)$$

where:
k = hydraulic conductivity in m/s,
CF = clay-sized fraction (percent by mass smaller than 0.002 mm),
GC = gravel content = percent retained between 75 mm and #4 sieve,
W = weight of field compactor (kN),
PI = plasticity index,
w = molding water content,
γ_w = unit weight of the water,
γ_d = dry unit weight, and
G_s = specific gravity of the solids.

Benson and Trast (1995) performed hydraulic conductivity tests on 13 compacted clays used for compacted clay liners around the United States. The test specimens were prepared at different water contents, compacted, and then tested to measure the hydraulic conductivity. The results were correlated by Benson and Trast to k using:

$$\ln k = -15 - 0.087\left(\frac{w}{\gamma_w/\gamma_d - 1/G_s}\right) - 0.054PI + 0.022CF + 0.91E \qquad (8\text{-}44)$$

where:
k = hydraulic conductivity (m/s),
w = molding water content,
γ_w = unit weight of the water,
γ_d = dry unit weight,
G_s = specific gravity of the solids.
PI = plasticity index,
CF = clay-sized fraction, and
E = compactive effort index (equal to -1, 0, and 1 for modified, standard, and reduced Proctor compactive effort, respectively).

8-8 SHEAR WAVE VELOCITY.

8-8.1 Correlations with Standard Penetration Test.

Many correlations have been developed to estimate the shear wave velocity (V_s) from SPT N values. Judgment is required regarding the use of uncorrected vs. corrected blow count. Older correlations where likely developed using 60% hammer efficiency as represented by N_{60}. The general form for most of the V_s correlations is:

$$V_s = BN^x z^y \quad \textbf{(8-45)}$$

where:
V_s = shear wave velocity (m/s),
B, x, and y = empirical coefficients,
N = SPT blow count, and
z = depth to the soil layer (m).

Correlations using the form of Equation 8-45 are summarized in Table 8-26. Other correlations are presented in Table 8-27. The range of values expected from these correlations can be seen in Figure 8-61.

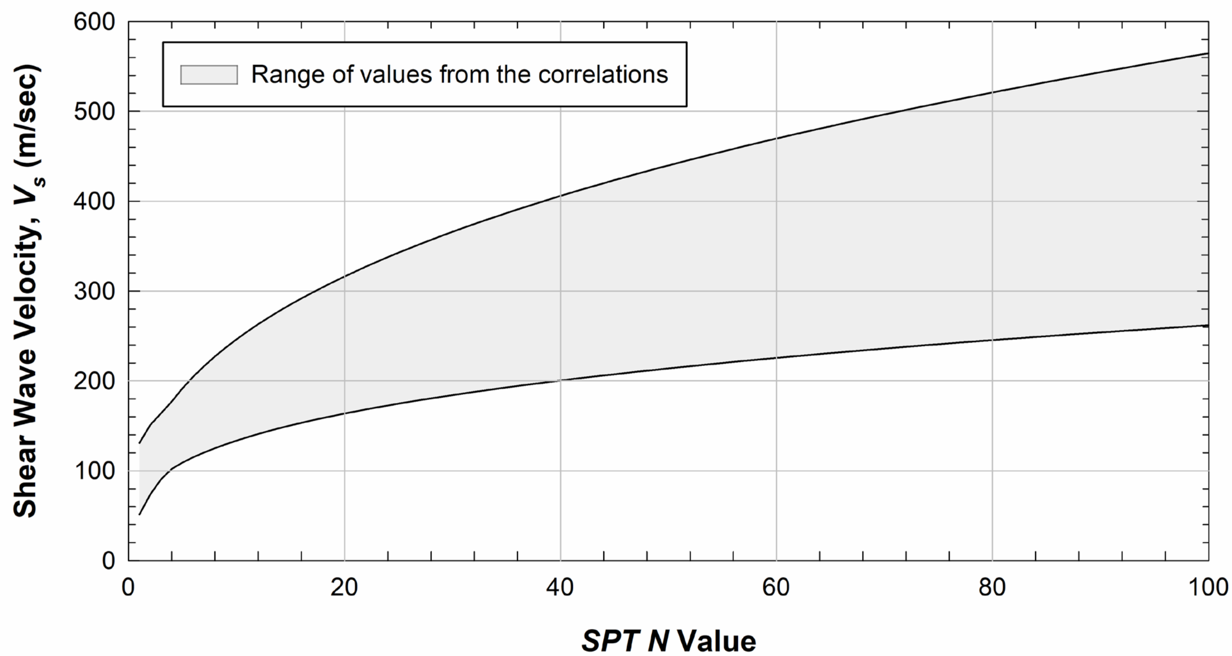


Figure 8-61 Range of Shear Wave Velocities based on SPT N Value Predicted by Correlations

Table 8-26 Shear Wave Velocity Correlated to SPT N Value and Depth

B	x	y	Comments	Reference
131	0.21	0	Sand, use N_{60}	Hasancebi and Ulusay (2007)
108	0.24	0	Use N_{60}	
105	0.26	0	Use N_{60}	
98	0.27	0	Clay	
90	0.31	0		
91	0.32	0	Sands	
101	0.27	0	Sand	Maheswari et al. (2010)
96	0.30	0		
89	0.36	0	Clay	
101	0.29	0		Sykora and Stokoe (1983)
68	0.29	0		Kiku et al. (2001)
80	0.29	0	Clay	Imai (1977)
81	0.33	0	Sand	
91	0.34	0		
84	0.31	0		Ohba and Toriumi (1970)
114	0.31	0	Clay	Lee (1990)
57	0.49	0	Sand	
106	0.32	0	Silt	
97	0.31	0		Imai and Tonouchi (1982)
76	0.33	0		Imai and Yoshimura (1975)
92	0.34	0		Fujiwara (1972)
90	0.34	0		Imai et al. (1975)
85	0.35	0		Ohta and Goto (1978)
108	0.36	0		Athanasopoulos (1995)
59	0.39	0		Dikmen (2009)
81	0.39	0		Ohsaki and Twasaki (1973)
61	0.50	0		Seed and Idriss (1981)
52	0.52	0		Iyisan (1996)
59	0.11	0.43		Akin et al. (2011)
69	0.17	0.20	Clay	Jamiolkowski et al. (1988)
82	0.25	0.14	Gravel	Yoshida et al. (1988)

Table 8-27 Shear Wave Velocity Correlated to SPT N Value

Equation	Reference
$V_s = 116(N+0.3185)^{0.202}$	Jinan (1987)
$V_{s,1} = 61.89(N_{1,60CS})^{0.36}$	Ulmer et al. (2020)
$V_{s,1}$ = normalized shear wave velocity = $V_s \cdot (P_a / \sigma'_v)^{0.25}$, and $N_{1,60cs} = N_{1,60}$ corrected for fine content	

8-8.2 Correlations with Cone Penetration Test.

Several correlations relating the shear wave velocity to the results of the cone penetration test have been developed and are summarized in Table 8-28. It should be noted that some cones are equipped with a geophone or accelerometer and can measure shear wave velocity directly.

Table 8-28 Correlations for Shear Wave Velocity with CPT results

Equation	Comments	Reference
$V_s = 134 + 0.0052q_c$	Sands	Sykora and Stokoe (1983)
$V_s = 0.1q_c$	Clays	Jaime and Romo (1988)
$V_s = 17.5q_c^{0.33}\sigma'_v{}^{0.27}$	Sands	Baldi et al. (1989)
$V_{s1} = 102q_{c1}^{0.23}$		Fear and Robertson (1995)
$V_s = \left(10.1\log q_c - 11.4\right)^{1.67}\left(100f_s/q_c\right)^{0.3}$		Hegazy and Mayne (1995)
$V_s = 14.1q_c^{0.359}e^{-0.473}$	Clays	
$V_s = 3.18q_c^{0.549}f_s^{0.025}$		
$V_s = 13.2q_c^{0.192}\sigma'_v{}^{0.179}$	Sands	
$V_s = 12q_c^{0.319}f_s^{-0.0466}$		
$V_s = 9.44q_c^{0.435}e^{-0.532}$	Clays	Mayne and Rix (1995)
$V_s = 1.75 \cdot q_c^{0.627}$		
$V_s = 32.3q_c^{0.089}f_s^{0.1219}z^{0.215}$		Piratheepan (2002)
$V_s = 11.9q_c^{0.269}f_s^{0.109}z^{0.127}$	Clays	
$V_s = 25.3q_c^{0.103}f_s^{0.029}z^{0.155}$	Sands	
$V_{s,1} = 0.0831q_c^{0.103}\left(\sigma'_v/P_a\right)^{0.25}e^{1.788I_c}$		Hegazy and Mayne (2006)
$V_s = 119\log f_s + 18.5$		Mayne (2006)
$V_s = \left[10^{0.55I_c+1.68}\left(q_t - \sigma'_v/P_a\right)\right]^{0.5}$		Robertson (2009)
$V_{s,1} = 149q_{c1}^{0.205}$		Karray et al. (2011)
$V_{s,1} = 16.88\left(q_{c1NCS}\right)^{0.489}$		Ulmer et al. (2020)

V_s = shear wave velocity (m/s), $V_{s,1}$ = normalized shear wave velocity = $V_s \cdot (P_a/\sigma'_v)^{0.25}$,
q_c = cone tip resistance (kPa), q_{c1} = normalized cone tip resistance = $(q_c / P_a)\ (P_a/\sigma'_v)^n$
q_{c1NCS} = normalized cone tip resistance as detailed by Boulanger and Idriss (2014)
f_s = cone sleeve resistance (kPa), e = void ratio, z = depth of the soil layer,
σ'_v = effective vertical stress (kPa), I_c = soil index for estimating grain characteristics, and
n = 0.5 for I_c < 2.6, else 0.75.

8-9 SUGGESTED READING.

Topic	Reference
Soil Properties	Kulhawy, F. H. and Mayne, P. W. (1990). *Manual on estimating soil properties for foundation design (No. EPRI-EL-6800)*. Electric Power Research Inst., Palo Alto, CA; Cornell Univ., Ithaca, NY, Geotechnical Engineering Group.
Geotechnical Correlations	Carter, M. and Bentley, S. P. (2016). *Soil properties and their correlations*. John Wiley & Sons.
	Duncan, J. M., Horz, R. C., and Yang, T. L. (1989). *Shear Strength Correlations for Geotechnical Engineering, CGPR#4*, Center for Geotechnical Practice and Research, Blacksburg, VA, 93 pp.

8-10 NOTATION.

Symbol	Description
A	Empirical coefficient for Equation 8-37
a	CPT cone net area ratio, and empirical coefficient related to the steepness of the power function (Equation 8-15)
B	Foundation width or diameter, and empirical coefficient in Equation 8-45
b	Empirical coefficient related to the curvature of the power function
CBR	California Bearing Ratio
CBR_{soaked}	Soaked California Bearing Ratio
$CBR_{unsoaked}$	Unsoaked California Bearing Ratio
C_c	Compression index
C_{ec}	Modified compression index or compression ratio
C^*_c	Intrinsic compression index
CF	Clay-sized fraction
C_r	Recompression index
$C_{\varepsilon r}$	Modified recompression index or recompression ratio
C_u	Coefficient of uniformity
c_v	Coefficient of consolidation
C_α	Secondary compression index
$C_{\alpha\varepsilon}$	Modified secondary compression index or secondary compression ratio
D	Foundation embedment
DCP	Dynamic cone penetration index
D_{ji}	The particle size of the coarser sieve in Equation 8-41
D_r	Relative density
D_{si}	The particle size of the finer sieve in Equation 8-41
D_5	Particle-size diameter corresponding to 5% passing on the cumulative particle-size distribution curve

Symbol	Description
D_{10}	Particle-size diameter corresponding to 10% passing on the cumulative particle-size distribution curve
D_{60}	Particle-size diameter corresponding to 60% passing on the cumulative particle-size distribution curve
E	Young's modulus, and compactive effort index in Equation 8-44
e	Void ratio
E_D	Dilatometer modulus
E	Young's modulus, typically drained
e_L	Void ratio at a water content equal to the liquid limit
E_{PMF}	Young's modulus from pressuremeter
E_u	Undrained Young's modulus
e_0	Initial void ratio
$e_{100}{}^*$	Intrinsic void ratio at 100 kPa
$e_{1000}{}^*$	Intrinsic void ratio at 1000 kPa
f	Empirical coefficient for Equation 8-33
FC	Fines content
f_i	Fraction of particles (by mass) between two adjacent sieve sizes in Equation 8-41
f_s	CPT sleeve resistance
G	Shear modulus
GC	Gravel content
G_u	Undrained shear modulus
G_s	Specific gravity of solids
I_c	Soil index
I_v	Void index
$I_{v,ICL}$	Void index for the intrinsic compression line
$I_{v,SCL}$	Void index for the sedimentation compression line
K	Bulk modulus
k	Hydraulic conductivity
K_D	Dilatometer horizontal stress index
K_0	Coefficient of earth pressure at rest
LL	Liquid limit
m	Semi-empirical fitting parameter for Equation 8-20, and modulus number
M_{ds}	Constrained modulus
N	SPT N value. May be assumed to be equal to N_{60}
n	Porosity, number of datapoints, and coefficient for q_{c1}
NC	Normally consolidated
N_c	Empirical bearing capacity factor

Symbol	Description
N_k	Empirical bearing capacity factor
N_{kt}	Empirical bearing capacity factor
N_p	Slope of the σ'_v vs q_c plot
N_q	Bearing capacity number
N_{60}	SPT N value corrected for 60% hammer energy efficiency
$N_{1,60}$	N_{60} value corrected to an effective vertical overburden of 1 atm
$N_{1,60,cs}$	$N_{1,60}$ corrected for fine content
N'	SPT N value corrected for dynamic pore pressure effects
OC	Overconsolidated
OCR	Overconsolidation ratio
P_a	Atmospheric pressure
PI	Plasticity index
PL	Plastic limit
p_0	Pressure required to initiate movement of the dilatometer
q_c	Static CPT tip resistance
q_{c1}	Cone penetrometer tip resistance normalized to 1 atm overburden pressure.
$q_{c,NC}$	Static CPT tip resistance in normally consolidated sand
$q_{c,OC}$	Static CPT tip resistance in overconsolidated sand
q_d	Dynamic cone resistance
q_p	Static CPT net resistance
q_t	Cone penetrometer tip resistance corrected for pore pressure effects
R	Correction factor for overconsolidated static cone tip resistance
r^2	Coefficient of determination
s	Effective stress shear strength
S	Surface area factor for Equation 8-41
$S.D.$	Standard deviation
S_t	Sensitivity
s_u	Undrained shear strength
$s_{u,fv}$	Undrained shear strength from field vane tests
u or u_2	Pore pressure measured behind the cone tip
u_0	Hydrostatic initial pore pressure
V_s	Shear wave velocity
$V_{s,1}$	Normalized shear wave velocity
W	Weight of the field compactor in Equation 8-43
w	Water content
w_n	Natural water content
w_{opt}	Optimum water content referenced to a given standard

Symbol	Description
x	Empirical exponent for Equation 8-37 and empirical coefficient for Equation 8-45
y	Empirical coefficient for Equation 8-45
z	Depth below the soil layer
α	Empirical coefficient for Equation 8-34
β	Inclination of the failure wedge for foundation loading, exponent in Equation 8-9, and angle of repose
Δq_p	Change in static CPT cone net resistance
$\Delta\sigma'_v$	Change in vertical effective stress
ϕ'	Effective stress friction angle
ϕ'_{FS}	Fully softened friction angle
ϕ'_r	Residual friction angle
ϕ'_{sec}	Effective stress secant friction angle (stress dependent)
γ_d	Dry unit weight
$\gamma_{d,max}$	Maximum dry unit weight referenced to a given standard
γ_m	Moist unit weight
γ_w	Unit weight of the water
σ_v	Vertical total stress
σ_{vm}	Mean vertical total stress
σ_{v0}	Initial vertical total stress
σ'_{ff}	Effective normal stress on the failure plane at failure
σ'_p	Preconsolidation pressure or maximum past pressure
σ'_v	Vertical effective stress
ν	Poisson’s ratio

This Page Intentionally Left Blank

APPENDIX A. REFERENCES

Aas, G. 1980. Setninger av bygg på sand; sammenligning mellom effektivspenning parametere bestemt ved henholdsvis trykksondering og triaksialforsøk. [In Norwegian].

AASHTO (American Association of State Highway and Transportation Officials). 1991. *T-289 Standard Method of Test for Determining pH of Soil for Use in Corrosion Testing*. Washington D.C.: AASHTO.

AASHTO (American Association of State Highway and Transportation Officials). 2012. *T-288 Standard Method of Test for Determining Minimum Laboratory Soil Resistivity*. Washington D.C.: AASHTO.

AASHTO (American Association of State Highway and Transportation Officials). 2017. *LRFD Design Specifications*. Washington D.C.: AASHTO.

AASHTO (American Association of State Highway and Transportation Officials). 2018. *Standard Specification for Transportation Materials and Methods of Sampling and Testing*. Washington D.C.: AASHTO. 4855 pp.

Adikari, G. S. N. 1977. "Statistical Evaluation of Strength and Deformation Characteristics of Bangkok Clays." *Asian Institute of Technology*.

Ahlvin, R. G., and Ulery, H. H. 1962. "Tabulated Values for Determining the Complete Pattern of Stresses, Strains, and Deflections Beneath a Uniform Circular Load on a Homogeneous Half Space." *Highway Research Board Bulletin 342*.

Akin, M. K., Kramer, S. L., and Topal, T. 2011. "Empirical Correlations of Shear Wave Velocity (Vs) and Penetration Resistance (SPT-N) for Different Soils in an Earthquake-prone Area (Erbaa-Turkey)." *Engineering Geology*, 119(1), 1–17.

Al-Hashemi, H. M. B., and Bukhary, A. H. 2016. "Correlation Between California Bearing Ratio (CBR) and Angle of Repose of Granular Soil." *Electronic journal of Geotechnical Engineering*, 21(17), 5655–5660.

Al-Khafaji, A. W. N., and Andersland, O. B. 1992. "Equations for Compression Index Approximation." *Journal of Geotechnical Engineering*, 118(1), 148–153.

Alpan, I. 1964. "Estimating the Settlements of Foundations on Sands." *Civil Engineering and Public Work Review*, 59(700).

Ameratunga, J., Sivakugan, N., and Das, B. M. 2016. *Correlations of Soil and Rock Properties in Geotechnical Engineering*. Springer.

American Lifelines Alliance. 2001. *Guidelines for the Design of Buried Steel Pipe.* American Society of Civil Engineers and Federal Emergency Management Agency, 83 pp.

Anderson, N., Croxton, N., Hoover, R., Sirles, P. 2008. "Geophysical Methods Commonly Employed for Geotechnical Site Characterization." *Transportation Research Circular E-C130*, Transportation Research Board, Washington, DC.

Asaoka. 1978. "Observational Procedure of Settlement Prediction." *Soils and Foundations*, 18(4), 87-101.

ASCE. 2001. *Design and Construction of Frost-Protected Shallow Foundations*. SEI/ASCE 32-01, https://doi.org/10.1061/9780784405642.

ASTM International. 2011. *D3999/D3999M-11e1 Standard Test Methods for the Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus*. West Conshohocken, PA; ASTM International. (Withdrawn 2020)

ASTM International. 2011. *D3080/D3080M-11 Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions*. West Conshohocken, PA; ASTM International. (Withdrawn 2020)

ASTM International. 2012. *D1557-12e1 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))*. West Conshohocken, PA; ASTM International.

ASTM International. 2012. *D4186/D4186M-12e1 Standard Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading*. West Conshohocken, PA; ASTM International.

ASTM International. 2012. *D4554-12 Standard Test Method for In Situ Determination of Direct Shear Strength of Rock Discontinuities*. West Conshohocken, PA; ASTM International.

ASTM International. 2012. *D698-12e2 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3))*. West Conshohocken, PA; ASTM International.

ASTM International. 2013. *D5311/D5311M-13 Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soil*. West Conshohocken, PA; ASTM International.

ASTM International. 2013. *D6467-13e1 Standard Test Method for Torsional Ring Shear Test to Determine Drained Residual Shear Strength of Cohesive Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2014. *D2113-14 Standard Practice for Rock Core Drilling and Sampling of Rock for Site Exploration*. West Conshohocken, PA; ASTM International.

ASTM International. 2014. *D4220/D4220M-14 Standard Practices for Preserving and Transporting Soil Samples*. West Conshohocken, PA; ASTM International.

ASTM International. 2014. *D4452-14 Standard Practice for X-Ray Radiography of Soil Samples*. West Conshohocken, PA; ASTM International.

ASTM International. 2014. *D4546-14e1 Standard Test Methods for One-Dimensional Swell or Collapse of Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2014. *D7012-14e1 Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures*. West Conshohocken, PA; ASTM International

ASTM International. 2014. *D854-14 Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer*. West Conshohocken, PA; ASTM International.

ASTM International. 2015. *D1556/D1556M-15e1 Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method*. West Conshohocken, PA; ASTM International.

ASTM International. 2015. *D1587/D1587M-15 Standard Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes*. West Conshohocken, PA; ASTM International.

ASTM International. 2015. *D2167-15 Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method*. West Conshohocken, PA; ASTM International.

ASTM International. 2015. *D2850-15 Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2015. *D3282-15 Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes*. West Conshohocken, PA; ASTM International.

ASTM International. 2015. *D4015-15e1 Standard Test Methods for Modulus and Damping of Soils by Fixed-Base Resonant Column Devices*. West Conshohocken, PA; ASTM International.

ASTM International. 2015. *D4044/D4044M-15 Standard Test Method for (Field Procedure) for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers*. West Conshohocken, PA; ASTM International.

ASTM International. 2015. *D5856-15 Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter*. West Conshohocken, PA; ASTM International.

ASTM International. 2015. *D6635-15 Standard Test Method for Performing the Flat Plate Dilatometer*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D1196/D1196M-12(2016) Standard Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D1452/D1452M-16 Standard Practice for Soil Exploration and Sampling by Auger Borings*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D1883-16 Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils.* West Conshohocken, PA; ASTM International. doi: https://doi.org/10.1520/D1883-16

ASTM International. 2016. *D2166/D2166M-16 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D3967-16 Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D4253-16e1 Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D4254-16 Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D4644-16 Standard Test Method for Slake Durability of Shales and Other Similar Weak Rocks*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D4648/D4648M-16 Standard Test Methods for Laboratory Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D4959-16 Standard Test Method for Determination of Water Content of Soil by Direct Heating*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D4971-16 Standard Test Method for Determining In Situ Modulus of Deformation of Rock Using Diametrically Loaded 76-mm (3-in.) Borehole Jack*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D5084-16a Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D5607-16 Standard Test Method for Performing Laboratory Direct Shear Strength Tests of Rock Specimens Under Constant Normal Force*. West Conshohocken, PA; ASTM International.

ASTM International. 2016. *D5731-16 Standard Test Method for Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D1140-17 Standard Test Methods for Determining the Amount of Material Finer than 75-μm (No. 200) Sieve in Soils by Washing*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D2487-17e1 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D2488-17e1 Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D2937-17e2 Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D4318-17e1 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D4327-17 Standard Test Method for Anions in Water by Suppressed Ion Chromatography*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D4394-17 Standard Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Rigid Plate Loading Method*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D4395-17 Standard Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Flexible Plate Loading Method*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D4491/D4491M-17 Standard Test Methods for Water Permeability of Geotextiles by Permittivity*. West Conshohocken, PA; ASTM International. https://doi.org/10.1520/D4491_D4491M-17.

ASTM International. 2017. *D4643-17 Standard Test Method for Determination of Water Content of Soil and Rock by Microwave Oven Heating*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D6528-17 Standard Test Method for Consolidated Undrained Direct Simple Shear Testing of Fine Grain Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D6913/D6913M-17 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D6938-17a Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)*. West Conshohocken, PA; ASTM International.

ASTM International. 2017. *D7928-17 Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*. West Conshohocken, PA; ASTM International.

ASTM International. 2018. *D1586/D1586M-18 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2018. *C33/C33M-18 Standard Specification for Concrete Aggregates*. West Conshohocken, PA; ASTM International.

ASTM International. 2018. *D2573/D2573M-18 Standard Test Method for Field Vane Shear Test in Saturated Fine-Grained Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2018. *D4221-18 Standard Test Method for Dispersive Characteristics of Clay Soil by Double Hydrometer*. West Conshohocken, PA; ASTM International.

ASTM International. 2018. *D4427-18 Standard Classification of Peat Samples by Laboratory Testing*. West Conshohocken, PA; ASTM International.

ASTM International. 2018. *D4944-18 Standard Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester*. West Conshohocken, PA; ASTM International.

ASTM International. 2018. *D6951/D6951M-18 Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*. West Conshohocken, PA; ASTM International.

ASTM International. 2018. *D7263-09(2018)e2 Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens*. West Conshohocken, PA; ASTM International.

ASTM International. 2019. *D2216-19 Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*. West Conshohocken, PA; ASTM International.

ASTM International. 2019. *D3213-19 Standard Practices for Handling, Storing, and Preparing Soft Intact Marine Soil*. West Conshohocken, PA; ASTM International.

ASTM International. 2019. *D4729-19 Standard Test Method for In Situ Stress and Modulus of Deformation Using the Flat Jack Method*. West Conshohocken, PA; ASTM International.

ASTM International. 2019. *D4829-19 Standard Test Method for Expansion Index of Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2019. *D4972-19 Standard Test Methods for pH of Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2019. *D8296-19 Standard Test Method for Consolidated Undrained Cyclic Direct Simple Shear Test under Constant Volume with Load Control or Displacement Control*. West Conshohocken, PA; ASTM International. doi: https://doi.org/10.1520/D8296-19

ASTM International. 2020. *D2435/D2435M-11(2020) Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading*. West Conshohocken, PA; ASTM International.

ASTM International. 2020. *D4647/D4647M-13(2020) Standard Test Methods for Identification and Classification of Dispersive Clay Soils by the Pinhole Test*. West Conshohocken, PA; ASTM International.

ASTM International. 2020. *D4719-20 Standard Test Methods for Prebored Pressuremeter Testing in Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2020. *D4767-11(2020) Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2020. *D5778-20 Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2020. *D6429-20 Standard Guide for Selecting Surface Geophysical Methods*. West Conshohocken, PA; ASTM International.

ASTM International. 2020. *D6572-20 Standard Test Methods for Determining Dispersive Characteristics of Clayey Soils by the Crumb Test*. West Conshohocken, PA; ASTM International.

ASTM International. 2020. *D7181-20 Standard Test Method for Consolidated Drained Triaxial Compression Test for Soils*. West Conshohocken, PA; ASTM International.

ASTM International. 2020. *D7698-20 Standard Test Method for In-Place Estimation of Density and Water Content of Soil and Aggregate by Correlation with Complex Impedance Method*. West Conshohocken, PA; ASTM International.

ASTM STP 501. 1972. *Underwater Soil Sampling, Testing and Construction Control*. American Society of Testing and Materials, Philadelphia, PA.

ASTM STP 777. 1981. *Geotechnical Properties, Behavior, and Performance of Calcareous Soils*. American Society of Testing and Materials, Philadelphia, PA.

Athanasopoulos, G. A. 1995. "Empirical Correlations Vs -N SPT for Soils of Greece: A Comparative Study of Reliability." *Proceedings of the 7th International Conference on Soil Dynamics and Earthquake Engineering*, 19–36.

Australian Drilling Industry Training Committee. 2015. *The Drilling Manual (5th ed)*. CRC Press/Taylor & Francis, Boca Raton, FL.

Ayadat, T., and Hanna, A. 2007a. "Identification of Collapsible Soil Using the Fall Cone Apparatus." *Geotechnical Testing Journal*, 30(4), 312–323.

Ayadat, T., and Hanna, A. 2007b. "Prediction of collapse behaviour in soil." *Revue Européenne de Génie Civil*, 11(5), 603–619.

Azzouz, A. S., Krizek, R. J., and Corotis, R. B. 1976. "Regression Analysis of Soil Compressibility." *Soils and Foundations*, 16(2), 19–29.

Balasubramaniam, A. S., and Brenner, R. P. 1981. "Consolidation and Settlement of Soft Clay." *Soft Clay Engineering,* E. W. Brand and R. P. Brenner, eds., Elsevier, 481–566.

Baldi, G., Bellotti, R., Ghionna, V., Jamiolkowski, M., and Lo Presti, D. C. F. 1989. "Modulus of Sands from CPT's and DMT's." In *Proc. 12th Int. Conf. on Soil Mechanics and Foundation Engineering*, Rio de Janeiro, 165–170.

Baldi, G., Bellotti, R., Ghionna, V., Jamiolkowski, M., and Pasqualini, E. 1981. "Cone Resistance of a Dry Medium Sand." In *Proc.10th Int. Conf. on Soil Mechanics and Foundation Engineering,* Stockholm, 427–432.

Bandyopadhyay, S.S. 1981. "Prediction of Swelling Potential for Natural Soils." *Journal of Geotechnical Engineering*, 107(5): 658–691.

Barber, E.W. 1959. "Subsurface Drainage of Highways." *Highway Research Board, Bulletin 209*, Highway Research Board, Washington, D.C.

Barron, R. A. 1948. "Consolidation of Fine-Grained Soils by Drain Wells." *Transactions of ASCE*, Paper No. 2346, 718-743.

Bartholomew, C.L. and Haverland, M.L. 1987. *Concrete Dam Instrumentation Manual*. United States Department of the Interior, Bureau of Reclamation, Denver, CO.

Barton, N., Lien, R., and Lunde, J. 1974. "Engineering Classification of Rock Masses for the Design of Tunnel Support." *Rock Mechanics*, 6(4), 189–236.

Bear, J. 1979. *Hydraulics of Groundwater*. McGraw-Hill, Inc., New York, NY, 574 pp.

Been, K., Jeffries, M. G., Crooks, J. H. A., and Rothenburg, L. 1987. "The Cone Penetration Test in Sands: Part II, General Inference of State." *Geotechnique*, 37(3), 285–299

Begemann, H. K. S. 1974. "General Report for Central and Western Europe." In *Proc. of the European Symposium on Penetration Testing*, Stockholm, 29–39.

Benson, C. H., and Trast, J. M. 1995. "Hydraulic Conductivity of Thirteen Compacted Clays." *Clays and Clay Minerals*, 43(6), 669–681.

Benson, C. H., Zhai, H., and Wang, X. 1994. "Estimating the Hydraulic Conductivity of Compacted Clay Liners." *Journal of Geotechnical Engineering*, 120(2), 366–387.

Bergdahl, U., Ottosson, E., and Malmborg, B. S. 1993. *Plattgrundläggning*. AB Svensk Byggtjänst och Statens geotekniska institute. [In Swedish].

Berney, E.S., Kyzar, J.D., Oyelami, L.O. 2012. *Device Comparison for Determining Field Soil Moisture Content*. USACE Report No. ERDC/GSL TR-11-42, United States Army Corps of Engineers, Vicksburg, MS.

Berney, E.S., Mejias-Santiago, M., Kyzar, J.D. 2013. *Non-nuclear Alternatives to Monitoring Moisture-Density Response in Soils*. USACE Report No. ERDC/GSL TR-13-6, United States Army Corps of Engineers, Vicksburg, MS.

Berney, E.S., Mejias-Santiago, M., Norris, D. 2016. *Validation Testing of Non-nuclear Alternatives to Monitoring Soil Density*. USACE Report No. ERDC/GSL TR-16-28, United States Army Corps of Engineers, Vicksburg, MS.

Bieniawski, Z. T. 1973. "Engineering Classification of Jointed Rock Masses." *Transactions of the South African Institution of Civil Engineers*, 15, 335–344.

Bieniawski, Z. T. 1976. "Rock Mass Classification in Rock Engineering." *Proc. Sym. on Exploration for Rock Engineering*, Ed. Z. T. Bieniawski, A. Balkema Rotterdam, 7-106.

Bieniawski, Z. T. 1990. *Tunnel Design by Rock Mass Classifications*, Update of Technical Report GL-79-19. Washington: Department of the Army U.S. Army Corps of Engineers.

Bieniawski, Z.T. 1989. *Engineering Rock Mass Classifications*. John Wiley & Sons, New York, NY.

Bjerrum, L. 1954. "Geotechnical Properties of Norwegian Marine Clays." *Geotechnique*, 4(2), 49–69.

Bjerrum, L. 1972. "Embankments on Soft Ground, State-of-the-Art Report." *Proc. of the Conference on Performance of Earth and Earth-supported Structures*, Lafayette, 1–54.

Bjerrum, L. 1973. "Problems of Soil Mechanics and Construction on Soft Clays and Structurally Unstable Soils." *Proc. of the 8th Int. Conf. on Soil Mechanics and Foundation Engineering,* Moscow, 111–159.

Bjerrum, L., and Simons, N. E. 1960. "Comparison of Shear Strength Characteristics of Normally Consolidated Clays." *Norwegian Geotechnical Institute*, 35, 13–22.

Boulanger, R. W., and Idriss, I. M. 2014. *CPT and SPT Based Liquefaction Triggering Procedures*. Report No. UCD/CGM-14/01, University of California at Davis, Davis, CA.

Bovis, M. J. 1985. "Earthflows in the Interior Plateau, Southwest British Columbia." *Canadian Geotechnical Journal*, 22(3), 313–334.

Bowles, L. E. 1996. *Foundation Analysis and Design*. McGraw-Hill.

Bradley, N. and VandenBerge, D. R. 2015. *Beginner's Guide for Geotechnical Finite Element Analyses, CGPR #82*. Center for Geotechnical Practice and Research, Blacksburg, VA, 99 pp.

Brandon, T. L., Duncan, J. M., and Gardner, W. S. 1990. "Hydrocompression Settlement of Deep Fills." *Journal of Geotechnical Engineering*, 116(10), 1536-1548.

Broch, E., and Franklin, J. A. 1972. "The Point-load Strength Test." *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 9(6), 669–676.

Brown, P. 1969. "Numerical Analyses of Uniformly Loading Circular Rafts on Elastic Layers of Finite Depth." *Geotechnique*, 19(2), 301-306.

Burgers, A. and Yoder, E.J. 1962. *Nuclear Moisture-Density Measurements in Construction Control*. Joint Highway Research Project, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana

Burland, J. B. 1970. "Discussion, Session A." *Proc. Conf. on In Situ Investigations in Soil and Rocks*, British Geotechnical Society, London, UK, 61-62.

Burland, J. B. 1990. "On the Compressibility and Shear Strength of Natural Clays." *Géotechnique*, 40(3), 329–378.

Burland, J. B. and Burbridge, M. 1985. "Settlement of Foundations on Sand and Gravel." *Proc. Institution of Civil Engineers, Part 1, Design and Contruction*, 78(1), 1325-1381.

Burland, J. B. and Wroth, C. P. 1974. "Settlement of Buildings and Associated Damage." *SOA Review, Conf. Settlement of Structures*, Cambridge, 611-654.

Burmister, D. M. 1962. "Physical, Stress-Strain, and Strength Responses of Granular Soils." *Sym. on Field Testing of Soils (STP 322)*, ASTM, Philadelphia, 67–97.

Butcher, A. P., McElmeel, K., and Powell, J. J. M. 1996. "Dynamic Probing and its Use in Clay Soils." *Proc. of the Int. Conf. on Advances in Site Investigation Practice*, 383–395.

California Department of Water Resources. 2013. *ULE Special Testing Program, DWR Guidance Document*. California Department of Water Resources, Sacramento, CA.

Callanan, J. F., and Kulhawy, F. H. 1985. *Evaluation of Procedures for Predicting Foundation Uplift Movements*. Report EL-4107, Palo Alto, CA.

Carman, P. C. 1938. "The Determination of the Specific Surface of Powders." *J. Soc. Chem. Ind. Trans.*, 57, 225.

Carman, P. C. 1956. *Flow of Gases Through Porous Media*. Butterworths Scientific Publications, London.

Carrier, W. D. 2003. “Goodbye, Hazen; Hello, Kozeny-Carman.” *Journal of Geotechnical and Geoenvironmental Engineering*, 129(11), 1054-1056.

Carrier, W. D., and Beckman, J. F. 1984. “Correlations Between Index Tests and the Properties of Remoulded Clays.” *Geotechnique*, 34(2), 211–228.

Carrillo, N. 1942. “Simple Two and Three Dimensional Case in the Theory of Consolidation of Soils.” *Journal of Mathematics and Physics*, 21(1-4), 1-5.

Carter, M., and Bentley, S. P. 2016. *Soil Properties and their Correlations*. John Wiley & Sons, Ltd.

Castellanos, B. A., Ritchie, J., and Brandon, T. L. 2021. *Estimating Fully Softened and Residual Shear Strength Parameters of Fine-Grained Soils*. Center for Geotechnical Practice and Research, Blacksburg, VA.

Chandler, R. J. 1969. “The Effect of Weathering on the Shear Strength Properties of Keuper Marl.” *Géotechnique*, 19(3), 321–334.

Chandler, R. J. 1970. “A Shallow Slab Slide in the Lias Clay near Uppingham, Rutland.” *Géotechnique*, 20(3), 253–260.

Chandler, R. J. 1988. “The In-Situ Measurement of the Undrained Shear Strength of Clays Using the Field Vane.” *Vane Shear Strength Testing in Soils: Field and Laboratory Studies, ASTM STP 1014*, A. F. Richards, ed., American Society for Testing and Materials, Philadelphia, 13–44.

Chapman, G. A., and Donald, I. B. 1981. “Interpretation of Static Penetration Tests in Sand.” *Proc. of the 10th Int. Conf. on Soil Mechanics and Foundation Engineering*, Stockholm, 455–458.

Chapuis, R. P. 2004. “Predicting the Saturated Hydraulic Conductivity of Sand and Gravel Using Effective Diameter and Void Ratio.” *Canadian Geotechnical Journal*, 41, 787-795.

Chen, F.H. 1975. *Foundations on Expansive Soils*. Elsevier Scientific Pub. Co., Amsterdam, New York, NY.

Cheng, Y. M., Hu, Y. Y., and Wei, W. B. 2007. “General Axisymmetric Active Earth Pressure by Method of Characteristics—Theory and Numerical Formulation.” *International Journal of Geomechanics*, 7(1), 1-15.

Christopher, B.R. and Fischer, G.R. 1991. “Geotextile Filtration Principles, Practices, and Problems.” *Proc. of the 5th GRI seminar on the topic of Geosynthetics in Filtration, Drainage, and Erosion Control*, Philadelphia, Pennsylvania, 1−17.

Clayton, C.R.I, Matthews, M.C., Simmons, N.E. 1995. *Site Investigation: Second Edition*.

Coduto, D. P., Yeung, M. C. R., and Kitch, W. A. 2011. *Geotechnical Engineering: Principles and Practices*. Prentice Hall.

Cokca, E. 2002. “Relationship Between Methylene Blue Value, Initial Soil Suction and Swell Percent of Expansive Soils.” *Turkish Journal of Engineering and Environmental Sciences*, 26: 521–529.

Cox, J. B. 1968. "A Review of the Engineering Characteristics of the Recent Marine Clays in South East Asia." *Research Report No. 6*.

Cozzolino, V. M. 1961. “Statistical Forecasting of Compression Index.” *Proc. of the 5th Int. Conf. on Soil Mechanics and Foundation Engineering*, Paris, France, 51–53.

D'Appolonia, D. J., Poulos, H. G., and Ladd, C. C. 1971. “Initial Settlement of Structures on Clay.” *Journal of the Soil Mechanics and Foundation Division*, 97(10), 1359-1377.

D’Appolonia, E., Alperstein, R., and D’Appolonia, D. J. 1967. “Behavior of a Colluvial Slope.” *Journal of Soil Mechanics and Foundations Division*, 93(4), 447–473.

Dakshanamurthy, V., and Raman, V. 1973. “A Simple Method of Identifying an Expansive Soil.” *Soils and Foundations*, 13(1), 97–104.

Davis, E. H., and Poulos, H. G. 1972. “Rate of Settlement Under Two and Three Dimensional Conditions.” *Geotechnique*, 22(1), 95-114.

Davis, R. O. and Selvadurai A. P. S. 1996. *Elasticity and Geomechanics*. Cambridge University Press, Cambridge, UK, 216 pp.

Day, R. W. 1990. “Differential Movement of Slab on Grade Structures.” *Journal of Performance of Constructed Facilities*, 4(4), 236-241.

Day, R. W. 1999. *Geotechnical and Foundation Engineering*. McGraw-Hill, New York, NY.

Decker, J. B., Rollins, K. M., and Ellsworth, J. C. 2008. “Corrosion Rate Evaluation and Prediction for Piles Based on Long-Term Field Performance.” *Journal of Geotechnical and Geoenvironmental Engineering*, 134(3), 341–351.

Deere, D.U. and Deere, D.W. 1988. “The Rock Quality Designation (RQD) Index in Practice.” *Proc., Rock Classification Systems for Engineering Purposes, ASTM STP 984, American Society for Testing and Materials*, Philadelphia, PA 91-101.

DeMello, V. F. B. 1971. “The Standard Penetration Test: A State-of-the-Art Report.” *Proc. of the 4th Panamerican Conference on Soil Mechanics and Foundation Engineering*, San Juan, PR, 1–86.

Dikmen, U. 2009. “Statistical Correlations of Shear Wave Velocity and Penetration Resistance for Soils.” *Journal of Geophysics and Engineering*, 6, 61–72.

Duncan, J. M. 1979. “Behavior and Design of Long-Span Metal Culverts.” *Journal of the Geotechnical Engineering Division*, 105(3), 399-418.

Duncan, J. M. and Chang C.-Y. 1970. “Nonlinear Analysis of Stress and Strain in Soils.” *Journal of the Soil Mechanics and Foundations Division*, 96(5), 1629-1653.

Duncan, J. M. and Wong, K. S. 1983. "Use and Mis-use of the Consolidated-undrained Triaxial Test for Analysis of Slope Stability During Rapid Drawdown." *Paper Prepared for 25th Anniversary Conference on Soil Mechanics*, Venezuela.

Duncan, J. M., and Buchignani, A. L. 1987. *Engineering Manual for Settlement Studies, CGPR #2*. Center for Geotechnical Practice and Research.

Duncan, J. M., and Mokwa, R. L. 2001. “Passive Earth Pressures: Theories and Tests.” *Journal of Geotechnical and Geoenvironmental Engineering*, 127(3), 248-257.

Duncan, J. M., Byrne, P., Wong, K. S., and Mabry, P. 1980. “Strength, Stress-Strain and Bulk Modulus Parameters for Finite Element Analyses of Stresses and Movements in Soil Masses.” *Report No. UCB/GT/80-01*, Univ. California-Berkeley, 77 pp. (Republished as CGPR #63, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA).

Duncan, J. M., Horz, R. C., and Yang, T. L. 1989. *Shear Strength Correlations for Geotechnical Engineering*. Center for Geotechnical Practice and Research, Blacksburg, VA.

Duncan, J. M., O’Neil, B., Brandon, T. L., and VandenBerge, D. R. 2011. *Evaluation of Potential for Erosion in Levees and Levee Foundations, CGPR #64*. Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA, 36 pp.

Duncan, J. M., Wright, S. G., and Brandon, T. L. 2014. *Soil Strength and Slope Stability, 2nd ed*. Wiley, Hoboken, NJ.

Dunn, C. 2017. “Field Soils Testing.” *North Dakota DOT Training*. http://www.dot.nd.gov/divisions/materials/ttqp/soilstesting.pdf, (August, 2019)

Dunnicliff, J. 1993. *Geotechnical Instrumentation for Monitoring Field Performance*. John Wiley & Sons, New York, NY.

Elnaggar, H. A. and Krizek, R. J. 1970. “Statistical Approximation for Consolidation Settlement.” *Highway Research Record No. 323*, 87-96.

Erzin, Y., and Erol, O. 2004. “Correlations for Quick Prediction of Swell Pressures.” *Electronic Journal of Geotechnical Engineering*, 9(F): Paper No. 0476. available from www.ejge.com/2004/Ppr0476/Abs0476.htm.

Erzin, Y., and Erol, O. 2007. “Swell Pressure Prediction by Suction Methods.” *Engineering Geology*, 92(3–4): 133–145. doi:10.1016/j.enggeo.2007.04.002.

Fear, C. E., and Robertson, P. K. 1995. “Estimating the Undrained Strength of Sand: A Theoretical Framework.” *Canadian Geotechnical Journal*, 32(5), 859–870.

Feleke, G. G., and Araya, A. A. 2016. “Prediction of CBR Using DCP for Local Subgrade Materials.” *Proc. of the Int. Conf. on Transport and Road Research*, 1–30.

FEMA (Federal Emergency Management Agency). 2011. *Filters for Embankment Dams, Best Practices for Design and Construction*, 332 pp.

Fenning, P. J., and Hasan, S. 1995. “Pipeline Route Investigations Using Geophysical Techniques.” *Engineering Geology of Construction*, Geological Society Engineering Geology, Special Publication No. 10, M. Eddleston et al (Eds), pp. 229–233.

Ferrent, T. A. 1963. “The Prediction of Field Verification of Settlement on Cohesionless Soils.” *Proc. of the 4th Australia-New Zealand Conference on Soil Mechanics and Foundation Engineering*, 11–17.

FHWA (Federal Highway Administration). 1998. *Geotechnical Instrumentation*. Reference Manual FHWA HI-98-034, United States Department of Transportation, Federal Highway Association, Washington, DC.

FHWA. 1998. *Rock Slopes Reference Manual, FHWA-HI-99-007*. Washington, D.C.

FHWA. 1999. *Geotechnical Engineering Circular No. 4 Ground Anchors and Anchored Systems*, FHWA-IF-99-015. Washington, D.C.

FHWA. 2002. “Evaluation of Soil and Rock Properties.” *Geotechnical Engineering Circular No. 5. Publication No. FHWA-IF-02-034*. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

FHWA. 2003. “Application of Geophysical Methods to Highway Related Problems.” *Contract No. DTFH68-02-P-00083*. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

FHWA. 2006. “Soils and Foundations, Reference Manual – Volume I.” *Publication No. FHWA NHI-06-088*, Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

FHWA. 2009. *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*. National Highway Institute - Federal Highway Administration.

FHWA. 2009. *Technical Manual for Design and Construction of Road Tunnels – Civil Elements, FHWA-NHI-09-010*. Washington, D.C., 694 pp.

FHWA. 2009a. *Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, FHWA-NHI-09-087*. Washington, D.C.

FHWA. 2009b. *Design of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes-Volume I and II, FHWA-NHI-10-024 and FHWA-NHI-10-025*. Washington, D.C.

FHWA. 2015. *Geotechnical Engineering Circular No. 7 Soil Nail Walls – Reference Manual, FHWA-NHI-14-007*. Washington, D.C.

FHWA. 2016. “Geotechnical Site Characterization.” *Geotechnical Engineering Circular No. 5. Publication No. NHI-16-072*. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

FHWA. 2017. *Geotechnical Engineering Circular No. 5 - Geotechnical Site Characterization*. U.S. Department of Transportation - Federal Highway Administration, Washington, DC.

FHWA. 2017. *Ground Modification Methods Reference Manual – Volume I, FHWA-NHI-16-027*, Geotechnical Engineering Circular 13, Washington D.C.

Filz, G., and Brandon, T. L. 1993. "Compactor Force and Energy Measurements," *ASTM Geotechnical Testing Journal*, Vol. 16, No. 4, December, pp. 442-449.

Foster, M., Fell, R., and Spannagle, M. 2000. “The Statistics of Embankment Dam Failures and Accidents.” *Canadian Geotechnical Journal*, 37(5), 1000-1024.

Frazer, R. A. and Wardle, L. J. 1976. "Numerical Analysis of Rectangular Rafts on Layered Foundations." *Geotechnique*, 26(4), 613-630.

Freeze, R.A. and Cherry, J.A. 1979. *Groundwater*, Prentice-Hall, Englewood Cliffs, NJ, 604 pp.

Fujiwara, T. 1972. “Estimation of Ground Movements in Actual Destructive Earthquakes.” *Proc. of the 4th European Symposium on Earthquake Engineering*, London, 125–132.

Fumal, T. E., and Tinsley, J. C. 1985. “Mapping Shear-Wave Velocities of Near-Surface Geologic Materials.” *Evaluating Earthquake Hazards in the Los Angeles Region -- An Earth-Science Perspective, U.S. Geological Survey Professional Paper 1360*, J. I. Ziony, ed., 127–149.

Gabr, M. A., Hopkins, K., Coonse, J., and Hearne, T. 2000. “DCP Criteria for Performance Evaluation of Pavement Layers.” *Journal of Performance of Constructed Facilities*, 14(4), 141–148.

Geological Society of London. 1977. “The Description of Rock Masses for Engineering Purposes.” *Quarterly Journal of Engineering Geology and Hydrogeology*, 10(4), 355–388.

George, J.T., Finley, R.E. and Riggins, M., 1999, January. "Determination of Rock Mass Modulus Using the Plate Loading Method." *9th ISRM Congress*. International Society for Rock Mechanics and Rock Engineering.

George, V., and Kumar, A. 2018. “Studies on Modulus of Resilience Using Cyclic Triaxial Test and Correlations to PFWD, DCP, and CBR.” *International Journal of Pavement Engineering*, 19(11), 976–985.

George, V., Nageshwar, C. R., and Shivashankar, R. 2009. “PFWD, DCP and CBR Correlations for Evaluation of Lateritic Subgrades.” *International Journal of Pavement Engineering*, 10(3), 189–199.

Gibson, R. E. 1953. “Experimental Determination of the True Cohesion and True Angle of Internal Friction in Clays.” *Proc. of the 3rd Int. Conf. in Soil Mechanics*, Zurich, 1, 126–130.

Gibson, R.E. and Anderson, W.F. 1961. “In-Situ Measurement of Soil Properties with the Pressuremeter.” *J. Civil Engineering and Public Works Review*, 56(658), London, 615-618.

Gielly, J., Lareal, P., and Sanglerat, G. 1969. “Correlations between In Situ Penetrometer Tests and the Compressibility of Soils.” *Proc. of the Conferences on In Situ Investigations of Soils and Rocks*, London, 167–172.

Giroud, J.-P. 1972. “Settlement of Rectangular Foundation on Soil Layer.” *Journal of the Soil Mechanics and Foundations Division*, 98(SM1), 149-154.

Giroud, J.P. 2010. “Development of Criteria for Geotextile and Granular Filters.” *Proc. of the 9th Int. Conf. on Geosynthetics*, Guaruja, Brazil, Vol. 1, 45–64.

Goldberg, G. D., Lovell, C. W., and Miles, R. D. 1979. “Use the Geotechnical Data Bank.” *Transportation Research Record*, 702, 140–146.

Goodman, R. 1970. *The Deformability of Joints*. Determination of the In Situ Modulus of Deformation of Rock, ASTM International, West Conshohocken, PA., 174-196.

Goodman, R.E. 1989. *Introduction to Rock Mechanics. 2nd Ed.* John Wiley & Sons, New York.

Griffiths, D. V., and P. A. Lane. 1999. “Slope Stability Analysis by Finite Elements.” *Geotechnique 49*, No. 3, pp. 387-403.

Hamel, J. V. 1970. *Stability of Slopes in Soft, Altered Rocks*. Ph.D. dissertation, University of Pittsburgh.

Hansbo, S. 1957. “A New Approach to the Determination of the Shear Strength of Clay by the Fall-Cone Test.” *Royal Swedish Geotechnical Institute Proceedings*, 14, 1–46.

Hansbo, S. 1979. “Consolidation of Clay by Band-Shaped Prefabricated Drains.” *Ground Engineering*, 12(5), 16-25.

Hara, A., Ohta, T., Niwa, M., Tanaka, S., and Banno, T. 1974. “Shear Modulus and Shear Strength of Cohesive Soils.” *Soils and Foundations*, 14(3), 1–12.

Harr, M. E. 1977. “Chapter 5 – Analysis of flow systems.” *Mechanics of Particulate Media*, McGraw Hill, New York, NY, 142-183.

Harrison, J. A. 1986. “Correlation of CBR and Dynamic Cone Penetrometer Strength Measurement of Soils.” *Australian Road Research1*, 16(2), 130–136.

Hasancebi, N., and Ulusay, R. 2007. “Empirical Correlations Between Shear Wave Velocity and Penetration Resistance for Ground Shaking Assessments.” *Bulletin of Engineering Geology and the Environment*, 66(2), 203–213.

Hatanaka, M., and Uchida, A. 1996. “Empirical Correlations Between Penetration Resistance and Internal Friction Angle of Sandy Soils.” *Soils and Foundations*, 36(4), 1–9.

Hazen, A. 1892. “Some Physical Properties of Sands and Gravels, with Special Reference to Their Use in Filtration.” *24th Annual Report, Massachusetts State Board of Health*, Pub. Doc. No. 34, 539-556.

Hazen, A. 1911. “Discussion of ‘Dams on Sand Foundations: Some Principles Involved in Their Design, and the Law Governing the Depth of Penetration Required for Sheet-Piling.’” *Transactions of the American Society of Civil Engineers*, 73(3), 190–207.

Hegazy, Y. A., and Mayne, P. W. 1995. “Statistical Correlations Between Vs and CPT Data for Different Soil Types.” *Proc. of the Int. Sym. on Cone Penetration Testing CPT95*, Spon Press, Linkoping, Sweden, 173–178.

Hegazy, Y. A., and Mayne, P. W. 2006. “A Global Statistical Correlation Between Shear Wave Velocity and Cone Penetration Data.” *Site and Geomaterial Characterization* (GeoShanghai International Conference), 243–248.

Helenelund, K. V. 1951. “On Consolidation and Settlement of Loaded Soil Layers.” Ph.D. Dissertation, Finland Technical Institute.

Hemphill, G.B. 2012. *Practical Tunnel Construction*. John Wiley & Sons.

Hill, S., Skempton, A. W., and Petley, D. J. 1967. “The Strength Along Structural Discontinuities in Stiff Clays.” *Proc. of the Geotechnical Conference Oslo 1967 on Shear Strength Properties of Natural Soils and Rocks*, 2, 29–46.

Hoek, E. 2007. *Practical Rock Engineering*. RocScience Inc., Toronto, ON.

Hoek, E. and Bray, J. 1981. *Rock Slope Engineering, 3rd Ed*. The Institution of Mining and Metallurgy, London.

Holden, J. C. 1976. “The Determination of Deformation and Shear Strength Parameters for Sands using the Electrical Friction-cone Penetrometer.” *Norwegian Geotechnical Institute*, 110, 55–60.

Holtz, R. D., and Holm, G. 1973. *Belastningsförsök på Svartmocka*. [In Swedish]. Stockholm.

Holtz, R. D., and Kovacs, W. D. 1981. *An Introduction to Geotechnical Engineering*. Prentice Hall.

Holtz, R. D., Kovacs, W. D., and Sheahan, T. C. 2011. *An Introduction to Geotechnical Engineering, 2nd Ed*. Prentice Hall, Upper Saddle River, NJ, 853 pp.

Hough, B. K. 1957. *Basic Soils Engineering*. The Ronald Press Company, New York, 114-115.

Hough, B. K. 1969. *Basic Soil Engineering*. 2nd ed., The Ronald Press Company, New York.

Houlsby, A.C. 1976. “Routine Interpretation of the Lugeon Water-Test.” *J. Engineering Geology*, 9, 303-313.

Hutchinson, J. N. 1967. “Written Discussion.” *Proc. of the Geotechnical Conference Oslo 1967 on Shear Strength Properties of Natural Soils and Rocks*, 2, 183–184.

Hutchinson, J. N. 1969. “A Reconsideration of the Coastal Landslides at Folkestone Warren, Kent.” *Géotechnique*, 19(1), 6–38.

ICC (International Code Council). 2018. *International Building Code*. International Code Council.

ICOLD (International Commission on Large Dams). 2014. “Internal Erosion of Existing Dams, Levees and Dykes, and Their Foundations.” *Bulletin 164*, Volume 1: Internal Erosion Processes and Engineering Assessment, Eds. Bridle, R. and Fell, R., International Commission on Large Dams, Paris.

Imai, T. 1977. “P-and S-wave Velocities of the Ground in Japan.” *Proc. of the 9th Int. Conf. on Soil Mechanics and Foundation Engineering*, 127–132.

Imai, T., and Tonouchi, K. 1982. “Correlation of N-value with S-wave Velocity and Shear Modulus.” *Pro. of the 2nd European Symposium on Penetration Testing*, Amsterdam, 67–72.

Imai, T., and Yoshimura, Y. 1975. “The Relation of Mechanical Properties of Soils to P and S-Wave Velocities for Ground in Japan.” *Technical Note OYO Corporation*.

Imai, T., Fumoto, H., and Yokota, K. 1975. “The Relation of Mechanical Properties of Soil to P and S-Wave Velocities in Japan” [In Japanese]. *Proc. of 4th Japan Earthquake Engineering Symposium*, 89–96.

Iwasaki, K., and Kamei, T. 1994. “Evaluation of In Situ Strength and Deformation Characteristics of Soils Using Flat Dilatometer.” *Doboku Gakkai Ronbunshu*, 1994(499), 167–175.

Iyisan, R. 1996. “Correlations Between Shear Wave Velocity and in-situ Penetration Test Results” [In Turkish]. *Teknik Dergi (Digest)*, 7, 1187–1199.

Jafari, M. K., Shafiee, A., and Razmkhah, A. 2002. “Dynamic Properties of the Fine Grained Soils in South of Tehran.” *Journal of Seismology and Earthquake Engineering*, 4(1), 25–35.

Jaime, A., and Romo, M. P. 1988. “Mexico Earthquake of September 19, 1985 - Correlations Between Dynamic and Static Properties of Mexico City Clay.” *Earthquake Spectra*, 4(4), 787–804

Jamiolkowski, M., Ghionna, V., Lancellotta, R., and Pasqualini, E. 1988. “New Correlations of Penetration Tests for Design Practice.” *Proc. of the 1st Int. Sym. on Penetration Testing*, Orlando, FL, 263–296.

Jamiolkowski, M., Ladd, C. C., Germaine, J. T., and Lancellotta, R. 1985. “New Developments in Field and Laboratory Testing of Soils.” *Proc. of the 11th Int. Conf. on Soil Mechanics and Foundation Engineering*, 1, 57–154.

Janbu, N. 1963. “Soil Compressibility as Determined by Oedometer and Triaxial Tests.” *Proc. of the 3rd European Conference on Soil Mechanics and Foundation Engineering*, Wiesbaden, 19–25.

Janbu, N. 1985. “Soil Models in Offshore Engineering.” *Geotechnique*, 35(3), 241–281.

Janbu, N., and K., S. 1974. “Effective Stress Interpretation of In Situ Static Penetration Tests.” *Proc. of the European Symposium on Penetration Testing*, Stockholm, 181–193.

Jimenez Salas, J. A. 1948. “Soil Pressure Computations: A Modification of Newmark's Method.” *Proc. 2nd Int. Conf. on Soil Mechanics and Foundation Engineering*, Rotterdam.

Jinan, Z. 1987. “Correlation Between Seismic Wave Velocity and the Number of Blow of SPT and Depth.” *Selected Papers from the Chinese Journal of Geotechnical Engineering*, 92–100.

Johnson, L.D. 1978. *Predicting Potential Heave and Heave with Time in Swelling Foundation Soils*. Technical Report S-78-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Johnson, L.D., and Snethen, D.R. 1978. “Prediction of Potential Heave of Swelling Soil.” *Geotechnical Testing Journal*, 1(3): 117–124. doi:10.1520/GTJ10382J.

Kahl, H., Muhs, H., and Meyer, W. 1968. “Ermittlung der Grösse und des Verlaufs des Spitzendrucks bei Drucksondierungen in Ungleischförmigen Sand-Kies-gemischen und in Kies.” [In German]. *Mitteilungen DEGEBO*, 21, 1–36.

Kamei, T., and Iwasaki, K. 1995. “Evaluation of Undrained Shear Strength of Cohesive Soils Using a Fat Dilatometer.” *Soils and Foundations*, 35(2), 111–116.

Karlsson, R., and Viberg, L. 1967. “Ratio c/p’ in Relation to Liquid Limit and Plasticity Index, with Special Reference to Swedish Clays.” *Proc. of the Geotechnical Conference Oslo 1967 on Shear Strength Properties of Natural Soils and Rocks*, 1, 43–47.

Karray, M., Lefebvre, G., Ethier, Y., and Bigras, A. 2011. “Influence of Particle Size on the Correlation Between Shear Wave Velocity and Cone Tip Resistance.” *Canadian Geotechnical Journal*, 48(4), 599–615.

Kayabali, K. 1996. “Soil Liquefaction Evaluation Using Shear Wave Velocity.” *Engineering Geology*, 44(1–4), 121–127.

Kenney, T. C. 1967. “The Influence of Mineral Composition on the Residual Shear Strength of Natural Soils.” *Proc. of the Geotechnical Conference Oslo 1967 on Shear Strength Properties of Natural Soils and Rock*s, Oslo, Norway, 1, 123–129.

Kenney, T. C. 1959. “Discussion of Geotechnical Properties of Glacial Lake Clays.” *Journal of the Soil Mechanics and Foundations Division*, 85(SM1), 67–79.

Kenney, T. C., Lau, D., and Ofoegbu, G. I. 1984. “Permeability of Compacted Granular Materials.” *Canadian Geotechnical Journal*, 21(4), 726-729.

Kerisel, J. 1961. “Fondations Profondes en Milieu Sableux.” [In French]. *Proc. of the 5th Int. Conf. on Soil Mechanic*s, Paris, France, 73–83.

Kezdi, A. 1974. *Handbook of Soil Mechanics Vol. 1: Soil Physics*. Elsevier, Hungary.

Kiku, H., Yoshida, N., Yasuda, S., Irisawa, T., Nakazawa, H., Shimizu, Y., Ansal, A., and Erkan, A. 2001. “In Situ Penetration Tests and Soil Profiling in Adapazari, Turkey.” *Proc. of the ICSMGE/TC4 Satellite Conference on Lessons Learned from Recent Strong Earthquakes*, 259–265.

Kirkham, D. 1950. “Seepage into Ditches in the Case of a Plane Water Table and an Impervious Substratum.” *Transactions, American Geophysical Union*, 31.3, 425-430.

Kirkham, D. 1960. “Seepage into Ditches from a Plane Water Table Overlying a Gravel Substratum.” *Journal of Geophysical Research*, 65(4), 1267-1272.

Kleyn, E. G., and Van Heerden, M. J. J. 1983. “Using DCP Soundings to Optimize Pavement Rehabilitation.” *Proc. of the Annual Transportation Convention*, 3, 319–334.

Koerner, R. 2012. *Designing with Geosynthetics, 6th Ed*. Xlibris Corp.

Komornik, A., and David, D. 1969. “Prediction of Swelling Pressure of Clays.” *Journal of the Soil Mechanics and Foundations Division*, 95(1): 209–226.

Koppula, S. D. 1981. “Statistical Estimation of Compression Index.” *Geotechnical Testing Journal*, 4(2), 68–73.

Kozeny, J. 1927. “Ueber kapillare Leitung des Wassers im Boden.” [In Swedish]. Wien, Akad. Wiss., 136(2a), 271.

Kulhawy, F.H. and Mayne, P.W. 1990. *Manual for Estimating Soil Properties for Foundation Design*. Report EL-6800, Electric Power Research Institute, Palo Alto, CA.

Ladd, C. C. 1991. "Stability evaluation during staged construction." *ASCE, Journal of Geotechnical Engineering*, 117, 540-615.

Ladd, C. C., and DeGroot, D. J. 2004. “Recommended Practice for Soft Ground Site Characterization: Arthur Casagrande Lecture.” *Proc. of the 12th Panamerican Conference on Soil Mechanics and Geotechnical Engineering*, 3–57.

Ladd, C. C., and Foott, R. 1974. “New Design Procedure for Stability of Soft Clays.” *Journal of the Geotechnical Engineering Division*, 100(GT7), 763–786.

Ladd, C. C., Foott, R., Ishihara, K., Schlosser, F., and Poulos, H. G. 1977. “Stress-Deformation and Strength Characteristics.” *Proc. of the 9th Int. Conf. on Soil Mechanics and Foundation Engineering*, Tokyo, Japan, 421–494.

Lambe, T. W., and Whitman, R. V. 1969. *Soil Mechanics*. John Wiley & Sons.

Larson, E. 1980. “Undrained Strength in Stability Calculation of Embankments and Foundation on Soft Clays.” *Canadian Geotechnical Journal*, 17(4), 591–602.

Lauffer, H. 1997. “Rock Classification Methods Based on the Excavation Response.” *Felsbau*, 15(3), 179–182.

Lee, S. H. H. 1990. “Regression Models of Shear Wave Velocities.” *J Chinese Insti Eng*, 13, 519–532.

Leonards, G. 1976. “Estimating Consolidation Settlements of Shallow Foundations on Oversonsolidated Clay.” *Special Report - Transportation Research Board, National Research Council*., 163, 13-16.

Leroueil, S., Tavenas, F., and Le Bihan, J. 1983. “Propriétés Caractéristiques des Argiles de l’est du Canada.” [In French]. *Canadian Geotechnical Journal*, 20(4), 681–705.

Livneh, M. 1989. “Validation of Correlations Between a Number of Penetration Tests and In Situ California Bearing Ratio Tests.” *Transportation Research Record*, 1219, 56–67.

Lo, Y. K. Y., and Lovell, C. W. 1982. “Prediction of Soil Properties from Simple Indices.” *Transportation Research Record*, 873, 43–49.

Loudiere, D., Fayoux, D., Houis, J., Perfetti, J., and Sotton, M. 1983. “The Use of Geotextiles in French Earth Dams.” *Water Power and Dam Construction*, January, 19-2.

Luettich, S.M., Giroud J.P, and Bachus, R.C. 1992. “Geotextile Filter Design Guide.” *Geotextiles and Geomembranes*, Vol 11, Issues 4-6, pp355-370.

Lumb, P., and Holt, J. K. 1968. “The Undrained Shear Strength of a Soft Marine Clay from Hong Kong.” *Geotechnique*, 18(1), 25–36.

Lunne, T., and Christoffersen, H. P. 1985. “Interpretation of Cone Penetrometer Data for Offshore Sands.” *Norwegian Geotechnical Institute*, 156, 1–12.

Lunne, T., and Kleven, A. 1982. “Role of CPT in North Sea Foundation Engineering.” *Norwegian Geotechnical Institute*, 139, 1–14.

Lunne, T., Robertson, P. K., and Powell, J. J. M. 1997. *Cone Penetration Testing in Geotechnical Practice*. Blackie Academic and Professional.

Lutenegger, A. and Hallberg, G. 1981. *Borehole Shear Test in Geotechnical Investigations*. STP740, Laboratory Shear Strength of Soil, R. Yong, R. and Townsend, F. eds., ASTM International, West Conshohocken, PA, 566-578.

Maheswari, R. U., Boominathan, A., and Dodagoudar, G. R. 2010. “Use of Surface Waves in Statistical Correlations of Shear Wave Velocity and Penetration Resistance of Chennai Soils.” *Geotechnical and Geological Engineering*, 28(2), 119–137.

Marchetti, S. 1980. “In Situ Tests by Fat Dilatometer.” *Journal of the Geotechnical Engineering Division*, 106(GT3), 299–321.

Marchetti, S. 1997. “The Flat Dilatometer: Design Applications.” *Proc. of the 3rd Geotechnical Engineering Conference at Cairo University*, Cairo, ed., 421–448.

Marchetti, S., Monaco, S., Totani, G., Calabrese. M. 2006. "The Flat Dilatometer Test in Soil Investigations." ISSMGE Committee TC102. *Proc. 2nd Int. Conf. on Flat Dilatometer, In-Situ Soil Testing*, Fairfax, VA.

Marinos, P. G., Marinos, V., and Hoek, E. 2007. “The Geological Strength Index (GSI): A Characterization Tool for Assessing Engineering Properties for Rock Masses.” *Proc. of The International Workshop on Rock Mass Classification in Underground Mining*, 87–94.

Marsland, A.R. 1953. “Model Experiments to Study the Influence of Seepage on the Stability of a Sheeted Excavation in Sand.” *Geotechnique*, 3(6), 223-241.

Marston. A and Anderson, A. O. 1913. “The Theory of Loads on Pipes in Ditches and Tests of Cement and Clay Drain Tile and Sewer Pipe.” *Bulletin No. 31*, Iowa Eng. Experiment Station, Ames, IA.

Mayne, P. W. 1985. “Stress Anisotropy Effects on Clay Strength.” *Journal of Geotechnical Engineering*, 111(3), 356–366.

Mayne, P. W. 2006. “The Second James K. Mitchell Lecture Undisturbed Sand Strength from Seismic Cone Tests.” *Geomechanics and Geoengineering: An International Journal*, 1:4, 239–257.

Mayne, P. W. 2007. *Cone Penetration Testing State-of-Practice*. NCHRP Project 20-05.

Mayne, P. W., and Rix, G. J. 1995. “Correlations Between Shear Wave Velocity and Cone Tip Resistance in Natural Clays.” *Soils and Foundations*, 35(2), 107–110.

Mayne, P.W. 2012. "SOA Report: Geotechnical Site Characterization in the Year 2012 and Beyond." *State-of-the-Art and Practice in Geotechnical Engineering*, GSP 226, GeoCongress 2012, Oakland, CA, ASCE Press, Reston, VA.

McCook. 2010. “Empirical Estimates of Permeability for Earth Dam Projects.” Webinar presentation. American Society of Dam Safety Officials, Lexington, KY.

McCormack, D.E., and Wilding, L.P. 1975. “Soil Properties Influencing Swelling in Canfield and Geeburg Soils.” *Soil Science Society of America Journal*, 39(3): 496–502. doi:10.2136/sssaj1975.03615995003900030034x.

McGuire, Michael; Filz, G. M.; and Brandon, T. L. 2009. *The Emergence of Intelligent Compaction in U. S. Practice, CGPR Report No. 53*, Center for Geotechnical Practice and Research, Virginia Tech, 69 pp.

Mehta, M.R. and Veletsos, A.S. 1959 "Stresses and Displacement in Layered Systems." *Structural Research Series No. 178*, University of Illinois, Urbana, IL.

Melzer, K. J. 1968. “Sondenuntersuchungen in Sand.” [In German]. *Mitteilungen der Vereinigung der Grosskesselbetreiber*, 43, 1–345.

Merritt, A. H., and Coon, R. F. 1970. “Predicting in Situ Modulus of Deformation Using Rock Quality Indexes.” *Determination of the In Situ Modulus of Deformation of Rock, ASTM STP 477*, 154–173.

Mesri, G. 1973. “Coefficient of Secondary Compression.” *Journal of Soil Mechanics and Foundation Division*, 99(1), 123-137.

Mesri, G. 1975. “Discussion on ‘New design procedure for stability of soft clays.’” *Journal of the Geotechnical Engineering Division*, 101(GT4), 409–412.

Mesri, G. and Castro, A. 1987. “C_α/C_c Concept and K_0 during Secondary Compression.” *Journal of Geotechnical Engineering*, 113(3), 230-247.

Mesri, G., and Godlewski, P. M. 1977. “Time- and Stress-compressibility Interrelationship.” *Journal of the Geotechnical Engineering Division*, 103(5), 417-430.

Meyerhof, G. G. 1956. “Penetration Tests and Bearing Capacity of Cohesionless Soils.” *Journal of the Soil Mechanics and Foundations Division*, 82(1), 1–19.

Meyerhof, G. G. 1965. “Shallow Foundations.” *Journal of the Soil Mechanics and Foundations Division*, 91(SM1), 21-31.

Meyerhof, G. G. 1976. “Bearing Capacity and Settlement of Pile Foundations.” *Journal of the Geotechnical Engineering Division1*, 102(3), 197–228.

Mitachi, T., and Kitago, S. 1976. “Change in Undrained Shear Strength Characteristics of Saturated Remolded Clay Due to Swelling.” *Soils and Foundations*, 16(1), 45–58.

Mitchell, J. K. 1981. “Soil Improvement: State-of-the-Art Report.” *Proc. of the 10th Int. Conf. on Soil Mechanics and Foundation Engineering*, Stockholm, 509–565.

Mitchell, J. K. 1993. *Fundamentals of Soil Behavior*. John Wiley and Sons, Inc., New York.

Mitchell, J. K., and Gardner, W. S. 1975. “In-Situ Measurement of Volume Change Characteristics.” *Proc. of the ASCE Specialty Conference on In Situ Measurement of Soil Properties*, Raleigh, NC, 279–345.

Molinda, G. M., and Mark, C. 1994. *Coal Mine Roof Rating (CMRR): A Practical Rock Mass Classification for Coal Mines*. Vol. 9387, United States Department of Interior, Bureau of Mines.

Moran, Proctor, Mueser, and Rutledge 1958. *Study of Deep Soil Stabilization by Vertical Sand Drains*. Bureau of Yards and Docks, Department of the Navy.

Morgenstern, N. R., and Price, V. E. 1965. "The Analysis of the Stability of General Slip Surfaces." *Geotechnique*, 15(1), 79–93.

Moser, A. P. 1990. *Buried Pipe Design*. McGraw-Hill Inc.

Muhs, H., and Weiss, K. 1971. “Untersuchung von Grenztragfähigkeit und Setzungsverhalten Flachgegründeter Einzelfundamente in Ungleichförmigen Nichtibindigen Boden.” [In German]. *Mitteilungen DEGEBO*, 26, 1–39.

NAVFAC. (1982). *Foundations and Earth Structures Design Manual 7.2.* Department of the Navy Naval Facilities Engineering Command, Alexandria, VA.

NAVFAC. (1983). *Soil Dynamics and Special Design Aspects Design Manual 7.3.* Department of the Navy Naval Facilities Engineering Command, Alexandria, VA.

Nayak, N.V. 1979. *Foundation Design Manual*. Dhanpat Rai and Sons, Delhi, India.

Nayak, N.V., and Christensen, R.W. 1971. “Swelling Characteristics of Compacted, Expansive Soil.” *Clays and Clay Minerals*, 19(4): 251–261. doi:10.1346/CCMN.1971.0190406.

Nazzal, M. 2003. “Field Evaluation of In Situ Test Technology for QC/QA Procedures During Construction of Pavement Layers and Embankments.” Louisiana State University.

NCHRP (National Cooperative Highway Research Program). 2001. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*.

NCHRP (National Cooperative Highway Research Program). 2018. *Manual on Subsurface Investigations*. National Cooperative Highway Research Program Publication No. CRP Project 21-20. Transportation Research Board, National Academies of Science Engineering, and Medicine, Washington, DC.

Nelson, J., and Miller, D. J. 1992. *Expansive Soils: Problems and Practice in Foundation and Pavement Engineering*. John Wiley & Sons.

Newmark, N. M. 1942. “Influence Charts for Computation of Stress in Elastic Foundations.” *Engineering Experiment Station Bulletin Series,* No. 338, University of Illinois at Urbana Champaign, College of Engineering.

Nishida, Y. 1956. “A Brief Note on the Compression Index of Soil.” *Journal of the Soil Mechanics and Foundations Division*, 82(3), 1–14.

NOAA (National Oceanic and Atmospheric Administration). 1978. *Geodetic Bench Marks. U.S. Department of Commerce - National Oceanic and Atmospheric Administration*.

Nonveiller, E. 1967. “Shear Strength of Bedded and Jointed Rock as Determined from the Zalesina and Vajont slides.” *Proc. of the Geotechnical Conference Oslo 1967 on Shear Strength Properties of Natural Soils and Rocks*, 1, 289–294.

NRC (Nuclear Regulatory Commission). 1996. *Working Safely with Nuclear Gauges*. Report No. NUREG/BR-0133, United States Nuclear Regulatory Commission.

NRCS (Natural Resources Conservation Service). 2002. “Rock Material Field Classification System.” *Part 631 Geology National Engineering Handbook*, 12-1-12–12.

NYDOT (New York State Department of Transportation). 2013. *Geotechnical Design Manual*. New York State Department of Transportation, Albany, NY.

O’Neil, M.W., and Ghazzally, O.I. 1977. “Swell potential related to building performance.” *Journal of the Geotechnical Engineering Division*, 103(12): 1363–1379.

Ohba, S., and Toriumi, I. 1970. “Dynamic Response Characteristics of Osaka Plain.” *Soils Foundations*, 13(4), 61–73.

Ohsaki, Y., and Twasaki, R. 1973. “On Dynamic Shear Moduli and Poisson’s Ratio of Soil Deposits.” *Soils and Foundations*, 13(4), 61–73.

Ohta, Y., and Goto, N. 1978. “Empirical Shear Wave Velocity Equations in Terms of Characteristics Soil Indexes.” *Earthquake Engineering & Structural Dynamics*, 6, 167–187.

Ohya, S., Imai, T., and Matsubara, M. 1982. “Relationships Between N Value by SPT and LLT Pressuremeter Results.” *Proc. of the 2nd European Symposium on Penetration Testing*, Amsterdam, 125–130.

Olson, R. E. 1977. “Consolidation Under Time Dependent Loading.” *Journal of the Geotechnical Division*, 103(GT1), 55-60.

Osterberg 1972. Personal communication cited in Azzouz et al. 1976.

Paikowsky, S. G., Palmer, C. J., and Rowles, L. E. 2006. "The Use of Tactile Sensor Technology for Measuring Soil Stress Distribution." *Proc. GeoCongress 2006–Geotechnical Engineering in the Information Technology Age*, ASCE, Atlanta.

Parcher, J. V., and Means, R. E. 1968. *Soil Mechanics and Foundations*. Charles E. Merrill, Columbus, OH.

Parkin, A., Holden, J., Aamot, K., Last, N., and Lunne, T. 1980. *Laboratory Investigations of CPT’s in Sand*. Report 52108-9.

Parry, R. H. 2004. *Mohr Circles, Stress Paths and Geotechnics*. CRC Press.

Parry, R. H. G. 1977. “Estimating Bearing Capacity in Sand from SPT Values.” *Journal of the Geotechnical Engineering Division*, Raleigh, NC, 1014–1019.

Parry, R.H.G. 1971. “A Direct Method of Estimating Settlements in Sand for SPT Values.” *Proc. Sym. on the Interaction of Structure and Foundation*, Birmingham, 29-32.

Patel, R. S., and Desai, M. D. 2010. “CBR Predicted by Index Properties of Soil for Alluvial Soils of South Gujarat.” *Proc. of the Indian Geotechnical Conference*, 79–82.

Pavlovsky, N. N. 1956. *Collected Works*. Akad. Nauk USSR, Leningrad.

Peck, R. B. 1969. "Deep Excavation and Tunneling in Soft Ground." *Proc. of the 7th Int. Conf. on Soil Mechanics and Foundation Engineering, Mexico: State-of-the-Art Report*, 225-325.

Peck, R. B. and Reed, W. C. 1954. “Engineering Properties of Chicago Subsoils.” *Engineering Experiment Station Bulletin,* No. 423, University of Illinois.

Peck, R.B, Hansin, W.E, and Thornburn, T.H. 1974. *Foundation Engineering, 2nd Ed*. John Wiley & Sons, Inc., New York, 514p.

Peck, R.B. 1969. "Advantages and Limitations of the Observational Method in Applied Soil Mechanics." *9th Rankine Lecture, Geotechnique*, 19, 171-187.

Peck, R.B. 1972. *Observation and Instrumentation*. United States Department of Transportation, Publication No. 131, Federal Highway Administration, Highway Focus 4(2), 1-5.

Peck, R.B., and Bazarra, A.R.S. 1969. "Discusion to Settlement of Spread Footings on Sand." *JSMFE (ASCE)*, 95 (SM3), 905-909.

Piratheepan, P. 2002. "Estimating Shear-Wave Velocity from SPT and CPT Data." M.S. thesis, Clemson University.

Pitilakis, K. D., Anastasiadis, A., and Raptakis, D. 1992. "Field and Laboratory Determination of Dynamic Properties of Natural Soil Deposits." *Proc. of 10th World Conference on Earthquake Engineering*, 1275–1280.

Polshin, D. E. and Tokar, R. A. 1957. "Maximum Allowable Non-uniform Settlement of Structures." *Proc. 4th Int. Conf. on Soil Mechanics and Foundation Engineering*, Butterworth's, London, Vol. 1, 402-405.

Potts, D. M. and L. Zdravkovic. 1999. *Finite Element Analysis in Geotechnical Engineering: Vol. 1 Theory and Application*. ICE Publishing, 500 pp.

Potts, D. M. and L. Zdravkovic. 2001. *Finite Element Analysis in Geotechnical Engineering: Vol. 2 Theory and Application*. ICE Publishing, 500 pp.

Poulos, H. G. 1975. "Settlement of Isolated Foundations." *Soil Mechanics - Recent Developments*, S. Valliappan, S. Hain, and Lee, I. K., eds., William H. Sellent Pty, Zetland, 181–212.

Poulos, H. G. 1988. *Marine Geotechnics*. Taylor & Francis Ltd.

Poulos, H. G., and Davis, E. H. 1974. *Elastic Solutions for Soil and Rock Mechanics*. John Wiley and Sons, 424 pp.

Poulos, H. G., and Davis, E. H. 1980. *Pile Foundation Analysis and Design*. John Wiley & Sons, New York, New York.

Randolph, M., and Gourvenec, S. 2011. *Offshore Geotechnical Engineering*. CRC Press.

Ranganathan, B.V. & Satyanarayana, B. 1965. "A Rational Method of Predicting Swelling Potential for Compacted Expansive Clays." *Proc. 6th Int. Conf. on Soil Mechanics and Foundation Engineerin*g, ISSMGE, London, 1, 92–96.

Rao, B. H., Venkataramana, K., and Singh, D. N. 2011. "Studies on the Determination of Swelling Properties of Soils from Suction Measurements." *Canadian Geotechnical Journal*, 48(3), 375-387.

Rendon-Herrero, O. 1983. "Closure of Universal Compression Index Equation." *Journal of Geotechnical Engineering*, 109(5), 755–761.

Ricceri, G. and Soranzo, M. 1985. "An Analysis on Allowable Settlement of Structures." *Riv. Ital. Geotec*., 4, 177-188.

Ricceri, G., Simonini, P., and Cola, S. 2002. "Applicability of Piezocone and Dilatometer to Characterize the Soils of the Venice Lagoon." *Geotechnical and Geological Engineering*, 20(2), 89–121.

Robertson, P. K. 2009. "Interpretation of Cone Penetration Tests - A Unified Approach." *Canadian Geotechnical Journal*, 46(11), 1337–1355.

Robertson, P. K., and Cabal, K. L. 2014. *Guide to Cone Penetration Testing for Geotechnical Engineering*. Gregg Drilling & Testing, Inc.

Robertson, P. K., and Campanella, R. G. 1983. "Interpretation of Cone Penetration Tests. Part I: Sand." *Canadian Geotechnical Journal*, 20(4), 718–733.

Robertson, P. K., and Campanella, R. G. 1984. *Guidelines for Use and Interpretation of the Electronic Cone Penetration Test*. Hogentogler & Company, Inc.

Robertson, P.K. 2009. "Cone Penetration Testing: A Unified Approach." *J., Canadian Geotechnical Journal*, 46(11), 1337–1355.

Roscoe, K. H., Schofield, A. N., Wroth, C. P., and Henkel, D. J. 1958. “Discussion: On the Yielding of Soils.” *Géotechnique*, 8(3), 22–53.

Rowland, S.; Duebendorfer, E.; and Schiefelbein, I. 2007. *Structural Analysis & Synthesis – A Laboratory Course in Structural Geology, 3rd Ed*. Blackwell, Malden, MA.

Saada, A. S. and Townsend, F. C. 1981. "State of the Art: Laboratory Strength Testing of Soils," *Laboratory Shear Strength of Soils, ASTM STP 740*, R. N. Yong and F. C. Townsend, Eds., ASTM, pp. 7-77.

Sabatini, P. J., Bachus, R. C., Mayne, P. W., Schneider, J. A., and Zettler, T. E. 2002. *Geotechnical Engineering Circular No. 5: Evaluation of Soil and Rock Properties*. Federal Highway Administration.

Sakai, Y. 1968. *A Study on the Determination of S-Wave Velocity by the Soil Penetrometer.* [In Japanese].

Salem, A. M., and Krizek, R. J. 1976. “Stress-Deformation-Time Behaviour of Dredgings.” *Journal of the Geotechnical Engineering Division*, 102(GT2), 139–157.

Salgado, R. 2008. *The Engineering of Foundations*. McGraw Hill, Boston, p. 882.

Santi, P. M. 1998. “Improving the Jar Slake, Slake Index, and Slake Durability Tests for Shales.” *Environmental & Engineering Geoscience*, IV(3), 385–396.

SCDOT (South Carolina Department of Transportation). 2010. *Geotechnical Design Manual*. South Carolina Department of Transportation, Columbia, SC.

Schmertmann, J. H. 1970. “Static Cone to Compute Static Settlement Over Sand.” *Journal of Soil Mechanics and Foundations Division*, 96(SM3), 1011-1043.

Schmertmann, J. H. 1975. “Measurement of In Situ Shear Strength.” *Proc. of the ASCE Specialty Conference on In Situ Measurement of Soil Properties*, 2, 57–138, 341–355.

Schmertmann, J. H. 1978. *Guidelines for Cone Penetration Test: Performance and Design*. Washington, DC.

Schmertmann, J. H., Hartman, J. P., and Brown, P. R. 1978. “Improved Strain Influence Factor Diagrams.” *Journal of the Geotechnical Engineering Division*, 104(8), 1131-1135.

Schneider G.L. and Poor, A.R. 1974. “The Prediction of Soil Heave and Swell Pressures Developed by an Expansive Clay,” *Research Report, No: TR-9-74*, Construction Research Center, Univ. Of Texas.

Schofield, A. N., and Wroth, C. P. 1968. *Critical State Soil Mechanics*. Mcgraw Hill Book Co Ltd.

Schultz, E., and Sherif, G. 1973. “Prediction of Settlement from Evaluated Settlement Observations for Sand.” *Proc. 8th ICSMFE*, Moscow, Vol. 1.3, 225-230.

Seed, H. B., and Idriss, I. M. 1981. “Evaluation of Liquefaction Potential Sand Deposits Based on Observation of Performance in Previous Earthquakes.” *ASCE National Convention (MO)*, 481–544.

Seed, H.B., Woodward, R.J., and Lundgren, R. 1962. “Prediction of Swelling Potential for Compacted Clays.” *Journal of the Soil Mechanics and Foundation Engineering Division*, 88(3): 53–87.

Sehn, A.L. 1990. *Experimental Study of Earth Pressures on Retaining Structures*. Ph.D. Dissertation, Virginia Tech, 347 pages.

Sherard, J.L., Dunnigan, L.P. and Talbot, J.R. 1984. “Basic Properties of Sand and Gravel Filters.” *Journal of Geotechnical Engineering*, 110(6), 684-700.

Shibata, T. 1970. *The Relationship Between the N-value and S-Wave Velocity in the Soil Layer*. Kyoto, Japan.

Shioi, Y., and Fukui, J. 1982. “Application of N-Value to Design of Foundations in Japan.” *Proc. of the 2nd European Symposium on Penetration Testing*, Amsterdam, 159–164.

Singh, D., Reddy, K. S., and Yadu, L. 2011. “Moisture and Compaction Based Statistical Model for Estimating CBR of Fine Grained Subgrade Soils.” *International Journal of Earth Sciences and Engineering*, 4(6), 100–103.

Sirles, P. 2006. *Use of Geophysics for Transportation Projects*. National Cooperative Highway Research Program Synthesis 357, Transportation Research Board, Washington, DC.

Skempton, A. W. 1944. “Notes on the Compressibility of Clays.” *Quarterly Journal of the Geological Society of London*, 100, 119-135.

Skempton, A. W. 1957. “Discussion on the Planning and Design of the New Hong Kong Airport.” *Proc. of the ICE*, 7(2), 307–307.

Skempton, A. W. 1964. “Long-term Stability of Clay Slopes.” *Géotechnique*, 14(2), 77–102.

Skempton, A. W. 1985. “Residual Strength of Clays in Landslides, Folded Strata and the Laboratory.” *Géotechnique*, 35(1), 3–18.

Skempton, A. W. and MacDonald, D. H. 1956. “The Allowable Settlement of Buildings.” *Proc. Institution of Civil Engineers*, 5(6), 727-769.

Skempton, A. W., and Northey, R. D. 1952. “The Sensitivity of Clays.” *Geotechnique*, 3(1), 30–53.

Skempton, A. W., Schuster, R. L., and Petley, D. J. 1969. “Joints and Fissures in the London Clay at Wraysbury and Edgware.” *Géotechnique*, 19(2), 205–217.

Skinner, E. H. 1988. “A Ground Support Prediction Concept: The Rock Structure Rating (RSR) Model.” *Rock Classification Systems for Engineering Purposes, STP 984*, 35–51.

Slichter, C.E. 1905. “Field Measurements of the Rate of Movement of Underground Water,” *Water-Supply and Irrigation Paper No. 140*, U.S. Geological Survey, Department of the Interior, Series 0, Underground Waters, 43.

Smith, R. B., and Pratt, D. N. 1983. “A Field Study of In Situ California Bearing Ratio and Dynamic Cone Penetrometer Testing for Road Subgrade Investigations.” *Australian Road Research*, 13(4), 285–294.

Sowers, G. F. 1970. *Introduction to Soil Mechanics and Foundations, 3rd Ed*. The Macmillan Company, Collier-Macmillan Ltd., London, 102.

Sowers, G. F. 1979. *Introductory Soil Mechanics and Foundations: Geotechnical Engineering*. Macmillan & Co, New York, New York.

Spangler, M. G. 1948. “Underground Conduits - An Appraisal of Modern Research.” *Transactions of ASCE*, 113, 316-374.

Spencer, E. 1967. "A Method of Analysis of the Stability of Embankments Assuming Parallel Inter–slice Forces." *Geotechnique*, 17(1), 11–26.

Sridharan, A., and Gurtug, Y. 2004. “Swelling Behaviour of Compacted Fine-grained Soils.” *Engineering Geology*, 72(1–2): 9–18. doi:10.1016/S0013-7952(03)00161-3.

Stark, T. D., and Hussain, M. 2013. “Empirical Correlations: Drained Shear Strength for Slope Stability Analyses.” *J. Geotech. Geoenviron. Eng.*, 139(6), 853–862.

Stroud, M. A. 1974. “The SPT in Insensitive Clays and Soft Rocks.” *Proc. of the European Symposium on Penetration Testing*, Stockholm, 367–375.

Stroud, M. A., and Butler, F. G. 1975. “The Standard Penetration Test and the Engineering Properties of Glacial Materials.” *Proc. of the Sym. on the Engineering Behaviour of Glacial Materials*, 117–128.

Sykora, D. E., and Stokoe, K. H. 1983. “Correlations of In-Situ Measurements in Sands of Shear Wave Velocity.” *Soil Dynamics and Earthquake Engineering*, 20, 125–136.

Tan, C. and Duncan, J. M. 1991. “Settlement of Footings on Sands-Accuracy and Reliability.” *Proc. Geotechnical Engineering Congress 1991*, 446-455.

Terzaghi, K. 1943. *Theoretical Soil Mechanics*. John Wiley and Sons, New York, NY.

Terzaghi, K. 1946. “Rock Defects and Loads on Tunnel Supports.” *Rock Tunneling with Steel Supports*, Ed. R. V. Proctor and T. White, Commercial Shearing Inc., Youngstown, OH.

Terzaghi, K. 1950. “Geologic Aspects of Soft Ground Tunneling.” *Applied Sedimentation*, Ed. R. Task and D. Parker, John Wiley and Sons, New York, NY, 193-209.

Terzaghi, K. and Peck, R. B. 1967. *Soil Mechanics in Engineering Practice, 2nd Ed.* John Wiley & Sons, Inc., New York.

Terzaghi, K., Peck, R. B., and Mesri, G. 1996. *Soil Mechanics in Engineering Practice, 3rd Ed.* John Wiley & Sons, Inc., New York.

Thakur, V.K.S., and Singh, D.N. 2005. “Rapid Determination of Swelling Pressure of Clay Minerals.” *Journal of Testing and Evaluation*, 33(4): 239–245. doi:10.1520/JTE11866.

Tiwari, B., and Ajmera, B. 2010. “A New Correlation Relating the Shear Strength of Reconstituted Soil to the Proportions of Clay Minerals and Plasticity Characteristics.” *Applied Clay Science*, Fullerton, 53(1), 88.

Tobar, T. and Meguid, M. A. 2010. "Comparative Evaluation of Methods to Determine the Earth Pressure Distribution on Cylindrical Shafts: A Review." *Tunnelling and Underground Space Technology*, 188-197.

Tschebotarioff, G. P. 1973. *Foundations, Retaining and Earth Structures*. Mcgraw Hill Book Co Ltd, New York, New York.

Tunbridge, L. 2017. "Hydraulic Conductivity Determination by Lugeon Test – Testing in Practice." *Proc. Workshop on Drainage of Large Rockslides*, Oslo, Norway.

TXDOT (Texas Department of Transportation). 2014. “Test Procedure for Determining Potential Vertical Rise.” *TXDOT Designation: TEX-124-E*, 10 pp.

Ulmer, K. J., Green, R. A., and Rodriguez-Marek, A. 2020. “A Consistent Correlation between V_s, SPT, and CPT Metrics for Use in Liquefaction Evaluation Procedures.” *Geo-Congress 2020, American Society of Civil Engineers*, Reston, VA, 132–140.

United States Department of the Army. 1984. *Engineering and Design - Pavement Criteria for Seasonal Frost Conditions - Mobilization Construction - EM 1110-3-138*.

USACE (United States Army Corps of Engineers). 1947. *Soil Mechanics Fact Finding Survey Progress Report: Cooperative Triaxial Shear Research Program of the Corps of Engineers: Pressure Distribution Theories, Earth Pressure Cell Investigations and Pressure Distribution Data*. Review prepared by Donald W. Taylor, Mississippi River Commission, Vicksburg, Miss., U.S. Army Engineer Waterways Experiment Station, 332 pages.

USACE. 1952. *Soil Mechanics Design, Seepage Control, Engineering Manual No. 1110-2-1901*. Civil Works Construction, Part CXIX.

USACE. 1956. *Investigating Underseepage and Its Control, Lower Mississippi River Levees, Technical Memorandum 3-424*. Waterway Experiment Station, Vicksburg, MS.

USACE. 1970. *Laboratory Soils Testing*.

USACE. 1984. *Engineering and Design - Pavement Criteria for Seasonal Frost Conditions - Mobilization Construction - EM 1110-3-138*.

USACE. 1986. *Engineering and Design, Seepage Analysis and Control for Dams, Engineering Manual, EM 1110-2-1901*. Office of the Chief of Engineers, Washington, D.C.

USACE. 1987. *Instrumentation for Concrete Structures*. Engineering Manual, EM 1110-2-4300. United States Army Corps of Engineers. Washington, DC.

USACE. 1990. *Settlement Analysis, EM- 1110-1-1904*. U. S. Army Corps of Engineers.

USACE. 1993. *Seepage Analysis and Controls for Dams*. U.S. Army Corps of Engineers.

USACE. 1995a. *Geophysical Exploration for Engineering and Environmental Investigations*. Engineer Manual 1110-1-1802, United States Army Corps of Engineers, Washington, DC.

USACE. 1995b. *Instrumentation of Embankment Dams and Levees*. Engineering Manual 1110-2-1908, United States Army Corps of Engineers, Washington, DC.

USACE. 2000. *Design and Construction of Levees, Engineering Manual 1110-2-1913*. Office of the Chief of Engineers, Washington, D.C.

USACE. 2003. *EM 1110-2-1902, Engineering and Design – Slope Stability. Department of the Army, U. S. Army Corps of Engineers*. Washington, DC. 204 pages.

USBR (United States Department of Interior Bureau of Reclamation). 2014. *Embankment Dams. Design Standards No. 13*, Denver Colorado.

USBR. 1998. *Earth Manual, Part 1, 3rd Ed*. Earth Sciences and Research Laboratory, Technical Service Center, Denver, CO., 348 pages

USBR. 2011. *Design Standards No. 13, Chapter 4: Stability Analyses*. U.S. Department of the Interior, Technical Service Center. October 2011, 159 pages.

USGS (United States Geological Survey). 2014. *Karst in the United States: A Digital Map Compilation and Database*. U.S. Department of the Interior, U.S. Geological Survey.

Valentine, R. J. 2013. *An Assessment of the Factors that Contribute to the Poor Performance of Geosynthetic-Reinforced Earth Retaining Walls, Proceedings of the International Symposium on Design and Practice of Geosynthetic-Reinforced Soil Structures.* Bologna, Italy, editors Ling, Gottardi, Cazzuffi, Han and Tatsuoka, DEStec Publications, pp. 318-327.

Van Der Merwe, D.H. 1964. “The Prediction of Heave from the Plasticity Index and Percentage Clay Fraction of Soils,” *Civil Engineers in South Africa*, 6, 337–42.

Vanapalli, S. K. and Lu, L. 2012. “A State-of-the-art Review of 1-D Heave Prediction Methods for Expansive Soils.” *International Journal of Geotechnical Engineering*, 6, 15-41.

VandenBerge, D. R., Duncan, J. M., and Brandon, T. L. 2014. *Rapid Drawdown Analysis using the Finite Element Method, CGPR #79*. Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA, 305 pp.

Veismanis, A. 1974. “Laboratory Investigation of Electrical Friction-Cone Penetrometers in Sand.” *Proc. of the European Symposium on Penetration Testing*, Stockholm, 407–419.

Vidalie, J.-F. 1977. *Relations entre les Propriétés Physico-Chimiques et les Caractéristiques Mécaniques des Sols Compressibles [Relations between the Physico-Chemical Properties and the Mechanical Characteristics of Compressible Soils]*. [In French]. *Rapport de Recherche,* No.65.

Vijayavergiya, V.N. & Ghazzaly, O. I. 1973. “Prediction of Swelling Potential for Natural Clays.” *Proc. of the 3rd Int. Conf. on Expansive Soils*, Haifa, Israel, 1, 227-236.

Villet, W. C. B., and Mitchell, J. K. 1981. “Cone Resistance, Relative Density and Friction Angle.” *Sym. on Cone Penetration Testing and Experience, Geotechnical Engineering Division, ASCE*, 178–208.

Voight, B. 1973. “Correlation Between Atterberg Plasticity Limits and Residual Shear Strength of Natural Soils.” *Géotechnique*, 23(2), 265–267.

Wahls, H. E. 1981. “Tolerable Settlement of Buildings.” *Journal of the Geotechnical Engineering Division*, 107(11), 1489-1504.

Webb, D. L. 1969. “Settlement of Structures on Deep Alluvial Sandy Sediments in Durban, South Africa.” *Proc. of the Conf. on the In Situ Behavior of Soils and Rocks*, 181–188.

Webster, S.L., Grau, R.H., Williams, T.P. 1992. *Description and Application of Dual Mass Dynamic Cone Penetrometers*. Report from U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Weston, D. J. 1980. “Expansive Roadbed, Treatment for Southern Africa.” *Proc. 4th Int. Conf. on Expansive Soils*, 1: 339-360.

White, D. J., Vennapusa, P., Tutumluer, E., Vavrik, W., Moaven, M., and Gillen, S. 2018. “Spatial Verification of Modulus for Pavement Foundation System.” *Transportation Research Record*, 2672(52), 333–346.

Whitman, R. V., and Bailey, W. A. 1967. "Use of Computers for Slope Stability Analyses." *ASCE, Journal of the Soil Mechanics and Foundations Division*, 93(4), 475–498.

Williamson, D., and Kuhn, C. R. 1988. “The Unified Rock Classification System.” *Rock Classification Systems for Engineering Purposes, STP984*, 7–16.

Windle, D. and Wroth, C.P. 1977. *The Use of a Self-boring Pressuremeter to Determine the Undrained Properties of Clays*. Ground Engineering, London.

Wolff, T. F. 1989. “Pile Capacity Prediction Using Parameter Functions.” *Predicted and Observed Axial Behavior of Piles: Results of a Pile Prediction Symposium*, ASCE, 96–106.

Wright, S. G. 2013. “2013 H. Bolton Seed Lecture: Slope Stability Calculations.” Accessed December 23, 2020. https://www.youtube.com/watch?v=Q_6aOU7msBM.

Wroth, C. P., and Wood, D. M. 1978. “The Correlation of Index Properties with some Basic Engineering Properties of Soils.” *Canadian Geotechnical Journal*, 15(2), 137–145.

Yang, H., D.J. White, V.R. Schaefer. 2006. "In Situ Borehole Shear Test and Rock Borehole Shear Test for Slope Investigation." *Site and Geomaterial Characterization (GSP 149, GeoShanghai)*, pp. 293–298.

Yashas, S., Harish, S., and Muralidhara, H. R. 2016. “Effect of California Bearing Ratio on the Properties of Soil.” *American Journal of Engineering Research*, 5(4), 28–37.

Yildirim, B., and Gunaydin, O. 2011. “Estimation of California Bearing Ratio by Using Soft Computing Systems.” *Expert Systems with Applications*, 38(5), 6381–6391.

Yoshida, Y., Ikemi, M., and Kokusho, T. 1988. “Empirical Formulas of SPT Blow Counts for Gravelly Soils.” *Proc. of the 1st Int. Sym. on Penetration Testing*, 2, 381–387.

Zeigler, T.W., 1972. *In Situ Tests for the Determination of Rock Mass Shear Strength.* U.S. Army Engineer Waterways Experiment Station, Soils and Pavements Laboratory.

APPENDIX B. LIST OF COMPUTER PROGRAMS

Table B-1 List of Computer Programs

Name	Company	Application	Website
FOSSA	ADAMA Engineering Inc.	Assessing stresses and settlements under embankment and footings acting on horizontal ground surfaces	http://www.geoprograms.com/
GeoCoPS	ADAMA Engineering Inc.	Interactive program for the design of geosynthetic tubes	http://www.geoprograms.com/
MSEW	ADAMA Engineering Inc.	Design and analysis of mechanically stabilized earth walls	http://www.geoprograms.com/
Reslope	ADAMA Engineering Inc.	Interactive, design-oriented, program for geosynthetic-reinforced slopes	http://www.geoprograms.com/
ReSSA+	ADAMA Engineering Inc.	Assessing the rotational and translational stability of reinforced slopes and walls	http://www.geoprograms.com/
ADINA	ADINA R&D Inc.	Stress analysis of solids (2D and 3D) and structures in statics and dynamics	http://www.adina.com/
AEC Slope	AEC Logic Pvt. Ltd	Analyzing stability of slopes for road, railways, river training works, canal embankment, dams etc.	http://www.aeclogic.com/
gINT Professional	Bentley System Inc.	Reporting and managing subsurface data, including borehole logs, well logs, CPT data, and geophysical logs.	https://www.bentley.com/
FB-Deep	Bridge Software Institute	Static axial capacity program used for drilled shafts and driven piles	https://bsi.ce.ufl.edu/
FB-MultiPier	Bridge Software Institute	Nonlinear finite element analysis program capable of analyzing multiple bridge pier structures interconnected by bridge spans.	https://bsi.ce.ufl.edu/
Bearing Pile designer	CADS	Used to select a suitable pile type for known soil strata by investigating the effects of soil parameters and different pile types. Allows the bearing capacity of individual piles and groups of piles of various lengths and types to be checked, including bored piles, continuous flight auger (CFA) piles, driven cast in place, driven tubular steel, driven steel H piles and driven precast piles.	https://cads.co.uk/
Piled Wall Suite	CADS	Analysis and design of embedded walls in concrete or steel. Includes analysis and design for sheet piles, king piles, contiguous and secant bored piles and diaphragm walls	https://cads.co.uk/
RC Pad Base Designer	CADS	Designing and checking of bases. Can be used stand-alone or as part of the CADS integrated analysis, design, and detailing solution.	https://cads.co.uk/
RC Pile cap designer	CADS	Pile Cap Designer software that automatically produces a selection of suitable designs to BS 8110 and EC2 for pile caps with 2-9 piles supporting circular or rectangular columns	https://cads.co.uk/

Name	Company	Application	Website
Reslope	CADS	Slope stability software package for calculating the factor of safety of earth slopes. Uses Bishop's simplified method and circular slip surfaces.	https://cads.co.uk/
AWALL	Callide Technologies Inc	The AWall CAD Tool allows a user to accurately represent the Plan and Elevation views of a retaining wall on their grading plan	http://www.ctiware.com/
VESPA2MSE	Callide Technologies Inc	Design and drawing of mechanically stabilized earth retaining walls.	http://www.ctiware.com/
Mfield	Canary System Inc.	Mobile application designed to bridge the gap between data collection and observations in the field, and the hosted project database.	http://canarysystems.com/
IS GeoMassi	CDM Dolmen and omnia IS srl	Performs for calculation of three-dimensional boulders falling on a slope using the "Lumped Mass hybrid" method associated with a statistical analysis.	https://www.cdmdolmen.it/
IS GeoPendii	CDM Dolmen and omnia IS srl	Stability analysis of slopes in loose terrain based on limit equilibrium methods.	https://www.cdmdolmen.it/
IS GeoRocce	CDM Dolmen and omnia IS srl	Classification of the quality of rock masses using the most widespread theories in the geo-mechanical field.	https://www.cdmdolmen.it/
IS Geostrati	CDM Dolmen and omnia IS srl	Numerical interpretation and graphic representation of the results of SPT, DP (Dynamic Probing), and CPT tests performed on project sites.	https://www.cdmdolmen.it/
IS Muri	CDM Dolmen and omnia IS srl	Finite element analysis, according to the NTC 2018 and Eurocode, of inland walls with constant or variable section, with buttresses, teeth, poles, and tie rods.	https://www.cdmdolmen.it/
IS Paratie	CDM Dolmen and omnia IS srl	Designing flexible containment structures for which the soil-structure interaction is analyzed in the nonlinear field with hysteresis taking into account the deformability of the face.	https://www.cdmdolmen.it/
IS ProGeo	CDM Dolmen and omnia IS srl	Geotechnical modules useful for the rough design of structures in contact with the ground.	https://www.cdmdolmen.it/
IS PL	CDM Dolmen and omnia IS srl	Complete analysis of piles.	https://www.cdmdolmen.it/
IS Plinti	CDM Dolmen and omnia IS srl	Analysis and design of surface foundations.	https://www.cdmdolmen.it/
MasterKey: Retaining wall	Civil and Structural Computer Services Limited	Designing retaining walls with full control over the design process.	https://www.masterseries.com/
AllPile	Civiltech, Inc.	Windows-based analysis program that handles virtually all types of piles, including steel pipes, H-piles, pre-cast concrete piles, auger-cast piles, drilled shafts, timber piles, jetted piles, tapered piles, piers with bell, micropiles (minipiles), uplift anchors, uplift plate, and shallow foundations.	https://civiltech.com/

Name	Company	Application	Website
Liquefy Pro	Civiltech, Inc.	Liquefaction analysis and settlement analysis due to liquefaction.	https://civiltech.com/
Shoring Suit	Civiltech, Inc.	Design and analysis tool containing four modules for shoring, earth pressure, surcharge, and heave.	https://civiltech.com/
Super Log	Civiltech, Inc.	Generating boring log and test pit graphical reports for field drilling and geotechnical investigation.	https://civiltech.com/
Galena	Clover Associates	Slope stability analysis.	http://www.galenasoftware.com/
CPT Tool 3.2	Datgel Pty Ltd	Analysis of CPT data.	https://www.datgel.com/
DGD Tool 4	Datgel Pty Ltd	Geotechnical *in situ* and lab result storage and reporting, including logs for boreholes, test pits, DCPs and vibrocores, and a large range of summary graphs, histograms, fence, table, and map reports.	https://www.datgel.com/
Datgel Lab and In Situ Tool 3	Datgel Pty Ltd	Analysis of laboratory and *in situ* tests.	https://www.datgel.com/d
DC Bearing	DC Software	Analysis of bearing capacity in accordance with Eurocode 7.	https://www.dc-software.de/
DC Cantilever	DC Software	Analysis of cantilever walls in accordance with Eurocode 7.	https://www.dc-software.de
DC Footing	DC Software	Analysis and design of single, block and sleeve footings, rectangular, strip and circular footings according to Eurocode 7.	https://www.dc-software.de
DC Gabion	DC Software	Design and analysis of gabions and supporting structures of layered blocks and concrete stack stones.	https://www.dc-software.de
DC Geotex	DC Software	Analysis of reinforced earth with geosynthetics in accordance with Eurocode 7.	https://www.dc-software.de
DC Inflit	DC Software	Analysis of infiltration.	https://www.dc-software.de/
DC Integra 3D	DC Software	3D display of foundation pits with exact wall geometry and automatic generation of slope intersections.	https://www.dc-software.de/
DC Lamellae	DC Software	Stability analysis of diaphragm wall lamellae.	https://www.dc-software.de/
DC Nail	DC Software	Analysis of soil nailing in accordance with Eurocode 7.	https://www.dc-software.de/
DC Pile	DC Software	Analysis and design of piles.	https://www.dc-software.de/
DC Settlement	DC Software	Settlement analysis according to Eurocode 7.	https://www.dc-software.de
DC Slope	DC Software	Slope stability analysis according to Eurocode 7.	https://www.dc-software.de
DC Underpinning	DC Software	Analysis and design of underpinning and retaining walls.	https://www.dc-software.de/
DC Bore	DC Software	Bore well logs, layer specifications, well, and gauge sinking.	https://www.dc-software.de/
DC Cone	DC Software	Conducting and interpreting CPT data.	https://www.dc-software.de/
DC Cons	DC Software	Data reduction of Atterberg limits according to DIN 18 122 / SN 670 345 / OENORM B 4411 /CEN ISO/TS 17892-12.	https://www.dc-software.de/
DC Lime	DC Software	Determination of lime content according to DIN 18 129.	https://www.dc-software.de/
DC Load	DC Software	Conduction and interpretation of plate load testing.	https://www.dc-software.de/

Name	Company	Application	Website
DC Pump	DC Software	Pump test graphics and evaluation.	https://www.dc-software.de/
DC Shear	DC Software	Shear strength test according to DIN 18 137 and interpretation of results.	https://www.dc-software.de/
DC Sieve	DC Software	Sieve and sedimentation analysis.	https://www.dc-software.de/
DeepFND	Deep Excavation LLC	Analysis and design of deep foundation.	http://www.deepexcavation.com/
DeepEX	Deep Excavation LLC	Geotechnical and structural design for many wall types that include soldier pile walls, sheet pile walls, and diaphragm walls with multiple sections of reinforcement. Can also perform slope stability analysis with soil nailing.	http://www.deepexcavation.com/
Deviate VR	Deep Excavation LLC	Inspecting pile installation records in three dimensions or using virtual reality.	http://www.deepexcavation.com/
Helixpile	Deep Excavation LLC	Design and analysis of helical piles.	http://www.deepexcavation.com/
HoloDeepex	Deep Excavation LLC	Full design-visualization program for deep excavations.	http://www.deepexcavation.com/
Snail Plus	Deep Excavation LLC	Soil nail analysis software. Follows the FHWA methodology for the design of soil nail walls.	http://www.deepexcavation.com/
Trench	Deep Excavation LLC	Evaluating the stability of slurry supported trenches and panels for 2D and 3D analyses.	http://www.deepexcavation.com/
TriAxial PRO	Deep Excavation LLC	Processing triaxial test data.	http://www.deepexcavation.com/
Deltares Geotechnical Softwares	Deltares	Package of eight design software: namely D-Foundations, D-Geo Pipeline, D-Geo Stability, D-Pile Group, D-Settlement, MWell, MSeep and D-Sheet Piling	https://www.deltares.nl/
Delft3D Flexible Mesh Suite	Deltares	Simulation of storm surges, hurricanes, tsunamis, detailed flows and water levels, waves, sediment transport and morphology, and water quality and ecology. Capable of handling the interactions between these processes.	https://www.deltares.nl/
D-Foundations	Deltares	Design of foundations following Eurocode 7 and Dutch and Belgian annexes.	https://www.deltares.nl/
D-Geo Pipelines	Deltares	Design of a pipeline installation in a trench and trenchless installation, using the micro tunneling technique or the Horizontal Directional Drilling (HDD) technique.	https://www.deltares.nl/
D Geostability	Deltares	Slope stability analysis.	https://www.deltares.nl/
D Pile Groups	Deltares	Three-dimensional behavior of single piles and pile groups, interacting via the pile cap and the soil, as a function of loading.	https://www.deltares.nl/
D Settlement	Deltares	Settlement analysis, offering accurate and robust models, capturing consolidation, creep, submerging, drains, staged loading, and unloading and reloading	https://www.deltares.nl/

Name	Company	Application	Website
D- sheet piling	Deltares	Design retaining walls and horizontally loaded piles.	https://www.deltares.nl/
M Seep	Deltares	Simulation of two-dimensional stationary groundwater flow in a cross section of layered soil structures or in one phreatic aquifer, composed of different material areas.	https://www.deltares.nl/
M Well	Deltares	Groundwater modeling to analyze time-dependent hydrogeological problems, such as dewatering, in multilayer soil profiles.	https://www.deltares.nl/
Diana	Diana FEA	Finite element software package for structural, geotechnical, tunneling, earthquake disciplines, and oil & gas engineering.	https://dianafea.com/
Foundation3D 2018	Dimensional Solutions, Inc	Designing foundations for industrial equipment such as horizontal exchangers, horizontal vessels, vertical vessels, fractionation towers, air filters, pipe racks and other plant supports or simply any structure that needs a simple spread or combined footing.	https://www.dimsoln.com/
Mat3D 2018	Dimensional Solutions, Inc	Design of soil and pile supported, multi-load point mat foundations.	https://www.dimsoln.com/
DSAnchor	Dimensional Solutions, Inc	Designing anchors for concrete foundations.	https://www.dimsoln.com/
Shaft3D	Dimensional Solutions, Inc	Design and analysis of drilled shafts or caisson type foundations.	https://www.dimsoln.com/
SoFA	Dr. Konstantinos Nikolaou	Shallow foundation analysis, including settlement calculations and static and seismic bearing capacity.	http://sofasoftware.weebly.com/
APILE	Ensoft Inc.	Axial capacity, as a function of depth, of a driven pile in clay, sand, or mixed-soil profiles.	https://www.ensoftinc.com/
DynaMat	Ensoft Inc.	Equivalent dynamic stiffness and damping of machine foundations using a three-dimensional hybrid method.	https://www.ensoftinc.com/
DynaN	Ensoft Inc.	Dynamic response of both shallow and deep foundations under harmonic, transient, and random loadings using the improved Novak's method.	https://www.ensoftinc.com/
DynaPile	Ensoft Inc.	Dynamic stiffness of single piles or pile groups.	https://www.ensoftinc.com/
GeoMat	Ensoft Inc.	Analysis of mats or structural slabs supported on soils.	https://www.ensoftinc.com/
GROUP	Ensoft Inc.	Analysis of pile groups subjected to both axial and lateral loadings.	https://www.ensoftinc.com/
LPILE	Ensoft Inc.	Analysis of a pile under lateral loading using the p-y method.	https://www.ensoftinc.com/
PileGPw	Ensoft Inc.	Distribution of load and axial deformation of the piles within a pile group.	https://www.ensoftinc.com/
PYWALL	Ensoft Inc.	Flexible retaining wall systems considering the soil-structure interaction using the beam-column model.	https://www.ensoftinc.com/
SETOFF	Ensoft Inc.	Settlement calculation for shallow and deep foundations.	https://www.ensoftinc.com/

Name	Company	Application	Website
SHAFT	Ensoft Inc.	Axial capacity and the short-term, load-settlement curves of drilled shafts or bored piles in various types of soils.	https://www.ensoftinc.com/
STABLPRO	Ensoft Inc.	2-D slope stability analysis using limit equilibrium method.	https://www.ensoftinc.com/
TZPILE	Ensoft Inc.	The t-z method to estimate the displacement as a function of load for driven piles and drilled shafts.	https://www.ensoftinc.com/
Walls Retain	Fides DV	Analysis and design of retaining walls.	http://www.fides-dvp.eu/
Fides geostability	Fides DV	Stability computations in geotechnics using kinematic element analysis methods (KEA).	http://www.fides-dvp.eu/
FIDES Groundslab	Fides DV	Interactive generation and calculations of elastic semi-infinite space model.	http://www.fides-dvp.eu/
FIDES-WinTube-3D	Fides DV	Interactive graphical preprocessing for tunneling and geotechnical models for SOFiSTiK solvers.	http://www.fides-dvp.eu/
Geo5	Fine	Geotechnical analysis based on analytical and finite element methods.	https://www.finesoftware.eu/
AnAqSim	Fitts Geosolutions LLC	Simulation and prediction of groundwater conditions and groundwater/surface-water interactions. Alternative to MODFLOW.	http://www.fittsgeosolutions.com/
SCALE	Fitzroy System Ltd.	Bundle software for structural design with foundation design components.	https://fitzroy.com/
LUCID	Fitzroy System Ltd.	It is a bundle software for structural design and useful for design of different type of foundations and retaining walls.	https://fitzroy.com/
Strata Explorer	GAEA Technologies Ltd.	Application suite for subsurface mapping and data management to evaluate contaminants, soil and rock properties, minerals, oil and gas deposits, and oil sands. It is ideal for the environmental, geotechnical, mining, oil sands, and petroleum industries.	http://gaea.ca/
WinLog RT	GAEA Technologies Ltd.	Creation of boring and well logs and managing boring and well data.	http://gaea.ca/
Winsieve	GAEA Technologies Ltd.	Creation of grain-size analysis charts in several standard or custom formats.	http://gaea.ca/
Reactiv	Geocentrix Ltd.	Design of reinforced slopes in a wide variety of soil types, using reinforced soil or soil nails.	http://www.geocentrix.co.uk/
ReWard	Geocentrix Ltd.	Design of embedded retaining walls, incorporating several UK and international design standards including BS 8002 and Eurocode 7.	http://www.geocentrix.co.uk/
Repute	Geocentrix Ltd.	Onshore pile design and analysis.	http://www.geocentrix.co.uk/
Geogiga Seismic Pro	Geogiga Technology corp.	Seismic data processing and interpretation software.	http://www.geogiga.com/
CPeT IT	Geologismiki	Interpretation of Cone Penetration data.	http://geologismiki.gr/
Cliq	Geologismiki	Cone Penetration Based soil liquefaction software that for CPT data interpretation, factor of safety, liquefaction potential index and post-earthquake displacements (both vertical and lateral).	https://geologismiki.gr/

Name	Company	Application	Website
LiqSvs	Geologismiki	Liquefaction analysis that accepts SPT and V_s field data.	https://geologismiki.gr/
SPAS	Geologismiki	Seismic signal processing and seismic analysis.	https://geologismiki.gr/
LiqIT	Geologismiki	Assessment of liquefaction potential based on commonly used field data.	https://geologismiki.gr/
StoneC	Geologismiki	Vibro-replacement and design of stone columns.	https://geologismiki.gr/
SteinP 3DT	Geologismiki	Settlement calculation taking into consideration the influence of nearby footing elements.	https://geologismiki.gr/
SteinN Pro	Geologismiki	Preliminary settlement analysis below a rectangular footing.	https://geologismiki.gr/
BLogPro	Geologismiki	Creation of simple soil borehole logs.	https://geologismiki.gr/
SPTCorr	Geologismiki	Estimation of various soil properties from the Standard Penetration Test blow count.	https://geologismiki.gr/
GEODelp	GEOS	Prediction of settlement from *in situ* measurements.	http://www.geos-ic.com/
GEO Fond	GEOS	Calculation of settlement under embankments and dimensioning of shallow and deep foundation.	http://www.geos-ic.com/
GEOMUR	GEOS	Design of retaining walls and analysis of internal and external stability.	http://www.geos-ic.com/
GEOSpar	GEOS	Design of nailed wall cladding and calculation of steel section and support plates.	http://www.geos-ic.com/
GEO Stab	GEOS	Slope stability, calculation of general stability of supports, and dimensioning reinforced floor and nailed walls.	http://www.geos-ic.com/
RIDO	GEOS	Calculation of elastoplastic equilibria and dimensioning of retaining screens.	http://www.geos-ic.com/
Z-soil	GEOS	2-D and 3-D finite element numerical simulation and geotechnical calculation of simple and complex structures.	http://www.geos-ic.com/
AIR/W	Geoslope	Finite element simulation of air transfer in mine waste and other porous media.	https://www.geoslope.com/
CTRAN/W	Geoslope	Finite element simulation of solute and gas transfer in porous media.	https://www.geoslope.com/
Quake/W	Geoslope	Finite element simulation of earthquake liquefaction and dynamic loading.	https://www.geoslope.com/
SEEP/W	Geoslope	Finite element simulation of groundwater flow in porous media.	https://www.geoslope.com/
SIGMA/W	Geoslope	Finite element simulation of stress and deformation in earth and structural materials.	https://www.geoslope.com/
SLOPE/W	Geoslope	2-D slope stability analysis using limit equilibrium method.	https://www.geoslope.com/
TEMP/W	Geoslope	Finite element simulation of heat transfer and phase change in porous media.	https://www.geoslope.com/
Geo Studio	Geoslope	Integrated suite for simulation of slope stability, ground deformation, and heat and mass transfer in soil and rock.	https://www.geoslope.com/
ILA	GeoSoft	Slope stability analysis, including features for retaining system designing	https://www.geoandsoft.com/
CE.CA.P	GeoSoft	Analysis and design of foundations	https://www.geoandsoft.com/
DIADIM	GeoSoft	Solution of dimensioning problems and verification through finite difference model.	https://www.geoandsoft.com/

Name	Company	Application	Website
INSITU	GeoSoft	Interpretation of static and dynamic geotechnical *in situ* tests.	https://www.geoandsoft.com/
VERCAM	GeoSoft	Analysis and design of retaining, gravity and in concrete walls.	https://www.geoandsoft.com/
LIQUITER	GeoSoft	Determination of safety factors pertaining to the liquefaction of incoherent saturated terrains subjected to earthquake phenomena.	https://www.geoandsoft.com/
CLUSTAR	GeoSoft	Computerized structural geology data collection and analysis, which recognizes the discontinuity sets of a rock mass through hierarchical and non-hierarchical clustering procedures derived from the multivariate analysis.	https://www.geoandsoft.com/
ROTOMAP	GeoSoft	3-D model for rock fall analysis and the design of rock fall protective systems.	https://www.geoandsoft.com/
ROCK3D	GeoSoft	Stability analysis of removable blocks on planar rock slopes.	https://www.geoandsoft.com/
Load cap	Geostru	Computation of bearing capacity on rocky or loose soils and analysis of soil reinforced with geogrid.	https://www.geostru.eu/
GDW	Geostru	Design and analysis of gabion walls, simple concrete weirs, and gabion weirs in static and seismic conditions.	https://www.geostru.eu/
GFAS	Geostru	Mechanical analysis of soil using the finite element method.	https://www.geostru.eu/
Pile and Micropile	Geostru	Calculation of the bearing capacity of the foundation terrain of a pile or micropile (Screw-piles).	https://www.geostru.eu/
MDC	Geostru	Design and analysis of reinforced concrete retaining walls resting either on their own foundation or on piles, optionally supported by tiebacks.	https://www.geostru.eu/
SPW	Geostru	Design and analysis of sheet pile walls, drilled piles, and diaphragm walls.	https://www.geostru.eu/
Rock Plane	Geostru	Evaluation of localized instability rocky elements affected by seismic movements and/or by presence of water pressures within intersurface fractures.	https://www.geostru.eu/
Down Hole	Geostru	Processing borehole seismic tests.	https://www.geostru.eu/
Dynamic Probing	Geostru	Interpretation of Dynamic Penetration test.	https://www.geostru.eu/
Adamas	Geosysta Ltd.	Integrated data management system for geotechnical data.	http://geosysta.com/
Drillysis	Geosysta Ltd.	Borehole logging application.	http://geosysta.com/
WALLAP	Geosolve	Stability analysis of cantilevered and propped cantilever retaining walls.	http://www.geosolve.co.uk/
Slope	Geosolve	Slope stability analysis.	http://www.geosolve.co.uk/
GWALL	Geosolve	Analysis of retaining wall problems including gravity walls and cantilever wall with bases.	http://www.geosolve.co.uk/
ELPLA	Geotec Software	Analysis of single piles, pile groups, and piled raft foundation.	https://www.elpla.com/
\1\ GeoSuite	Geotechnical Software and Services	Comprehensive geotechnical software package	http://geoadvanced.com/ /1/

Name	Company	Application	Website
GeoLiqu	Geotechnical Software and Services	Soil liquefaction analysis, including liquefaction potential, seismic settlement (dry and saturated) and lateral spreading based on standard penetration test (SPT) data, cone penetration test (CPT) data and shear wave velocity (Vs) data profiles.	http://geoadvanced.com/
GeoComp	Geotechnical Software and Services	Calculation of compression deformation utilizing Standard Penetration test (SPT), cone penetration test (CPT), and shear wave velocity (V_s) data.	http://geoadvanced.com/
GeoBP	Geotechnical Software and Services	Bearing capacity analysis of soil.	http://geoadvanced.com/
GeoEP	Geotechnical Software and Services	Calculation of static and seismic lateral earth pressures, utilizing trial wedge method, for surface configurations such as level, ascending and/or descending or stepped surfaces.	http://geoadvanced.com/
GGU 3D SSFLOW	GGU Soft	Simulation of steady-state groundwater flow in three-dimensional groundwater systems using finite element methods.	https://www.ggu-software.com/
GGU 3D Transient	GGU Soft	Analysis of transient groundwater flow using the finite element method based on a 3-D groundwater system analyzed using GGU 3D SSFLOW.	https://www.ggu-software.com/
GGU-Axpile	GGU Soft	Bored and driven pile calculations and graphical representation of results.	https://www.ggu-software.com/
GGU Consolidate	GGU Soft	Analysis of 1-D consolidation processes in single-layered systems (analytical), multi-layered systems (numerical), and single- or multi-layered systems with vertical drains.	https://www.ggu-software.com/
GGU Elastic	GGU Soft	Analysis of plane and axis-symmetrical deformation using the finite element method.	https://www.ggu-software.com/
GGU Retain	GGU Soft	Analysis of retaining walls based on the Recommendations of the German Working Group for Excavations and for Waterfront Structures (EAB + EAU).	https://www.ggu-software.com/
GGU Settle	GGU Soft	Settlement analysis of triangular and rectangular foundations, including mutual influence of neighboring foundations.	https://www.ggu-software.com/
GGU Slab	GGU Soft	Analysis of elastically-supported slabs based on the modulus of subgrade reaction and constrained modulus methods using the finite element method.	https://www.ggu-software.com/
GGU Stability	GGU Soft	Slope stability analysis and analysis of soil nailing and reinforced earth walls. Nailing can consist of anchors, soil nails, geosynthetics (reinforced earth), or injection piles.	https://www.ggu-software.com/
GGU Trench	GGU Soft	Analysis of diaphragm wall stability in accordance with DIN 4126	https://www.ggu-software.com/
GGU-Underpin	GGU Soft	Analysis and design of underpinning.	https://www.ggu-software.com/
BorinGS	Gookin Software	Creation and management of boring logs.	http://www.gookinsoftware.com/

Name	Company	Application	Website
FSCONSOL	GWP Geo software Inc.	Determination of the rate and magnitude of consolidation of soil slurries, such as mine tailings, deltaic deposits, and other soft soils.	http://www.fsconsol.com/
FTG	Inducta Pty. Ltd.	Design of pad and strip footings.	https://www.inducta.com.au/
PileAXL	Innovative Geotechnics Pty Ltd, Australia	Analysis of single pile behavior under axial loading applied at the pile head for both onshore and offshore engineering problems.	https://www.pilegroups.com/
PileSuite	Innovative Geotechnics Pty Ltd, Australia	Deep foundation analysis and design for both onshore and offshore projects.	https://www.pilegroups.com/
PileGroup	Innovative Geotechnics Pty Ltd, Australia	Finite element simulation of deformations and loads of pile groups subject to general 3-D loading, such as axial and lateral forces and moments applied on the pile caps.	https://www.pilegroups.com/
PileLAT	Innovative Geotechnics Pty Ltd, Australia	Finite-element simulation of laterally loaded piles (single piles mainly under lateral loading) based on automatically generated nonlinear p-y curves for various soil and rock types.	https://www.pilegroups.com/
PileROC	Innovative Geotechnics Pty Ltd, Australia	Prediction of settlement for piles socketed into rock under compressive axial loading and estimates of ultimate and factored axial capacities for a range of socket lengths.	https://www.pilegroups.com/
Geo Tec B	Interstudio S.r.1	Analysis of stratified slopes in the presence of water and loads.	http://en.interstudio.net/
3DEC	Itasca Consulting Group	3-D simulation for advanced geotechnical analysis of soil, rock, ground water, structural support, and masonry using the distinct element method.	https://www.itascacg.com/
FLAC	Itasca Consulting Group	2-D finite difference simulation for advanced geotechnical analysis of soil, rock, groundwater, and ground support.	https://www.itascacg.com/
FLAC3D	Itasca Consulting Group	3-D finite difference simulation for advanced geotechnical analysis of soil, rock, groundwater, and ground support.	https://www.itascacg.com/
PFC	Itasca Consulting Group	Distinct Element Method (DEM) for advanced, fast multi-physics simulation.	https://www.itascacg.com/
UDEC	Itasca Consulting Group	2-D simulation of the quasi-static or dynamic response to loading of media containing multiple, intersecting joint structures using the distinct element method.	https://www.itascacg.com/
FLAC/Slope	Itasca Consulting Group	Slope stability analysis.	https://www.itascacg.com/
CESAR- LPCP	itech-soft	Simulation of stability and deformation using the finite element method in 2-D and 3-D.	http://www.cesar-lcpc.com/
Lean Wall	Javasoft	Design of concrete or masonry leaning walls.	https://javasoft-softwares.com/
Retain Wall	Javasoft	Design of concrete or masonry retaining walls.	https://javasoft-softwares.com/

Name	Company	Application	Website
Key Wall Pro	Key wall Retaining wall system Inc	Design and analysis of gravity walls and soil reinforced wall sections for all Keystone structural units and most common soil reinforcement materials.	http://keystonewalls.com/
HoleBaseSI	Keynetix Ltd	Geotechnical knowledge management system for inclusion of geotechnical data within the BIM process.	https://www.keynetix.com/
Twall Design	LG Soft	External stability analysis of reinforced concrete cantilever walls (sliding, overturning and bearing capacity) under both static and seismic conditions.	https://www.dec.uc.pt/
Limit state GEO	LimitSTATE Ltd	Geotechnical stability analysis using the limit state approach to determine the critical failure mechanism.	http://www.limitstate.com/
Midas GTS	MIDAS IT	Finite element simulation of deep foundations, excavations, complex tunnel systems, seepage, consolidation, embankments, dynamic conditions, and slope stability analysis.	http://midasgtsnx.com/
4D Geotechnical Hazard assesment	Mira Geoscience Ltd.	Quantitative forecasting of geotechnical hazard for design or real time monitoring applications.	http://www.mirageoscience.com/
GSLOPE	Mitre Software Cooperation	Limit equilibrium slope stability analysis of existing natural slopes, unreinforced man-made slopes, or slopes with soil reinforcement.	http://www.mitresoftware.com/
GTILT	Mitre Software Cooperation	Management of slope inclinometer data.	http://www.mitresoftware.com/
EDIPLIN	Newsoft SAS	Design and verification of foundation of reinforced concrete poles.	https://www.newsoft-eng.it/
FEQDrain	NISEE - University of California, Berkeley	Analysis of earthquake generation and dissipation of pore water pressure in layered sand deposits with vertical drains.	https://nisee.berkeley.edu/
NovoCPT	Novo Tech Software Inc.	CPT interpretation.	http://www.novotechsoftware.com/
Novoformula	Novo Tech Software Inc.	Geotechnical correlations.	http://www.novotechsoftware.com/
NovoLiq	Novo Tech Software Inc.	Soil liquefaction analysis.	http://www.novotechsoftware.com/
Vislog	Novo Tech Software Inc.	3-D soil profile visualization.	http://www.novotechsoftware.com/
Frew	Oasys Ltd	Embedded retaining wall analysis.	https://www.oasys-software.com/
Greta	Oasys Ltd	Stability analysis for gravity retaining walls.	https://www.oasys-software.com/
PDisp	Oasys Ltd	Soil settlement calculation and displacement analysis.	https://www.oasys-software.com/
Piles	Oasys Ltd	Calculation of load capacity and settlement for single piles.	https://www.oasys-software.com/
Safe	Oasys Ltd	2-D finite element simulation in plane stress, plane strain, or axial symmetry.	https://www.oasys-software.com/
Siren	Oasys Ltd	Seismic site response analysis.	https://www.oasys-software.com/
Slope	Oasys Ltd	2-D slope stability analysis.	https://www.oasys-software.com/
Xdisp	Oasys Ltd	Prediction of ground movement, settlement, and assessment of building and utility damage.	https://www.oasys-software.com/

Name	Company	Application	Website
Alp	Oasys Ltd	Analysis of laterally loaded piles.	https://www.oasys-software.com/
Seisopt 2D	Optim Software	Creation of detailed velocity models from surface refraction array data using a proprietary simulated annealing optimization algorithm.	http://www.optimsoftware.com/
Seisopt Remi	Optim Software	Implementation of the Refraction Microtremor (ReMi) method to measure the *in situ* shear wave velocity profile.	http://www.optimsoftware.com/
Optum G2	Optum Comput. Engineering	2-D finite element simulation for geotechnical stability and deformation analysis in plane strain or axisymmetry.	https://optumce.com/
Optum G3	Optum Comput. Engineering	3-D finite element simulation for geotechnical stability and deformation analysis in plane strain or axisymmetry.	https://optumce.com/
SPW911	Pile Buck	Sheet pile design.	http://www.pilebuck.com/
GRLWEAP	Pile Dynamics Inc.	1-D wave equation analysis to simulate motions and forces in a pile when driven by either an impact or vibratory hammer.	https://www.pile.com/
Pile Driving Analyzer	Pile Dynamics Inc.	Dynamic load testing and pile driving monitoring.	https://www.pile.com/
CAPWAP	Pile Dynamics Inc.	Simulation of static load test in compression and tension, prediction of load displacement behavior, and determination of stresses at each depth along the pile.	https://www.pile.com/
Thermal Integrity Profiler	Pile Dynamics Inc.	Quality control or assessment of drilled shafts/bored piles, auger cast in place (ACIP)/continuous flight auger (CFA) or drilled displacement piles, slurry walls, barrettes, soil nails, and jet grouted columns.	https://www.pile.com/
PDI TOMO 3D	Pile Dynamics Inc.	3-D tomography imaging tool for analyzing wave speeds to yield a wave speed of entire shaft volume.	https://www.pile.com/
PDA-DLT	Pile Dynamics Inc.	Dynamic load testing for drilled shafts.	https://www.pile.com/
Plaxis 2D	Plaxis	2-D finite element simulation with add-ons for ground water flow, dynamic loading, and thermal analysis of soils and rocks.	https://www.plaxis.com/
Plaxis 3D	Plaxis	3-D finite element simulation with add-ons for ground water flow, and dynamic loading of soils and rocks.	https://www.plaxis.com/
Geo Program	Presta Shop	Complete geotechnical analysis.	http://www.programgeo.it/
Various books and software for soil mechanics	Prof. Arnold Verruijt (Deflt University of Technology)	Analysis of sheet pile walls in layered soils, slope stability, piles, groundwater flow, and finite element simulation of steady and non-steady groundwater flow.	http://geo.verruijt.net/
PROKON	Prokon Software Consultants	Structural design that is useful for slope stability analysis, rock stability and capacity analyses and pile capacity analysis.	https://www.prokon.com/
Geotech Masters	Q System Engineering LLC	Analysis and design of foundations and piles.	http://qsystemsengineering.net/

Name	Company	Application	Website
Retain Pro 10	Retainpro Software div. ENERCAL, Inc.	Design and analysis of earth retaining structures.	https://retainpro.com/
CPillar	Rocscience	Evaluation of the stability of surface or underground crown pillars, and laminated roof beds.	https://www.rocscience.com/
Dips	Rocscience	Stereographic projection.	https://www.rocscience.com/
Examine	Rocscience	Stress analysis and data visualization tool for underground excavations in rock.	https://www.rocscience.com/
RocData	Rocscience	Analysis of rock and soil strength data, and determination of strength envelopes and other physical parameters.	https://www.rocscience.com/
RocFall	Rocscience	2-D statistical analysis to assist with assessment of slopes at risk for rock falls.	https://www.rocscience.com/
RocPlane	Rocscience	Planar rock slope stability analysis and design.	https://www.rocscience.com/
RocSupport	Rocscience	Estimation of support requirements of tunnels in weak rock.	https://www.rocscience.com/
RocTopple	Rocscience	Toppling analysis and support design for rock.	https://www.rocscience.com/
RS2	Rocscience	2-D finite element simulation.	https://www.rocscience.com/
RS3	Rocscience	3-D finite element simulation.	https://www.rocscience.com/
RSPile	Rocscience	Pile analysis.	https://www.rocscience.com/
Settle	Rocscience	3-D soil settlement analysis.	https://www.rocscience.com/
Slide2	Rocscience	2D slope stability analysis using limit equilibrium method and finite element seepage analysis.	https://www.rocscience.com/
Slide3	Rocscience	3-D slope stability analysis	https://www.rocscience.com/
SWedge	Rocscience	Evaluation of the geometry and stability of surface wedges in rock slopes.	https://www.rocscience.com/
UnWedge	Rocscience	3-D stability analysis and visualization program for underground excavations in rock containing intersecting structural discontinuities.	https://www.rocscience.com/
ELK	Sharper Geo	Analysis of *in situ* tests and slope stability.	http://www.sharpergeo.com/
SVDesigner	Soil Vision system Ltd	3-D conceptual modeler and visualization tool for the geotechnical and hydrogeological fields.	https://soilvision.com/
SVseismic	Soil Vision system Ltd	Dynamic analysis by the finite element direct time step-by-step integration method.	https://soilvision.com/
SVslope	Soil Vision system Ltd	3-D slope stability analysis.	https://soilvision.com/
SVsoils	Soil Vision system Ltd	Estimation and mathematical representation of soil constitutive models for subsequent numerical modeling.	https://soilvision.com/
SVflux	Soil Vision system Ltd	1-D, 2-D, and 3-D finite element simulation of groundwater.	https://soilvision.com/
SVsolids	Soil Vision system Ltd	Determination of the stress state and deformation of soils under various loading conditions and solving stress-deformation problems.	https://soilvision.com/
TSLOPE 3D	TAGA Engineering Software Ltd.	3-D slope stability analysis.	https://tagasoft.com/

Name	Company	Application	Website
CASTeR	Technology Development Center	Generation of soil test reports.	http://www.tdcindia.com/
GTeCS	Technology Development Center	Analysis of slope stability, bearing capacity, pile capacity, settlement, and under-reamed pile capacity.	http://www.tdcindia.com/
TensarSoils	Tensar International Corporation	Analysis and design of retaining walls.	https://www.tensarcorp.com/
Dimensions	Tensar International Corporation	Calculation of bearing capacity and projected settlement beneath shallow foundations.	https://www.tensarcorp.com/
Foxta V3	Terrasol	Design of shallow, deep, and raft foundations.	https://www.terrasol.fr/
K-REA V4	Terrasol	Design of retaining walls using the subgrade reaction method, including diaphragm walls, sheetpile walls, and soldier pile walls.	https://www.terrasol.fr/
Straticad	Terrasol	Semi-automatic processing of geotechnical data within drawings and their display in 2-D and 3-D.	https://www.terrasol.fr/
Talren V5	Terrasol	Slope stability analysis, including stability of geotechnical structures, reinforcement, natural slopes, cut or fill slopes, earth dams, and dikes.	https://www.terrasol.fr/
Unipile 5.0	UniSoft GS	Analysis of piles and pile groups.	https://www.unisoftgs.com/
Unisettle 4.0	UniSoft GS	Stress and settlement calculations involving complex load combinations and site conditions.	https://www.unisoftgs.com/
UTEXAS	University of Texas at Austin	2-D slope stability analysis using limit equilibrium method.	http://www.ce.utexas.edu/prof/wright/UTEXASED4/UTEXASED4%20Home.htm
SigmaSpectra	University of Texas at Austin	Selection of suites of earthquake ground motions from a library of ground motions such that the median of the suite matches a target response spectrum at all defined periods.	https://github.com/arkottke/sigmaspectra
Strata	University of Texas at Austin	1-D linear-elastic and equivalent-linear site response analyses using time series or random vibration theory ground motions.	https://github.com/arkottke/strata
SLAMMER	University of Texas at Austin	Sliding-block analyses to evaluate seismic slope performance.	https://pubs.usgs.gov/tm/12b1/
MODFLOW	USGS	Simulation and prediction of groundwater conditions and groundwater/surface-water interactions. MODFLOW is the USGS's modular hydrologic model.	https://water.usgs.gov/ogw/modflow/
HYDRO-THERM	USGS	Simulation of multi-phase groundwater flow and associated thermal energy transport in three dimensions.	https://volcanoes.usgs.gov/software/hydrotherm/
VERSAT-P3D	Wutec Geotechnical International, B.C., Canada	Finite element simulation for quasi-3D nonlinear dynamic analyses of single piles and pile groups in the frequency and time domains.	http://www.wutecgeo.com/

Name	Company	Application	Website
VERSAT-2D	Wutec Geotechnical International, B.C., Canada	Software package (VERSAT-2D Processor, VERSAT-S2D and VERSAT-D2D) for 2-D finite element simulation of stresses, deformations, and soil-structure interactions for static loading and dynamic analyses of earth structures subjected to dynamic loads from earthquakes, machine vibration, waves, or ice action.	http://www.wutecgeo.com/

This Page Intentionally Left Blank

APPENDIX C. SYMBOLS USED IN GEOTECHNICAL ENGINEERING

One potentially confusing aspect of geotechnical engineering is the lack of standardization used for common engineering parameters. Different symbols were adopted at the various U.S. and overseas universities, as well as organizations such as NGI, USBR, and USACE, who were involved in the early years of soil mechanics. As an example, when presenting the results of the compression curve of a conventional consolidation test, the symbols used for the x-axis (vertical effective stress) include: p, p', σ'_v, $\bar{\sigma}_v$, and others. The purpose of this Appendix is not to offer suggestions for standardization, but to provide a listing of the different symbols that have been used historically in the geotechnical literature to be used as a cross-reference when consulting old figures, papers, and texts.

Table C-1 Symbols Used in Geotechnical Engineering

Symbol	Description
a	Isotropic transformation factor for flow nets
a	CPT net area ratio used for pore pressure corrections
a	Acceleration
a	Strength parameter used with a power function for nonlinear failure envelope
a	Attraction
A	Cross sectional area of the flow region perpendicular to the flow direction
A	Skempton pore pressure parameter
$\bar{A}$	Skempton pore pressure parameter
ACU	Anisotropically consolidated-undrained triaxial test
$\bar{A}_f$	Skempton pore pressure parameter at failure
a_v	Coefficient of compressibility
b	Strength parameter used with a power function for nonlinear failure envelope
B	Width of a foundation, loaded area, or tunnel
B	Skempton’s pore pressure parameter
$\bar{B}$	Skempton’s pore pressure parameter
B_c	Diameter of a flexible pipe
B_d	Width of trench in pipe loading calculations
B_t	Bulk modulus of soil
c	Total stress cohesion intercept (sometimes undrained shear strength)
c'	Effective stress cohesion intercept.
C	Number of surfaces on which pullout resistance is mobilized
$C_{\alpha\varepsilon}$	Modified secondary compression index or secondary compression ratio
CAU	Anisotropically consolidated undrained triaxial test
CBR	California Bearing Ratio
CBR_{soaked}	Soaked California Bearing Ratio
$CBR_{unsoaked}$	Unsoaked California Bearing Ratio
C_c	Compression index

Symbol	Description
C_c	Coefficient of curvature for grain-size distribution curve.
C^*_c	Intrinsic compression index
$C_{c\varepsilon}$	Modified compression index
c_{CU}	Total stress cohesion intercept from CU triaxial test
C_d	Load coefficient in pipe loading calculations
CF	Clay-sized fraction
c_h	Coefficient of consolidation in horizontal direction
CIU	Isotropically consolidated-undrained triaxial test
C_r	Recompression index
$C_{r\varepsilon}$	Modified recompression index
CRR	Cyclic resistance ratio
C_s	Swelling index, often used as a synonym for recompression index
CSR	Cyclic stress ratio
C_t	Creep factor for coarse-grained settlement methods
C_u	Coefficient of uniformity for grain-size distribution curve
C'_u	Linear coefficient of uniformity (geotextile design)
c_v	Coefficient of consolidation in vertical direction
$C_{\varepsilon c}$	Modified compression index
$C_{\varepsilon r}$	Modified recompression index
$C_{\varepsilon\alpha}$	Modified coefficient of secondary compression
d	Distance between the loaded points
d	Y-intercept of the failure envelope (K_f*-line*) in MIT stress path space (p vs q)
d'	Y-intercept of the failure envelope (K_f*-line*) in MIT stress path space (p' vs q)
d_c	Effective drainage diameter
d_w	Equivalent diameter of well or PVD
D	Diameter of the lab or field vane
D	Diameter
D	Outer diameter of pipe
D	Foundation embedment
D	Damping ratio
D_5	Particle-size diameter corresponding to 5% passing on the cumulative particle-size distribution curve
D_{10}	Particle-size diameter corresponding to 10% passing on the cumulative particle-size distribution curve
D_{15}	Particle-size diameter corresponding to 15% passing on the cumulative particle-size distribution curve
D_{30}	Particle-size diameter corresponding to 30% passing on the cumulative particle-size distribution curve
D_{60}	Particle-size diameter corresponding to 60% passing on the cumulative particle-size distribution curve
DCP	Dynamic cone penetrometer or DCP penetrometer index
D_e	equivalent core diameter
D_r	Relative density

Symbol	Description
DSS	Direct simple shear test
D'_x	Particle size for which X% of the soil is finer for linearized particle distribution (geotextile design)
D_xB	Particle size for which X% of the soil is finer for a base soil
D_xF	Particle size for which X% of the soil is finer for a filter material
e	Void ratio
e_0	Initial void ratio
e^*_{100}	Intrinsic void ratio at 100 kPa
e^*_{1000}	Intrinsic void ratio at 1000 kPa
e_f	Final void ratio or void ratio at failure
e_L	Void ratio at a water content equal to the liquid limit
e_{max}	Maximum index void ratio
e_{min}	Minimum index void ratio
E	Elastic modulus our Young's Modulus
E	Compactive effort index
E'	Equivalent modulus
E_a	Active earth pressure force
E_D	Dilatometer modulus
E_i	Initial tangent modulus
EI	Expansion index
E_m	Modulus of elasticity of mat
E_P	Pressuremeter modulus
E_s	Modulus of elasticity of soil
ESP	Effective stress path (MIT p' vs q stress path space)
E_u	Undrained Young’s modulus
F	Factor of safety
F	Percentage passing a No. 200 (75 µm) sieve (only considering the particles passing a 3-inch sieve)
F	Size correction factor
F^*	Pullout resistance factor
FC	Fine contents
f_i	Fraction of particles between two adjacent sieve sizes (Kozeny-Carman equation)
F_n	Radial drainage factor related to drain spacing
F_r	Radial drainage factor related to well resistance
F_r	Factor of safety for geosynthetic strength
FR	Cone penetration test friction ratio
f_s	Cone penetrometer friction sleeve resistance
F_s	Radial drainage factor related to soil disturbance (smear)
FS	Factor of safety
FS_g	Factor of safety for geotextile permeability
F_w	Factor of safety against wedge failure

Symbol	Description
G	Shear modulus
GC	Gravel Content
GI	group index
G_s	Specific gravity of solids
GSI	Geological Strength Index
G_u	Undrained shear modulus
H	Height
H	Depth of soil cover or vertical distance between ground surface and tunnel roof
H	Initial thickness in settlement
H_{dr}	Drainage path length
H_i	Thickness of each soil layer (may be listed without subscript)
H_i	Average height of the slice in slope stability analysis
H_i	Initial height of the test specimen
h_l	Head loss across flow region
h_p	Pressure head
h_t	Total hydraulic head
H_t	Tunnel height
H_t	Total thickness of transformed soil system
h_v	Velocity head
h_z	Elevation head
i	Hydraulic gradient
I	Influence factor for change in stress calculations
I_1	First stress invariant
I_c	Soil index
ICU	Isotropically consolidated-undrained triaxial test
I_D	Dilatometer material index
I_s	Uncorrected point load strength index
$I_{s(50)}$	Size corrected point load strength index
I_v	Void index
$I_{v,ICL}$	Void index for the intrinsic compression line
$I_{v,SCL}$	Void index for the sedimentation compression line
I_z	Schmertmann strain influence factor
I_{zp}	Schmertmann peak influence factor
k	Hydraulic conductivity or permeability
K	Wedge factor
K	Bulk modulus
K_0	Coefficient of lateral earth pressure at rest
K_0-line	Line through p' and q (MIT) for at-rest conditions
K_a	Active earth pressure coefficient
K_b	Bulk modulus parameter for Duncan-Chang model
K_c	Anisotropic consolidation stress ratio = $\sigma'_{1c} / \sigma'_{3c}$

Symbol	Description
K_D	Dilatometer horizontal stress index
K_f-*line*	Failure envelope in MIT stress path space (p'_f vs. q_f)
k_g	Hydraulic conductivity of geotextile across plane of fabric
k_h	Hydraulic conductivity in horizontal direction
K_m	Mat stiffness factor
K_p	Passive earth pressure coefficient
k_s	Coefficient of subgrade reaction
k_s	Hydraulic conductivity of the disturbed zone
K_{ur}	Unload-reload modulus parameter Duncan-Chang model
k_v	Hydraulic conductivity in horizontal direction
l	Distance between two points along a structure
L	Length
L	Longest dimension of a foundation or loaded area
L	Length of flow path
L_e	Length of reinforcement embedded behind the trial failure surface
LI or I_L	Liquidity index
LIR	Load Increment Ratio for consolidation test
LL	Liquid limit
L_m	maximum distance water must flow through a vertical drain
m	Modulus number
$MARV$	Minimum average roll value used for various properties of geosynthetics
M_{ds}	Constrained modulus
MSE	Mechanically stabilized earth
m_v	Coefficient of volume compressibility
n	Porosity
n	Vertical drain spacing ratio
N	Standard Penetration Test blow count (blows/ft). Often assumed to be N_{60}
N'	Average Standard Penetration Test value
N_1	Standard Penetration Test blow count normalized to overburden pressure of 1 tsf
$N_{1,60}$	Standard Penetration Test blow count corrected for 60% of hammer energy and normalized to an overburden pressure of 1 tsf.
$N_{1,60,cs}$	SPT blow count corrected for 60% of hammer energy and fines content, and normalized to an overburden pressure of 1 tsf.
N_{60}	SPT blow count corrected for 60% of hammer energy
N_c	Bearing capacity factor
NC	Normally consolidated
N_{crit}	Undrained stability factor
N_d	Number of equipotential (head) drops in the flow net
N_f	Number of flow channels in the flow net
N_k	Bearing capacity factor used for reduction of CPT data in fine-grained soil
N_{kt}	Bearing capacity factor used for reduction of CPT data in fine-grained soil

Symbol	Description
N_q	Bearing capacity factor
N'_{silty}	Standard Penetration Test blow count for saturated silty sands
O_{95}	Geotextile apparent opening size
OC	Overconsolidated
OCR	Overconsolidation ratio
p	MIT stress path parameter = $(\sigma_1 + \sigma_3)/2$ or $(\sigma_v + \sigma_h)/2$
p'	MIT stress path parameter = $(\sigma'_1 + \sigma'_3)/2$ or $(\sigma'_v + \sigma'_h)/2$
p_0	Pressure required to initiate movement of the dilatometer
p_0	Pressuremeter liftoff pressure
P_a	Atmospheric pressure
p_a	Tunnel air pressure
P_c	Maximum past pressure or preconsolidation pressure
p_f	MIT stress path parameter p at failure
p_f	Inflection point in pressuremeter curve assumed to delineate the change from pseudo elastic to plastic response and the point where creep may be expected
p'_f	MIT stress path parameter p' at failure
PI	Plasticity index
p_L	Pressuremeter limit pressure where the curve becomes asymptotic on a pressure versus volume curve
PL	Plastic limit
P_p	Maximum past pressure or preconsolidation pressure
P'_p	Maximum past pressure or preconsolidation pressure
p_r	Pressuremeter yield point during the reloading portion of an unload–reload cycle where recompression ends and the soil reinitiates plastic shearing
P_r	Geosynthetic reinforcement’s resistance to pullout
PSR	Principal stress ratio
p_u	Pressuremeter minimum pressure during unloading during the unload–reload cycle
q	Volumetric flow rate
q	MIT stress path parameter = $(\sigma_1 - \sigma_3)/2$ or $(\sigma_v - \sigma_h)/2$
Q	Rock tunneling quality index
Q	Quantity of flow
Q	Unconsolidated-undrained (UU) triaxial test
q_0	Applied pressure or load
q_0	Applied stress at the base of the foundation or structure
$q_{0\text{-}net}$	Net vertical stress applied by the structure
q_c	Cone penetrometer tip resistance or cone bearing (not corrected for pore pressure effects)
q_{c1}	Cone penetrometer tip resistance or cone bearing normalized to an overburden pressure of 1 tsf
q_d	Dynamic cone resistance
q_f	Applied stress following removal of surcharge
q_f	MIT stress path parameter q at failure
q_s	Surcharge load

Symbol	Description
q_t	Cone penetrometer tip resistance corrected for pore pressure effects
q_u	Unconfined compressive strength
q_w	Discharge capacity of the drain
r	Horizontal distance from centerline of a foundation
R	Radius of influence in well design
R	Correction factor for overconsolidated static CTP cone tip resistance
R	Isotropically consolidated undrained triaxial test with pore water pressure measurements.
R	Isotropically consolidated undrained triaxial test without pore water pressure measurements.
RC	Relative compaction
R_f	Reduction factor for Duncan-Chang model
RF_{CR}	Reduction factor for creep
RF_D	Reduction factor for durability
RF_{ID}	Reduction factor for installation damage
RMR	Rock mass rating
RQD	Rock Quality Designation
r_u	Pore pressure coefficient
s	Ratio of the disturbed zone diameter to the diameter of the drain
s	Settlement
s	Shear strength
S	Degree of saturation
S	Surface area factor for grain shape (Kozeny-Carman equation)
S	Seepage force
s_c	Primary consolidation settlement
SRF	Strength reduction factor
s_s	Secondary compression settlement
s_{su}	Undrained steady state shear strength
S_t	Sensitivity
$S_{t,fv}$	Sensitivity measured using field vane shear apparatus
s_u	Undrained shear strength for a $\phi = 0$ envelope = $(\sigma_{1f} - \sigma_{3f})/2$
$s_{u,fv}$	Undrained shear strength determined using field vane apparatus
$s_{ur,fv}$	Remolded undrained shear strength determined using field vane apparatus
t	Thickness
t	Stand up time for tunneling in raveling soils
t	Time after start of consolidation
t	Time
T	Elapsed time between excavation and completion of permanent structure
T	Temperature
T	Time factor in consolidation theory
t_{50}	Time for 50% consolidation to be achieved
t_{90}	Time for 90% consolidation to be achieved

Symbol	Description
T_{all}	Geosynthetic's long-term tensile strength
t_g	Geotextile thickness
t_m	Thickness of mat
T_{max}	Maximum net torque for vane shear test
t_p	Time required to finish primary consolidation
T_r	Time factor for radial consolidation
T_{res}	Residual torque reading for vane shear test
TSP	Total stress path (MIT)
(T-u_s)SP	Total stress path – static pore water pressure (MIT)
T_{ULT}	Ultimate tensile strength of the geosynthetic based on the MARV
T_v	Time factor for vertical drainage
u	Pore water pressure
U	Uplift force applied by water at the failure plane
$\overline{U}$	Degree of consolidation
u_0	Initial pore water pressure
u_2	Cone penetrometer pore water pressure for sensing element located directly behind cone tip
u_a	Pore air pressure
$\overline{U}_c$	Combined degree of consolidation
UC	Unconfined compression test
$\overline{U}_{fs}$	Degree of consolidation following surcharge application
$\overline{U}_r$	Degree of radial consolidation
USR	Undrained strength ratio = s_u/σ'_v
USR_{NC}	Undrained strength ratio for normally consolidated conditions
UU	Unconsolidated-undrained triaxial test
u_x	Excess pore water pressure
U_z	Degree of compression
$\overline{U}_z$	Average degree of consolidation
v	Specific volume = $1 + e$
V	Total volume
V	Total volume (phase relationships)
V_0	Initial calculated volume within the uninflated membrane for pressuremeter
V_a	Volume of air (phase relationships)
v_d	Discharge velocity
v_s	Seepage velocity
V_s	Volume of solids (phase relationship)
V_s	Shear wave velocity
V_{s1}	Normalized shear wave velocity
V_v	Volume of voids (phase relationship)
V_w	Volume of water (phase relationships)
w	Water content (gravimetric)

Symbol	Description
W	Width of the system perpendicular to the page
W	Weight
W	Total weight (phase relationships)
w_0	Initial water content
W_c	Flexible pipe load
W_d	Rigid pipe load
w_f	Final water content
W_i	Weight of each slice (limit equilibrium slope stability analysis)
w_L	Liquid limit
w_n	Natural water content
w_{opt}	Optimum water content
w_p	Plastic limit
W_p	Prism load on pipe
W_s	Weight of solids (phase relationships)
W_T	Total weight of sample (phase relationships)
W_w	Weight of water (phase relationships)
y	Height of the flow region
z	Depth along vertical drain
z	Elevation of a point of interest above the elevation datum
z	Depth below the soil layer
z_{crit}	Critical depth for unsupported shafts in clay soils
z_i	Layer thickness for settlement calculations
z_p	Depth below an applied load
α	Angle between the major principal plane and the plane of interest
α	Settlement correction factor
α	Dip direction or dip azimuth
α	Scale correction factor to account for nonlinear stress reduction
α	Slope of the failure line (K_f) in MIT p - q space
α'	Slope of the failure line (K_f) in MIT p' - q space
β_α	Empirical or semi-empirical coefficient relating k to D_α
δ	Effective soil-geosynthetic interface friction angle
Δe	Change in void ratio
ΔH	Change in layer thickness
ΔH	Change in height
Δh_L	Total head loss for one equipotential drop on a flow net
δ_L	Angular distortion
Δ_L	Deflection ratio
δ_{max}	Differential settlement
Δq_p	Change in cone tip resistance
$\Delta\sigma$	Change in applied stress
$\Delta\sigma'_v$	Change in vertical effective stress

Symbol	Description
$\Delta\sigma_d$	Change in deviatoric stress or change in principal stress difference = $\Delta\sigma_1 - \Delta\sigma_3$
$\Delta\sigma_v$	Change in total vertical stress
Δu	Change in pore water pressure
ε_a	Vertical or axial strain
ε_{crit}	Critical strain for structural distress
$\dot{\varepsilon}$	Strain rate
ε_h	Horizontal strain
ε_r	Radial strain
ε_{vol}	Volumetric strain
ε_v	Volumetric strain
ε_v	Vertical strain
ϕ	Total stress friction angle
ϕ'	Effective stress friction angle
ϕ_{UU} or ϕ_U	Total stress friction angle from UU triaxial test (S < 100%)
$\bar{\phi}$	Effective stress friction angle
ϕ_{CU}	Total stress friction angle from CU triaxial test
ϕ'_{FS}	Fully softened friction angle
$\bar{\phi}_{FS}$	Fully softened friction angle
ϕ'_{RES}	Residual friction angle
$\bar{\phi}_{RES}$	Residual friction angle
ϕ'_R	Residual friction angle
$\bar{\phi}_R$	Residual friction angle
ϕ'_{SEC}	Effective stress secant friction angle (stress dependent)
$\bar{\phi}_{SEC}$	Effective stress secant friction angle (stress dependent)
γ	Unit weight
γ	Shear strain
γ'	Effective unit weight
γ_b	Buoyant unit weight
γ_d	Dry unit weight
$\gamma_{d\text{-}max}$	Maximum dry unit weight
γ_m	Moist unit weight
γ_{SAT}	Saturated unit weight
γ_T	Total, wet, or moist unit weight
γ_w	Unit weight of water
$\dot{\gamma}$	Shear strain rate
λ	Ratio of the circumferential stress to the vertical stress in circular openings
μ	Coefficient of friction
μ'	Coefficient of friction for trench backfill
μ_0	Influence factor associated with embedment of load

Symbol	Description
μ_I	Influence factor associated with geometry and Poisson's ratio
μ_R	Vane correction factor
ν	Poisson's ratio
ν_m	Poisson's ratio of mat
θ	Volumetric moisture content
σ	Total normal stress
σ'	Effective normal stress
$\overline{\sigma}$	Effective normal stress
σ_1	Total major principal stress
σ'_1	Effective major principal stress
$\overline{\sigma}_1$	Effective major principal stress
$\sigma'_{1,con}$	Effective major consolidation stress
$\overline{\sigma}_{1,con}$	Effective major consolidation stress
σ_2	Total intermediate principal stress
σ'_2	Effective intermediate principal stress
$\overline{\sigma}_2$	Effective intermediate principal stress
σ_3	Total minor principal stress
σ'_3	Effective minor principal stress
$\overline{\sigma}_3$	Effective minor principal stress
$\sigma'_{3,con}$	Effective minor consolidation stress
$\overline{\sigma}_{3,con}$	Effective minor consolidation stress
σ'_c	Consolidation stress
$\overline{\sigma}_c$	Consolidation stress
σ_{cell}	Cell pressure for triaxial test
σ_d	Principal stress difference or deviatoric stress
$\sigma_1 - \sigma_3$	Principal stress difference or deviatoric stress
σ'_{fc}	Effective normal stress on the failure plane during consolidation
$\overline{\sigma}_{fc}$	Effective normal stress on the failure plane during consolidation
σ_{ff}	Total normal stress on failure plane at failure
σ'_{ff}	Effective normal stress on failure plane at failure
σ_h	Total horizontal stress
σ'_h	Effective horizontal stress
$\overline{\sigma}_h$	Effective horizontal stress
σ'_m	Mean effective stress
$\overline{\sigma}_m$	Mean effective stress
σ'_N	Effective normal stress on failure surface
$\overline{\sigma}_N$	Effective normal stress on failure surface
σ'_p	Maximum past pressure or preconsolidation stress

Symbol	Description
$\overline{\sigma}_p$	Maximum past pressure or preconsolidation stress
σ'_{crit}	Critical confining stress
σ'_{ps}	Effective stress after perfect sampling
σ'_p	Effective stress after perfect sampling
σ_t	Interior tunnel pressure from compressed air or breasting
σ_v	Total vertical stress
σ'_v	Vertical effective stress
$\overline{\sigma}_v$	Vertical effective stress
σ_{v0}	Initial vertical total stress
σ'_z	Vertical effective stress
σ_{z0}	initial geostatic vertical total stress
σ'_{z0}	Initial or *in situ* vertical effective stress
σ'_{zp}	Initial vertical effective stress at depth of Schmertmann peak influence factor
τ	Shear stress
τ_{cyc}	Applied peak cyclic shear stress
τ_f	Shear stress at failure
τ_{ff}	Shear stress on the failure surface at failure
τ_{eq}	Shear stress required for equilibrium
ω	Tilt angle due to differential settlement
ψ	Matric suction
Ψ	Dip
Ψ_g	Geotextile permittivity, provided by manufacturers or from testing (ASTM D4491)

Table C-2 Acronyms and Abbreviations

Term	Definition
2-D or 2D	Two dimensional
3-D or 3D	Three dimensional
AASHTO	American Association of State Highway and Transportation Officials
ACU	Anisotropically consolidated undrained
AMTS	Automated total station
AR	Augmented reality
BLM	U.S. Bureau of Land Management
BPT	Becker penetration test
CB	Cement-bentonite
CD	Consolidated drained
CU	Consolidated undrained
CK_0U	K_0 consolidated undrained
CPMT	Cone pressuremeter
CPT	Cone penetration test
CPTu	Piezocone test
CRS	Constant rate of strain (consolidation test)
CYCDSS	Cyclic direct simple shear
DCP	Dynamic cone penetration
DMT	Flat plate dilatometer test
DOT	Department of Transportation
DPI	Dynamic cone penetration index
DPT	“Dutch” cone penetrometer test
DSS	Direct simple shear
DST	Direct shear test
DTM	Digital terrain model
EDG	Electrical density gauge
EIS	Electrical impedance spectroscopy
EROS	Earth Resources Observation System
FDM	Finite difference method
FEA or FEM	Finite element analysis or method
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FHWA	Federal Highway Administration
GIS	Geographic information system
GPS	Global positioning system
HCMM	Heat Capacity Mapping Mission
ICL	Intrinsic compression line for remolded clays (Burland 1990)
ICOLD	International Committee on Large Dams

Term	Definition
ICU	Isotropically consolidated undrained
ID	Inside diameter
ISO	International Organization for Standardization
ISRM	International Society for Rock Mechanics
IST	Impact soil tester
LEL	Lower explosive limit
LFD	Lightweight falling deflectometer
LIDAR	Light detection and ranging
LIR	Load increment ratio
LPT	Large penetration test
LVDT	Linear pvariable displacement transducer
M-DI	Moisture-density indicator
MEMS	Micro-electro-mechanical
MSE	Mechanically stabilized earth
MSW	Municipal solid waste
NAIP	National Agriculture Imagery Program
NCIC	National Information Center
NCHRP	National Cooperative Highway Research Program
NCRS	National Resources Conservation Service
NDG	Nuclear density gauge
NFS	Not frost-susceptible
NP	Nonplastic
NRC	Nuclear Regulatory Commission
OD	Outside diameter
OSHA	Occupational Safety and Health Administration
PFS	Possibly frost-susceptible
PLT	Plate load test
PMT	Pressuremeter test
RMR	Rock mass rating
RTD	Resistance temperature device
SAR	Synthetic aperture radar
SB	Soil-bentonite
SBPMT	Self-boring pressuremeter
SBT	Soil behavior type
SCB	Soil-cement-bentonite
SCL	Sedimentation compression line for natural clays (Burland 1990)
SCPTu	Seismic piezocone test
SDG	Soil density gauge

Term	Definition
SLAR	Side-looking airborne radar
SPT	Standard Penetration Test
SS	Surface stiffness
TVA	Tennessee Valley Authority
UAV	Unmanned aerial vehicle
UEL	Upper explosive limit
USACE	United States Army Corps of Engineers
USBR	United Stated Bureau of Reclamation
USCS	Unified Soil Classification System
USDA	United State Department of Agriculture
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
UU	Unconsolidated undrained
VST	Vane shear test

This Page Intentionally Left Blank

APPENDIX D. GLOSSARY

Active zone – The near-surface zone affected by seasonal variation in water content. Also, zone within a soil mass subjected to active earth pressure conditions.

Activity of clay – The ratio of plasticity index to percent by weight of the total sample that is smaller than 0.002 mm in grain size. This property can be correlated with the type of clay mineral.

Adobe – Sandy clays and silts of medium plasticity usually found in the semiarid regions of the southwestern United States. The name is also applied to some high plasticity clays with high clay content and high swell and shrink potential usually found in the western United States.

Aeolian soil – Material transported and deposited by wind.

Aquiclude – A relatively impervious rock or soil layer underlying or overlying an aquifer.

Aquifer – Relatively permeable rock or soil stratum that can store and easily transmit water. Also used for the sand layer often found beneath levees in the lower Mississippi Valley.

Alluvial soils – Materials transported and deposited by running water.

Anisotropic soil – A soil mass having different properties in different directions, often referring to strength or permeability characteristics.

As-compacted – Condition of the soil after compaction is completed.

Azimuth – Is the angle of a feature measured from North at 0° in a spherical coordinate system.

Baby poop – Very soft clay located just above limestone in karst. Frequently orange and formed by dissolution.

Back-packing – Any material (commonly granular) that is used to fill the empty space between the lagging of a wall system and a rock surface.

Backswamp – The prolonged accumulation of floodwater sediments in flood basins bordering a river; materials are generally clays but tend to become siltier near the riverbank

Balanced load – See Compensated foundation

Bank-run sand and gravel – Raw material excavated from a borrow pit, but not sorted or separated into specific grades.

Bedding – Planes of dissimilar materials caused by deposition normally encountered in sedimentary rocks.

Bentonite – High plasticity clay consisting of mostly montmorillonite, resulting from the weathering of volcanic ash mainly in the presence of water. It is normally hard when dry but swells considerably when wet. This clay is commonly used with water as drilling mud and as liner in landfills.

Black cotton soil – Black expansive soil commonly encountered in India. The name originates from the fact that this soil is common in areas where the main crop is cotton.

Blocky – Adjective for soils that can be broken down into small angular lumps which are difficult to break down further.

Blow sand – Wind-driven or drifted sands.

Blue marl – Name given to a bluish-green clay from the Miocene that can be found along the fall line from Richmond, VA, into Maryland. This soil is considered to be acidic, usually with a pH less than 4.0, which can affect water quality and prevent plant or aquatic life.

Bog – Wetland covered with peat with a high water table that accumulates dead plants, usually mosses, and mainly sphagnum. It is generally nutrient poor and acidic.

Boney ground – Ground containing significant amounts of large gravel, cobbles, and boulders.

Borehole jack – An *in situ* test device used to estimate the deformability of rocks. Equipment description and operating procedures are presented in ASTM D4971.

Boulder – Rock particles that have a greatest dimension of at least 12 inches.

Boulder clay – Geological term used to designate clays formed from glacial drift that has not been subjected to the sorting action of water and therefore contains particles from boulders to clay sizes. Boulder clays are also called tills.

Boundary condition – Physical parameters assigned to the edges or boundaries of the domain in numerical analysis. Examples are constant total head boundaries in FE seepage analysis or restrained displacement boundaries in FE stress analysis.

Breaker run – Crushed rock with large particles refers to large broken stone obtained as part of quarrying or mining activities.

Buckshot – Term applied to clays of the southern and southwestern United States that cracks into small, hard, relatively uniform sized lumps on drying. The lumps are similar to the size of buckshot and the soil is very sticky when wet.

Bull's liver – An inorganic silt or silty sand usually encountered in the New York City area. The name Bull's liver comes from its red color and jelly-like behavior when it is subjected to vibration.

Bull's tallow or Bull tallow clay – Tan or gray high plasticity clay typically found in relatively thin layers directly above partially weathered rock or rock in the Charlotte, NC, area. This clay normally has high shrink and swelling potential.

Caliche – Sedimentary rock from arid and semiarid climate in which soil particles, such as gravel, sand, clay, and silt, are cemented and coated by carbonate (often calcium or magnesium carbonate). The level of cementation varies significantly within a deposit. The soil has light coloration often exhibits light colored concretions of various sizes depending on the level of development of the soil profile. The consistency of caliche varies from soft rock to firm soil.

Capillary stresses – Pore water pressures less than atmospheric values produced by surface tension of pore water acting on the meniscus formed in void spaces between soil particles.

Channel fill – Deposits laid down in abandoned meander loops isolated when rivers shorten their courses; composed primarily of clay. However, silty and sandy soils are found at the upstream and downstream ends

Chip – Name given to crushed angular rock fragments smaller than a few centimeters.

Clay – Soil particles passing a No. 200 (75-µm) sieve that exhibit plasticity (putty-like properties) within a range of water contents, and considerable strength when air dried. For classification of clayey soils, refer to Section 1-3.3.

Clay size fraction – The portion of the soil which is finer than 0.002 mm. This is not a viable measure of the plasticity of the material or its characteristics as a clay.

Coarse-grained soils – Soils that contain 50% or more particles retained on a No. 200 (75 µm) sieve.

Cobbles – Rock particles that pass through a 12-inch square opening sieve but are retained on a 3-inch square opening sieve.

Coffee grounds – Soil formed from freshwater marshes that has been dry for decades and has decomposed to the point that is black and inert with little to no plasticity. It is black and granular even when wet.

Colluvial soils – Material transported and deposited by gravity, often found in the vicinity of slopes.

Colluvium – Loose soil deposited at the bottom of a slope.

Compacted – Soil specimen formed by compaction in a mold at a given water content and relative compaction usually referred to a given compaction standard.

Compensated foundation – Method used to support heavy structures over compressible strata. In this approach, the weight of the structure is balanced, completely or partially, by soil that is permanently excavated from the building footprint.

Compression index – Parameter which quantifies the compressibility of normally consolidated soil in one-dimensional compression. Normally, it is the log-linear slope of the compression curve defined by void ratio (y-axis) and the logarithm of vertical effective stress (x-axis).

Cone Penetration Test (CPT) – An *in situ* test that utilizes a standard cone-shaped instrument that is pushed at a standard constant rate from the ground surface to obtain a continuous record of the penetration resistance of the cone tip and the frictional resistance of the soil acting on the friction sleeve of the probe. Testing is currently conducted in accordance with ASTM D5778.

Consolidation tests – Tests in which the volume change of the soil is determined for a change in applied stress, normally for one-dimensional compression.

Coquina – Soft, porous sedimentary rock, mainly limestone, composed largely of shells, coral, and fossils cemented together, with particles averaging 0.079 in (2 mm) or greater in size.

Compression curve – Curve relating the void ratio or strain to the effective stress applied (usually in log scale).

Critical depth – The depth over which soil compression caused by changes in stress contributes to significant surface settlement. The critical depth in fine-grained soils corresponds to the depth at which the change in stress is less than 10% of the existing vertical effective stress. In coarse-grained soils, the critical depth occurs when the change in stress is less than 20% of the existing vertical effective stress. Critical depth can also be used to refer to the depth from the ground surface for which no support is required for vertical shafts in clay.

Cyclic Stress Ratio (CSR) – Amplitude of the cyclic shear stress imposed by an earthquake normalized by the initial effective vertical stress. In a cyclic triaxial test, this is equal to one-half of the applied cyclic deviator stress divided by the isotropic consolidation stress.

Deflection ratio – The maximum expected deviation from uniform settlement divided by the overall length of the structure, which is an approximate measure of the curvature caused by settlement.

Deltaic – Deposits formed at the mouths of rivers, which result in extension of the shoreline.

Desert varnish – Also called patina, rock varnish, or rock rust, is thin, dark red to black mineral coating found on pebbles and rocks surfaces in arid regions.

Desiccation – The process of shrinkage or consolidation of the fine-grained soil produced by increase of effective stresses in the grain skeleton accompanying the development of capillary stresses in the pore water. Desiccation is often a result of soil drying.

Dewatering – Process where water is pumped from a foundation excavation or pumped from a pervious soil stratum with the purpose of lowering the water table.

Diatomaceous earth – Soft, siliceous sedimentary rock that usually crumbles into powder. When crumbled, the particles are silty and contain large amounts of diatoms, the siliceous skeletons of minute marine or freshwater organisms.

Differential settlement – Difference in vertical displacement between horizontally spaced points. Often, difference in settlement between structural elements, such as footings or columns.

Dip – Angle that the surface of the rock forms with a horizontal plane.

Dissipate – Increase or decrease of pore water pressure in order to achieve an equilibrium condition. Can also refer to the decrease in the magnitude of a value with depth, such as the dissipation of stress increase with depth.

Dispersive clays – Clays containing a high percentage of dissolved sodium in the pore water, such that when exposed to water, are very susceptible to erosion.

Distortion – The slope of the expected settlement profile or the ratio of the settlement between two points to the distance separating the points.

Disturbed specimen – Soil specimen obtained without care taken to preserve the volume or structure of the soil. Disturbed specimens are used for index tests, and are not used for strength or compressibility tests.

Double Drainage – Condition when the excess pore water pressure can drain from the top and bottom boundaries of the laboratory test specimen or from a layer of clay *in situ*.

Dune sands – Mounds, ridges, and hills of uniform fine sand characteristically exhibiting rounded grains

Dynamic cone penetration (DCP) – An *in situ* test performed by driving a standard-sized cone into the ground using a drop hammer. This test is detailed in ASTM D6951.

Effective diameter – The grain size that has the primary influence on the average pore size of the soil, which is typically selected as the grain size corresponding to 5 to 20% passing on the cumulative particle-size distribution curve.

Effective Stress – The net stress across points of contact of soil particles, generally considered as equivalent to the total stress minus the pore water pressure.

Ejecta – Loose deposits of volcanic ash, lapilli, bombs, etc.

Elevation head – measure of potential energy of water defined by the vertical distance of the water surface from a datum.

Equalization – Action of letting something reach equilibrium.

Equipotential line – Lines or curves define points of constant total head.

Equivalent Fluid Pressure – Horizontal pressures of soil, or soil and water in combination, which increase linearly with depth and are equivalent to those that would be produced by a heavy fluid of a selected unit weight.

End of Primary Consolidation (EOP) – When all the excess pore pressure in the soil created by the increase in stress is dissipated and the soil enters into secondary compression.

Estuarine – Mixed deposits of marine and alluvial origin laid down in widened channels at mouths of rivers and influenced by tide of body of water into which they are deposited

Excess Pore Pressures – Increment of pore water pressures greater than hydrostatic values, produced by application of normal stresses or shear stresses.

Exit Gradient – The hydraulic gradient (difference in head at two points divided by the distance between them) at the point where water exits soil. Exit gradients are often used as an indicator of erosion at the downstream toe of dams and levees.

Expansion Index – Percent swell multiplied by 10 for the ASTM D4829 test.

Extraction wells – Pumped wells that withdraw groundwater or contaminated groundwater from an aquifer.

Fibric peat – Peat in which the original plant fibers are slightly decomposed and contain 67% or more fibers.

Field Boring Log – Logged information of a boring prepared during the drilling process. A typical field log includes all the relevant information for the boring that was completed, including a unique boring identification number, date of drilling, personnel on-site, boring advancement method (i.e., auger, rotary wash, direct push, sonic), depths where samples were obtained, type of samples (i.e., split-barrel and Shelby tube), hammer type, raw SPT N-values, water level observations, and preliminary estimates of stratigraphy. If available, the global positioning system (GPS) coordinates should be included. The field log provides a unique designation of each recovered sample, whether disturbed or undisturbed, as well as a field visual classification of the sample in accordance with ASTM D2488.

Fill – Any constructed soil deposit. It can range from soils that are free of organic matter and that are carefully compacted (controlled fill) to heterogeneous accumulations of rubbish and debris (uncontrolled fill).

Final boring log – Official engineering record of the drilling and sampling efforts that is prepared using the information from the field boring log, and lab and field test results.

Fine-grained soils – Soils that contain 50% or more particles passing a No. 200 (75 µm) sieve.

Finite difference method (FDM) – Numerical method that approximates derivatives by finite differences to solve differential equations with geotechnical applications, including consolidation, seepage, and stress-deformation analysis. In many cases, a physical body (e.g., soil mass, retaining wall, etc.) is discretized by dividing the geometry into small regions where properties are be assumed to be uniform.

Finite element method (FEM) – Numerical method in which a physical body (e.g., soil mass, retaining wall, etc.) is discretized by dividing the geometry into small areas, called elements, where properties are be assumed to be uniform. Adjacent elements in the body are connected at nodes. Global equations are developed to relate the elements, the constitutive theory assigned to the elements, and the selected boundary conditions. FEM is commonly used to solve stress-deformation and seepage problems in geotechnical engineering.

Fissured – Soils that break along predetermined surfaces with little resistance. Fissuring in soils may be an indicator of overconsolidation.

Flat plate dilatometer (DMT) or Marchetti Dilatometer – An *in situ* test that utilizes a device consisting of a robust steel blade that is pushed into the ground and then periodically stopped to allow the controlled measured inflation of a flexible steel membrane. The testing procedures are presented in ASTM D6635.

Floating foundation – see compensated foundation.

Floodplain – Deposits laid down by a stream that within a portion of its valley is subject to inundation by floodwaters

Flow banding – Layering that is sometimes seen in rocks formed from magma.

Flow line – Paths that water particles take when flowing through a soil. Flow lines are an element of flow nets.

Flow net – Graphical solution to the La Place equation used to show the spacial variation of total head. Flow nets are used for seepage calculations in geotechnical engineering.

Flow slide – Shear failure in which a soil mass moves over a relatively long distance in a fluid-like manner, occurring rapidly on flat slopes in loose, saturated, uniform sands, saturated silts, or in highly sensitive clays.

Foliation – Laminated structure of the minerals in a rock created by deformation.

Free swell – Condition in which the soil is allowed to swell with no confining stress being applied.

Full scale – Loading condition for a sensor where the maximum design load is applied.

Fuller's earths – Soils having the ability to absorb fats or dyes. These soils have the capability to decolorize oil or other liquids without chemical treatment. They are usually high plasticity sedimentary clays.

Fully softened shear strength – The drained shear strength of a clay in its normally consolidated state.

Glacial soils – Material transported and deposited by glaciers, or by meltwater from glaciers.

Glacial till – An accumulation of debris, deposited beneath, at the side (lateral moraines), or at the lower limit of a glacier (terminal moraine). Material lowered to the ground surface in an irregular sheet by a melting glacier is known as a ground moraine. See also Boulder Clay.

Glacio-fluvial deposits – Coarse- and fine-grained material deposited by streams of meltwater from glaciers. Material deposited on the ground surface beyond the terminal edge of a glacier is known as an outwash plain. Gravel ridges are known as kames and eskers. Depressions are known as kettles and can be filled with peat.

Glacio-lacustrine deposits – Material deposited within lakes by meltwater from glaciers, consisting of clay in central portions of lake and alternate layers of silty clay or silt and clay (varved clay) in peripheral zones.

Glassified sand – Granular deposits at the ground surface occurring after an intense forest fire.

Goodman jack – See Borehole jack.

Goonies – Cobbles found floating in a soil matrix.

Gravel – Soil particles that pass through a 3-inch square opening sieve but are retained on a No. 4 (4.75 mm) sieve. Gravels can be divided into: (1) coarse gravels, gravel particles that are retained on a ¾-inch square opening sieve, and (2) fine gravels, gravel particles that pass through a ¾-inch square opening sieve.

Grove sand – See Sugar sand

Gumbo – Fine-grained, highly plastic clay of the Mississippi Valley. It has a sticky, greasy feel and forms large shrinkage cracks on drying.

Gyp or gip soil – Gypsum soil (or soil containing gypsum) or caliche soil.

Hardpan – Soil layers that have become hard as rock due to cementing minerals, and do not become plastic when mixed with water, and are relatively impervious. It has also been applied to any hard or overconsolidated layer that is hard to excavate. Because of this ambiguity, Sower (1979) recommends that engineers should avoid this term because many lawsuits have centered about definition. The name implies a condition of a soil rather than a type of soil.

Hillwash – Fine colluvium consisting of clayey sand, sand silt, or clay.

Hogging – Manifestation of differential settlement in a structure that results in concave downward shape.

Homogeneous soil – Soils with the same color, appearance, and properties from point to point. No soil deposit is truly homogeneous.

Humus – Brown or black material formed by the partial decomposition of vegetable or animal matter. It is the organic portion of soil.

Hydraulic conductivity – Discharge velocity of water through a unit area under a unit hydraulic gradient. Can also be viewed as a coefficient of proportionality relating seepage velocity to hydraulic gradient. Often called permeability in geotechnical engineering practice.

Hydraulic gradient – Head loss divided by the length over which the head loss occurs.

Hydraulic head or Total head – Measure of potential energy calculated as the sum of the elevation head, velocity head, and pressure head.

Hydrodynamic Lag Time – See Lag Time.

Hydrostatic – Condition of equilibrium of fluids for no-flow conditions. Also referred to a condition where stresses or pore water pressures are equal in all directions.

Hydrostatic pore pressures – Pore water pressures or groundwater pressures exerted under conditions of no flow where the magnitude of pore pressures increase linearly with depth below the ground surface.

Igneous rocks – Rocks formed from the cooling and solidification of magma.

Inherent anisotropy – Variation of shear strength as a function of the direction of the failure plane. It is the result of significant differences in the soil structure which occur during the formation of the soil.

Intact sample – See Undisturbed sample.

Isotropic soil – A soil mass having essentially the same properties in all directions, referring primarily to stress-strain or permeability characteristics.

Isotropic – Equal in all directions.

Kaolin – White or pink clay of low plasticity. It is composed largely of minerals of the kaolinite family.

Karst – Terrain usually formed from the dissolution of rocks such as limestone, dolomite, and gypsum. It normally contains an underground drainage system composed of sinkholes and caves.

Lacustrine – Material deposited within lakes (other than those associated with glaciation) by waves, currents, and organo-chemical processes; deposits consist of unstratified organic clay or clay in central portions of the lake and typically grade to stratified silts and sands in peripheral zones

Lag time – Time required for an instrument to respond to a change in input.

Laminated – Layering consisting of different materials or material colors of less than ¼ inch in thickness.

Lamination – Sequence of fine layers in a small scale (usually less than one centimeter in thickness) normally observed in sedimentary rocks.

Landslide deposits – Considerable masses of soil or rock that have slipped down, more or less as units from their former position on steep slopes.

Laterites – Residual soils rich in iron formed in hot and humid climates (tropical regions). The cementing action of iron oxides and hydrated aluminum oxides makes dry laterites extremely hard. The high content of iron oxide makes many laterites to be rusty-red. Laterites are usually developed after significant weathering of the parent rock.

Ledge – Colloquial name for bedrock in Vermont and New Hampshire.

Lens or Lensed – Small pockets of dissimilar soil scattered throughout the mass of a clay.

Load increment ratio (LIR) – Variable used to quantify the change in load to a test specimen. Defined as the ratio of the change in stress to the current stress. A load increment ratio of unity indicates that the load was doubled.

Loam – Low plasticity sandy silt or silty sand mixed with organic matter that is well suited to tilling. Mainly applies to the uppermost soil layer and should not be used to describe deep deposits of parent materials. Major soil type in the USDA system. Not considered a USCS soil type in conventional geotechnical engineering (ASTM D2487 and D2488).

Loess – A wind deposited, calcareous, unstratified deposit of silts or sandy or clayey silt traversed by a network of vertical tubes formed by the decay of root fibers. Loess slopes have the ability to withstand vertical cuts.

Lugeon – Flow of one liter of water per meter per minute under a pressure of 10 bars (145 psi) in a constant head double packer test.

Marine soils – Material transported and deposited by ocean waves and currents in shore, near shore, and offshore areas.

Marl – Calcium carbonate or lime-rich sedimentary rock. It is mainly composed of a mixture of sand, silt, and/or clay. Marls are often light to dark gray or greenish in color and sometimes contain colloidal organic matter.

Matric suction – Difference between pore air pressure minus pore water pressure. Often used in the characterization of partially saturated soils.

Maximum past pressure – See Preconsolidation pressure.

Metamorphic rocks – Rocks transformation by heat, pressure, or both. This transformation can alter the physical and chemical properties of the rock.

Minimally disturbed sample – See undisturbed sample.

Modified compression index – Parameter which quantifies the compressibility of normally consolidated soil in one-dimensional compression. Normally, it is the log-linear slope of the compression curve defined by axial (y-axis) and the logarithm of vertical effective stress (x-axis).

Modified recompression index – Parameter which quantifies the compressibility of overconsolidated soil in one-dimensional compression. Normally, it is the log-linear slope of the compression curve defined by axial (y-axis) and the logarithm of vertical effective stress (x-axis). Normally obtained by a rebound-reload loop in a consolidation test. Also called the modified swelling index.

Montmorillonite – A group of very small clay minerals with extreme swelling and shrinking properties. Normally results from volcanic or hydrothermal activities.

Mucks – Peat deposits which have advanced in decomposition to such extent that the botanical character is no longer evident.

Muskeg – North American term for peat. According to Sowers (1979), the bogs in which the peat forms are often called *muskegs*.

Nominally disturbed sample – See Undisturbed sample.

Normal consolidation or normally consolidated – Condition of a soil where the current effective stress is the maximum effective stress ever realized, and all excess pore pressures have been dissipated.

Nested piezometers – Multiple standpipe piezometers that are installed in a single boring with an impervious seal separating the different measurement zones.

Neutral stress – Synonym for pore water pressure. This is a term that is normally used in older geotechnical literature.

One-dimensional compression test – A compression test, normally a consolidation test, in which the soil specimen is confined laterally and deformation occurs in the same direction as the vertically applied load.

Open standpipe piezometer – Type of standpipe piezometer, similar to an open well, except that the screen extends only across a specific stratum of interest. Seals are installed above and below this zone to only allow water to enter from the stratum of interest.

Open well piezometer – Type of standpipe piezometer with a full-length screen and a surficial seal that is best suited to relatively homogeneous soil profiles. In layered soils, the measured groundwater level will correspond to the layer with the highest total head.

Organic soils – Soil material containing enough organic or vegetable matter as to influence the engineering properties. .

Osmotic pressure – Pressure in a solution that is the product of the molar concentration of the solute solution, the universal gas constant, and the temperature, in degrees Kelvin.

Overconsolidation – The condition that exists if a soil deposit has been fully consolidated under an effective stress greater than the existing effective stress.

Peat – Organic soil derived from decomposing plant material, normally sedimented in an anaerobic environment. Peats are considered to have less than 25% ash (mineral components) per dry weight.

Perched water table – Spatially limited unconfined water table, separated from the main groundwater regime, caused by the presence of a low permeability layer.

Piedmont soils – Alluvial deposits at the foot of hills or mountains; extensive plains or alluvial fans

Piezocone test (CPTu) – Cone penetration test where the pore pressures behind the tip of the cone are measured during penetration.

Piezometer – A device installed for measuring the pressure head of pore water at a specific point within the soil mass.

Pinnacle – Is an individual and isolated column of rock, often associated with karst terrain.

Piping – The movement of soil particles as the result of unbalanced seepage forces produced by percolating water, leading to the development of boils or erosion channels.

Pit run sand and gravel – See bank run.

Plane strain – A strain boundary condition where strains are only allowed in two directions. Plane strain boundary conditions often result in a three-dimensional stress state. Many geotechnical engineering analyses that are performed in two-dimensions assume that plane strain boundary conditions exist in the third dimension.

Plastic equilibrium – The state of stress of a soil mass that has been loaded and deformed to such an extent that its ultimate shearing resistance is mobilized at one or more points. Solutions employing plastic equilibrium assume full mobilization of the soil's shear strength within a soil mass or along a specified failure surface.

Pluff Mud – Colloquial term for a very soft, odorous mud encountered in South Carolina.

Point bar – Alternating deposits of arcuate ridges and swales (lows) formed on the inside or convex bank of river bends. The ridge deposits consist primarily of silt and sand, while swales are often clay filled

Positive cutoff – The provision of a line of tight sheeting or a barrier of impervious material extending downward to an essentially impervious lower boundary to intercept completely the path of subsurface seepage.

Preconsolidation pressure – Maximum effective stress, under conditions of full pore pressure dissipation, that has been applied to a soil in the past. Synonym for maximum past pressure.

Prefabricated vertical drain (PVD) – Plastic strip, normally encased in a filter fabric, that can be inserted into the soil by a mandrill to facilitate the dissipation of excess pore water pressures.

Pressure head – Synonym for piezometric head. Component of total head that is equal to the water pressure divided by the unit weight of water.

Primary consolidation – The time-dependent compression of a soil under the application of a stress that occurs while excess pore pressures dissipate with time.

Pumice – Porous rock associated with lava flows. May be mixed with nonvolcanic sediments.

Pyroclastic soils – Soil-like material ejected from volcanoes and transported by gravity, wind and air.

Radial consolidation – Consolidation of a soil mass where pore water pressures are dissipated laterally or radially. Radial consolidation occurs when the drainage boundary is cylindrical (stone column) or a strip or line (PVD).

Recompression index – Parameter which quantifies the compressibility of overconsolidated soil in one-dimensional compression. Normally, it is the log-linear slope of the compression curve defined by void ratio (y-axis) and the logarithm of vertical effective stress (x-axis). Normally obtained by a rebound-reload loop in a consolidation test. Also called the *swelling index.*

Reconstituted – Soil sample formed for laboratory testing at a given density and water content. This term is mainly used for coarse-grained test specimens.

Recycled concrete aggregate (RCA) – Recycled road or structural concrete. The concrete is usually processed and screened. The processing consists of crushing the concrete into smaller pieces. Any leftover steel is removed using a magnet. This type of material can serve as a replacement for natural stone aggregates.

Recycled or reclaimed asphalt pavement (RAP) – Excavated and processed asphalt concrete from road wearing surface. When properly processed, it consists of high-quality and well-graded aggregates coated by asphalt cement.

Recycled or reclaimed asphalt shingles (RAS) – Recycled shingles that are used as aggregate for hot mix asphalt. Depending on the quality, this can reduce the cost of the new asphalt mix and the amount of fine aggregate used in the mix.

Recycled pavement material (RPM) – Pulverized mixture of asphalt and base course material usually forming a broadly graded material.

Relative density – Parameter used to quantify the density of a soil relative to the loosest and densest states. It is calculated as the ratio of the difference between the maximum void ratio and current void ratio to the difference between the maximum and minimum void ratios.

Remolded – Soil sample mixed to a given water content to achieve a desired consistency. This term is mainly used for fine-grained soils.

Residual shear strength – The lowest drained shear strength of a soil that is achieved by shear displacement along a failure plane until particle alignment is achieved. This term is normally reserved for fine-grained soils. Residual conditions are often associated with slickensides forming on the failure plane.

Residual soil – Material formed by disintegration of underlying parent rock or partially indurated material.

Response to wetting tests – Tests in which the volume change of the soil is measured as the soil is given access to water or if the water content is reduced by drying.

Riprap – Boulder-size material normally place to strengthen structures against scour, wave action, and ice erosion.

Rippability – The characteristic of dense and/or rocky soils that can be excavated by ripping with a rock rake or ripper.

Riverjack – Alluvial cobbles and boulders.

Rock – Natural solid mineral or aggregate of minerals which is normally classified by the way it was formed.

Rock borehole shear test – *In situ* method to measure the strength of relatively weak rock or rock that is easily disturbed upon drilling and coring (e.g., weathered rock, fractured rock, shale, etc.). This test is a modification of the Iowa borehole shear test originally developed for soil.

Rock dirt combination (RDC) – Local term used in the Harrisonburg, VA, area to describe material from a quarry consisting of a mixture of overburden soil and rock.

Rock flour – Fine-grained soil, normally with silt-sized particles, formed by the grinding of bedrock by glaciers or by drilling. Rock flour normally classifies as a nonplastic silt.

Rock mass – A large body containing rock in intact and weathered conditions accompanied by structural discontinuities like fault, joints, etc., which can be interbedded with soil material.

Rock Quality Designation (RQD) – Calculated parameter used to quantify the quality of a rock core. It is equal to the total length of recovered core pieces greater than 4 inches in length divided by the recorded core run.

Rock Mass Rating (RMR) – Rock classification system based on uniaxial compressive strength, RQD, spacing and properties of the joints, and groundwater conditions.

Sagging – Manifestation of differential settlement in a structure that results in concave upward shape.

Sand – Soil particles that pass through a No. 4 (4.75 mm) sieve and are retained on a No. 200 (75 µm) sieve. Sands can be divided into: (1) coarse sands, sand particles that are retained on a No. 10 (2.00 mm) sieve, (2) medium sands, sand particles that pass through a No. 10 (2.00 mm) sieve and are retained on a No. 40 (425 µm) sieve, and (3) fine sands, sand particles that pass through a No. 40 (425 µm) sieve.

Secondary compression – Time dependent settlement of soil at constant effective stress. Normally considered to be a result of particle rearrangement.

Shale – Fine-grained sedimentary rock made of silt and clay particles. Shale usually breaks along planes of weakness and can slake when subjected to wet-dry cycles.

Shape factor – Ratio of the number of flow channels in a flow net to the number of equipotential drops.

Shore deposits – Deposits of sands and/or gravels formed by the transporting, erosion, and sorting action of waves on the shoreline.

Shot rock – Material from a rock quarry that has not been sorted or screened. It includes everything (from fine sand to small boulders) that can be loaded after a quarry blast. It is also a name given to riprap, although riprap is typically sorted and graded.

Sedimentary rocks – Rocks formed by the accumulation and cementation of smaller particles.

Seismic CPT (SCPT) – Cone penetration test where the cone contains a geophone or accelerometer in order to measure the shear wave velocity. A seismic source is applied at the ground surface in the vicinity of the cone hole.

Settlement – Vertical deformation of a foundation element (footing, mat, or pile). Can also be used to describe the compression of a soil layer under an applied change in stress.

Silt – Nonplastic or slightly plastic soil particles passing a No. 200 (75-µm) sieve that exhibit little or no strength when air dried. Silt-sized soils are normally considered to be larger than 0.002 mm. For classification of silty soils, refer to ASTM D2487.

Size-corrected Point Load Strength Index – Strength obtained from a point load test where the data have been corrected for the size of the test specimen.

Smear – Alignment of clay particles along a shear surface that creates a thin layer of low hydraulic conductivity.

Specific surface area – Surface area of soil particles, usually expressed as the area (units of L^2) per gram.

Slickenside – Condition of a shear surface where considerable displacement has taken place. The clay particles align in the direct of shear, and the shear surface is usually polished, glossy, or sometimes striated.

Slickensided clay – Clay that has experienced repeated or accumulated displacement along a fissure or a failure plane causing the surface to be smooth and shiny.

Split Cylinder Test – A test used to determine the tensile strength of rock cores in which the test specimen is loaded diametrically via hardened steel end platens.

Splitting tensile strength – Tensile strength obtained from a split cylinder test.

Staged – Condition where loading or shearing is performed in incremental stages.

Standard Penetration Resistance – The number of blows of a 140-pound hammer, falling 30 inches, required to advance a 2-inch O.D., split barrel sampler 12 inches in a soil mass.

Standard Penetration Test – An *in situ* test that measures resistance to the penetration of a standard, thick-walled drive sampler in an open borehole using a drop hammer. This test proceeds by driving a thick-walled, split-barrel (a.k.a., split spoon) sampler into the ground using incremental blows from a drop hammer. The sampler is driven a total of 18 inches into the ground. The procedure is presented in ASTM D1586.

Standpipe piezometer – Watertight pipe with a screened section installed in a borehole with one or more seal to allow long-term measurement of groundwater levels. The term is used to refer to both open wells and open standpipe piezometers.

Stone – Gravel-size particles manufactured by crushing rock.

Stratified – Earth materials with layers of different material or color of at least ¼ inch in thickness.

Stress path triaxial test – Triaxial test in which both the vertical and horizontal stresses, and possibly the pore water pressure, are varied systematically to follow prescribed loading paths.

Strike – Line representing the linear feature of the intersection of a rock surface with the horizontal plane.

Sugar sand – Local name used for specific types of sands in various places. It is a fine sandy soil in New Jersey. In Kansas, it refers to a type of granular calcite found in Ness and Hodgeman counties. In Florida, it refers to a fine sand that does not hold water or nutrients very well.

Surcharge – Fill or other material used to apply a temporary stress to a compressible soil layer. The fill is removed after a predetermined amount of compression or consolidation has occurred.

Swelling index – See recompression index.

Talus - Deposits created by gradual accumulation of unsorted rock fragments and debris at the base of cliffs or slopes.

Terrace – Relatively narrow, flat-surfaced, river-flanking remnants of floodplain deposits formed by entrenchment of rivers.

Till – See Boulder Clay.

Tilt – Outward rotational displacement of a retaining wall or other structure.

Time curve – See Time-deformation curve.

Time-deformation curve – A plot relating the deformation of a foundation element or laboratory test specimen as a function of time after being subjected to a change in stress.

Tire derived aggregate (TDA) – Lightweight construction material obtained by shredding or chipping scrap tires. The particle size usually ranges from 0.5 inches to 12 inches. TDA has been used in a wide range of projects, including lightweight embankment fill, landslide repair or stabilization, retaining wall backfill, roads, vibration mitigation, among others.

Topsoil – Upper and outermost layer of soil that supports plant life. Usually contains considerable organic matter.

Total stress – At a point in a soil mass, the sum of the net stress across contact points of soil particles (effective stress) plus the pore water pressure at the point.

Trap – Dark-colored, fine-grained, non-granitic intrusive rock. The most common trap rock is basalt, but also includes peridotite, diabase, and gabbro.

Triaxial permeameter – Pressure chamber holding a cylindrical soil test specimen in a flexible membrane used to perform hydraulic conductivity tests. Also called a *flexible wall permeameter*.

Tuff – Soft porous rock composed of consolidated volcanic ash.

Uncorrected Point Load Strength Index – Strength obtained from a point load test that has not been corrected for the size of the test specimen.

Underconsolidation – Condition that exists if a soil deposit is not fully consolidated under the existing overburden pressure and excess hydrostatic pore pressures exist within the material.

Velocity head – One of the three components of total head, equal to the flow velocity squared divided by twice the acceleration of gravity. Flow velocity in earth materials is often slow enough (laminar flow) that the influence of the velocity head can be ignored.

Vertical drains – Drainage conduits, such as stone columns or prefabricated vertical drains, that are used to allow radial dissipation of pore water pressures and accelerate consolidation.

Virgin compression – Compression of a soil at stresses in excess of the preconsolidation pressure or maximum past pressure.

Water Level Indicator - An electrical device used to measure the distance from the ground surface or top of the casing to the top of the water surface in open pipe piezometers. Graduations on the electrical cable are used to measure the depth to the water surface.

Well resistance – Resistance to flow in a prefabricated vertical drain.

Undisturbed Specimen – Soil sample taken with a thin-walled sampler or block sample with special attention given to maintaining the volume, density, soil structure, and water content. Undisturbed is often written in quotes since no soil sample can be truly "undisturbed." Recently, this term has been replaced with the term *intact specimen*.

Varved Silt or Clay – A fine-grained glacial lake deposit with alternating thin layers of silt or fine sand and clay, formed by variations in sedimentation from winter to summer during the year.

UFC-3-220-20
16 January 2025

UNIFIED FACILITIES CRITERIA (UFC)

FOUNDATIONS AND EARTH STRUCTURES (DM 7.2)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

This Page Intentionally Left Blank

UNIFIED FACILITIES CRITERIA (UFC)

FOUNDATIONS AND EARTH STRUCTURES (DM 7.2)

Indicate the preparing activity beside the Service responsible for preparing the document.

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING SYSTEMS COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **\1** ... **/1/**)

Change No.	**Date**	**Location**

This Page Intentionally Left Blank

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site https://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

AUTHORIZED BY:

THOMAS P. SMITH, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

S. KEITH HAMILTON, P.E., SES
Chief Engineer and Assistant Commander
Planning, Design and Construction
Naval Facilities Engineering Systems Command

THOMAS P. BROWN, SES
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection (HAF/A4C)
HQ United States Air Force

MARK S. SINDER, SES
Deputy Assistant Secretary of Defense
(Infrastructure Modernization and Resilience)
Office of the Secretary of Defense

This Page Intentionally Left Blank

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PROLOGUE P. SHEAR STRENGTH FOR GEOTECHNICAL DESIGN

P-1 SCOPE.

The design methods presented in this manual require shear strength parameters for the soil materials encountered. However, the correct methods to measure or estimate the shear strength parameters are not explained in detail in the forthcoming chapters. The purpose of this prologue is to provide the designer with suggestions on how to arrive at the parameters necessary for successful design and analysis.

The procedures included in this prologue are accepted in mainstream geotechnical engineering practice. There are more advanced theories of soil behavior that are reported in various geotechnical publications, but those are more appropriately applied to designs that are more advanced than those presented in this manual.

This prologue divides soils generally into coarse-grained or granular soils, often called *cohesionless* materials; and fine-grained or *cohesive* materials. These distinctions are useful in that coarse-grained soils do not develop significant pore pressures during normal construction loading, while fine-grained soils can show increases in pore pressures for compressive loads and decreases in pore pressures during reductions in loads or excavations.

This prologue is organized by first addressing factors that apply to both fine-grained and coarse-grained soils, and then specifically outlining the methods of arriving at design shear strength parameters.

P-2 STRENGTH ENVELOPES.

P-2.1 Mohr-Coulomb Failure Criteria.

The limit equilibrium procedures described in this manual, such as pile capacity, bearing capacity of shallow foundations, and stability of retaining structures, require shear strength parameters that are defined by Mohr-Coulomb failure criteria. In short, the Mohr-Coulomb theory relates the shear strength of the soil to the normal stress on the failure plane. For the case of drained or effective stress strengths, the shear strength is related to the effective normal stress on the failure plane. For the case of undrained or total stress strengths, the shear strength is related to the total normal stress on the failure plane. For saturated soils, there exists a special case whereby the undrained strength is independent of the stress of the failure plane ($\phi = 0$ case). Examples of these three failure envelopes, with the simplifying assumption of a linear envelope, are shown in Figure P-1.

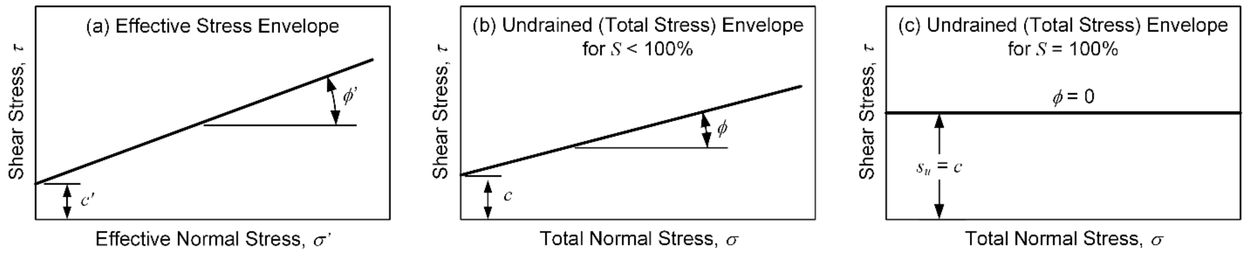


Figure P-1 Mohr-Coulomb Failure Envelopes for Effective and Total Stress Conditions

Shown in Table P-1 are the basic shear strength parameters for these three envelopes and the general equation used to calculate shear strength (s) as a function of the normal stress. In geotechnical engineering practice, the prime symbol (′) is used to denote effective stress or drained parameters. In some older references and manuals, a bar above the parameter is used instead of the prime symbol (e.g., $\overline{\phi}$ and $\overline{c}$). Unfortunately, many papers, manuals, and textbooks are not consistent in clearly indicating drained or effective stress parameters. The prime symbol is often omitted even though the shear strength parameters refer to effective stress or drained parameters, and the reader should be aware of this issue.

The strength equations shown in Table P-1 are simple equations for a line, with the σ and σ' parameters denoting the total and effective stress normal to the failure plane. For the limit equilibrium analyses presented in this manual, the use of these equations is often embedded into the derivation of the equilibrium equation and is not readily apparent.

Table P-1 Effective Stress and Total Stress Shear Strength Parameters and Associated Equation for Calculating Shear Strength on the Failure Plane

Case **(S = degree of saturation)**	**Parameters[A]**	**Strength Equation**
Drained (0 ≤ S ≤ 100%)[B]	ϕ' = effective stress friction angle c' = effective stress friction angle	$s = c' + \sigma' \tan \phi'$
Undrained (S < 100%)	ϕ = total stress friction angle c = total stress cohesion	$s = c + \sigma \tan \phi$
Undrained (S = 100%)	ϕ = 0 = total stress friction angle c = total stress cohesion	$s_u = c$

A “Drained” is often used synonymously for “effective stress.” “Undrained” is often used synonymously for “total stress.”

B Effective stress or drained parameters can be used for any degree of saturation, but in conventional practice, these are used for zero or positive pore water pressures.

P-2.2 Nonlinear Envelopes.

The envelopes in Figure P-1 are linear, and the equations used to calculate the shear strength use the intercept (c' or c) and the slope ($\tan\,\phi'$ or $\tan\,\phi$) to calculate the shear strength.[1] Although strength envelopes for soils are commonly nonlinear, a single value of intercept and slope may be accurate enough to represent the strength of a soil over a specific pressure range. Figure P-2 shows a curved envelope, and a linear representation for the pressure range indicated. For the range of normal stresses shown, the resulting shear strength calculated from the values of c' and ϕ' would be sufficiently accurate for design analyses. However, for normal stresses less than or greater than the range of stresses shown, the linear envelope would overpredict the shear strength. This should be kept in mind when using a design procedure or formula that requires single values of ϕ' and c' (or ϕ and c). There are many ways to accommodate nonlinear failure envelopes. Examples of four different methods are outlined in Duncan et al. (2014).

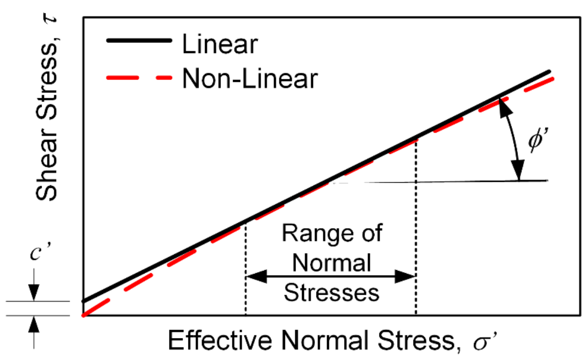


Figure P-2 Example Use of a Linear Envelope to Represent a Nonlinear Strength Envelope for a Specific Range of Stress

P-2.2.1 Two-Parameter Power Function.

The use of a two-parameter power function to model the envelope is one method available in some limit equilibrium slope stability programs, which are useful for checking global stability for retaining walls and other structures. Instead of the usual shear strength parameters of ϕ' and c', the alternative parameters a and b can be used in the equation below:

[1] The $\phi = 0$ envelope experimentally determined for saturated clays using the unconsolidated-undrained triaxial test may be slightly nonlinear for a large range of cell pressures, but should always be interpreted as a horizontal linear envelope for saturated fine-grained soils.

$$s = aP_a \left(\frac{\sigma'}{P_a} \right)^b \tag{P-1}$$

where:
a and b = power function strength parameters and
P_a = atmospheric pressure.

Although less common, the two-parameter power function can also be used to represent undrained shear strengths. For example, as shown in Figure P-3(a), undrained strength can be related to the effective consolidation stress as:

$$s_u = a_u P_a \left(\frac{\sigma'_{1,con}}{P_a} \right)^{b_u} \tag{P-2}$$

where:
s_u = undrained shear strength,
a_u and b_u = power function strength parameters.

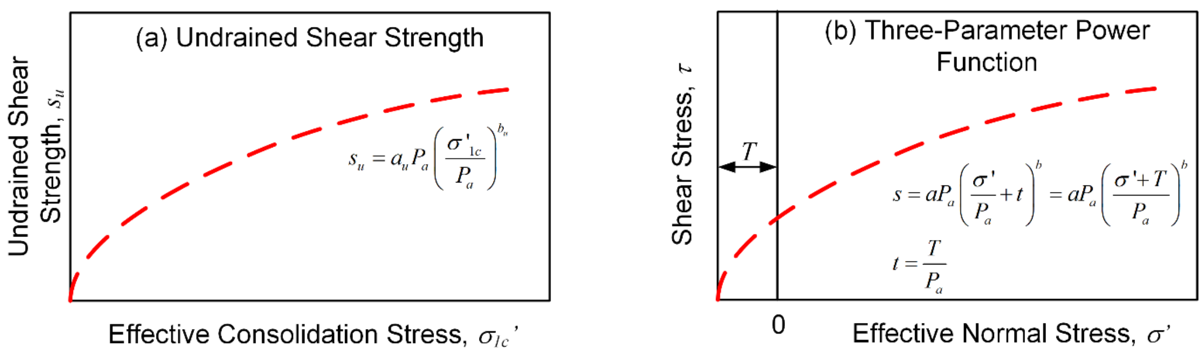


Figure P-3 Other Types of Power Function – (a) Undrained Shear Strength and (b) Three-Parameter

P-2.2.2 Three-Parameter Power Function.

Equation A-1 cannot model a shear strength intercept. A three-parameter function is required for cases where an intercept is warranted. Jiang et al. (2003) suggested the following form which is plotted in Figure P-3(b):

$$s = aP_a \left(\frac{\sigma'}{P_a} + t \right)^b \tag{A-3}$$

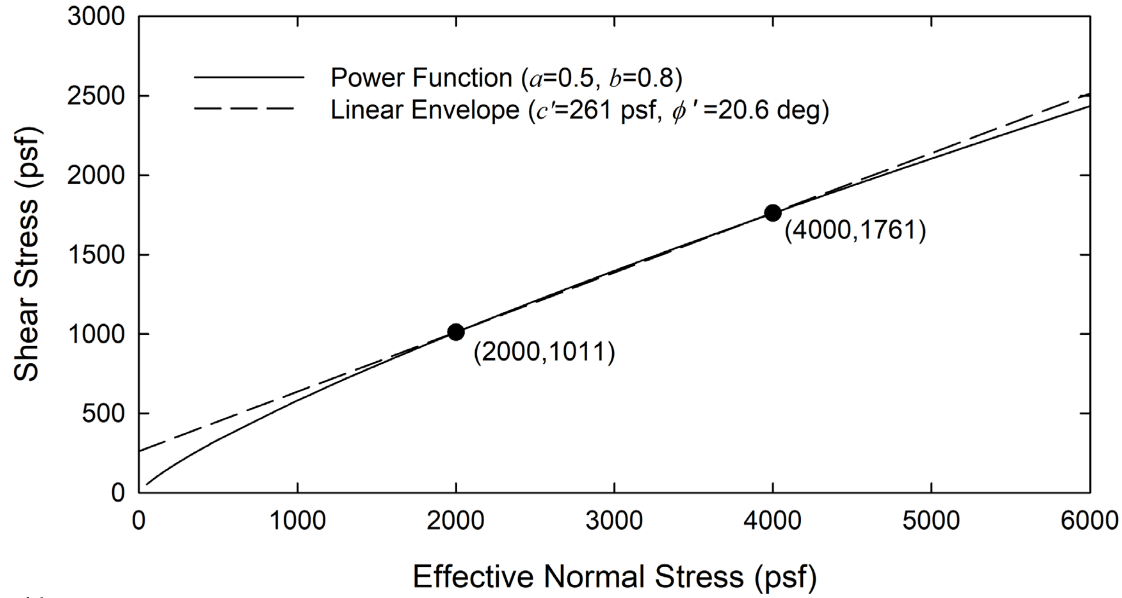
where:
t = tensile intercept (T) normalized by atmospheric pressure.

An alternate method with a normalized cohesion intercept outside the parentheses was given by McGuire and VandenBerge (2017). For practical purposes, the two forms give equivalent results. A useful summary of nonlinear failure envelopes is found in VandenBerge et al. (2018).

P-2.2.3 Application of Power Functions in Geotechnical Analysis.

To use a power function in analysis, the computer software must be programmed to accept the a and b parameters and correctly calculate the shear strength. Further details for using the power function can be found in VandenBerge et al. (2018).

If the parameters a and b are available, it is possible to estimate ϕ' and c' for a range of pressures, as shown in Figure P-2 for a curved envelope. Figure P-4 shows an example for calculating the ϕ' and c' shear strength parameters for the normal effective stress range of 2000 to 4000 psf.



Problem:

Given a nonlinear failure enveloped presented by a power function with a = 0.5 and b = 0.8, Find an equivalent linear envelope for σ' between 2000 and 4000 PSF.

Solution:

Shear Strength at 2000 psf: $s = (0.5)(2116\,psf)\left(\frac{2000\,psf}{2116\,psf}\right)^{0.8} = 1011\,psf$

Shear Strength at 4000 psf: $s = (0.5)(2116\,psf)\left(\frac{4000\,psf}{2116\,psf}\right)^{0.8} = 1761\,psf$

Equivalent Friction Angle: $\phi'_{EQ} = \tan^{-1}\left(\frac{1761-1011}{4000-2000}\right) = 20.6^{\circ}$

Equivalent Cohesion Intercept: $c' = 1011-(2000-0)\left(\frac{1761-1011}{4000-2000}\right) = 261\,psf$

Figure P-4 Determining Equivalent Mohr-Coulomb Parameters from Power Function Parameters

Some analysis methods or software that accommodate power functions may use parameters with units rather than the normalized parameters presented in Eqn. P-1 and P-2. The equivalent parameters can be determined by setting the two equations equal to each other and solving. An example is provided in Figure P-5.

A. Give a nonlinear failure envelope represented by a power function with a = 0.5 and b = 0.8, find equivalent parameters with units for the equation:

$$s = A\left(\sigma'\right)^B$$

1) Equate the two forms of the power function:

$$aP_a\left(\frac{\sigma'}{P_a}\right)^b = aP_a^{1-b}\left(\sigma'\right)^b = A\left(\sigma'\right)^B$$

2) It is evident that normalization does not change the exponent:

$$B = b$$

3) Canceling the effective normal stress terms:

$$A = aP_a^{1-b}$$

4) For this particular example:

$$A = (0.5)(2116\,psf)^{1-0.8} = 2.312\,psf^{0.2}$$

$$B = 0.8$$

B. Given a nonlinear failure envelope represented by a three-parameter power function with a = 0.6, b = 0.9, and t = 0.4, find equivalent parameters with units for the equation:

$$s = A\left(\sigma' + T\right)^B$$

1) Equate the two forms of the power function:

$$aP_a\left(\frac{\sigma'}{P_a} + t\right)^b = aP_a^{1-b}\left(\sigma' + tP_a\right)^b = A\left(\sigma' + T\right)^B$$

2) Solving for the various parameters results in:

$$T = tP_a \qquad B = b \qquad A = aP_a^{1-b}$$

3) For this particular example:

$$T = (0.4)(2116\,psf) = 846\,psf \qquad B = 0.9 \qquad A = (0.6)(2116)^{1-0.9} = 1.29\,psf^{0.1}$$

Figure P-5 Example Conversion between Normalized Parameters and Parameters with Units

P-3 SELECTION OF SHEAR STRENGTH PARAMETERS.

The shear strength parameters for different soil types may be measured or estimated using one or more of the following:

1. Laboratory tests on disturbed, reconstituted, or compacted test specimens
2. Laboratory tests on "undisturbed" or intact test specimens
3. *In situ* or field tests
4. Correlations

Details regarding these methods can be found in DM-7.1. The selection of shear strength parameters will be discussed for two general types of deposits:

(1) *In situ* undisturbed soils. These normally would be natural soils, but also can include existing fill soils.

(2) Engineered and un-engineered fill materials. The category would include embankments, dams and levees, retaining wall backfills, dredge materials, etc.

P-3.1 *In situ* Deposit of Coarse-Grained Soil (Sand to Gravel).

The most common shear strength parameter used for coarse-grained soil is the drained or effective stress friction angle (ϕ'). Although these materials can have nonlinear failure envelopes, particularly over a wide range of stresses, a single value of the friction angle normally is required at a specific depth for design.

The methods for arriving at an effective stress friction angle for *in situ* deposits of coarse-grained soils are discussed based on the four methods listed earlier.

Table P-2 Shear Strength Methods for *In situ* Coarse-Grained Soil

Method	Guidance
Laboratory tests on disturbed, reconstituted, or compacted test specimens	**Rarely Appropriate** For *in situ* deposits of sands and gravel, laboratory tests on reconstituted test specimens are rarely useful. Many important field effects, such as aging, cementation, and OCR, cannot be modeled in laboratory specimens.
Laboratory tests on "undisturbed" or intact test specimens	**Rarely Appropriate** Intact samples of coarse-grained soils cannot usually be obtained. Although there are some elaborate methods, such as ground freezing, that can be used, these methods are rare in practice.
In situ or field tests	**Very Appropriate** *In situ* and field tests are the best approach for determining the *in situ* friction angle of coarse-grained soils. These tests include the Standard Penetration Test (SPT), Cone Penetration Test (CPT), and Becker Hammer Test (BPT). Equations for calculating ϕ' from the SPT blow count and q_c from the CPT can be found in Chapter 8 of DM 7-1. Both the SPT and CPT can have testing issues for materials much coarser than sands. The BPT has been successful in testing material in very coarse granular soils (Harder and Seed 1986).
Correlations	**Often Appropriate** There are many correlations to determine the drained friction angle based on a variety of parameters, such as classification, gradation, particle shape, etc. A large collection of these is found in Chapter 8 of DM-7.1. The correlation developed by Mike Duncan (Duncan et al. 2014) is particularly well-documented and useful. The input parameters are soil type (SP, SW, or GP), normal stress on the failure plane, and relative density. This correlation has an advantage in that the curvature of the strength envelope is considered. A key to applying this correlation to *in situ* soils is the estimate of the relative density. The relative density can be estimated using the SPT or CPT.

P-3.2 Engineered Deposit of Coarse-Grained Soil (Sand to Gravel).

Again, the most common shear strength parameter used for engineered deposits is the drained or effective stress friction angle (ϕ'). When it is necessary to provide a total stress friction angle (ϕ) for an analysis, the effective stress friction angle is commonly used since these are drained materials. The methods for determining the shear strength of engineered coarse-grained soils are summarized in Table P-3.

Table P-3 Shear Strength Methods for Engineered Coarse-Grained Soil

Method	Guidance
Laboratory tests on disturbed, reconstituted, or compacted test specimens	**Very Appropriate** Laboratory tests are appropriate for engineered coarse grained soils, provided that the test specimen has a maximum particle size within the limits set by the ASTM standards. Examples of triaxial test results conducted on common gravel gradations can be found in Duncan et al. (2007). Some direct shear test apparatuses are large enough to test gravel-sized material. Laboratory test specimens should be compacted to the appropriate dry unit weight expected for the field compaction or placement method. Unless the soil has a significant amount of fines (> 15%), the compaction water content for the laboratory specimens is not critical as long as long as the specified dry unit weight is achieved. The test specimens should be saturated, and either drained or undrained tests (with pore pressure measurements) can be conducted. Laboratory tests should be conducted at a range of stresses similar to those expected during the operation of the structure. The stresses on the failure planes of the laboratory specimens should bracket those calculated or estimated for field conditions.
Laboratory tests on "undisturbed" or intact test specimens	**Rarely Appropriate** Not applicable for new fills. Existing fills have the same sampling difficulties as natural coarse-grained soils.
In situ or field tests	**Marginally Appropriate** Not applicable for fills, except as used for QA/QC tests on fills. The Dynamic Cone Penetration Test (DCP) can be used for indicating the density of a fill, but no reliable correlations exist for the DCP and the effective stress friction angle. If the fill has been in place for a considerable time, then the methods outlined for *in situ* deposits can be followed (see Table).
Correlations	**Often Appropriate** Table and Chapter 8 of DM-7.1 discuss correlations to determine the drained friction angle. Duncan's correlation (Duncan et al. 2014) is also useful for compacted granular soils. It is especially useful for coarse soils that have maximum particle sizes too large for normal laboratory test apparatuses. The relative density required for this correlation can be determined from the compaction specifications or the compaction control testing.

P-3.3 *In situ* Deposit of Fine-Grained Soil.

For *in situ* deposits of saturated fine-grained soils, the methods used depend on whether drained or undrained strengths are appropriate. Undrained strengths are generally important when the stability for short term conditions is required, particular if the project loading increases the pore water pressure.

For partially saturated fine-grained soils, undrained strengths are often necessary for locations above the phreatic surface. The appropriate undrained strength characterization is a c-ϕ envelope.[2] Often in engineering practice, the soil is

[2] Ideally, these parameters should be obtained from Unconsolidated-Undrained triaxial tests on intact test specimens.

characterized with an s_u for an assumed $\phi = 0$ condition. This is not ideal, but as long as the value of s_u is interpreted using a conservative method, it should suffice.

Drained strength parameters are appropriate for long-term conditions where the pore water pressures can be measured, calculated, or estimated with reasonable accuracy. An example of this would be when increases or decreases in pore water pressure caused by the project loading have dissipated, and the pore water pressures have returned to hydrostatic conditions. A second example would be when a steady-state seepage condition has been achieved, and pore water pressures can be calculated. Drained strength parameters are often assigned to partially-saturated soils above the phreatic surface.

The next two sections discuss methods to determine undrained shear strengths and drained shear strength of fine-grained soils, particularly those which behave in a clay-like manner and classify as lean clay, fat clay, or elastic silt. Nonplastic and low plasticity silts behave differently and are discussed in the third section.

P-3.3.1 Undrained Shear Strength - *In situ* Deposit of Fine-Grained Soil.

The design procedures in this manual may require the distribution of undrained strength versus depth for saturated, fine-grained deposits. This strength is associated with a $\phi = 0$ strength model. Figure P-6 shows an example stratigraphy and shear strength distribution. The goal is often to have enough data points to represent the strength distribution with accuracy. The methods to determine the value of undrained strength versus depth are summarized in Table P-4.

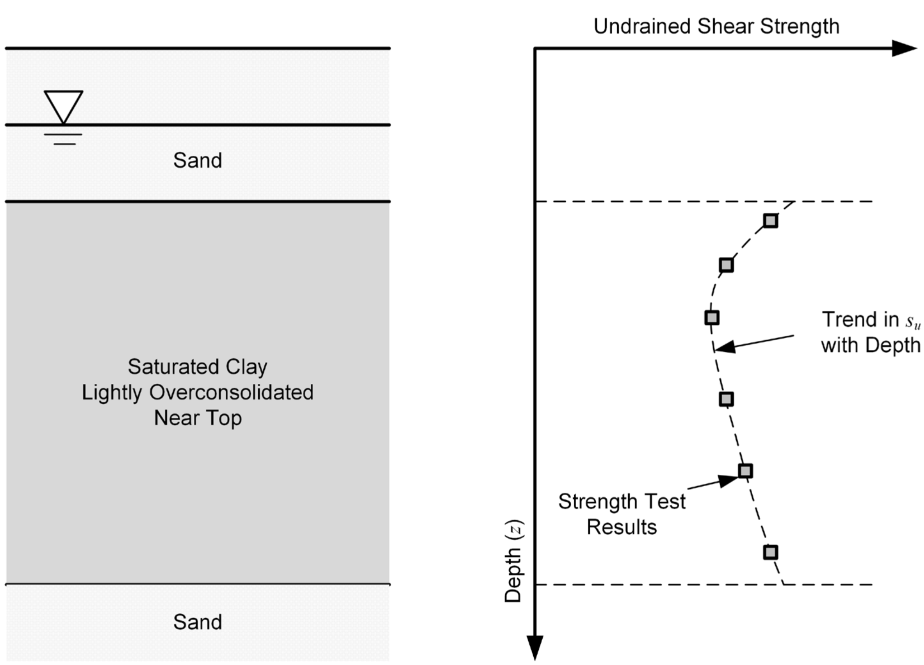


Figure P-6 Undrained Strength Distribution Example

Table P-4 Undrained Shear Strength Methods for *In situ* Fine-Grained Soil

Method	Guidance
Laboratory tests on disturbed, reconstituted, or compacted test specimens	**Marginally Appropriate** The only value of testing disturbed specimens is to determine the undrained strength for normally consolidated conditions. The soil can be remolded, and the undrained strength can be measured with a variety of tests. These include the miniature vane shear test, the fall cone test, UU triaxial tests, and the direct simple shear test. Details of these tests are provided in Chapter 3 of DM-7.1. These tests, conducted on carefully remolded samples, could provide a lower bound undrained strength. However, the resulting strengths do not allow the undrained strength versus depth relationship to be accurately determined for in situ conditions.
Laboratory tests on "undisturbed" or intact test specimens	**Very Appropriate** Laboratory tests on intact test specimens is a common method to acquire undrained strengths for design. The applicable tests are discussed individually below, and discussed in greater detail in Chapter 3 of DM-7.1. *Laboratory miniature vane shear test (LMVT)* – The LMVT can be performed directly on undisturbed test specimens. The results are most applicable for saturated fine-grained soils that have undrained strengths less than about 1400 psf. The test is well suited for measuring the strength of soft soils (s_u < 500 psf) where other test methods may have difficulty. *Fall cone tests (FC)* – There is not an ASTM specification for a fall cone test, but there are standards developed in Norway, Germany, and other countries. This test works best on soft clays. *Unconsolidated-Undrained (UU) triaxial test* – UU triaxial tests are probably the most common test method for determining values of s_u for intact test specimens. A range of confining pressures should be used, and these pressures should bracket the minor total stress at the sample location. Provided the test specimens are saturated, a horizontal envelope should be interpreted from the data. Other triaxial tests, such as the Consolidated-Undrained (CU) triaxial test, have been used in the past, but the resulting values of undrained strength are too high. *Direct Simple Shear Test (DSS)* – The DSS test can be used in a variety of ways for determining s_u. The Bjerrum Method (Bjerrum 1973) is perhaps the most straight forward, in that the intact test specimens are consolidated to the vertical effective stress (at the time of sampling). Each test produces one value of undrained shear strength. A more complicated method to use the DSS test is described by Ladd and DeGroot (2003). This method, referred to as the SHANSEP method, requires consolidation test results to define the preconsolidation pressure profile. A relationship between the undrained strength ratio and the overconsolidation ratio is developed, and used in conjunction with the preconsolidation pressure profile to plot the undrained strength versus depth.
In situ or field tests	**Very Appropriate** Field tests are very useful in determining the undrained strength versus depth relationship. For deposits that have undrained strengths less than about 2000 psf, the Vane Shear Test is probably the best overall test method. The test data should be corrected for strain-rate effects as indicated in the ASTM specification. The CPT test is often used to determine undrained strength distributions. A variety of methods are available to determine the undrained strengths from various CPT parameters, and these are presented in Chapter 2 and Chapter 8 of DM-7.1. The methods that rely on the tip resistance (q_c or q_t) are the most reliable. The SPT has been used in the past, but it is considered unreliable. Other *in situ* test methods are reported in geotechnical literature, but these are not as useful as the VST and CPT.
Correlations	**Sometimes Appropriate** Correlations have limited usefulness for determining the undrained strength distribution vs. depth. Several correlations are available to determine the undrained strength or undrained strength ratio for remolded clays or clays in a normally consolidated state, but these have limited value in practice. Other correlations are available that rely on the preconsolidation pressure profile, if those data are available. Some methods of interpreting laboratory or field test data are in essence site-specific correlations. Examples include SHANSEP and the various methods (N_c, N_k, and N_{kt}) for relating CPT data to undrained shear strength.

P-3.3.2 Drained Strength - *In situ* Deposit of Fine-Grained Soil.

Three sets of drained strength parameters can be measured for fine-grained soils. These are shown for direct shear test results in Figure P-7. If the soil is initially overconsolidated *in situ*, then an envelope results from plotting the peak strengths. This is shown as the upper envelope in Figure P-7, with the indicated shear strength parameters c'_p and ϕ'_p.[3] A second strength envelope can be determined if the test specimens are remolded, loaded to normally consolidated conditions, and then sheared. This results in the fully softened envelope shown with a friction angle defined as ϕ'_{FS} in Figure P-7. The effective stress cohesion for the fully softened condition is normally equal to zero, or the fully softened envelope is nonlinear and passes through the origin. The third envelope is obtained by shearing undisturbed or remolded test specimens to very high displacements, and this produces the residual strength envelope, with a drained friction angle of ϕ'_r. The residual strength envelope is expected to pass through the origin.

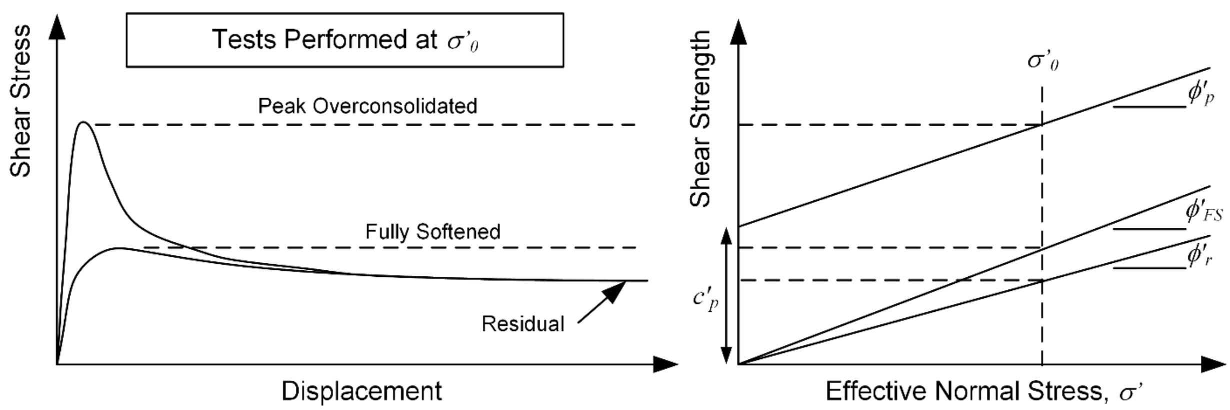


Figure P-7 Drained Envelopes for Saturated Fine-Grained Soils (after Castellanos and Brandon 2014)

Different types of projects require one of the three different failure envelopes. The peak strength envelope is often used for fine-grained soils having a $PI < 20$ and $LL < 40$ that are relatively free of fissures. The peak shear strength parameters depend on the preconsolidation pressure of the test specimens. Figure P-8 shows that one envelope is appropriate for a fine-grained soil in the normally consolidated condition, but the ϕ' and c' of the envelopes for the overconsolidated condition depend on the preconsolidation pressure.

[3] Although the figure shows the stress-displacement relationship for only one test, at least three tests, at different normal stresses, are required to define any of the three envelopes shown.

The fully softened strength envelope is used for soils that do contain fissures and have a $PI > 20$ and $LL > 40$ (Castellanos et al. 2016). This envelope is particularly appropriate for stability assessment of *in situ* fine-grained soils where the stresses have been reduced due to excavation. The fully softened envelope is also used for clays that are essentially normally consolidated *in situ*. The residual strength envelope is used when there has been large displacement due to a shear failure, and the residual condition has been achieved.

Table P-5 summarizes methods for determining the drained shear strength of *in situ* fine-grained soil deposits.

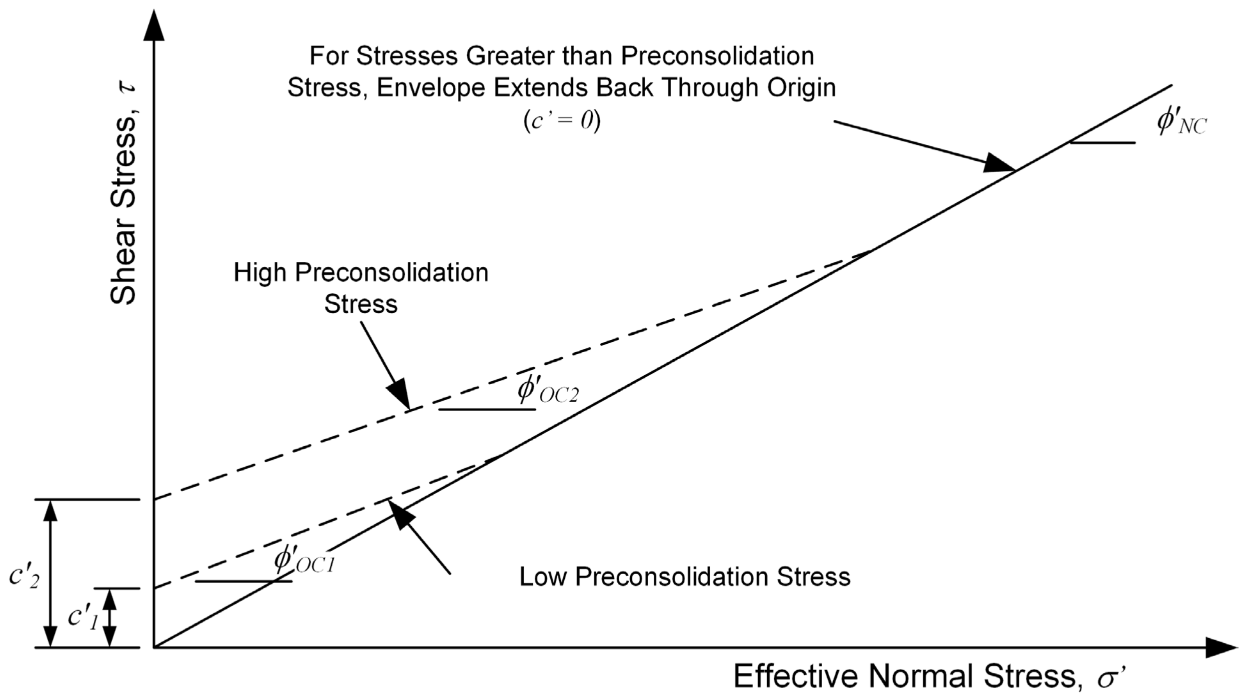


Figure P-8 Drained Strength Envelopes for Fine-Grained Soils in the Normally Consolidated and Overconsolidated Conditions for Different Values of Preconsolidation Stress (after Duncan et al. 2014)

Table P-5 Drained Shear Strength Methods for *In situ* Fine-Grained Soil

Method	Guidance
Laboratory tests on disturbed, reconstituted, or compacted test specimens	**Often Appropriate** Test specimens prepared in the laboratory are useful for determining fully softened and residual shear strengths of fine-grained soils. The best test methods for fully softened strengths are the direct shear test and the consolidated-undrained (CU) triaxial compression test. The best test method for residual shear strength is the ring shear test. In both cases, specimens are prepared to a water content at or above the liquid limit and consolidated to the desired test stresses prior to shearing.
Laboratory tests on "undisturbed" or intact test specimens	**Often Appropriate** Intact specimens are required to measure peak drained shear strength of fine-grained soil. The best test methods are the direct shear test and the consolidated-undrained (CU) triaxial compression test. Test specimens should be consolidated to a range of test stresses, such that the range of effective normal stresses on the failure plane at failure brackets the range of normal stresses anticipated in the analysis.
In situ or field tests	**Rarely Appropriate** Field tests are not useful for drained strength of fine-grained soils. Accurate measurement of drained strength requires knowledge of pore pressure during shearing, which cannot be determined accurately by *in situ* test methods.
Correlations	**Sometimes Appropriate** Correlations are not useful for peak drained shear strength of fine-grained soil because of the dependence of the shear strength on the preconsolidation stress. Chapter 8 of DM-7.1 presents many correlations between index properties (e.g., LL, PI, clay fraction) the fully softened and residual shear strength. These correlations are useful for preliminary analysis, for checking laboratory test results, and for limited design for conditions with limited consequences of failure.

P-3.3.3 *In situ* Deposit of Nonplastic or Low Plasticity Silt.

Silt deposits with low plasticity (i.e., $PI < 10$ and $LL < 50$) require different types of characterization than clayey fine-grained soils. These silts are very dilatant and easily disturbed, which makes them extremely hard to sample and test in the laboratory. Compared to clays with similar liquid limit, the silts tend to be stronger and much less compressible (Brandon et al. 2006). Consolidation tests on low plasticity silts are difficult to interpret and show little effect of preconsolidation, likely due to sampling disturbance.

If it can be determined, the coefficient of consolidation can be used to determine how the silt will behave when loaded. Silts with lower c_v (1 to 10 ft^2/day) will retain excess pore pressures for significant time periods and behave in an undrained manner. Silts with higher values of c_v (greater than 100 ft^2/day) will dissipate excess pore pressures quickly and will behave mostly in a drained manner. Low plasticity silts typically have effective stress friction angles in the range of 35 to 40 degrees with little to no cohesion intercept (Duncan et al. 2014). This indicates that low plasticity silts are relatively competent soils, provided confining stress is maintained. Guidance for determining appropriate shear strength parameters for low plasticity silt is provided in Table P-6.

Table P-6 Strength Methods for *In situ* Nonplastic and Low Plasticity Silt

Method	Guidance
Laboratory tests on disturbed, reconstituted, or compacted test specimens	**Often Appropriate** *Undrained* - Undrained strengths can be measured using CU triaxial compression tests. Dilative tendency during shear can create large negative excess pore pressures. In order to prevent cavitation, back pressures must be significantly higher than required for saturation. The failure criterion will have a large effect on the undrained shear strength. The point where excess pore pressure is zero (i.e., $\bar{A}_f = 0$) is recommended. *Drained* – Drained strengths can be measured using CU triaxial compression tests. The effects of disturbance are less pronounced on the drained strength. In addition, the failure criterion has less impact on the measured ϕ'.
Laboratory tests on “undisturbed” or intact test specimens	**Marginally Appropriate** While such tests can be performed in theory, high-quality, undisturbed specimens of low plasticity silt are extremely difficult to obtain. UU triaxial compression tests are not advised because disturbance creates substantial scatter. See the previous row for further guidance.
In situ or field tests	**Rarely Appropriate** Because of their intermediate values of c_v, it is difficult to determine whether low plasticity silts behave in a drained, undrained, or intermediate state during *in situ* testing. This makes the field test results difficult to interpret with respect to shear strength. Correlations developed for sand and clay have been shown to be unreliable for low plasticity silt.
Correlations	**Marginally Appropriate** Published correlations are not available for low plasticity silts. However, typical values of undrained ratio ($USR = s_u / \sigma'_{vc}$) can sometimes be used to estimate the undrained shear strength. Assuming zero excess pore pressure at failure and $c' = 0$, the USR for various failure modes can be calculated as: • ICU triaxial compression: $USR = \sin \phi' / (1 - \sin \phi')$ • ACU triaxial compression: $USR = \sin \phi'$ • DSS: $USR = \sin \phi' - 0.5 \sin^2 \phi'$

P-3.4 Engineered Deposit of Fine-Grained Soil.

Fine-grained soils are used as engineered fill in many different scenarios, including embankments, dams and levees, and seepage barriers. In many ways, the considerations for shear strength are similar to those for *in situ* deposits of fine-grained soil. The primary cases where undrained shear strength is required for fine-grained engineered fill are end-of-construction (EOC), rapid drawdown (RDD), and seismic analysis. Drained shear strengths are used for long-term conditions with peak strengths being appropriate for compacted fine-grained soils with $PI < 20$ and $LL < 40$. For soils with higher LL or PI, fully softened shear strengths should be considered for compacted slopes (Kayyal and Wright 1991) and retaining walls (Wright 2005). Methods for determining both undrained and drained shear strength of fine-grained engineered deposits are summarized in Table P-7 and Table P-8.

Table P-7 Undrained Shear Strength Methods for Engineered Fine-Grained Soil

Method	Guidance
Laboratory tests on disturbed, reconstituted, or compacted test specimens	**Very Appropriate** Undrained shear strength can be measured on specimens compacted to match the field compaction conditions. Alternatively, the 15-point method (see Chapter 2) can be used to evaluate the variation in shear strength parameters across the compaction plane. *End-of-Construction* - At least three UU triaxial compression tests should be performed for each combination of water content and compacted dry unit weight. The results can be interpreted as c–ϕ envelopes for each compaction state. The variation in c and ϕ can be plotted with the Proctor curves to evaluate appropriate compaction specifications. *RDD and Seismic* – These design scenarios require undrained strength of compacted soils after consolidation to a long-term condition. For this reason, these undrained strengths are measured using CU triaxial compression tests. Test specimens must be saturated prior to consolidation. The amount of swelling allowed during saturation has a substantial impact on the measured undrained strength. Interpretation of the test data for such conditions is specific to the analysis method.
Laboratory tests on “undisturbed” or intact test specimens	**Often Appropriate** Although relatively uncommon in practice, intact specimens may be obtained from a fine-grained engineered fill during or after construction. These specimens can be tested using the test methods described in Table P-4 especially the UU triaxial compression test, to determine EOC shear strength parameters.
In situ or field tests	**Rarely Appropriate** Not applicable except possibly as QA/QC during construction of the fill.
Correlations	**Marginally Appropriate** Published correlations are not useful for compacted fine-grained fill. It may be possible to develop regional or soil-specific correlations between undrained strength and relative compaction. The 15-point is an example of a material specific correlation. Other correlations may be useful for non-engineered fine-grained fills, especially those placed in a normally consolidated state, such as some types of dredge spoils or mine tailings.

Table P-8 Drained Shear Strength Methods for Engineered Fine-Grained Soil

Method	Guidance
Laboratory tests on disturbed, reconstituted, or compacted test specimens	**Very Appropriate** Compacted specimens can be tested to determine the peak drained shear strength. The direct shear test and CU triaxial compression test are best suited for this purpose. Test specimens must be saturated and allowed to reach equilibrium at a range of consolidation stresses. The drained shear strength parameters for compacted fine-grained soils tend to be relatively insensitive to the compaction state. If needed, the fully softened and residual strength of compacted fine-grained soil can be determined as described in Table P-5.
Laboratory tests on “undisturbed” or intact test specimens	**Often Appropriate** Although relatively uncommon in practice, intact specimens may be obtained from a fine-grained engineered fill during or after construction. These specimens can be tested using direct shear or CU triaxial compression tests to determine drained shear strength parameters.
In situ or field tests	**Rarely Appropriate** Not applicable for compacted fine-grained soils.
Correlations	**Sometimes Appropriate** Correlations are not useful for the peak drained shear strength of compacted fine-grained soil. As noted in Table P-5, correlations can be used in some situations to estimate the fully softened and residual shear strength parameters.

P-4 NOTATION.

Variable	Definition
a	Power function strength parameter defining the steepness of the curve
A	Power function strength parameter for three-parameter function
$\bar{A}_f$	Skempton's pore pressure parameter at failure
a_u	Power function strength parameter
b	Power function strength parameter defining the amount of curvature
B	Power function strength parameter for three-parameter function
b_u	Power function strength parameter
c	Total stress or undrained cohesion intercept
c'	Drained or effective stress cohesion intercept
$\overline{c}$	Effective stress or drained cohesion intercept
c'_p	Peak drained or effective stress cohesion intercept
c_v	Coefficient of consolidation
N_c, N_k, N_{kt}	Bearing capacity factors for cone penetration interpretation of undrained strength
q_c	Cone penetrometer tip resistance
s	Shear strength
S	Degree of saturation
s_u	Undrained shear strength for ϕ = 0 envelope
t	Tensile intercept normalized by atmospheric pressure
T	Tensile strength or attraction
USR	Undrained strength ratio
ϕ	Total stress or undrained friction angle
ϕ'	Effective stress or drained friction angle
$\overline{\phi}$	Effective stress or drained friction angle
ϕ'_{EQ}	Equivalent friction angle
ϕ'_{FS}	Fully softened friction angle
ϕ'_{OC}	Drained or effective stress friction angle for portion of strength envelope where the specimen is overconsolidated at failure

Variable	Definition
ϕ'_p	Peak drained or effective stress friction angle
ϕ'_R	Residual friction angle
σ	Total normal stress
σ'	Effective normal stress
σ'_0	Vertical consolidation stress
$\sigma'_{1,con}$	Major effective consolidation stress

This Page Intentionally Left Blank

CHAPTER 1. GEOTECHNICAL DESIGN IN PROBLEM SOILS AND SPECIALTY CONSTRUCTION METHODS

1-1 INTRODUCTION.

Most of the design techniques that will be described in the next six chapters will generically characterize soils as sand or coarse-grained (often called “cohesionless”) or as clay or fine-grained (often called “cohesive”). This is a useful expedient in that the two soil groups represent the endpoints of common soil behavior. Sands are most often drained under normal types of loading, and the strength parameters can be represented as a linear envelope with a slope equal to the effective stress friction angle, ϕ' (with $c' = 0$), or a curved or non-linear envelope represented by a power function or other equation. Clays[4] can be undrained in the short term and drained in the long term; therefore, both types of strength parameters (drained and undrained) are needed for the various types of design methods presented. Sands are often considered to be relatively incompressible and/or the compression occurs quickly. Clays are considered to be much more compressible, and the compression occurs more slowly for an extended time period.

Separating the soils into two major groups, sands and clays, is very useful since these are the recognized endpoints for both drained vs. undrained behavior as well as relatively incompressible vs. compressible behavior. However, there are soils that fit within these two groups that can exhibit special problems. In addition, there are other soils with specific names, such as *loess*, that can be problematic for the design methods presented.

This section is organized by listing the different soils that are identified as being problematic in the upcoming chapters and, in general, geotechnical engineering practice.

1-2 TYPES OF PROBLEM SOILS.

The following sections describe problematic soil conditions that can affect the design of excavations, earthwork, retaining walls, and foundations. Tables are included at the conclusions of Chapters 2 through 6, which map some of these problem soil conditions to the particular contents of each chapter. For example, the tables in Section 2-7 describe how problem soil conditions relate to sloped and supported excavations.

[4] In geotechnical engineering nomenclature, *clay* normally refers to *inorganic* or *mineral* clays. Clays with an appreciable organic content are referred to specifically as *organic clays*.

1-2.1 Stiff Fissured Clays.

Stiff fissured clay is both a general and specific term. Specifically, stiff fissured clays have an unconfined compressive strength greater than or equal to 2000 psf and contain fissures that are often attributed to unloading from very high stresses. According to ASTM D2488 (ASTM 2023), the criterion for fissures is "breaks along definite planes of fracture with little resistance to fracturing." Generally, the term *stiff fissured clays* most often refers to heavily overconsolidated clays that contain fissures, with examples being London brown clay (U.K.), Beaumont clay (Texas), and Pierre shale (North Dakota and South Dakota). According to Skempton (1964), stiff fissured clays often have a liquidity index near zero. The problematic soils generally often have liquid limit values greater than 40 and plasticity indices greater than 20 (Castellanos and Brandon 2016).

The main issue with stiff fissured clays is that the long-term mobilized shear strength in the field is often less than the peak shear strength measured using laboratory tests. This reduction in strength or softening results from unloading, weathering, and water ingress through the fissures. Softening is likely an artifact of progressive failure, whereby the peak shear strength is not fully mobilized on the failure surface at the same point in time. These mechanisms take time to occur, and failures in stiff-fissured clays can occur many years after a cut, excavation, or unloading has taken place. Because of these factors, the fully softened shear strength is normally used for drained or effective stress analyses for long-term conditions.

The fully softened shear strength is appropriate for drained or effective stress analyses of long-term conditions in stiff fissured clays where the strength is expected to decrease over time (Skempton 1970). The fully softened strength is empirically equal to the normally consolidated peak strength measured for remolded test specimens. Detailed information about measuring the fully softened strength and other engineering aspects of stiff fissured clays can be found in Castellanos et al. (2016) and Castellanos and Brandon (2017).

1-2.2 Stiff Desiccated Clays.

Stiff desiccated clays exhibit many of the same characteristics as stiff fissured clays. These are often fat clays (CH) that are normally located near the ground surface, and contain cracks or fissures that can be several feet deep. Aubeny and Lytton (2003) recorded desiccation cracks up to 8 feet deep, but these cracks are typically 3 to 4 ft deep. These soils are often heavily overconsolidated due to the negative pore water pressures caused by desiccation. The cracks or fissures can allow water to seep into the soil and can cause softening. Fissures also can be problematic for excavations.

Fully softened shear strengths are normally appropriate for these soils for long-term conditions if they classify as CH soils. For stiff desiccated clays having $LL < 40$ and $PI < 20$ (CL soils), the peak strength may be applicable for long-term conditions.

1-2.3 Loess.

Loess is a fine-grained soil deposited by wind. These soils are often silt-sized and have little to no plasticity. They often may be slightly cemented by calcium carbonate. Cycles of deposition and plant growth result in vertical root casts, and these features impact the behavior of these soils. Loess soils can be very erodible in slopes that are non-vertical, but vertical slopes can often be stable for many years. Another issue with loess deposits is that they can be very collapsible when inundated. Large irreversible settlements can occur when these soils are flooded. More information on loess can be found in Section 5-6.3.

1-2.4 Sensitive or Quick Clays.

Sensitivity (S_t) is defined as the peak undrained shear strength divided by the remolded undrained shear strength. The remolded shear strength is best measured using field or laboratory vane shear tests, or laboratory fall cone tests. For soils with low values of sensitivity, soil samples can be remolded by hand kneading and formed into cylindrical specimens. The resulting specimens can be tested to determine the remolded undrained shear strength. Sensitivity values as high as 1000 have been measured (Terzaghi et al. 1996). Soils that have sensitivity values greater than 4 are considered to be *very sensitive soils*. Soils with sensitivities greater than 16 are considered to be *quick clays*. Quick clays are found in Scandinavia and parts of Canada and are formed by fresh water leaching of salt within the clays' structure. Sensitive soils can be formed by other means, such as clays formed from volcanic ash as the parent material, or other depositional or post-depositional factors that create a metastable structure. Sensitive soils are most often fine-grained materials. Table 1-1 shows general sensitivity categories. Chapter 1 of DM 7.1 contains an additional discussion of sensitive clays.

Table 1-1 Sensitivity categories (after Rosenqvist 1953)

Sensitivity Category	Sensitivity, S_t
Insensitive	~1.0
Slightly Sensitive	1-2
Medium Sensitive	2-4
Very Sensitive	4-8
Slightly Quick	8-16
Medium Quick	16-32
Very Quick	32-64
Extra Quick	>64

Some sensitive clays may be overconsolidated, and these can be especially problematic. These deposits can have a high undisturbed strength and can support imposed loads without significant settlement due to their preconsolidation. Loss of strength can occur on disturbance, but it will be less dramatic than with quick clays.

These soils will exhibit unrealistically low Standard Penetration Test (SPT) N values due to the sensitivity of the clay.

1-2.5 Residual Silts and Clays.

Residual soils are formed by physical and chemical weathering of parent rocks in-place or from weathering of volcanic ash deposits. Residual soils can be found in many different areas, such as the piedmont regions of Virginia, North Carolina, South Carolina, and Georgia; and in wet tropical environments. The term *residual soil* covers a wide range of materials, ranging from clay-sized soils to sandy soils. Soils containing the relic features of the parent rock, often called *saprolites*, can have even larger particle sizes. An excellent reference on residual soils is *Geotechnical Engineering in Residual Soils* by L. Wesley (2010).

Residual soils are more heterogeneous than alluvial soils and other soils that have been formed by sedimentary processes. Therefore, stress history does not have the same impact on strength and compressibility (Wesley 2010). One of the main problems regarding geotechnical engineering in residual soils is that correlations developed for sedimentary soils, which are commonplace in engineering practice, do not necessarily apply to residual soils. Considerable engineering judgment is required for efficient design in residual soils.

1-2.6 Laterites.

Laterites are a category of residual soils formed by weathering of igneous parent materials, often in tropical climates. In many cases, laterites can be strongly cemented or can contain aggregates of clay ranging in size from sand to gravel. In geotechnical engineering nomenclature, the term *laterite* is not strictly defined, and it has been applied to a range of soils, both strongly cemented and not cemented (Wesley 2010). Laterites may be poor materials for the support of foundations or embankments, particularly if loaded cyclically or exposed to flowing groundwater (McCarthy 2007).

1-2.7 Talus.

Talus is a loose deposit of rock debris located at the base of a cliff. Talus is a colluvial material deposited by gravity. Depending on the location with respect to the cliff and the slope of the deposit, the global stability of a talus deposit may be low.

1-2.8 Loose Sands.

Sand, in general, is not considered to be a problematic soil. However, *loose sands* can exhibit significant compression when loaded and can liquefy in the event of seismic loading. Fine loose sands are also prone to erosion or scour. Loose sands can be defined as sand-sized soils having a relative density less than 40% and an SPT blow count less than 10 blows/ft (Duncan et al. 2014).

Blast vibrations and equipment loading may cause settlement of loose sands. Settlement and global stability of loose sands may be evaluated using the methods of Chapters 5 and 7 of DM 7.1 for static loading conditions.

One behavioral condition that is unique to loose sands and non-plastic silts is *static liquefaction*. This can occur when excavations are made in loose contractive sand deposits that were formed by sluicing, such as for tailings or dams. An increase in stress by application of additional load can also cause static liquefaction. Saturated loose sands can fail catastrophically by liquefying under undrained loading if the *in situ* stress exceeds the yield shear strength as deformation occurs (Olson 2002). The yield shear strength is typically reached at very low strains, often less than 1%.

1-2.9 Soft Clays.

Soft clays have undrained strengths in the range of 500 psf to 1000 psf. Clays with undrained strengths less than 500 psf are termed *very soft*. Soft clays are most often normally consolidated or slightly overconsolidated. Soft clays often have liquidity indices near one.

1-2.10 Glacial Till.

Glacial tills can contain a range of particle sizes from clay size (0.002 mm) to boulders. In most cases, glacial tills are an excellent construction material. However, tills that contain large amounts of silt-sized and sand-sized materials can be prone to erosion, particularly if they are not protected by a graded filter.

1-2.11 Organic Soils.

Organic soils have been the bane of conventional geotechnical engineering practice for many years. Specifications for earth fills often state that 0% organics are allowed. This strict specification is neither practical nor enforceable. There are a variety of types of organic soils, and these differ in the amount and type of problems they can cause in geotechnical projects.

Organic clays, as defined by ASTM D2487, are fine-grained soils with Atterberg limits plotting above the A-line and having a ratio of the oven-dried liquid limit to the not-dried liquid limit less than or equal to 0.75. These have the group symbol of OH if the liquid limit (not-dried) is greater than 50, and they have the group name of *organic clay*. OH soils are considered to have “sufficient organic content to influence the soil properties.” If the liquid limit is less than 50, the group symbol is OL, but the group name remains *organic clay*.

Organic silts are defined similarly, but the Atterberg limits plot below the A-line. The same criterion regarding the ratio of the oven-dried to not-dried liquid limit also applies. An organic silt has the same group symbol of OH as an organic clay if the not-dried liquid limit is greater than 50. Organic silts that have a liquid limit less than 50 have a group symbol of OL, and the group name is still *organic silt*.

Peats, represented by the group symbol PT, are described in ASTM D2487 as “primarily organic matter, dark in color, and organic odor.” This classification is not based on Atterberg limits, and peats are described as having a texture from fibrous to amorphous. *Muskeg* is a peat soil that is found in parts of Alaska and Western Canada (Sowers 1989).

Peats are further classified based on the measured organic content, as described in ASTM D4427 (Standard Classification of Peat Samples by Laboratory Testing). Peats have an ash content less than 25%, as determined by ASTM D2974, which means true peats have at least 75% organic material.[5] Peats are also differentiated by the fiber content, acidity, and absorbency. More information about the classification and engineering behavior of organic soils can be found in VandenBerge et al. (2017) and Sleep et al. (2009).

One of the main issues with organic soils, and particularly with peats, is that they are very compressible. Organic soils can have very high *in situ* moisture contents – sometimes in excess of 1000% for peats. This results in very low unit weights and correspondingly low *in situ* effective stresses. A peat can be normally consolidated, and since the effective stresses are very low, the equilibrium void ratio can be very high – often greater than 4. If the effective stress is increased due to a geotechnical project loading, large settlements can occur. Preloading a site can help to alleviate extreme settlement magnitudes.

Organic soils can also decompose over time. If organics are incorporated into a fill material, the decomposition of the organics may result in settlement over time; however, there is some debate regarding the amount of decomposition possible in an anaerobic environment. Even so, there are strict limits normally placed on the organic content of structural fills, with a limit of 0% to 10% often being specified.

Although peats are very compressible, research conducted on fibrous peats show that other engineering parameters are often within the range of other soil deposits (Edil and Wang 2000; Landva and La Rochelle 1983; and Landva et al. 1983). Listed below are general facts about fibrous peats:

- Peats have a high strain to failure for both drained and undrained loading.
- Peats develop high pore pressures during undrained loading, with $\bar{A}$ values at failure greater than 0.5 and often equal to 1.0.

---

[5] Other groups and organizations have their own definitions of peat, which often differ from ASTM D4427 in the required ash content.

- K_0 values of fibrous peats are around 0.3.
- Peats normally have a c' close to zero and a high value of ϕ'. Values reported in the literature for ϕ' range from about 40 degrees to 65 degrees.
- Peats are not weak *per se*. The undrained strength ratios of peats reported in the literature range from about 0.4 to 1.5, with Edil and Wang (2000) reporting an average value of 0.59. The reason that peats are often considered to be weak is that, owing to the very low unit weight, the effective stresses within peat deposits are very low. If a peat deposit is overlain by a mineral soil, the undrained shear strength can be much higher than that of a normally consolidated clay.
- Peats have a high permeability (10^{-3} cm/sec) in a normally consolidated condition at low effective stresses. If a peat is consolidated by placing a fill on top of it, the permeability drastically decreases during consolidation.
- Vane shear tests have often been used to measure the undrained shear strength of peat.
- The shear strength of peat is highly anisotropic since the fibers are usually horizontally oriented.

1-2.12 Expansive Soils.

Certain types of fine-grained soils can expand when given access to water. The pressure developed from expansion can be large enough to cause significant damage to geotechnical structures. There are five related factors that influence the swell potential of fine-grained soils (Bursey et al. 2006):

1) Clays at low initial degrees of saturation expand more than clays at higher degrees of saturation.
2) The swell potential increases with increasing soil unit weight.
3) Clays with very active soil minerals (smectite and montmorillonite) expand more than soils with less active clay minerals (kaolinite and illite).
4) Soils with higher plasticity expand more than soils with lower plasticity.
5) Clays with a flocculated structure swell more than clays with a dispersed structure.

The International Building Code (IBC) provides threshold guidelines to determine if a soil has a potential swelling problem. Soils are deemed *not expansive* if the plasticity index is less than 15, less than 10% passes the No. 200 mesh sieve, or less than 5% of the soil is finer than 0.005 mm. If a soil is considered to be potentially expansive, two ASTM test procedures are available to assess the swell potential:

1) ASTM D4546 “Standard Test Methods for One-dimensional Swell or Settlement Potential of Cohesive Soil” and
2) ASTM D4829 “Standard Test Method for Expansion Index of Soil.”

In addition, the conventional one-dimensional consolidation test (ASTM D2435) can be used to measure the swell pressure of soils. The *swell pressure* is the applied stress that prevents volume change when the test specimen is inundated. Also, many correlations are available to estimate the swell potential of soils, and these can be found in Chapter 8 of DM 7.1.

Expansive soils can be a problem because the volume change characteristics can be reversible. Soils that expand significantly when wetted can also shrink considerably when dried. Shrink-swell issues in fine-grained soils often occur over the range of depth corresponding to seasonal moisture content variation.

1-2.13 Expansive Shale.

Many types of shales can also expand when provided with access to water. Since shale usually contains clay minerals, the same basic factors that influence the swell potential of soils apply to shales, particularly if the shale is excavated and used for a structural fill.

Pyritic shales pose a particularly severe problem if they are exposed during excavation. The problems can be more severe than just ground heave since the byproducts of oxidation of pyritic shales (gypsum and sulfuric acid) can cause degradation of steel and concrete. Issues with pyritic shales are documented in the southeastern and mid-Atlantic states as well as in Canada, the United Kingdom, and many other countries. Bryant et al. (2003) summarize many case histories of issues with pyritic shales.

Engineers developing sites which have Devonian age shales in the stratigraphy should be aware of the problems with pyritic shales. Problematic shales are normally dark gray to black (Bryant et al. 2003), and certain types of fossils are prevalent in these shales, which can serve to identify their age. Pyrite crystals may be visible in pyritic shales. Chemical tests can be conducted to identify the total sulfur present in shales to identify ones that are of concern.

1-2.14 Collapsible Soils.

Some soils can exhibit large compressive volume changes upon wetting. Types of soils that can exhibit this behavior are loess, alluvial flood plain deposits, colluvial deposits, residual soils, volcanic tuff, and lean clays and silts compacted dry of optimum (Brandon et al. 1990, Xanthakos et al. 1994).

Geotechnical laboratory tests are available to determine the amount of compression due to wetting (*hydrocompression* or *hydrocompaction*). Basic test procedures are outlined in Brandon et al. (1990). The test procedure given in ASTM D4546 (Standard Test Method for One-Dimensional Swell or Collapse of Soil) can be used for measuring the collapse potential of compacted soils.

The collapse potential of compacted soils can sometimes be controlled by careful selection of the compaction specifications. The collapse potential can be reduced by compacting the soils wet of optimum at modest values of relative compaction. However, there are trade-offs in controlling collapse with compaction specifications, because other properties, such as strength and stiffness, might be compromised.

The collapse potential of natural *in situ* soils can be difficult to address. In some cases, berms have been constructed around portions of the site, and the site is flooded so that the soil is forced to collapse prior to development. In other cases, soil improvement methods, such as dynamic compaction, can be used to densify the soil and to reduce the amount of future collapse. Further discussion of collapse in the context of shallow foundations is provided in Section 5-6.3.

1-2.15 Dispersive Soils.

Some fine-grained soils are prone to *dispersion* or *deflocculation* when subjected to flowing water having a particular chemistry. These types of soils are termed *dispersive soils* and are normally clay or silt soils. Dispersive soils can erode quickly due to separation of the particles, and some dam failures have been attributed to erosion of dispersive soils (Sherard 1986).

Owing to the engineering importance of dispersive soils in earth dams and canals, several tests have been developed to identify these soils:

1) ASTM D4221 “Standard Test Method for Dispersive Characteristics of Clay Soil by Double Hydrometer,”
2) ASTM D4647 “Standard Test Methods for Identification and Classification of Dispersive Clay Soils by the Pinhole Test,”
3) ASTM D6572 “Standard Test Methods for Determining Dispersive Characteristics of Clayey Soils by the Crumb Test,” and
4) ASTM D4542 “Standard Test Method for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer.”

Interpreting the results of these tests requires engineering judgment. The results of the tests are very general, in that soils can be considered dispersive, slightly dispersive, or non-dispersive (ASTM D4647). As an example, if twenty specimens are tested at a site, and two are considered to be dispersive, judgment is required to determine if dispersion is a problem or not. Dispersive soils are also discussed in Section 3-6.6.

1-2.16 Dredged Soils.

Dredged soils are excavated or pumped materials that are obtained from below a water surface. A main source of dredged soils comes from the maintenance of navigable waterways and harbors. The US Army Corps of Engineers maintains over 25,000 miles of waterways and over 400 ports, and they are responsible for the excavation of the bulk of dredged materials in the US (ERDC 2001). Environmental dredging is another category of dredging, and it is used to remove contaminated sediments from waterways and harbors. The US Navy and Coast Guard also direct dredging projects as well as local, state, and other federal government organizations.

In some cases, dredged materials can be used for engineering projects, such as land reclamation, or if properly sorted, construction materials. Dredging can also be used for excavation around infrastructure projects, such as bridge abutments and pier locations. There are many different types of dredges including mechanical, hydraulic, and pneumatic dredges. In many cases, the dredged soils are mixed with water so that they can be pumped to the location of disposal.

The dredged soils can be deposited at onshore placement facilities (confined disposal facilities) or in nearshore or open water areas. For onshore deposition, the dredged materials need to be dewatered to transition from a slurried consistency to a semi-solid soil consistency. The slurried dredge materials are normally deposited within an area surrounded by containment dikes. Over time, the soil particles settle out and the supernatant is drained from the surface. The remaining soil materials are remolded and have very high water contents, very low densities, and very low shear strengths. The character of the dredged materials depends on the source, and the grain sizes can vary considerably from clay to gravel size. Shear strengths of dredged soils can be increased by the installation of wick drains and preloading the site.

Owing to their experience with dredging and dredged soils, the US Army Corps of Engineers has an impressive research portfolio on many aspects of dredging. They have investigated factors that influence the dredgeability of soils, construction of containment dikes, and properties of dredged soils.

Conventional geotechnical laboratory and field test equipment can be used with dredged soils; however, the very low shear strengths mean that test interpretation is at the lower end of normal calibrations. CPTs can be used in dredged soils, but it is necessary to maximize the sensitivity of the cone tip by using a low-capacity cone or cones having larger tip areas. Special penetrometers have been developed for very soft soils. Vane shear tests have also been used with good results in fine-grained dredged deposits.

It is difficult to sample dredged soils, but successful sampling is possible with fixed-piston samplers. When samples are obtained, trimming triaxial test specimens may be challenging owing to the very low shear strengths. Laboratory miniature vane shear tests (ASTM D4648) or fall cone tests might be better alternatives for measuring undrained shear strengths. For drained strength parameters, trimming direct shear test specimens is often easier than triaxial specimens.

1-2.17 Low Plasticity and Nonplastic Silts.

Silts can be characterized by their Atterberg limits or by their size. Soils that plot under the A-line with $LL > 50$ have the group symbol MH and the group name *elastic silt*[6]. These soils are ordinarily not problematic and can be treated in the same manner as clay. Soils that plot under the A-line, with an $LL < 50$ and a $PI < 4$, have the group symbol ML and a group name of *silt*. Soils that have a grain size ranging from 0.002 mm to 0.075 mm are considered to be *silt-sized*.

Problematic silts are those that have very low plasticity ($PI < 4$ and $LL < 25$), particularly silts that are *nonplastic*. According to ASTM D4318, a soil is considered to be nonplastic, if it is not possible (1) to roll out a plastic limit thread or (2) to maintain the cut groove in the liquid limit test for more than 25 blows. Low plasticity and nonplastic silts can be difficult to deal with in engineering projects because of the following issues (Brandon et al. 2006):

1) Unconsolidated-Undrained (UU) triaxial tests conducted on saturated silts often exhibit substantial scatter.
2) Correlations developed for clay soils (CL and CH) may not apply to silts. These include correlations for interpreting the results of *in situ* tests.
3) The consolidation compression curve often does not exhibit a clear preconsolidation pressure.

Many of the problems with these silts may be due to the fact that their grain size, and corresponding permeability, give them behavioral characteristics that are unlike clays and sands. Whereas many *in situ* tests in clays are considered to be undrained, these tests might be partially drained in silt. Silts may cavitate during undrained loading owing to their dilative tendencies (Skempton and Golder 1948). Also, the lack of significant plasticity may prevent their behavior from being greatly influenced by the preconsolidation pressure.

Most of the problems with low plasticity and nonplastic silts occur when trying to characterize the undrained strength. If the undrained strength is characterized using Consolidated-Undrained triaxial tests, the issue with scatter in UU triaxial tests can be avoided. The undrained strength can also be estimated based on drained shear strength parameters combined with an assumed pore pressure at failure that is greater than or equal to zero to avoid relying on negative pore water pressures for undrained strength (Duncan et al. 2014).

---

[6] While these soils are called *elastic silts*, there is nothing indicative in their behavior which provides the expectation that these soils behave elastically in a classic sense (e.g., no volume change under application of shear stress or significant recoverable strain).

1-2.18 Municipal Solid Waste.

Municipal solid waste (MSW) is generated in huge quantities throughout the US. Research into the geotechnical properties began in earnest in the early 1990s in response to new EPA regulations. Knowledge of the properties is important for several reasons:

1) The engineering properties of the MSW can factor into the design of the landfill, particularly the stability of landfill interior slopes and cover system.

2) After landfills are closed, light site development is often planned for the site. Facilities such as public parks and golf courses have been constructed on top of closed landfills.

3) MSW deposits exist in unengineered landfills that predate current regulations. Development at old landfill sites can occur both with and without initial knowledge of the presence of the existing MSW.

It is not possible to definitively state the properties of MSW since the engineering properties depend on a wide array of factors. The composition of the waste stream can vary for different geographical areas as well as for different seasons of the year. In addition, as the MSW decomposes, the properties change over time (Reddy et al. 2011); therefore, it is only possible to give ranges of properties.

Measuring the shear strength of MSW is difficult since the size of the material is larger than can be accommodated by most shear testing apparatuses that were designed for soils. Also, obtaining a representative sample of material that is so heterogeneous is very difficult. Some researchers have resorted to manufacturing “synthetic” test specimens of MSW to obtain repeatable test specimens for property measurement (Dixon et al. 2008; Reddy et al. 2009; Reddy et al. 2011). Other research programs have tried to back-calculate the strength parameters from failed slopes in landfills (Eid et al. 2000; Bray et al. 2008).

The use of *in situ* tests to characterize MSW is not recommended since penetration of the landfill material can be difficult, and no reliable correlations exist regarding interpretation of the tests. These factors are compounded with the fact that the pore fluid may be leachate with unknown properties instead of water.

Bray et al. (2009) suggested using an effective stress cohesion intercept of 300 psf and a drained friction angle of 36 degrees at a normal stress of 2000 psf with the friction angle decreasing by 5 degrees for each tenfold increase in normal stress. Other references cite strength parameters considerably smaller (Reddy et al. 2009). Pandey and Tiwari (2015) report published values of c' ranging from 0 to 1000 psf and friction angles (ϕ') ranging from 27 to 41 degrees for MSW.

It is an easier task to measure the compressibility of MSW. One-dimensional consolidometers can be constructed to test large specimens of MSW. Although it isn't possible to test "undisturbed" specimens, reconstituted specimens can be formed that are within the range of densities found in landfills. Pandy and Tiwari (2015) summarize the results of consolidation tests for specimen diameters up to 20 inches, and strain-based compression ratios ($C_{\varepsilon c}$) from 0.16 to 0.35 were measured, with most results falling between 0.25 and 0.30.

In summary, MSW can be a very difficult material to deal with using conventional geotechnical engineering tools. It is very heterogeneous, and it isn't practically possible to take undisturbed samples. Disturbed samples can be taken, normally by excavation as opposed to rotary borings, but it can be hazardous owing to the constituents in the waste. Conventional laboratory test apparatuses are ill-suited for testing MSW, and *in situ* tests are of little value. Accurate and reliable correlations are not available for MSW; therefore, a great deal of engineering judgment is required when dealing with this material.

1-3 SPECIALTY GEOTECHNICAL CONSTRUCTION METHODS.

Geotechnical construction methods are constantly being updated, refined, and newly developed. Many innovative specialty contractors are engaged in geotechnical construction, and new and inventive construction methods are introduced every year. Some of the specialty construction methods make use of existing equipment while others employ complex custom equipment.

There are many valuable resources available that provide important details about specialty geotechnical construction methods. In November 2012, *GeoTechTools* was launched and now can be accessed through the ASCE Geo-Institute web page (https://www.geoinstitute.org/geotechtools/). GeoTechTools was created with funding from the Strategic Highway Research Project 2 (SHRP2), administered by the Transportation Research Board in conjunction with the Federal Highway Administration (FHWA) and the American Association of State Transportation and Highway Officials (AASHTO). Details can be found in the *Ground Modifications Methods Reference Manual* - *Volumes 1 and 2* (FHWA 2017). These references are commonly referred to as the FHWA Geotechnical Engineering Circular No. 13 (GEC 13).

The website provides detailed information about many geotechnical technologies. Some of these have been incorporated into civil engineering construction for many years, such as *excavation and replacement* and *conventional compaction*. Others are less common in typical construction, such as intelligent compaction, or are current topics of research, such as *bio-treatment* of soils. Table 1-2 lists the various technologies that are addressed. Although the development of the manuals and website was focused on transportation projects, the technologies described have direct applications to the topics covered in this manual.

Table 1-2 List of Technologies Included in GeoTechTools and GEC 13.

Aggregate Columns	Beneficial Reuse of Waste Materials
Bio-Treatment for Subgrade Stabilization	Blast Densification
Bulk-Infill Grouting	Chemical Grouting/Injection Systems
Chemical Stabilization of Subgrades and Bases	Column-Supported Embankments
Combined Soil Stabilization with Vertical Columns	Compaction Grouting
Continuous Flight Auger Piles	Dynamic Compaction
Deep Mixing Methods	Drilled/Grouted and Hollow Bar Soil Nailing
Electro-Osmosis	Excavation and Replacement
Fiber Reinforcement in Pavement Systems	Geocell Confinement in Pavement Systems
Geosynthetic Reinforced Construction Platforms	Geosynthetic Reinforced Embankments
Geosynthetic Reinforcement in Pavement Systems	Geosynthetic Separation in Pavement Systems
Geosynthetics in Pavement Drainage	Geotextile Encased Columns
High-Energy Impact Rollers	Hydraulic Fill with Geocomposite and Vacuum Consolidation
Injected Lightweight Foam Fill	Intelligent Compaction
Jet Grouting	Lightweight Fill
Mass Mixing Methods	Mechanical Stabilization of Subgrades and Bases
Mechanically Stabilized Earth Wall System	Micropiles
Onsite Use of Recycled Pavement Materials	Partial Encapsulation
Prefabricated Vertical Drains and Fill Preloading	Rapid Impact Compaction
Reinforced Soil Slopes	Sand Compaction Piles
Screw-in Soil Nailing	Shoot-in Soil Nailing
Shored Mechanically Stabilized Earth Wall System	Traditional Compaction
Vacuum Preloading with and without Prefabricated Vertical Drains (PVDs)	Vibro-Concrete Columns
Vibrocompaction	

Many of these technologies can be broadly classified as ground modification techniques. The basic goals of applying these techniques is to (1) increase the soil shear strength and bearing capacity, (2) increase the soil dry unit weight, (3) increase or decrease soil permeability and/or drainage, (4) increase soil stiffness or control volume change, (5) accelerate consolidation of fine-grained soils, (6) decrease loads applied to structures, (7) increase earthquake stability of soils, and (8) transfer stresses from less competent layers to more competent layers (FHWA 2017). Table 1-3 shows the types of technologies associated with the different improvement goals.

Table 1-3 Technologies Used to Address Basic Goals of Soil Improvement (after FHWA 2017)

Function	Technologies
Increase shear strength and bearing capacity	Vibro-Compaction Dynamic Compaction Compaction Grouting Mixing Methods PVDs Stone Columns Rammed Aggregate Piers Chemical Stabilization Mechanical Stabilization
Increase soil dry unit weight	Vibro-Compaction Dynamic Compaction Blasting Compaction Compaction Grouting Mixing Methods PVDs
Decrease permeability	Bulk-infill Grouting Chemical Grouting Jet Grouting Deep Mixing Methods
Control deformations (settlement, heave, distortions)	Column Supported Embankments Reinforced Load Transfer Platforms Non-Compressible Columns Mixing Methods Vibro-Compaction Dynamic Compaction Stone Columns Rammed Aggregate Piers Chemical Stabilization Mechanical Stabilization Encapsulation
Increase drainage	PVDs Aggregate Columns Geotextile Encased Columns Electro-Osmosis Geosynthetic Drains
Accelerate consolidation	PVDs Aggregate Columns Geotextile Encased Columns
Decrease imposed loads	Granular Fills (Wood Fiber; Blast Furnace Slag; Fly Ash; Boiler Slag; Expanded Shale, Clay, and Slate; Tire Shreds) Compressive Strength Fills (Geofoam, Foamed Concrete) Geosynthetic Reinforcement
Increase resistance to liquefaction	Aggregate Columns Dynamic Compaction Deep Mixing Jet Grouting Vibro-compaction
Transfer embankment loads to more competent layers	Column Supported Embankments Reinforced Soil Load Transfer Platforms Compressible and Non-Compressible Columns

Certain technologies are applicable to a broad range of soil types while others are best suited for specific soil types. Table 1-4 presents various soil types and ground conditions paired with the general types of technologies that apply.

Table 1-4 Soil Types and Foundation Conditions for Different Technologies (after FHWA 2017).

	Soil Types and Foundation Conditions	Applicable Technologies
General	All soil types, in particular weak soils that cannot support surface loads	Non-compressible columns
	All soil types, except very soft soils; low undrained shear strength	Compressible columns
	Clays, silts, loose silty sands, and uncompacted fill	Aggregate columns
	Broad applicability; no geologic or geometric limitations	Lightweight fills: geofoam, foamed concrete, wood fiber, blast furnace slag, fly ash, boiler slag, expanded shale, tire shreds
	Wide range of soil types, including weakly cemented rock-fill materials	Chemical (permeation) grouting
	Coarse-grained soils, collapsible soils, and unsaturated fine-grained soils (may be used to fill voids in sinkholes or abandoned mine shafts and can arrest settlement under a structure and lift foundations that have settled).	Compaction grouting
	Suitable in large range of soils, particularly those that can be stabilized with cement, lime, slag, or other binders	Deep soil mixing
	Wide range of soil types and groundwater conditions	Jet grouting
Clay	Compressible saturated clays	Prefabricated vertical drains, with and without preloading for accelerated consolidation
	Soft soil foundations, with no limitation on depth of soft soils	Reinforced embankments
	Soft compressible clay, peats, and organic soils where settlement and global stability are concerns	Column supported embankments and reinforced soil load transfer platform
	Peat, soft clay, dredged soil, soft silt, sludges, and contaminated soils	Mass soil mixing
Sands	Loose pervious and semi-pervious soils with fines contents less than 15%; materials containing large voids, spoils, and waste areas	Dynamic compaction (DC)
	Coarse-grained soils; clean sands with less than 15% silts and/or less than 2% clay	Vibro-compaction
Strong Soil / Rock	Steep-sided terrain, soils subject to instability, and poor foundation conditions	Reinforced soil walls
	Firm foundation soils	Reinforced soil slopes
	Fractured rock	Rock fissure grouting
	Dense to very dense granular soils with apparent cohesion, weathered rock, stiff to hard fine-grained soils, engineered fill, residual soils, and glacial till	Soil nail walls

1-3.1 GeoTechTools Website Interactive Selection System.

The GeoTechTools website allows a user to interactively select between various technologies for four basic screening categories. The application categories are (1) construction over unstable soils, (2) construction over stable or stabilized soils, (3) geotechnical pavement components, and (4) working platforms. These four categories are shown graphically in Figure 1-1.

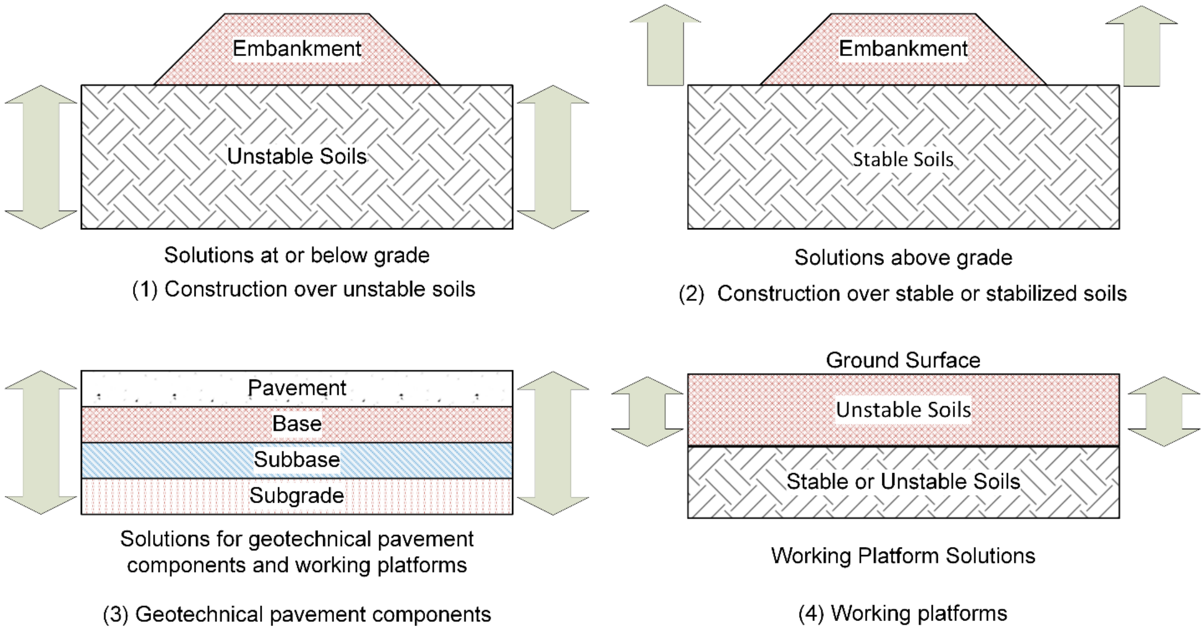


Figure 1-1 Interactive Selection Categories for GeoTechTools Website

All of these categories have applications to the design elements presented in this manual. If category No. 1 is selected, the user has a choice of various unstable ground conditions, such as (a) wet and weak fine-grained soils, (b) unsaturated loose granular soils, (c) saturated loose granular soils, (d) voids – sinkholes and abandoned mines, and (e) problem soils and sites. If (a) wet and weak fine-grained soils are selected, the user is prompted to indicate the depth below the ground surface where treatment is required, and various treatment options are suggested based on the depth selection. For this example, if a treatment depth of 10 to 30 ft is selected, the following treatment technologies are offered:

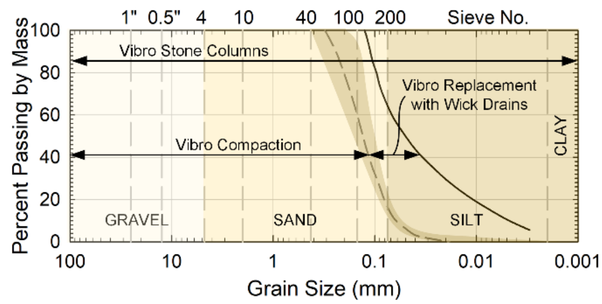
- Aggregate columns
- Column-supported embankments
- Combined soil stabilization with vertical columns
- Continuous flight auger piles
- Deep mixing methods
- Electro-osmosis
- Geosynthetic reinforced embankments
- Geotextile encased columns
- Jet grouting
- Lightweight fill
- Mass mixing methods
- Micropiles
- Prefabricated vertical drains and fill
- Sand compaction piles
- Vacuum preloading
- Vibrocompaction

Selecting one of the suggested technologies connects the user with both general and detailed information about the choice. There is a brief overview, a fact sheet, photographs of the technology, case histories, design guidance, QA/QC information, cost information, example specifications, and references for further study are provided.

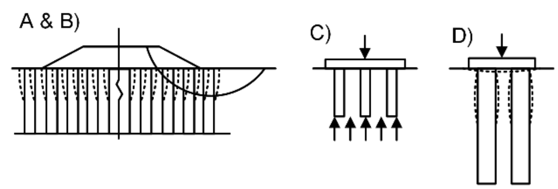
1-3.2 Geotechnical Site Technology Examples.

In the following pages, examples of several popular geotechnical site technologies are presented. Figure 1-2 through Figure 1-16 summarize the benefits of the procedure and the basic construction process. Advantages and disadvantages are presented, along with the site conditions that are most favorable for the specific technology. The key design parameters are listed, and other alternative technologies are included. More information on most of the technologies can be found in FHWA (2017) or in the other references provided in each figure.

Aggregate Columns



Typical application and failure modes



A) Lateral spreading – wide embankment load
B) General circular failure
C) Punch failure of short columns - homogeneous soft soils
D) Bulging failure – small group

(after FHWA 2017)

Controlling Engineering Principles

Aggregate columns:

- Create a pier element by using compacted aggregate,
- Increase bearing capacity,
- Increase the soil shear strength,
- Increase the consolidation rate,
- Increase liquefaction resistance, and
- Reduce settlement.

Basic Construction Process

Aggregate Columns can be installed by vibro-replacement, vibro-displacement, or the replacement method. The installation includes:

- Form holes in the soil either by excavation or vibratory method,
- Backfill with gravel or crushed rock, and
- Compact the backfill either by ramming or vibratory methods.

COMPARATIVE INFORMATION

Advantages

- Potentially economical alternative to deep foundations
- Can be quicker than site pre-loading on time-critical projects
- Can reduce dynamic settlement to an acceptable level in seismic areas

Disadvantages

- Not a solution for all soft soil problems
- Dense overburden, boulders, cobbles, or other obstructions may require pre-drilling
- Cost can be high when compared to other methods

Preferred Applications

- Soft organic clays, loose silt and sand
- Embankments over highly compressible soil
- Bridge approach fills
- Bridge abutment and foundation support
- Liquefaction mitigation

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER
• Soil shear strength and compressibility • Aggregate column friction angle and modulus	• FHWA (2017) – Chapter 5 • DM 7.1 – Chapter 5	• Sand compaction piles • Prefabricated vertical drains • Deep and mass mixing • Jetted grout columns

Figure 1-2 Summary of Key Elements of Aggregate Columns

Bulk Infill Grouting

<u>Controlling Engineering Principles</u>

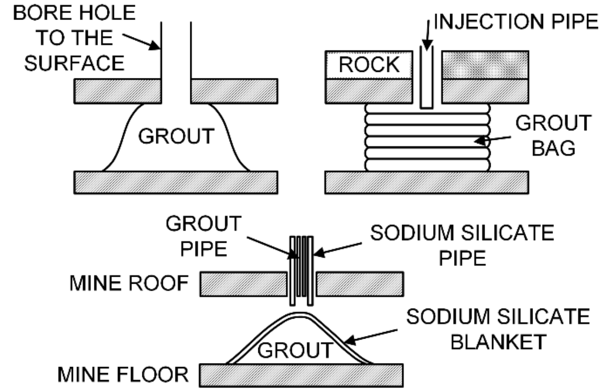
Bulk infill grouting:

- Uses a large quantity of cement-based grout to fill subsurface voids and
- Provides remediation for sinkholes.

<u>Basic Construction Process</u>

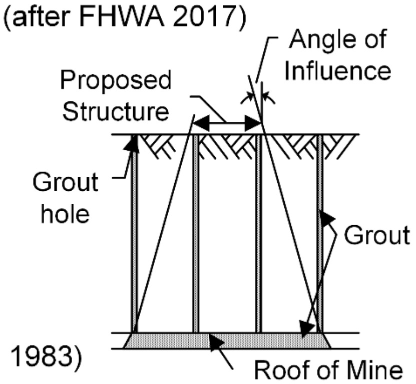
The process of bulk infill grouting includes

- Identifying subsurface voids such as mines, karst topography, etc.,
- Boring a hole from ground surface to the floor of the void,
- Adding a grout bag and starting to inject grout into the void,
- Leaving a sodium silicate blanket over the grout, and
- Removing the grout bag.



(after FHWA 2017)

Typical application and construction process



(after Ryan 1983)

COMPARATIVE INFORMATION

<u>Advantages</u>

- Low cost per unit volume when using cheap fillers
- Minimum disturbance
- Strength of grout can be fit to the *in situ* condition
- Essentially yields full roof contact
- Grout can penetrate all voids with low risk of grout flowing, washing away, or settling

<u>Disadvantages</u>

- Little control where the grout goes
- Difficult to obtain sufficient knowledge of the voids position, shape, and infilling
- Cannot provide consistent reliable support in common karst conditions

<u>Preferred Applications</u>

- Can be used in karst topography, chalk deposits, and salt deposits
- Embankments over unstable soils
- Abandoned or old mines
- Repairing of scour problems under bridges

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Grout mix proportions • Knowledge of subsurface voids	• FHWA (2017) – Chapter 8	• Drilled shafts • Other forms of grouting • Deep dynamic compaction • Excavation and replacement

Figure 1-3 Summary of Key Elements of Bulk Infill Grouting

Blast Densification

Controlling Engineering Principles

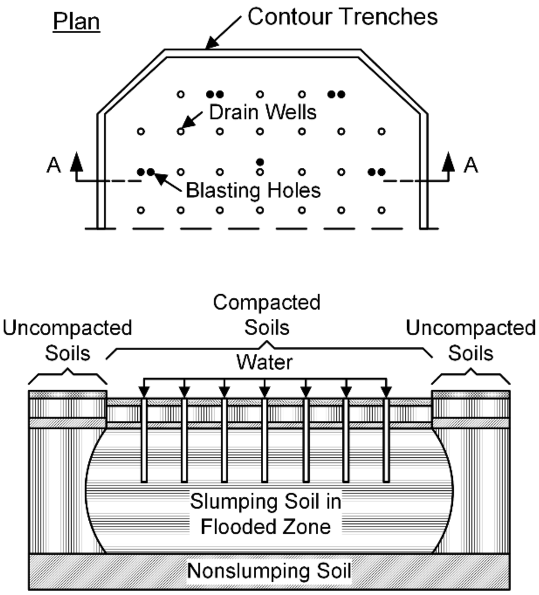
Blast densification:

- Uses a detonation to induce liquefaction,
- Consolidates the soil to a denser and more stable configuration,
- Reduces long-term settlement, and
- Improves the foundation soil strength.

Basic Construction Process

Blast densification can be successfully done by using either pre-drilled or jetted holes. The process includes:

- Placing charges in a grid pattern of holes and
- Detonating charges with delays to enhance cyclic loading while also minimizing peak acceleration.



(after Mitchell 1981)

Typical application and construction process

COMPARATIVE INFORMATION

Advantages

- Ability to treat deep soils
- Rapid
- Inexpensive
- Successful under a variety of climate and environmental extremes

Disadvantages

- Lack of validated theoretical design
- Improvement may be time dependent
- Limits on how much densification can occur
- Difficult to place large charges at great depths
- Oversized charges may cause cratering, slope failure, or vibration-related damages

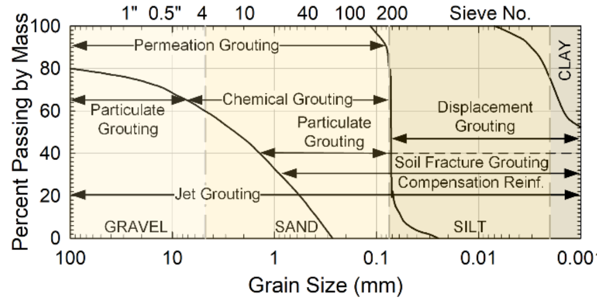
Preferred Applications

- Best suited for clean sands and silty sands with relative densities less than 50% to 60% and maximum clay content of 5% to 10%
- Embankment foundations
- Liquefaction mitigation

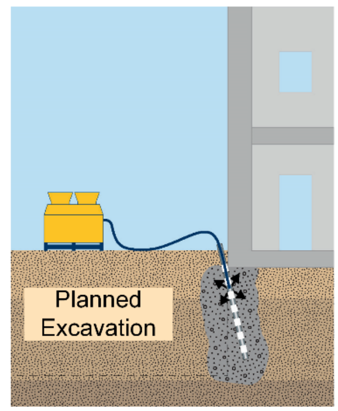
KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Layer depth • Charge spacing • Relative density of soil • Clay content	• FHWA (2017) – Chapter 4 • Narin and Mitchell (1994, 1995)	• Dynamic compaction • Vibro-compaction

Figure 1-4 Summary of Key Elements of Blast Densification

Chemical Grouting



Typical application and construction process



(Courtesy of Keller)

<u>Controlling Engineering Principles</u>

Chemical grouting:

- Uses grouts with no suspended particles,
- Bonds soil particles together and fills voids,
- Can increase soil strength for construction, and
- Can create a seal to limit water intrusion into a subsurface area.

<u>Basic Construction Process</u>

Chemical grouting can be accomplished by:

- Injecting the grout through a manchette or packing system and
- Filling discrete flow paths with an expansive and/or flexible material using simple drill and injection principles.

COMPARATIVE INFORMATION

<u>Advantages</u>

- Chemical grouts can be used in soils with finer pores than particulate grouts
- Computer monitoring of grouting shows real-time analysis of construction process

<u>Disadvantages</u>

- Experienced contractors are needed
- Time-consuming process
- Some chemical grouts break down over time, reducing capacity to improve the soil and releasing toxic material into the soil
- Expensive

<u>Preferred Applications</u>

- Soils with permeability as low as 10^{-4} cm/s and fines contents less than about 20%
- Embankment over unstable soils
- Stabilization of pavement working platforms

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Fines content and permeability of soil • Grout proportions	• FHWA (2017) – Chapter 8 • USACE (1997)	• Jet grouting

Figure 1-5 Summary of Key Elements of Chemical Grouting

Column Supported Embankments

Controlling Engineering Principles

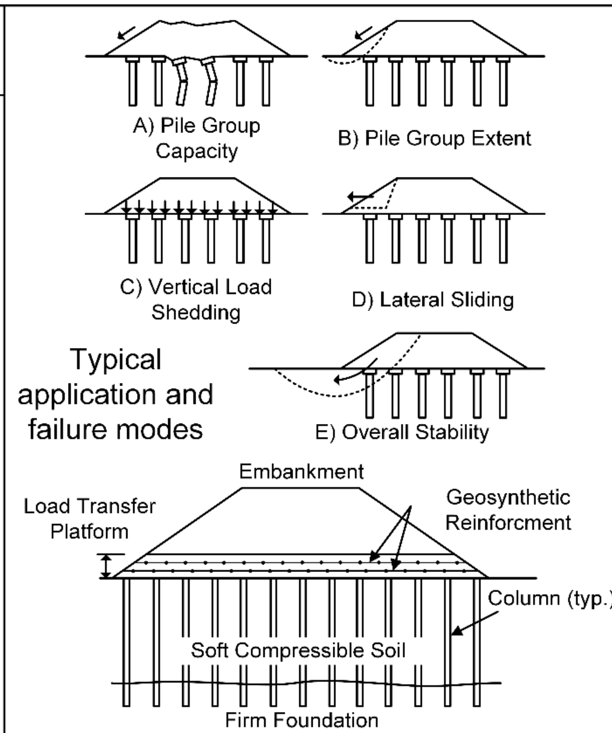
Column supported embankments:

- Use vertical columns to transfer the load of the embankment through a soft compressible layer down to a firm foundation layer and
- Can use a load transfer platform to transfer the load to the columns and maintain acceptable deformation.

Basic Construction Process

Column supported embankments can use a variety of column types and installation methods. General installation includes:

- Construction of columns,
- Placement of load transfer platform and geosynthetic reinforcement, and
- Construction of embankment.



(after FHWA 2017)

COMPARATIVE INFORMATION

Advantages

- Accelerates construction compared to conventional methods
- Reduces total and differential settlement
- Protects adjacent facilities from distress
- Can use a wide variety of columns to accommodate different site conditions

Disadvantages

- Can have a higher cost than other technologies
- Lack of standard design procedures
- Lack of knowledge about technology benefits, design procedures, and construction techniques

Preferred Applications

- Soft soil underlain by stiffer soil or bedrock
- Embankment stabilization
- Roadway widening
- Bridge approach fill stabilization
- Bridge abutment and other foundation support

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Embankment height • Allowable settlement • Geosynthetic strength • Foundation soil strength and compressibility	• FHWA (2017) – Chapter 6	• Prefabricated vertical drains • Lightweight fill • Staged construction • Excavation and replacement

Figure 1-6 Summary of Key Elements of Column Supported Embankments

Compaction Grouting

Controlling Engineering Principles

Compaction grouting:

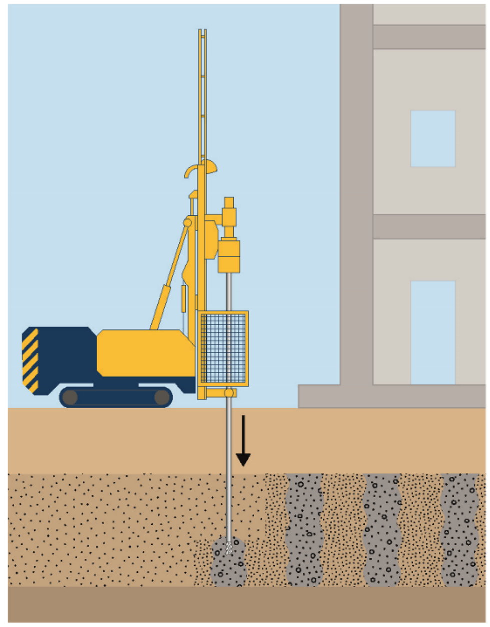
- Displaces soil with low mobility grout,
- Compacts surrounding soil, and
- Strengthens and stiffens soil by densification of the soil itself rather than through the strength of the grout.

Basic Construction Process

Compaction grouting is accomplished by:

- Driving or drilling the grout casing to the desired depth and location,
- Pumping the grout until the design termination criteria have been reached, and
- Forming grout bulbs every 1 to 3 feet depending on the application of the project.

Typical application and construction process



(Courtesy of Keller)

COMPARATIVE INFORMATION

Advantages

- Effectiveness has been well-proven in practice
- Can be implemented in areas of restricted vertical room
- Directly treats the area that needs improvement
- Can be installed under existing structures

Disadvantages

- Grout rheology requires further investigation
- Can cause a build-up of excess pore pressure in fine-grained soil
- QA/QC procedures need further development
- Design methodology is not well defined

Preferred Applications

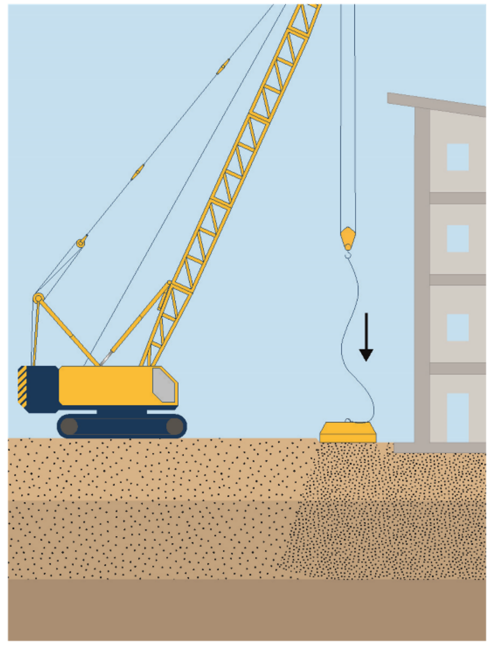
- Silts and well-graded sands have greater success than clays and poorly-graded sands and gravels
- Embankment foundations
- Working platforms
- Correction of differential settlement
- Settlement controls over tunnels or sinkholes

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Depth and area of soil to be modified • Grout mix proportions	• FHWA (2017) – Chapter 8	• Jet grouting • Deep mixing • Deep dynamic compaction • Micropiles

Figure 1-7 Summary of Key Elements of Compaction Grouting

Dynamic Compaction

Typical application and construction process



(Courtesy of Keller)

Controlling Engineering Principles

Dynamic compaction:

- Uses cranes to drop tampers onto the soil which compact the soil,
- Increases the soil's resistance to liquefaction,
- Increases bearing capacity, and
- Reduces settlement.

Basic Construction Process

Dynamic compaction can be accomplished by:

- Dropping a tamper by a crane in a systematic pattern,
- Using a first phase with high-energy to improve the deeper soil, and
- Following with a second phase of lower-energy to improve the upper layers of soil.

COMPARATIVE INFORMATION

Advantages

- Suitable for many types of soils
- Low cost for large area improvement
- Ability to measure improvement
- Non-specialty contractors
- Simple equipment
- Produces relatively uniform compressibility
- Not weather dependent

Disadvantages

- Vibrations can travel far
- Lateral ground displacement can occur
- Mobilization costs
- Limited effective treatment depth
- Some safety concerns
- Ineffective in fine-grained soils

Preferred Applications

- Loose pervious and semi-pervious soils with fines contents less than 15%
- Densification of loose deposits
- Collapse of large voids and collapse-susceptible soils
- Embankments over compressible coarse-grained soils

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Soil type • Required depth of compaction	• FHWA (2017) – Chapter 4	• Deep foundation systems • Sand compaction columns • Vibrocompaction • Blast densification

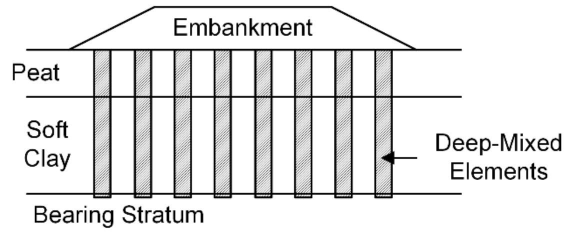
Figure 1-8 Summary of Key Elements of Dynamic Compaction

Deep Mixing Method

<u>Controlling Engineering Principles</u>

The deep mixing method:

- Creates soil-cement zones that have the improved properties,
- Increases strength, and
- Decreases compressibility.



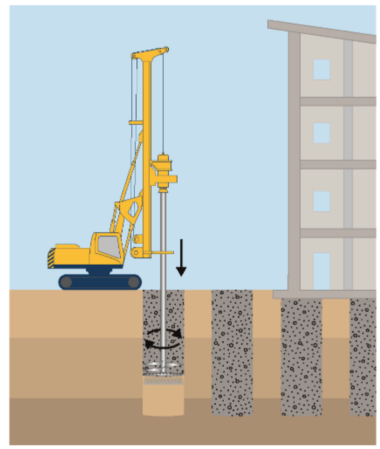
(after FHWA 2017)

<u>Basic Construction Process</u>

Deep mixing can be completed using either water-binder slurry or dry power binder, which is based on the type of soil that exists on the site. The process includes:

- Inserting the soil mixing equipment (either vertical axis, horizontal axis, or chainsaw-like),
- Delivering the binder, and
- Mixing of soil and binder.

Typical application and construction process



(Courtesy of Keller)

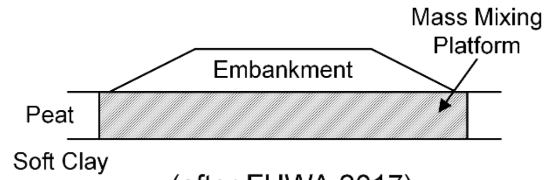
COMPARATIVE INFORMATION

Advantages	Disadvantages	Preferred Applications
• Economical on large projects • Less noise and vibrations compared to other technologies • High production capacity • Relatively easy installation procedures	• Mobilization and unit cost may be higher than other technologies • Obstructions can interfere with penetration of mixing equipment • The wet method requires heavy equipment that may be too heavy for softer soils • Can be slower than other methods	• Wide range of applicable soils • Can be used above water or below water • Embankments • Retaining walls • Abutments • Bridge piers

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Soil-cement shear strength and modulus	• FHWA (2017) – Chapter 7	• Prefabricated vertical drains • Dynamic compaction • Piles, aggregate columns, or vibro-concrete columns

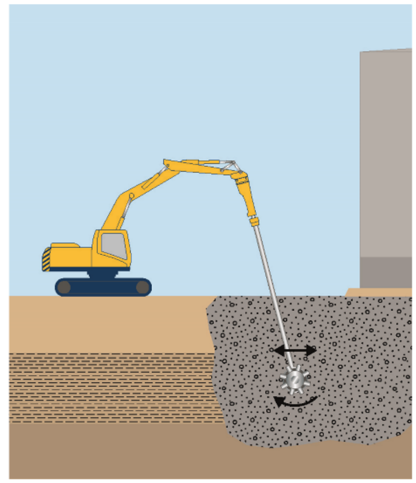
Figure 1-9 Summary of Key Elements of the Deep Mixing Method

Mass Mixing Method



(after FHWA 2017)

Typical application and construction process



(Courtesy of Keller)

Controlling Engineering Principles

The mass mixing method:

- Creates soil-cement zones that have improved properties,
- Increases shear strength, and
- Limits settlement.

Basic Construction Process

Mass mixing can be completed using either water-binder slurry or dry power binder mixed with the existing soil. The process includes:

- Dividing the treatment area into overlapping blocks prior to treatment,
- Mixing the soil and binder using an excavator-mounting mixing tool, and
- Topping the soil-cement with a preload after mixing to induce consolidation of the treated soil while curing occurs.

COMPARATIVE INFORMATION

Advantages

- Can be done rapidly
- Can stabilize peat and other soft soils, and can treat contaminated soils
- Less expensive than deep mixing on a unit volume basis
- Can stabilize large blocks of soil
- Lower environmental impacts compared to other technologies

Disadvantages

- Limited treatment depth
- Cannot easily penetrate dense or stiff soils
- Cost-effectiveness is dependent on accuracy of the measurement of binder quality
- Organic soils may require higher binder content or specific binder types

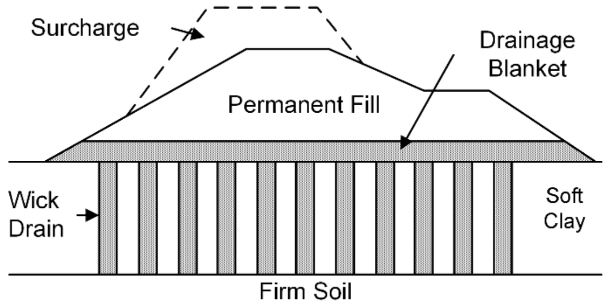
Preferred Applications

- Soft clay, dredged soil, sludges, contaminated soils, and soft silts
- Embankments over highly compressible soil
- Tanks
- Stabilizing excavations
- Land reclamation
- Contaminant fixation

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Soil-cement shear strength and modulus • Organic content	• FHWA (2017) – Chapter 7	• Prefabricated vertical drains • Column-supported embankments • Deep mixing methods

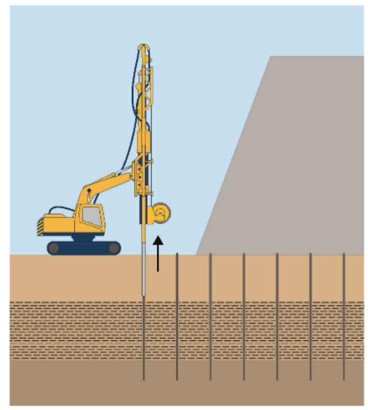
Figure 1-10 Summary of Key Elements of the Mass Mixing Method

Pre-Fabricated Vertical Drains



(after FHWA 2017)

Typical application and construction process



(Courtesy of Keller)

Controlling Engineering Principles

Pre-fabricated vertical drains (PVDs):

- Create a shorter drainage path for consolidation,
- Increase the consolidation rate,
- Increase rate of strength gain, and
- Can be combined with surcharging or preloading.

Basic Construction Process

PVDs can be installed by static, vibratory, jetting, or combined methods. PVD installation includes:

- Threading PVD material into mandrel,
- Attaching an anchor to bottom of mandrel,
- Inserting the mandrel and PVD into the ground,
- Withdrawing the mandrel, and
- Cutting off and anchoring the PVD.

COMPARATIVE INFORMATION

Advantages

- Economical method
- Very fast installation
- Permanent drainage path
- Minimal soil removal or displacement
- Simple QA/QC
- Adaptable equipment
- Water typically not required (unless jetted)

Disadvantages

- Equipment must be taller than PVD depth
- PVD material degrades in sunlight
- Soil improvement limited by size of added load or surcharge
- Less appropriate for soils with significant secondary compression
- Can weaken stiff clays

Preferred Applications

- Saturated normally consolidated or lightly overconsolidated silt
- Embankments over highly compressible soil
- Tank foundations
- Reduction of pile negative skin friction
- Liquefaction mitigation
- Land reclamation

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Compressible layer thickness • Coefficients of consolidation, c_v and c_h	• FHWA (2017) – Chapter 2 • DM 7.1 – Chapter 5	• Aggregate columns • Geotextile encased columns

Figure 1-11 Summary of Key Elements of Pre-Fabricated Vertical Drains

Sand Compaction Piles

<u>Controlling Engineering Principles</u>

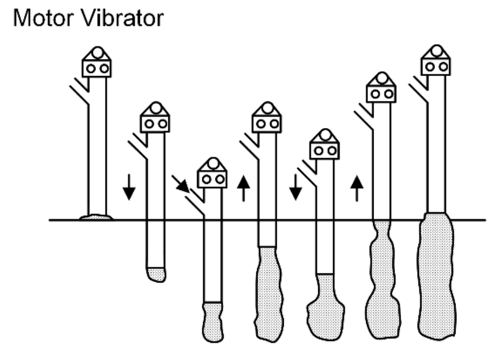
Sand compaction piles:

- Create a drainage pathway for clay soils,
- Increase the bearing capacity,
- Prevent stability failures,
- Reduce settlement,
- Accelerate consolidation, and
- Increase liquefaction resistance.

<u>Basic Construction Process</u>

Sand compaction piles are installed either in loose sand or soft clay. Installation of sand compaction piles includes:

- Driving pipe through soil using vibratory or nonvibratory means,
- Backfilling the pipe with sand, and
- Densifying the surrounding soil by repeated penetration and extraction of the pipe.



After Tanimoto (1973)

Typical application
and construction process

COMPARATIVE INFORMATION

<u>Advantages</u>

- Rapid construction, less risk of intrusion of soil into the pile compared to stone columns
- Fully-supported hole during construction prevents collapse
- Liquefaction prevention
- Settlement reduction

<u>Disadvantages</u>

- Not commonly used in the United States
- Smearing effects when constructed in clay
- Greater replacement ratios are necessary compared to other columns
- Vibration and noise during construction
- Sand can be costly and availability limited

<u>Preferred Applications</u>

- Wide range of soils, from soft clays to sandy soils
- Embankments over unstable soils

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Type of soil • Sand backfill properties	• Aboshi, H. (1991) • Barksdale, R.D. (1987) • Kitazume, M. (2005)	• Vibrocompaction • Stone columns • Aggregate piers • Vibroconcrete columns

Figure 1-12 Summary of Key Elements of Sand Compaction Piles

<table>
<tr><th colspan="3">Soil Nail Walls</th><th colspan="3">Typical application
and construction process</th></tr>
<tr><td colspan="3"><u>Controlling Engineering Principles</u>
Soil nail walls:
• Reinforce existing soil,
• Provide tensile resistance, and
• Require temporary stability during installation.

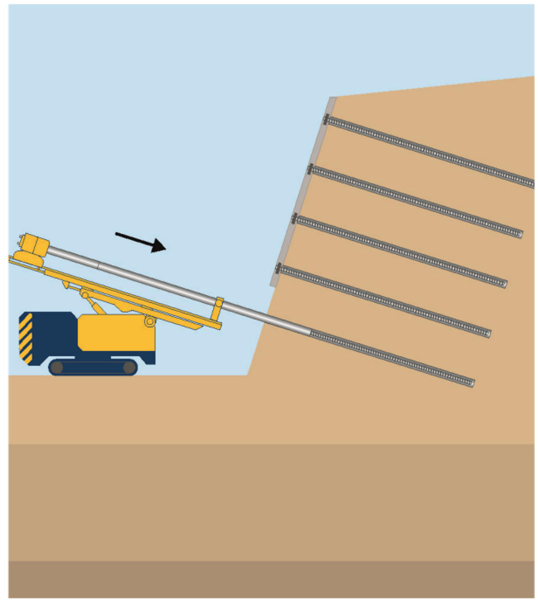
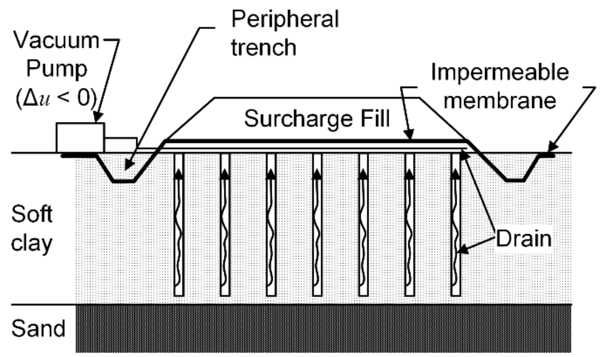
<u>Basic Construction Process</u>
The soil nail wall is a top-down constructed retaining system. Installation includes:
• Excavating an initial lift,
• Drilling a nail hole,
• Installing and grouting the nail,
• Repeating for additional nails,
• Placing initial facing,
• Installing drainage,
• Constructing subsequent levels, and
• Placing final facing.</td><td colspan="3">
(Courtesy of Keller)</td></tr>
<tr><td colspan="6">COMPARATIVE INFORMATION</td></tr>
<tr><td colspan="2"><u>Advantages</u>
• Relatively fast installation
• Good for temporary walls
• More cost effective in remote locations due to availability of smaller equipment
• Perform well during seismic events
• Can withstand large deformations
• Easily monitored and tested</td><td colspan="2"><u>Disadvantages</u>
• Not well-suited in areas with large amounts of groundwater seeping into the excavation
• Permanent soil nail walls require permanent underground easements
• If projects have strict wall movement criteria, additional measures may be required</td><td colspan="2"><u>Preferred Applications</u>
• Soil that can stand unsupported temporarily
• Ground conditions that remain stable without collapse until grouted
• Tunnel portals
• Roadway cuts
• Shored Mechanically Stabilized Earth (SMSE) walls
• Basement walls</td></tr>
<tr><td colspan="2">KEY DESIGN PARAMETERS</td><td colspan="2">DESIGN GUIDANCE</td><td colspan="2">COULD ALSO CONSIDER:</td></tr>
<tr><td colspan="2">• Soil strength
• Ground water table</td><td colspan="2">• FHWA (2017) – Chapter 5</td><td colspan="2">• Cantilever wall
• Gravity wall
• MSE wall
• Counterfort concrete wall</td></tr>
</table>

Figure 1-13 Summary of Key Elements of Soil Nail Walls

Vacuum Preloading



(after Fernandes, 2020)

Typical application
and construction process

Controlling Engineering Principles

Vacuum preloading:

- Increases effective stress in foundation soils through reduction in pore pressures,
- Improves saturated soils by consolidation, and
- Can be combined with prefabricated vertical drains.

Basic Construction Process

The steps for vacuum preloading include:

- Covering soil site with an airtight membrane,
- Using dual venturi and vacuum pumps to create a vacuum over the site which will create and maintain the loads, and
- Maintaining the water table at the base of the granular platform through a combination of dewatering and vacuum action.

COMPARATIVE INFORMATION

Advantages	Disadvantages	Preferred Applications
• Fill not required • Staged loading is not required • No heavy equipment • Environmentally friendly • Established design methods and QC/QA requirements • Cheaper and faster compared to surcharge loading	• Maintenance of vacuum pressure is difficult • May cause cracks in surrounding soils • Vacuum pressure is limited to 1 atm • Inward lateral movements from vacuum preloading can cause damage to adjacent structures	• Compressible soft, uniform clays • Sites with shallow ground water table • Embankment over unstable soil • Stabilization of working platforms

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Compressible layer thickness • Coefficients of consolidation, c_v and c_h	• FHWA (2017) – Chapter 2	• Deep foundation elements • Prefabricated vertical drains • Stone columns • Grouting

Figure 1-14 Summary of Key Elements of Vacuum Preloading

Vibro-Compaction

Controlling Engineering Principles

Vibro-compaction:

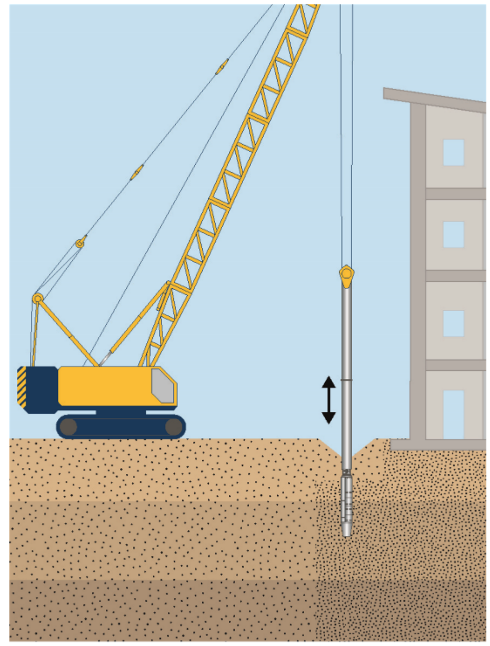
- Uses a probe and vibrator to densify the surrounding soil,
- Increases the soil's resistance to liquefaction,
- Increases bearing capacity, and
- Increases shear strength.

Basic Construction Process

Vibro-compaction can be accomplished by:

- Using a vibrator and probe to rearrange the soil particles into a denser state following the grid layout,
- Inserting the probe in phase one using a high frequency, and
- Densifying the soil in phase two using a low frequency.

Typical application and construction process



(Courtesy of Keller)

COMPARATIVE INFORMATION

Advantages	Disadvantages	Preferred Applications
• Economical and fast method for deep foundations • Effective above and below the water table • Many case histories in United States	• Only effective for coarse-grained (cohesionless) soils • Maximum depth is about 165 feet • Noise and vibrations • Contractor experience is critical • Quality control should be monitored carefully	• Coarse-grained cohesionless soils • Embankment foundations • Underwater embankments • Tunnels • Liquefaction mitigation • Compaction of potential cavities • Foundation soils beneath proposed structures

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Initial and final relative density • Grain size distribution	• FHWA (2017) – Chapter 4	• Sand compaction piles • Deep dynamic compaction • Aggregate columns • Vibro-concrete columns

Figure 1-15 Summary of Key Elements of Vibro-Compaction

Vibro-Concrete Columns

Controlling Engineering Principles

Vibro-concrete columns:

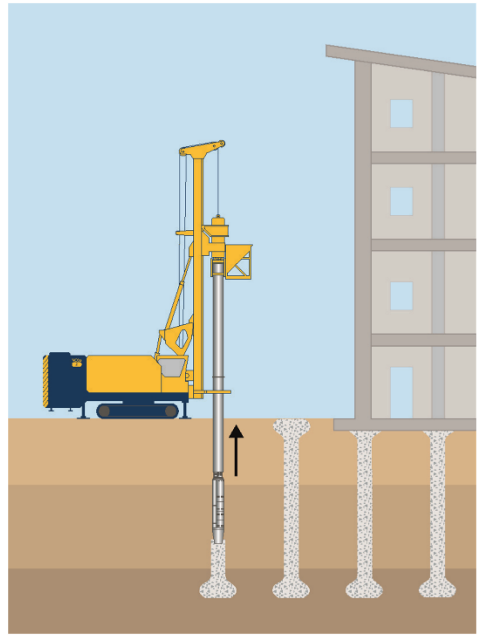
- Create columns similar to aggregate columns with concrete in place of aggregate,
- Increase the bearing capacity, and
- Can be combined with column-supported embankments to reduce total and differential settlement.

Basic Construction Process

The vibro-concrete column installation includes:

- Using a vibrator to penetrate soil to specified depth,
- Pumping concrete to fill the void while the vibrator is being extracted, and
- Repenetrating with the vibrator during extraction to create bulbs at top and bottom of the columns.

Typical application and construction process



(Courtesy of Keller)

COMPARATIVE INFORMATION

Advantages

- Reduces total, differential, and seismic settlements
- Greater column stiffness compared to aggregate columns
- Quick construction
- Environmentally friendly (no spoils)

Disadvantages

- Lack of well-established design procedure
- More expensive than aggregate columns

Preferred Applications

- Best used in soft clays or peat with low undrained shear strength
- Embankments over unstable soils

KEY DESIGN PARAMETERS	DESIGN GUIDANCE	COULD ALSO CONSIDER:
• Compressible layer thickness • Strength of bearing layer	• FHWA (2017) – Chapter 5	• Aggregate columns • Prefabricated vertical drains • Driven piles • Vibrocompaction

Figure 1-16 Summary of Key Elements of Vibro-Concrete Columns

1-4 NOTATION.

Variable	Definition
$\bar{A}$	Skempton's pore pressure parameter for change in shear stress
c'	Drained or effective stress cohesion intercept
$C_{\varepsilon c}$	Modified compression index (in terms of strain)
c_h	Coefficient of consolidation in the horizontal direction
c_v	Coefficient of consolidation in the vertical direction
K_0	Lateral earth pressure coefficient for at-rest conditions
LL	Liquid limit
N	Standard penetration test blow count (uncorrected)
PI	Plasticity index
S_t	Sensitivity
ϕ'	Drained or effective stress friction angle

CHAPTER 2. EXCAVATIONS

2-1 INTRODUCTION.

This chapter covers the methods of evaluating the stability of shallow and deep excavations. There are two basic types of excavations: 1) *open cut excavations* where stability is achieved by providing stable side slopes and 2) *braced excavations* where vertical or sloped sides are supported laterally by internal or external structural elements. The topics in this chapter include:

- Open cut excavations,
- Trenching,
- Deep excavation systems,
- Rock excavation, and
- Groundwater control.

The primary site conditions controlling the selection and design of an excavation system include soil and rock type and stratigraphy, soil and rock strength and consolidation parameters, and groundwater conditions. These can be identified using methods described in Chapters 2 and 3 of DM 7.1 and FHWA (2017) Additional considerations include the required excavation depth, side and bottom stability, construction procedures, excavation support system stability, and vertical and lateral movements of adjacent areas and existing structures.

2-2 OPEN CUT EXCAVATIONS.

2-2.1 Sloped Excavations.

The methods described in Chapter 7 of DM 7.1 may be used to evaluate the stability of sloped excavations in soils and rocks. In clay soils, instability typically involves side slopes but may also include soils below the base of the excavation. Clay soils that increase in shear strength with depth typically exhibit failures that occur on the side slopes. For clay soils that exhibit relatively constant shear strength with depth, the failure may extend into the base of the excavation. In coarse-grained soils, instability usually does not extend significantly below the base of the excavation, provided seepage is controlled. In rock, stability is often controlled by adversely orientated planes of weaknesses such as joints, foliation planes, or faults.

In some problem soils, and in rocks with adversely orientated geologic planes of weaknesses, special considerations are needed when evaluating stability of open cut excavations as discussed in Section 2-7. In any soil, the stability of excavated slopes may decrease with time, saturation, and disturbance. Some soils may not conform to common shear strength correlations used in design. For example, the properties of residual soil, which cover about half of Earth’s land mass, are difficult to relate to stress history. Local knowledge may be helpful when determining the analysis approach in these problem soils.

Slope stability can be improved by reducing the driving forces that cause instability. The top of a slope can be lowered, or the slope angle can be reduced, if an adequate factor of safety against instability is not achieved. Surcharge loading from equipment and/or stockpiles should be kept away from the top of an excavation when these negatively impact stability.

2-2.2 Vertical Excavations.

2-2.2.1 Clay Soils.

Many cuts in clays will stand with vertical slopes for a period of time before failure occurs. The maximum depth of a vertical cut in clay, or *critical depth*, (H_{crit}) is defined as:

$$H_{crit} = \frac{4s_u}{\gamma_t} \qquad (2\text{-}1)$$

where:
s_u = undrained shear strength and
γ_t = total or moist unit weight of the clay.

However, changes in the shear strength of the clay with time and stress release resulting from the excavation can lead to progressive deterioration in stability. The Occupational Safety and Health Administration (OSHA) requires all excavations be sloped and trenches supported if greater than 5 ft in depth (OSHA 2020).

2-2.2.2 Rock.

Excavations in rock can be made vertical without support (rock bolts or tieback anchors) depending on the rock quality, lack of adversely oriented joints and faults, and sufficient mobilized shear strength along structural features to provide a stable condition. The stability of rock slopes is also covered in Chapter 7 of DM 7.1.

2-2.3 Other Design Considerations for Open Cut Excavations.

Dewatering may be required to allow construction without water in the excavation.[7] Dewatering increases effective stress and can cause settlement under nearby structures. It may be necessary to consider installation of a low permeability cutoff trench, filled with soil-bentonite or soil-cement-bentonite mixtures, between the

[7] Sometimes referred to as "in the dry."

excavation and nearby structures. Dewatering in an area of carbonate rocks may cause sinkhole development. Additional discussion about dewatering can be found in Section 2-6 and Unified Facilities Criteria (UFC) UFS 3-220-05 (DoD 2004). Perimeter drains should be used around an excavation to prevent surface water from flowing into the excavation and causing erosion.

The excavation and surrounding area should be monitored during excavation. Bottom heave, slope movement, and settlement of areas beyond the slope should be carefully observed and monitored. Monitoring can be accomplished by conventional survey techniques, heave points, and piezometers (see DM 7.1, Chapter 2). Piezometers can be used to investigate excess pore pressures below an excavation and the potential for piping or heaving.

Structures near excavated slopes may need to be underpinned. Underpinning (Section 2-4.4) should be considered when the bearing elevation of the foundations is higher than the bottom of the excavation and influenced by critical failure surfaces for the slope.

The effect of vibrations from blasting, pile driving, and heavy equipment movements on settlement or damage to adjacent structures should also be considered. Prior to any activity that may cause damage due to vibrations, a preconstruction survey with photographs should be performed. In addition, a test blast program should be required before any blasting. During construction, vibration monitoring is critical. The impact of vibrations on rock with adversely oriented rock structure should also be evaluated. See Section 2-5.3 for additional discussion of blasting.

2-3 TRENCHING.

2-3.1 Site Exploration.

Individual trenching projects frequently extend over long distances. An exploration program should be performed to define the soil and groundwater conditions over the full extent of the project so that the design of the shoring system can be adjusted to accommodate varying subsurface conditions.

2-3.2 Trench Stability.

Excavation support for trenches is regulated by OSHA (2020). Principal factors influencing trench stability are the lateral earth pressures (see Chapter 4) on the wall support system, bottom heave, and the pressure and erosive effects of infiltrating groundwater (see Chapter 6 of DM 7.1). Additional external factors which influence trench stability include:

- Surface surcharge loads,
- Vibration loads,

- Groundwater seepage, and
- Surface water flow.

2-3.2.1 Surface Surcharge Loads.

Surface loads may be present adjacent to a trench and cause loading on the trench support system. The effects of surface loads should be considered if the load is between the edge of the excavation and the intersection of the ground surface with the possible failure plane. Section 4-4.2 provides additional guidance on earth pressures caused by surface loading.

2-3.2.2 Vibration Loads.

The effects of vibrating machinery, blasting, other dynamic loads, and earthquakes in the vicinity of the excavation must be considered. The effects of vibrations are cumulative over periods of time and can be particularly dangerous in soft clays which amplify vibrations. In addition, vibrations from earthquakes or blasting can cause loose contractive sands and silts to fail as brittle materials at low strains. Once disturbed, these materials flow, which can result in catastrophic damage. Excavations in these types of soil are very problematic. While dense coarse-grained soils are also brittle and fail at low strains, they do not flow and are not problematic for excavations. If blasting is required in a trench, the size of the charge should be as small as possible, and the effect of vibrations on settlement of or damage to adjacent structures must be considered.

2-3.2.3 Groundwater Seepage.

Groundwater seepage at the bottom of an excavation can result in bottom heave. *Bottom heave* refers to upward movement of the base of the excavation caused by a high upward gradient that exceeds the critical gradient of the soil. This is also referred to as a *quick* condition. Heaving or quick soils lose all or most of their shear strength because the effective stress approaches zero. Bottom heave can occur in coarse-grained soils that are improperly dewatered.

In addition to heave, seepage can result in *internal erosion*, which is the movement of soil particles from within the soil structure. Fine sands and silts are most susceptible to internal erosion. Prediction methods and design for internal erosion are discussed in Chapter 6 of DM 7.1.

2-3.2.4 Surface Water Flow.

Uncontrolled surface water can enter the retained soil, increase the water content, and potentially result in saturation. Saturation greatly increases loads on the wall support system and may reduce the shear strength of the soil. Site drainage should be designed to divert surface water away from trenches. This is especially important for the zone between the edge of the excavation and the intersection of a possible failure plane with the ground surface.

2-3.3 Support Systems.

OSHA (2020) requires protective measures for any trench greater than 5 feet deep, except in stable rock. Protective measures are also required for some excavations at any point less than 5 feet deep where there is evidence of a potential cave-in as determined by a *competent person*. OSHA (2020) describes a competent person as someone capable of identifying hazards or unsafe working conditions who possesses authority to take corrective measures.[8]

Shoring and sheeting plans should be certified by a registered professional engineer. For trenches greater than 20 feet deep, a licensed professional engineer must approve the design (OSHA 2020).

The commonly used excavation support systems discussed in the following sections include trench shields, hydraulic shoring, timber shoring, and steel shoring. Cross braces or trench jacks shall be placed in true horizontal position; spaced vertically; and secured to prevent sliding, falling, or kickouts.

2-3.3.1 OSHA Soil Types.

OSHA (2020) defines Soil Types A, B, and C for the design of trenches as summarized in Table 2-1. Appendix A of the OSHA manual provides definitions of terms used in defining these soil types. OSHA's definitions do not conform to the Unified Soil Classification System (ASTM D2487).

2-3.3.2 Trench Shield.

A *trench shield* is a rigid prefabricated steel support system used in lieu of other types of shoring, which extends from the bottom of the excavation to the ground surface. The trench shield is placed within a wider excavation with vertical walls and protects the enclosed space from trench collapse. Piping systems or other structures are constructed within the shield, which is pulled ahead, as trenching and construction proceed. Figure 2-1(a) illustrates a trench shield. This system is useful in most soils with the exception of very dense or hard soils. The trench shield must extend to the ground surface of vertical excavations. Where part of the excavation is sloped, the trench shield extends 18 inches above the toe of the slope as shown in Figure 2-1(b).

---

[8] See OSHA (2020) Paragraph 652(a)(1)(ii) for the legal definition of competent person.

The trench shield must be designed for the full height of the excavation including the sloped portion above the trench shield.

Table 2-1 Soil Types (after OSHA CFR Part 1926, Subpart P, Appendix A)

Soil Type	Soil Description	Unconfined Compressive Strength (tsf)	Estimated Soil Classification (USCS) (ASTM D2487)	Exclusions or Inclusions
A	Cohesive[A]	>1.5	CH, CL, MH, SC, GC, OH, including cemented soils	Type A cannot be: • Fissured, • Previously disturbed, • Dipping into excavation at a slope > 4H:1V • Subject to vibration from traffic
B	Cohesive	>0.5 to < 1.5	CH, CL, SC, GC, OH	Include soil that categorizes as Type A but is fissured, previously disturbed, or subject to vibrations. Exclude soils from Type B that have layers that dip into the excavation at a slope > 4H:1V.
	Granular cohesionless[B]	--	ML, OL, SM, SW, SP, GM, GW, GP	
C	Cohesive	<0.5	CH, CL, SC, GC, OH	Include soil that categorizes as Type A or B but has layers that dip into excavation at a slope > 4H:1V
	Granular cohesionless	--	ML, OL, SM, SW, SP, GM, GW, GP	

OSHA Defintions:

[A] "Cohesive soil means clay (fine grained soil), or soil with a high clay content, which has cohesive strength. Cohesive soil does not crumble, can be excavated with vertical side slopes, and is plastic when moist. Cohesive soil is hard to break up when dry, and exhibits significant cohesion when submerged. Cohesive soils include clayey silt, sandy clay, silty clay, clay and organic clay."

[B] "Granular soil means gravel, sand, or silt (coarse grained soil) with little or no clay content. Granular soil has no cohesive strength. Some moist granular soils exhibit apparent cohesion. Granular soil cannot be molded when moist and crumble easily when dry."

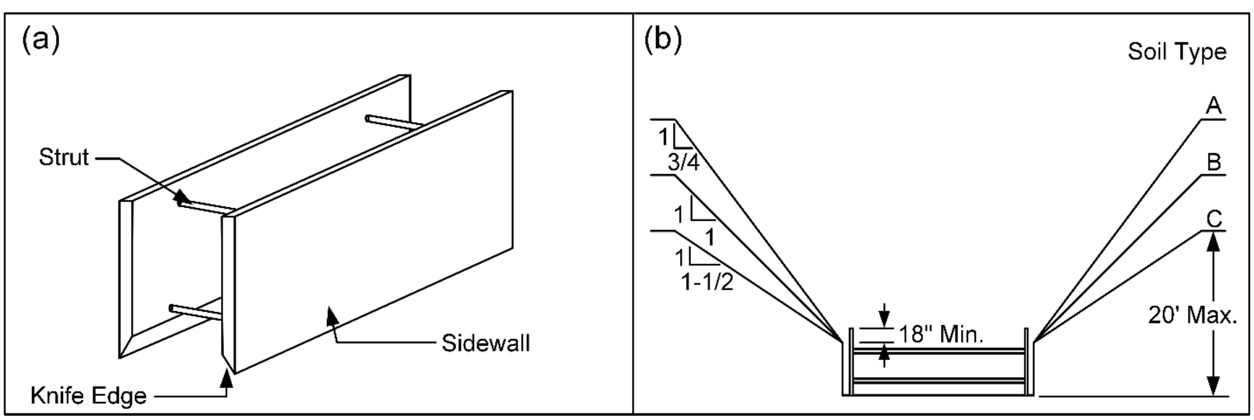


Figure 2-1 Trench Shield; a) Typical Trench Shield, b) Maximum Slopes for Various Soil Types Defined by OSHA (after OSHA Technical Manual)

Excavation depths of up to 20 feet are permitted by OSHA (2020) using manufactured trench shields designed in accordance with OSHA standards. These shields should be used in accordance with the manufacturer's specifications, recommendations, tabulated data, and limitations. Shield systems must not be subjected to loads exceeding those which the system was designed to withstand.

Excavations up to 2 feet below the shield are permitted when the shield is designed to resist the forces for the full depth of the trench. This type of excavation is only permitted when there is no indication of loss of soil from behind or below the bottom of the shield. When designing for an excavation below the bottom of the shield, consideration must be given to the potential for internal erosion or heaving. During use, the excavation should be observed for evidence of these problem conditions. Surcharge loading, vibrations, or loads from adjacent structures also must be considered.

2-3.3.3 Hydraulic Shoring.

Hydraulic shoring consists of aluminum hydraulic cylinder braces and heavy plywood (Finform) sheets. It has gained popularity over timber shoring, because it is less costly and does not require workers to enter a trench to construct the shoring. Table 2-2 and Table 2-3 provide hydraulic shoring requirements from OSHA (2020). Figure 2-2 illustrates typical applications of hydraulic shoring (OSHA 2020).

Hydraulic shoring can typically be used to a depth of about 25 feet with trench widths up to 12 feet. The trench width can be increased with cylinder extensions referred to as *steel tube oversleeves*. Hydraulic shoring design guidelines are found in OSHA (2020) Appendix D, Item (g).

Table 2-2 Aluminum Hydraulic Shoring - Soil Types A and B, No Walers (after OSHA 2020 Appendix D, Tables D-1.1 and D-1.2)

OSHA Soil Type	Depth of Trench, H (ft)[A]	Hydraulic Cylinder Spacing and Diameter				
		Maximum Horizontal Spacing, (ft)	Maximum Vertical Spacing (ft)	Cylinder Diameter for Trench Width, B (ft)		
				$B < 8$	$8 \le B < 12$	$12 \le B < 15$
A	$5 \le H < 10$	8	4	2 in.	2 in.[B]	3 in.
	$10 \le H < 15$	8	4			
	$15 \le H < 20$	7	4			
B	$5 \le H < 10$	8	4	2 in.	2 in.[B]	3 in.
	$10 \le H < 15$	6.5	4			
	$15 \le H < 20$	5.5	4			

Notes:
[A] Design trench with depths greater than 20 feet using manufacturers' tabulated data, and refer to Code of Federal Regulations (CFR) Part 1926, Subpart P 652(c)(2) and 652(c)(3).
[B] At this width, 2-inch diameter cylinders shall have structural steel tube oversleeves (3.5x3.5x0.1875 in), or structural oversleeves of manufacturers' specification, extending the full, collapsed length.

Table 2-3 Aluminum Hydraulic Shoring – Soil Types B and C with Wales (after OSHA 2020 Appendix D, Tables D-1.3 and D-1.4)

OSHA Soil Type	Depth of Trench, *H* (ft)[A]	Wales		Hydraulic Cylinder Spacing and Diameter for Trench Width, *B* (ft)						Timber Uprights (in. x. in.)		
				B < 8		8 ≤ *B* < 12		12 ≤ *B* < 15				
		Vertical Spacing (ft)	Section Modulus (in.^{3})	Horizontal Spacing (ft)	Cylinder Diameter (in.)	Horizontal Spacing (ft)	Cylinder Diameter (in.)	Horizontal Spacing (ft)	Cylinder Diameter (in.)	Solid Sheet	2 ft Horizontal Spacing (O.C.)[C]	3 ft Horizontal Spacing (O.C.)
B	5 to <10	4	3.5	8.0	2	8	2[B]	8	3	--	--	3x12
			7.0	9.0	2	9	2[B]	9	3			
			14.0	12.0	3	12	3	12	3			
	10 to <15	4	3.5	6.0	2	6	2[B]	6	3	--	3x12	--
			7.0	8.0	3	8	3	8	3			
			14.0	10.0	3	10	3	10	3			
	15 to <20	4	3.5	5.5	2	5.5	2[B]	5.5	3	3x12	--	--
			7.0	6.0	3	6	3	6	3			
			14.0	9.0	3	9	3	9	3			
C	5 to <10	4	3.5	6.0	2	6.0	2[B]	6.0	3	3x12	--	--
			7.0	6.5	2	6.5	2[B]	6.5	3			
			14.0	10.0	3	10.0	3	10.0	3			
	10 to <15	4	3.5	4.0	2	4.0	2[B]	4.0	3	3x12	--	--
			7.0	5.5	3	5.5	3	5.5	3			
			14.0	8.0	3	8.0	3	8.0	3			
	15 to <20	4	3.5	3.5	2	3.5	2[B]	3.5	3	3x12	--	--
			7.0	5.0	3	5.0	3	5.0	3			
			14.0	6.0	3	6.0	3	6.0	3			

Notes:
[A] Design trench with depths greater than 20 feet using manufacturers' tabulated data, and refer to CFR Part 1926, Subpart P 652(c)(2) and 652(c)(3).
[B] At this width, 2-inch diameter cylinders shall have structural steel tube oversleeves (3.5x3.5x0.1875) or structural oversleeves of manufacturers' specification, extending the full, collapsed length.
[C] O.C. stands for on center spacing.

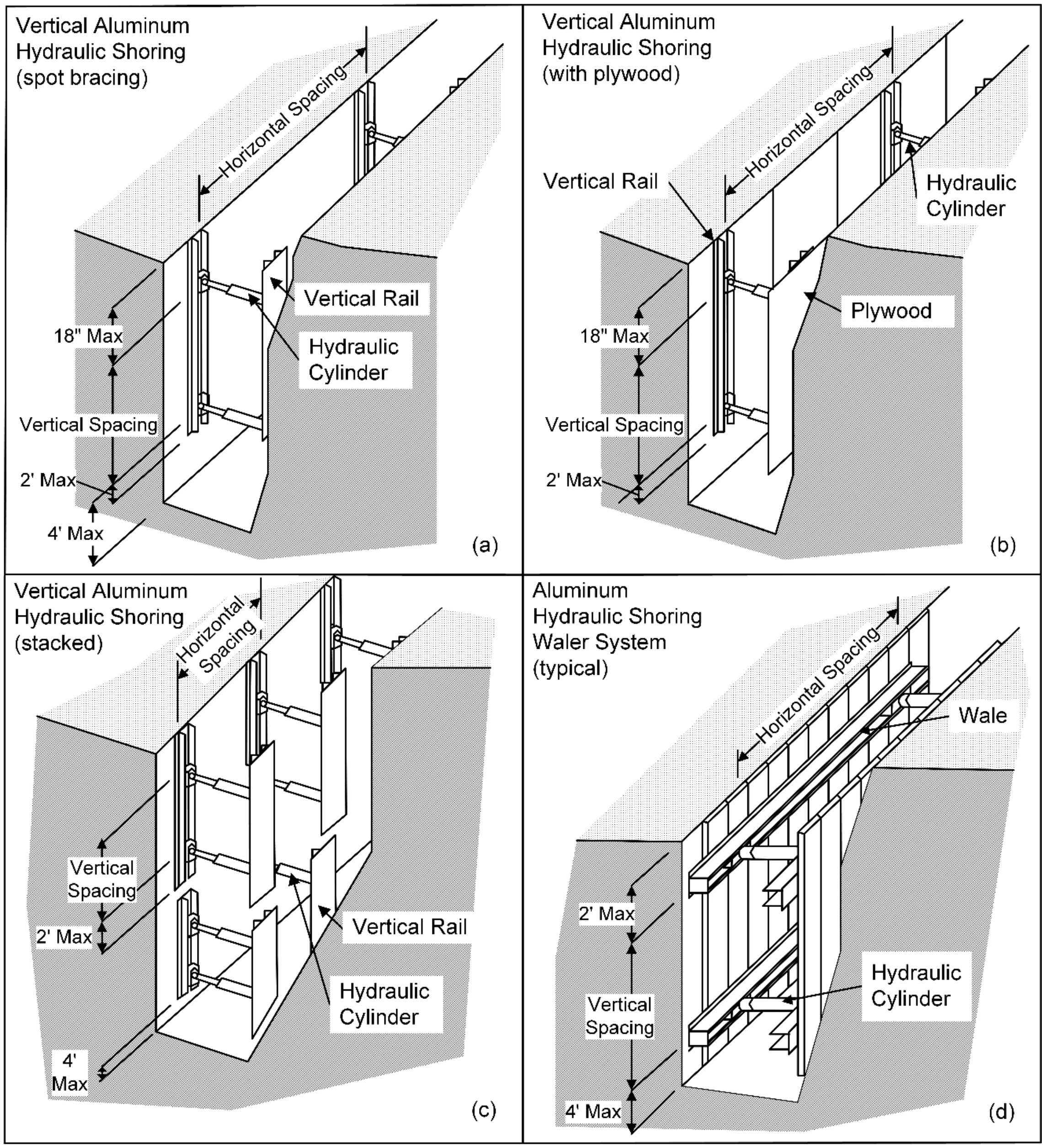


Figure 2-2 Hydraulic Shoring - a) Spot Bracing, b) Plywood, c) Stacked, and d) Waler System (after OSHA Technical Manual 2020)

2-3.3.4 Timber Shoring.

Timber shoring uses a temporary structure made of wood to support a trench. The four types of timber shoring are illustrated in Figure 2-3. The systems use vertical uprights or horizontal timbers against the soil, which are supported by a system of wales and cross-braces. *Skeleton shoring* does not use continuous upright members and is applicable when running soils[9] are not expected. It can be used to depths up to 20 feet. *Close (tight) shoring* uses continuous upright timbers to support the soil and is useful where seepage and cave-ins are expected. *Box shoring* uses horizontal timbers to support the soil. Box shoring is applicable to trenching in any soil and is only limited in depth by the structural strength and size of the timber. *Telescopic shoring* is used for very deep trenches and consists of nested trenches that decrease in width as the trench depth increases.

Timbers used for shoring must be sound and free from large or loose knots. Timber shoring must be designed and installed to the bottom of the excavation. Braces and uprights for timber shoring must be installed at the same time as the excavation. Braces and diagonal shores of timber should not be subjected to compressive stresses in excess of the allowable compressive stress. The allowable compressive stress will vary by species of wood. Additional information on the structural properties of timber can be found in Section 6-7.1.1.3 as well as the *Wood Handbook* (USDA 2010). The allowable compressive stress will decrease as the slenderness of the shoring member increases. The ratio of length to least width is typically limited to 50 or less.

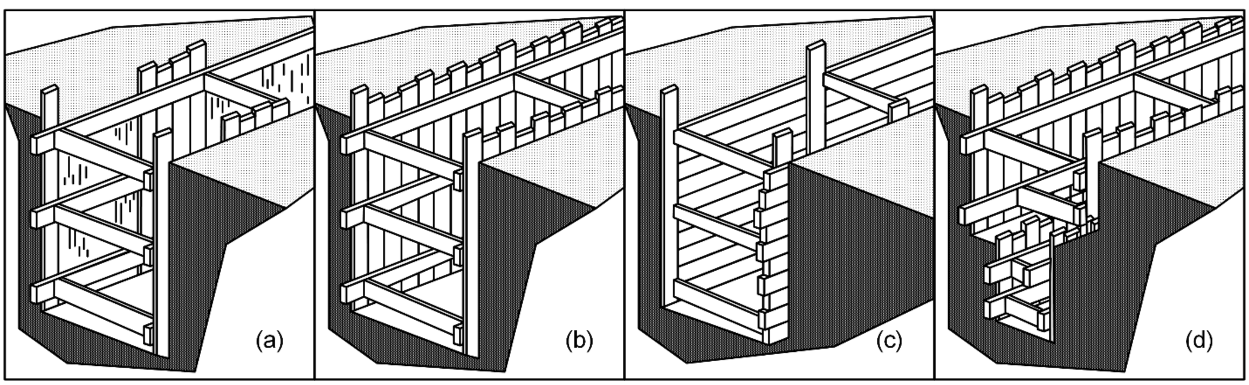


Figure 2-3 Timber Shoring: a) Skeleton; b) Close (tight); c) Box; d) Telescoping (after OSHA Technical Manual 2020)

Table 2-4 summarizes the OSHA (2020) minimum requirements for trench shoring. The data in the table are for nominal size timber with spacing measured center to center. A maximum of two feet of soil surcharge adjacent to the trench and a maximum equipment surcharge of 20,000 lb are assumed in the design. The region adjacent to the trench is defined as a horizontal distance on each side of the trench equal to its depth. OSHA (2020) indicates that tight sheeting, such as tongue and groove timber at least three inches thick or steel sheet piling, must be used when submerged conditions are encountered to resist the lateral water pressure and to reduce loss of fines behind

---

[9] Running soils have no ability to hold a vertical face and will flow or cave into the excavation if unsupported. Clean, dry coarse-grained soils are an example. Seepage can also result in running soil.

the sheeting. Table 2-4 does not cover the case of submerged conditions. A licensed professional engineer must approve the design for trenches greater than 20 ft deep, submerged conditions, and other conditions as noted in Table 2-4.

Table 2-4 Minimum Requirements for Timber Trench Shoring (after OSHA 2020)

OSHA Soil Type	Trench Depth, H (ft)	Size (Nominal) and Spacing of Members[B,C,D]									
		Cross Brace Spacing and Size							Wales		Upright Size (in x in) @ Maximum Allowable Horizontal Spacing, (ft) (0 = OSHA Close Spacing)
		Brace Spacing (ft)		Size of Members (in x in) for Specified Trench Width:							
		Horizontal	Vertical	≤ 4 ft	≤6 ft	≤9 ft	≤12 ft	≤15 ft	Size (in x in)	Vertical Spacing (ft)	
A	5 to 10	≤ 6	4	4x4	4x4	4x4	4x4	4x6	None	-	4x6@6
		≤ 8					4x6				4x8@8
		≤ 10		4x6	4x6	4x6	6x6	6x6	8x8	4	4x6@5
		≤ 12[A]									4x6@6
	10 to 15	≤ 6	4	4x4	4x4	4x4	6x6	6x6	None	-	4x10@6
		≤ 8		4x6	4x6	4x6			6x8	4	4x6@4
		≤ 10[A]		6x6	6x6	6x6			8x8		4x8@5
		≤ 12[A]							8x10		4x6@4,4x10@6
	15 to 20	≤ 6	4	6x6	6x6	6x6	6x6	6x6	6x8	4	3x6@0
		≤ 8[A]							8x8		3x6@0, 4x12@4
		≤ 10[A]						6x8	8x10		3x6@0
		≤ 12[A]					6x8		8x12		3x6@0, 4x12@4
B	5 to 10	≤ 6	5	4x6	4x6	4x6	6x6	6x6	6x8	5	3x12 @3, 4x12@5
		≤ 8				6x6			8x8		3x8@2, 4x8@4
		≤ 10						6x8	8x10		4x8@3
	10 to 15	≤ 6	5	6x6	6x6	6x6	6x8	6x8	8x8	5	3x6@0, 4x10@2
		≤ 8		6x8	6x8	6x8	8x8	8x8	8x10		
		≤ 10[A]				8x8			10x12		
	15 to 20	≤ 6	5	6x8	6x8	6x8	6x8	8x8	8x10	5	4x6@0
		≤ 8[A]					8x8		10x12		
		≤ 10[A]		8x8	8x8	8x8			12x12		
C	5 to 10	≤ 6	5	6x6	6x6	6x6	6x6	8x8	8x8	5	3x6@0
		≤ 8					8x8		10x10		
		≤ 10				8x8			10x12		
	10 to 15	≤ 6	5	6x8	6x8	6x8	8x8	8x8	10x10	5	4x6@0
		≤ 8		8x8	8x8	8x8			12x12		
	15 to 20	≤ 6	5	8x8	8x8	8x8	8x10	8x10	10x12	5	4x6@0

Refer to OSHA (2020) Appendix C, Tables C-2.1 through C-2.3 for more information. Notes:

[A] A licensed professional engineer must approve the design in accordance with CFR Part 1926 Subpart P Excavations Paragraph 926.652(c) for combinations of depth, soil type, and spacing not listed.

[B] Member sizing considers effective horizontal stress calculated as follows where H = depth of trench: Soil Type A: σ'_h = (25×H)+72 psf; Soil Type B: σ'_h = (45×H)+72 psf; and Soil Type C: σ'_h = (80×H)+72 psf. An assumed 2 ft surcharge is accounted for by the added 72 psf.

[C] Timber is Douglas fir or equivalent with a bending strength ≥ 1,500 psi.

[D] Manufactured members of equivalent strength may be substituted for wood.

2-3.3.5 Steel Shoring.

Steel sheeting and bracing can be used in lieu of hydraulic or timber shoring. Structural members should be designed to safely withstand water and lateral earth pressures. Steel sheeting with timber wales and struts have also been used.

2-4 DEEP EXCAVATION SYSTEMS.

The discussion of deep excavation support systems includes consideration of the factors that influence wall design and selection, design against basal heave, prediction of the movement of walls and the adjacent soil and structures, and construction. Further information can be found in FHWA (2008) and Clough and O’Rourke (1990). Detailed discussion of earth pressures is included in Chapter 4.

2-4.1 Types of Wall and Support Systems.

Deep excavation support systems are sometimes required to facilitate the construction of structures below ground. Design of these support systems must consider how much they will move during construction and how this movement will impact surrounding structures and the project to be built within the excavation. Movements of deep excavation walls are a function of many variables including:

- Soil type, strength, compressibility, permeability, and earth pressures;
- Groundwater level and changes in the groundwater level during construction;
- Depth and shape of excavation;
- Type and stiffness of wall;
- Type and stiffness of support system;
- Method of construction of the wall;
- Adjacent building and surcharge loads; and
- Length of time the deep excavation support system is in place.

Experience with deep excavations indicates three major types of movement during construction of braced and tied-back deep excavation walls (Clough and O’Rourke 1990). The first stage of movement occurs when the wall is unsupported or in the cantilever condition as shown in Figure 2-4(a). In this first stage, the largest movements occur near the top of the wall. As the excavation moves downward, the upper part of the wall is supported, reducing further movement. However, additional lateral and vertical movement can occur as the resistance of the support system is mobilized. Movement can also occur before the additional supports are installed, and basal movement can occur as shown in Figure 2-4(b). Clough and O’Rourke described this movement as *deep inward movement*. The cumulative movement is shown in Figure 2-4(c).

Variation occurs in the magnitude of movement because of differences in wall stiffness, depth of excavation without support installation, and soil conditions. Clough and

O'Rourke note that in sands and stiff to hard clays, cantilever movement typically dominates, and settlement behind the wall has a triangular distribution. In soft to medium clays, deep inward movement dominates, and settlement behind the wall takes on a trapezoidal distribution.

The major types of deep excavation wall systems include sheet piling, combined sheet piling with H-piles or pipe piles (See Figure 2-5), soldier piles (H-piles) and lagging, concrete diaphragms, secant and tangent pile walls, and deep soil mixing. The factors involved in the selection of a wall type are summarized in Table 2-5.

Support systems, shown in Figure 2-6, may be internal to the excavation, such as rakers, cross lot struts, or braces. External support systems include prestressed tieback anchors and soil nails. Berms can be added to any support system to help reinforce the toe of the wall. Berms used for temporary support must consider the movement required to achieve passive resistance. A berm constructed from stiff or dense soil is more effective compared to a loose berm because passive pressure is developed with less movement. A low factor of safety against basal heave may allow the berm to move with the soil and provide minimal passive resistance. Table 2-6 summarizes project conditions that influence the selection of a support system.

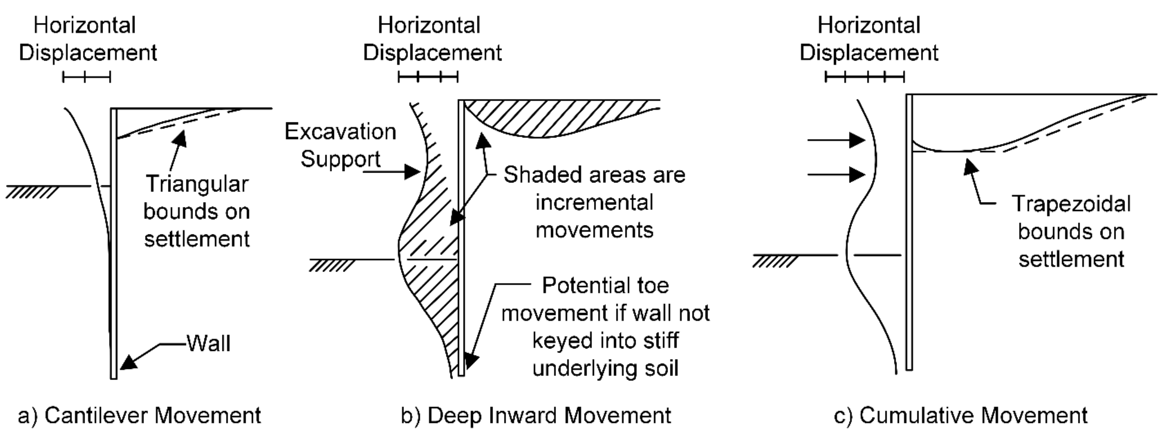


Figure 2-4 Typical Profiles of Movement for Braced and Tieback Anchor Walls (after Clough and O'Rourke 1990)

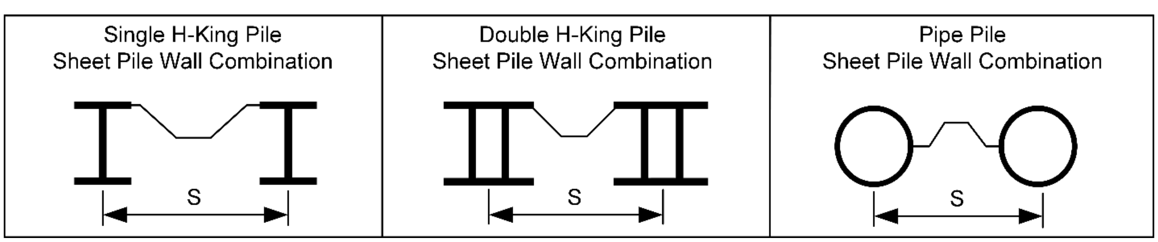


Figure 2-5 Examples of Combined Sheet Piling Cross Sections (after DeepEX Combined Sheet Pile Walls Software 2021)

Table 2-5 Types of Walls and Factors Involved with Selection

Wall Type	Relative Stiffness and Cost	Factors Involved with Selection
Steel Sheet Piling	Flexible Low Cost	• Simple, rapid construction. • Essentially impervious but leakage may occur if interlocks separate. • Materials are easily handled and can be reused. • Easy to modify length by welding. • Interlocks may separate during hard driving. • Use of vibratory hammers may cause settlement. • Every fourth or fifth sheet may be driven deeper to achieve improved bearing and passive resistance. • Basal heave factor of safety, F_{BH} , greater than 2 required in soft to medium clay.
Soldier Pile (H-pile) and Lagging	Flexible Low Cost	• Simple, rapid construction. • Permits drainage of groundwater. • Piles can be driven, or preaugered and backfilled with lean concrete. • Lean concrete compressive strength of 300 psi is usually adequate. • Lagging is usually wood although precast concrete is used for permanent installations. • Backfilling behind lagging helps transfer soil load to H-piles and prevents loss of soil.

Combined Sheet Piling	Inter-mediate Flexibility and Cost	• Types of Combined Sheet Piling (See Figure 2-5) include:
		  o Single king pile (H-pile) with sheet piling,
		  o Double king pile (H-pile) with sheet piling, and
		  o Pipe pile with sheet piling.
		• Essentially impervious but leakage may occur if interlocks separate.
		• King piles can be driven or drilled deeper than sheet piling to achieve bearing or greater passive resistance.
		• Use of vibratory hammers may cause settlement.
		• Complicated construction techniques required.
		• Can reduce potential for basal heave.

Secant Pile	Stiff Inter-mediate Cost	• Surface guide required to properly align piles. • Drilled piles constructed with about 3 inches of overlap. • Essentially impervious, but leakage may occur at overlap of piles if out of alignment. • Piles may be constructed from lean concrete with compressive strength of about 300 psi or structural concrete if foundation bearing unit. • Secondary, unreinforced piles constructed first. • Primary, reinforced piles constructed second. • Vertical tolerances may be difficult to achieve for deep piles • Lean concrete can be shaped to provide anchor bearing with H-pile reinforcement. • Requires significant area for equipment. • Can reduce potential for basal heave.
Tangent Pile		• Piles constructed adjacent to each other without overlap. • Groundwater leakage likely between piles. • See Secant Piles for other factors.
Deep Soil Mix	Stiff Inter-mediate Cost	• Consist of overlapped soil cement columns. • Essentially impervious. • Soil-cement compressive strength of 100 to 150 psi is usually adequate. *In situ* strengths usually less than laboratory strengths of soil-grout mixture. • Reinforcing (H-piles or cages) installed in alternating columns before slurry sets. • Soil cement can be shaved off in excavation if needed to provide anchor or brace bearing with H-pile reinforement. • Not compatible in soils with cobbles and boulders. • Requires significant area for equipment. • Reduces potential for basal heave.
Concrete Diaphragm	Very Stiff High Cost	• Impervious - use when part of permanent structure and when dewatering of adjacent soils must be avoided. • Constructed in panels with reinforcing cages. • Requires significant area for equipment. • Reduces potential for basal heave.

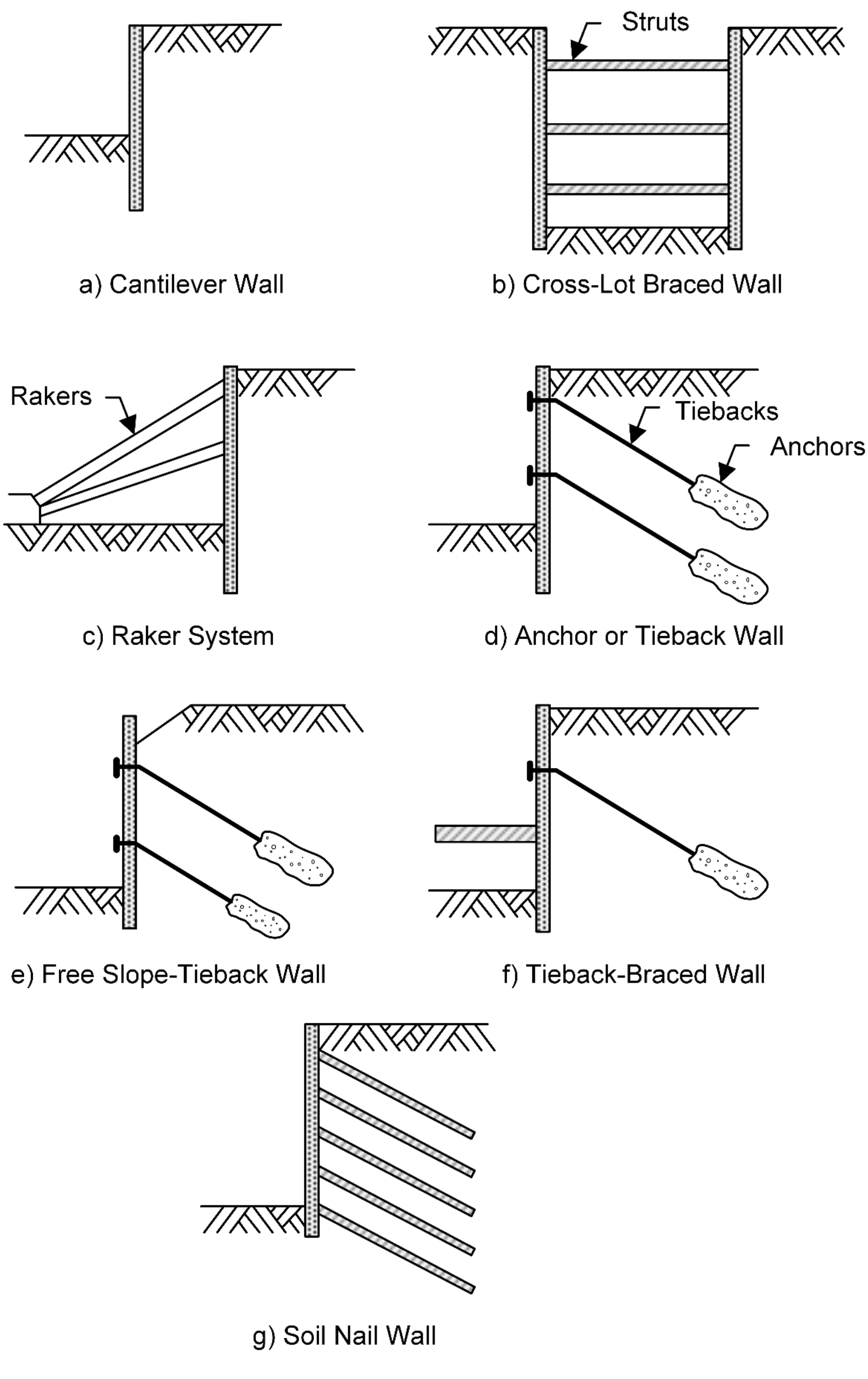


Figure 2-6 Examples of Support Systems (after USACE 1983b and FHWA 2015)

Table 2-6 Factors Influencing the Selection of Support Systems

Requirement	Lends Itself to Use of:	Comments
Low Cost	• Soil slopes combine with soldier pile (H-pile) and lagging or sheet pile wall. • Rakers. • Soil nails.	• Tieback anchors may be required to eliminate internal interference with construction. • Tieback anchors costlier than rakers. • Soil nails are not prestressed.
Avoid Dewatering	• Concrete diaphragm walls are impervious. • Sheet piling, combined sheet piling, secant, and soil mixing walls are essentially impervious.	• Soldier pile and lagging walls are pervious.
Minimize movement	• High prestress on tieback anchors, struts, or rakers.	• Analyze for basal heave.
Wide Excavation ≥ 65 ft	• Tieback anchors or rakers.	• Tieback anchors preferred but costlier than rakers.
Narrow Excavation < 65 ft	• Cross lot bracing.	• Tieback anchors may be required for better interior access.

2-4.2 Site Considerations for Deep Excavations.

2-4.2.1 Influence of Soil Type.

The type of soil supported by a deep excavation will influence the selection of an appropriate type of wall and support system. Table 2-7 provides a guide for this selection process based on soil type.

The soil type will also control the earth pressures and forces on deep excavation systems, which are discussed in detail in Chapter 4. Earth pressures depend on wall movement relative to the soil. When little to no movement occurs, the earth pressure condition is referred to as at-rest. The stress state in the soil approaches an active condition at locations where the wall moves away from the soil. This occurs behind the wall system above the base of the excavation. The stress state in the soil approaches a passive condition at locations where the wall moves toward the soil. This occurs on an embedded portion of the wall system below the base of the excavation. Different amounts of wall movement must occur to fully mobilize active and passive pressures. The movement required to mobilize active pressure is much lower than that required for passive pressure. Restricting wall movement in the passive case greatly reduces the mobilized passive earth pressure, but this is necessary in most design cases due to movement limitations.

Actual earth pressures depend on wall deformation, and this in turn depends on several factors including stiffness of wall and support system, stability of the base of the excavation, and depth of excavation. These factors are discussed in more detail in Sections 2-4.3 and 2-4.4.

Table 2-7 Influence of Soil Conditions on Selection of Deep Excavation Wall and Support Systems

Soil Type	Wall Stiffness Critical to Design	Appropriate Wall and Support Type								Comments
		Sheet Pile	Soldier Pile and Lagging	Combined Sheet Pile	Secant & Tangent Pile	Deep Soil Mix	Concrete Diaphragm	Internal Support	External Support	
Deep Soft to Medium Clays	✓	✓	✓	✓	✓	✓	✓	✓		• High wall stiffness (concrete diaphragm) preferred to reduce movements and basal heave. • Tieback anchors may not be suitable due to low strength of clay. • Soil nails not suitable due to lack of prestressing.
Stiff to Hard Clays and Sands		✓	✓	✓	✓	✓	✓	✓	✓	• Soil nails may not be suitable in sands. • Increased soil stiffness reduces lateral movements. • Higher at-rest earth pressure coefficient, K_0, has potential to increase earth pressure at excavation and cause increased lateral movements.
Dense Sands, Gravels, and Clayey Sands			✓		✓	✓	✓	✓	✓	• Sheet piling and combined sheet piling difficult to drive and interlocks may separate. • Soil nails may not be suitable in sands. • Increased soil stiffness reduces lateral movements.
Soils with Boulders/ Residual Floaters			✓		✓		✓	✓	✓	• Chisels or hydromills may be needed to excavate for concrete diaphragm wall. • Soldier (H-pile) and lagging, secant and tangent piles but may require rock coring. • Vertical alignment of piles may be difficult

2-4.2.2 Influence of Groundwater.

Groundwater conditions must be evaluated during the selection and design of a deep excavation. Some walls are impervious and prevent seepage through the wall. Where water is retained, water pressures on the wall may be greater than earth pressure. Excess pore pressures at the base of an excavation can result in heave, loss of passive resistance, seepage, and internal erosion. Particle erosion can also occur between open pile interlocks, lagging, and gaps in tangent pile walls.

In some cases, the soil adjacent to and below an excavation can be dewatered to improve stability and reduce wall loads. Some walls are not watertight and will allow water to seep into the excavation. The adjacent water level will drop provided the water is removed from the excavation. Dewatering will tend to cause settlement that may be detrimental to adjacent infrastructure. Water levels adjacent to excavations should be monitored before and during construction to confirm design assumptions. The selected wall type must be compatible with the observed groundwater conditions.

2-4.3 Wall and Excavation Stability.

The deep excavation wall and supports must be designed to carry the forces from the earth and water pressures. Chapter 4 provides detail on the methods used to determine these forces so that the structural design of the wall can be completed. Those designs should also include the effects of thermal expansion and contraction on internal bracing, as well as the effects of frost penetration on tiebacks and struts. In addition, wall settlement, global stability, and basal heave must be considered.

2-4.3.1 Wall Settlement.

Earth pressure forces and inclined support system forces have vertical components that can cause settlement of deep excavation wall systems. Wall settlement can cause destressing of tiebacks and stressing of internal bracing systems. Wall settlement must be considered and controlled, because wall design methods typically assume no vertical movement or settlement of the wall.

With the exception of sheet piling or combined sheet piling, the wall system should be driven, drilled, or excavated to a suitable bearing layer to avoid excessive wall settlement. For sheet piling or combined sheet piling, settlement can be reduced by driving or drilling sufficient sheet piles (e.g., every 5^{th} pile) to a suitable bearing stratum. If a bearing stratum is not present, estimates of wall movement should be made using the methods of Chapter 6, and efforts should be made to reduce the vertical component of the support system forces.

2-4.3.2 Global Stability.

Deep excavation design should consider the possibility of deep seated stability below the wall and behind any ground anchors. The stability analyses should consider surface loads from surcharges or adjacent buildings. If there are any berms or slopes in the system, these must also be considered. The stability analyses should be performed using the methods described in Chapter 7 of DM 7.1.

Excavations in rock below the wall may require rock bolting at the toe if bedding or adversely oriented joints dip into excavation or the rock surface slopes into excavation.

2-4.3.3 Basal Instability or Heave.

Basal heave is the tendency of the bottom of an excavation to move upward because of the weight of the soil adjacent to the excavation. Basal heave in deep excavations is usually only an issue where the width of excavation (B) is greater than depth (H). It is primarily a concern for soft to medium clays that extend to significant depth.

A method for calculating basal instability of braced excavations in coarse-grained soils is provided in Figure 2-7(a). Basal instability is less common in coarse-grained soils than clays.

For clays, the method used to calculate the factor of safety against basal heave (F_{BH}) depends on the relative wall flexibility. Flexible walls (e.g., sheet piling) will deform with the soil, and the portion of the wall that penetrates below the base of the excavation is ignored. Stiff walls (e.g., concrete diaphragm) prevent the soil from deflecting toward the base of the excavation. The soil must flow beneath the wall and up towards the base of the excavation for heave to occur. Thus, for stiff walls, the wall penetration below the base is considered. A factor of safety of at least 1.5 should be used against basal heave failure as discussed by Mana and Clough (1981). The normalized wall stiffness, K_{wall}, as defined by Mana and Clough (1981) can be found as:

$$K_{wall} = \frac{EI}{\gamma_t h^4} \tag{2-2}$$

where:
E = Young's modulus of wall,
I = second moment of the area of the wall section ($I = t^3 / 12$ for wall thickness t),
γ_t = total unit weight of the retained soil, and
h = vertical spacing of the support system braces or anchors.

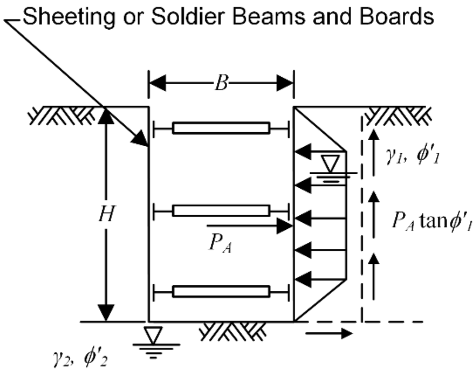
The normalized wall stiffness is greatly influenced by the spacing of the support system, because this variable is raised to the fourth power. A secondary consideration is the movement required to mobilize the support system. Ground anchors and internal bracing can be prestressed to reduce mobilization movement. In contrast, soil nails require movement to develop support forces.

The calculation of basal heave for clays is shown in Figure 2-7(b) and (c). For flexible walls, the driving force is the weight of the soil extending a distance, B_1, beyond the excavation plus the surcharge loading. The resisting force is developed along the sides of the block of soil defined by B_1 and in the soil below the excavation.[10]

[10] This definition of F_{BH} differs from that proposed by Terzaghi (1943) and used by Mana and Clough (1981). The two definitions give similar results for $F_{BH} < 1.5$. Terzaghi (1943) subtracted the strength above the base from the net driving force, which can lead to unreasonably high factors of safety for narrow excavations.

For very stiff walls, the shear resistance in the clay along the inside of the wall may be included. An adhesion factor (α) between the wall and clay is multiplied by the undrained strength of the clay in this layer. Very stiff walls are much more effective at reducing lateral movement and basal heave than flexible walls, producing the higher factors of safety against basal heave.

(a) Cut in Cohesionless Soil



Stability is independent of H and B, but varies with γ, ϕ' and seepage condition.

Factor of Safety: $F_{BH} = 2N_\gamma \left(\frac{\gamma_2}{\gamma_1}\right) K_A \tan\phi'_1$

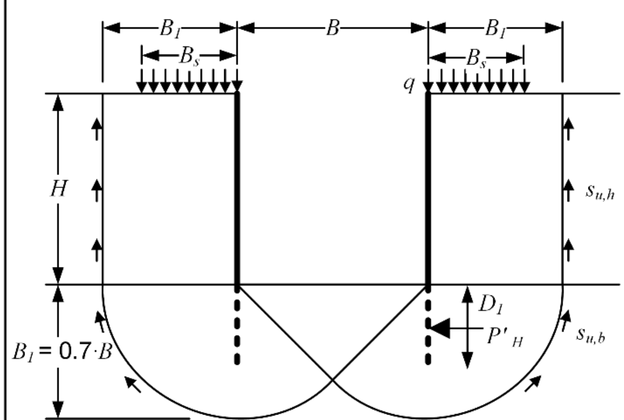
N_γ = bearing capacity factor for soil below excavation (Chap. 5)

K_A = active earth pressure coefficient (see Chap. 4)

Groundwater conditions:

- If groundwater is at a depth of (B) or more below base of cut: γ_1 and γ_2 are moist unit weights
- If groundwater is static at base of cut: γ_1 = moist unit weight, γ_2 = submerged unit weight.
- If seepage is moving upward to base of cut: γ_2 = saturated unit weight – uplift pressure / unit length

(b) Cut in Clay – Flexible Wall



Ignore sheeting below base of cut.

Factor of Safety: $F_{BH} = \dfrac{5.7 s_{u,b} B_1 + s_{u,h} H}{\gamma_t H \cdot B_1 + q \cdot B_s}$

$s_{u,b}$ = average s_u below the base of the excavation

$s_{u,h}$ = average s_u above the base of the excavation

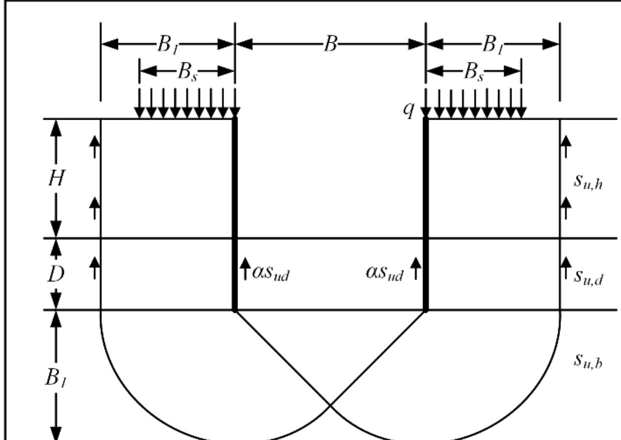
q = Surface surcharge

If the base is unstable, a force, P'_H, acts on the buried length:

$D_1 > 0.47B$: $P'_H = 0.7\left(H\left(\gamma_t \cdot B - 1.4 \cdot s_u\right) - \pi \cdot s_u \cdot B\right)$

$D_1 < 0.47B$: $P'_H = 1.5 D_1 \left(H\left(\gamma_T - \frac{1.4}{B} \cdot s_u\right) - \pi \cdot s_u\right)$

(c) Cut in Clay – Very Stiff Wall



Include adhesion on inside of the wall.

Factor of Safety: $F_{BH} = \dfrac{5.7 s_{u,b} B_1 + s_{u,h} H + (1+\alpha) s_{u,d} D}{\gamma_t H \cdot B_1 + q \cdot B_s}$

$s_{u,h}$ = average s_u above the base of the excavation

$s_{u,d}$ = average s_u along embedded section of the wall

$s_{u,b}$ = average s_u below the base of the excavation

α = adhesion between the clay and the wall

Figure 2-7 Methods for Calculating Factor of Safety Against Basal Instability or Heave (after Wong and Goh 2002)

Flexible walls, such as sheet piling, tend to have normalized wall stiffness in the range of K_{wall} = 10 to 50. Stiffer concrete diaphragm walls often have normalized wall stiffness greater than 100. Soldier piles and wood lagging walls are stiffer than sheet piling walls but are likely to deflect similar to a sheet piling wall. Secant piles, tangent piles, deep soil mix and combined sheet piling walls are not as stiff as concrete diaphragm walls below the base of an excavation. These walls may deflect more than a concrete diaphragm wall but the soil must move around them and up to the excavation. The actual factor of safety against basal heave for walls of intermediate stiffness may lie between the values calculated using the equations found in Figure 2-7(b) and (c), and judgment is required to select the appropriate method to calculate F_{BH}.

2-4.4 Ground Movements Adjacent to Deep Excavations.

Prediction of wall movement is an important part of the design of deep excavation systems. This section presents procedures to estimate (1) the anticipated maximum horizontal or lateral movements and the maximum settlement immediately behind the excavation support wall, (2) the profile of movement with distance from the wall, and (3) methods to predict damage to structures adjacent to excavations.

Observations of settlement behind sheet piling walls and soldier pile (H-pile) and lagging walls in the mid-20th century suggested the trends shown in Figure 2-8 (Peck 1969). The settlement (δ_V) and distance from the wall (d) are both normalized by the depth of excavation (H). The movements shown in Figure 2-8 were state of the practice in the late 1960s and can occur today with poor construction workmanship or by lowering the groundwater during construction, which may increase the load on the wall. Peck separated typical movements into three zones of interest based on soil type and basal stability:[11]

- Zone I – Sand and hard clays (limited soft clay): $F_{BH} > 2$,
- Zone II – Soft clays below excavation: $1 < F_{BH} < 2$, and
- Zone III – Soft clays to significant depth below excavation: $F_{BH} \approx 1$.

[11] Peck (1969) used the stability number. Factor of safety is used here for consistency.

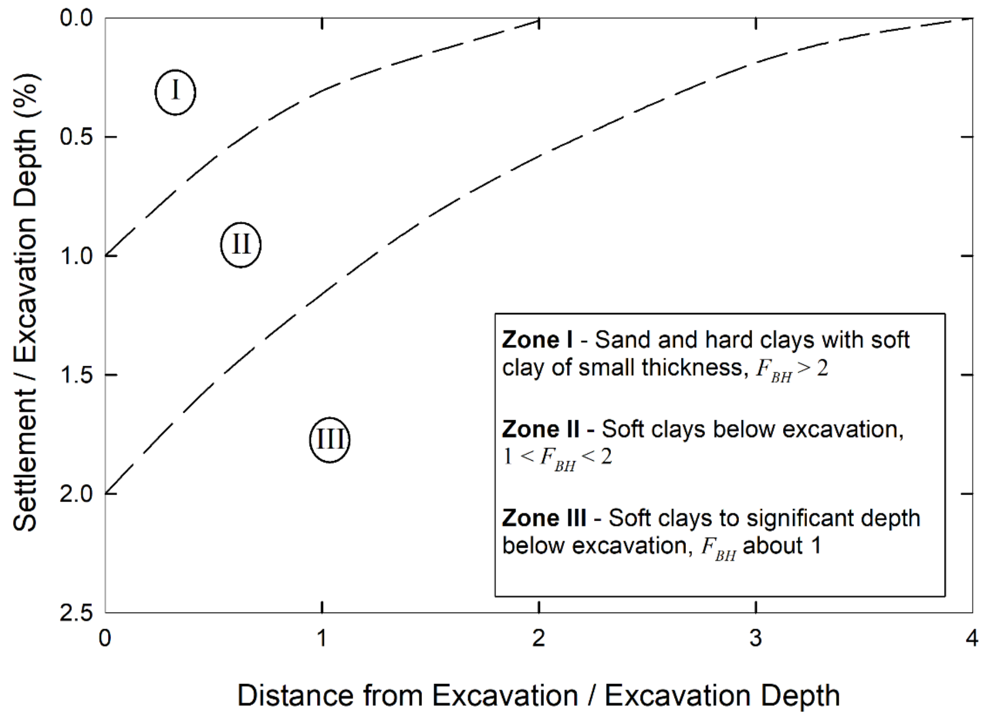


Figure 2-8 Zones of Soil Settlement Behind Excavation Walls (after Peck 1969)

Control of movements has improved in deep excavations. New methods of support and new walls have been introduced since Peck developed Figure 2-8. Clough and O'Rourke (1990) updated Peck's approach and attempted to screen projects to remove movements that were not primarily related to the excavation support processes (O'Rourke 1981, Mana and Clough 1981, Clough et al. 1989). This section presents the subject in the following categories:

- Maximum movements of excavation support walls in stiff clays, sands and residual[12] soils;
- Profiles of movements beyond excavation support walls in stiff to hard clays and sands; and
- Maximum movements of excavation support walls and profiles of movements beyond excavation support walls in soft to medium clays.

Typical values of settlement and horizontal movement at the wall are summarized in Table 2-8. The values are presented as a percentage of the excavation depth (H). The lateral extent of movement is also summarized as a ratio compared to H. More detailed discussion of each soil category is provided in the following sections.

[12] In this context, the term residual soils refer to Piedmont and Blue Ridge Physiographic Province soils derived from weathering of underlying rock which typically are silty to clayey sand and sandy silt.

Table 2-8 Typical Settlement and Horizontal Movement Relative to Height (after Clough and O'Rourke 1990)

Soil Category	Calculated Factor of Safety Against Basal Heave	Settlement, δ_{Vm} / H	Horizontal, δ_{Hm} / H		Lateral Extent of Movement, d / H
			Stiff K_{wall} > 200	Flexible K_{wall} < 50	
Stiff to Hard Clays	High	0.15% average 0.3% max.	0.2%		3
Sand	High	0.15% average 0.3% max.	0.2%		3
Soft to Medium Clay	About 1	2%	1%	> 3%	1.5 to 2
	About 1.5		0.3% to 0.5%	0.8% to 1.7%	
	Greater than 2	1%	0.2%	0.8%	

2-4.4.1 Movements in Stiff Clays, Sands, and Residual Soils.

Based on case histories of walls in these soils, the maximum horizontal (lateral) movement (δ_{Hm}) and the maximum settlement (δ_{Vm}) vary approximately linearly with excavation depth as shown in Figure 2-9 (Clough and O'Rourke 1990). This suggests that the retained soil masses behave approximately as an elastic material. The maximum settlement is presented in Figure 2-9(a) and indicates that the average δ_{Vm} was about $0.15\% \cdot H$ and ranged up to about $0.5\% \cdot H$. Figure 2-9(b) presents the maximum lateral movement and indicates that the average δ_{Hm} was about $0.2\% \cdot H$ and also ranged up to about $0.5\% \cdot H$.

The points with very large movements likely relate to factors other than the support system, such as lowered groundwater or poor construction practices. Some of these points would plot in Zones II and III of Figure 2-8 at $d/H = 0$. The ground movements below the $0.5\%H$ lines can be attributed to movement of the support system and not extraneous factors.

Two important concepts are illustrated in Figure 2-9. The horizontal movement data is more scattered than the settlement data. In addition, there are no significant differences in the data for different types of wall construction (e.g., sheet piling, soldier pile (H-pile) and lagging, diaphragm, drilled piers, deep soil mix).

Clough and O'Rourke (1990) used finite element analyses to confirm the the δ_{Hm} = $0.2\% \cdot H$ trend line indicated by the data in Figure 2-9(b). The effects of soil modulus (E_s), normalized wall stiffness (K_{wall}), support spacing (h), and coefficient of lateral earth pressure (K_0) on wall movements were also studied. K_0 accounts for the higher horizonal earth pressures found in overconsolidated soils. The finite element analyses, which considered the elastic nature of these relatively stiff soils, found that:

- E_s and K_0 generally had a greater impact on wall δ_{Hm} than wall stiffness,
- Higher E_s and lower K_0, yielded lower δ_{Hm}, and

- Lower E_s and higher K_0, yielded higher δ_{Hm}.

In these cases, the soil was stiff enough to minimize the influence of wall stiffness. Figure 2-9 can be used to estimate δ_{Hm} and δ_{Vm} of new excavation support systems in stiff clays, sands, and residual soils.

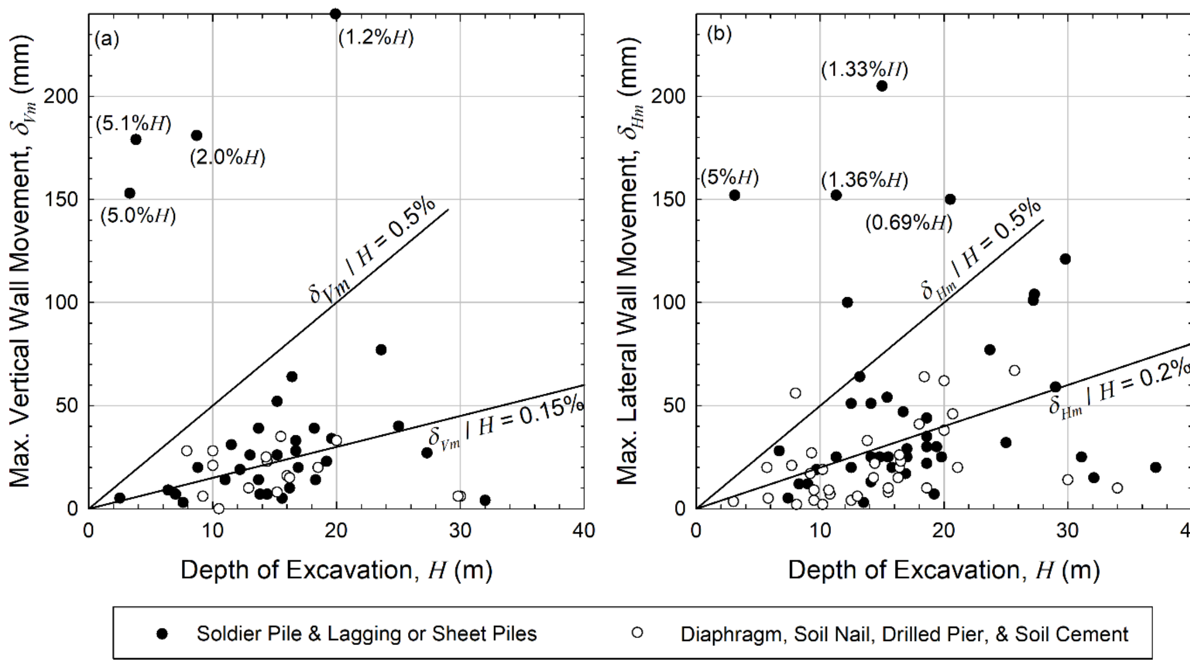


Figure 2-9 Observed Maximum Movements for Stiff Clays, Residual Soils and Sands: (a) Vertical and (b) Horizontal (after Clough and O'Rourke 1990)

Clough and O'Rourke (1990) separated the case history data for stiff and hard clay soils from the sands and residual soils and analyzed the profiles for settlement and horizontal movement of these soils. The next two sections present the profiles of settlement and horizontal movement extending various distances behind the excavation support walls for stiff to hard clays and for sands.

2-4.4.1.1 Profiles of Movement in Stiff to Hard Clays

Figure 2-10 summarizes case histories for stiff to hard clays. The wall and bracing systems include soldier piles and lagging with tieback anchors, concrete diaphragm walls with tieback anchors, concrete diaphragm walls with cross lot struts, drilled shaft walls and tieback anchors, and walls with with internal raker braces. For more information on specific data points, see Clough and O'Rourke (1990).

Settlements: Figure 2-10 indicates that δ_{Vm} ranged from 0% to $0.3\%{\cdot}H$ and averaged about $0.15\%{\cdot}H$. This average maximum settlement is consistent with Figure 2-9(a). The settlement decreased from the wall to negligible values at $d/H = 3.0$ where d is the distance from the face of the excavation support wall. A few of the cases experienced heave due to stress relief experienced by the stiff to very hard clays surrounding the deep excavations. The dimensionless settlement profile (Figure 2-10(c)) may be used to estimate the vertical movement pattern adjacent to an excavation in stiff to hard clay.

Horizontal Movements: Two categories of horizontal movement are shown in Figure 2-10(b). Support system with high horizontal stiffness reduce movement, resulting in a δ_{Hm} of about $0.3\% \cdot H$. An average value of $\delta_{Hm} = 0.2\% \cdot H$ is appropriate for most estimates, which similar to the typical trend shown in Figure 2-9(b). Support systems with low horizontal stiffness allow increased movement, and the maximum lateral movement is up to $0.8\% \cdot H$. Similar to the settlement profile, a triangular horizontal movement profile can be used to estimate the horizontal movement with δ_H decreasing to a negligible value at $d/H = 3.0$.

Very stiff to hard clays and shales may have high *in situ* K_0 in the range of 2 to 3. The value of K_0 can be estimated from the overconsolidation ratio and friction angle (see Equation 4-2). Excavations in these materials may induce lateral stress relief and large lateral movement. Anchors in these materials may move with the soil if not installed beyond the zone of movement, which can conservatively be assumed to extend up from the base of the excavation at an angle of 45° from horizontal.

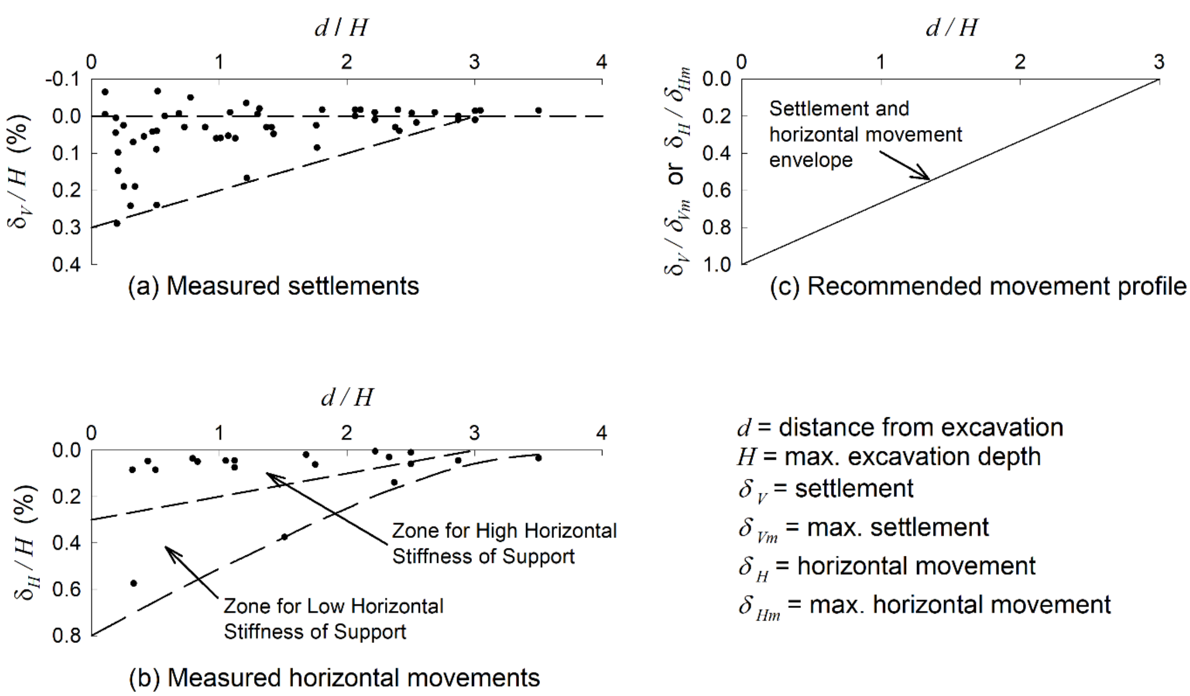


Figure 2-10 Movements Adjacent to Excavations in Stiff to Very Stiff Clays – (a) Measured Settlement, (b) Measured Horizontal Movement, and (c) Recommended Movement Profile (after Clough and O'Rourke 1990)

2-4.4.1.2 Profiles of Movement in Sands

Figure 2-11 summarizes case histories for subsurface profiles consisting of sand or sand and gravel with limited clay layers (Clough and O'Rourke 1990). Groundwater was either lowered, or recharged to reduce settlement, but did not vary during construction. The wall systems include both flexible and stiff walls, including soldier piles and lagging with cross lot struts or tieback anchors, sheet piling with tieback anchors, and concrete diaphragm walls with cross lot struts.

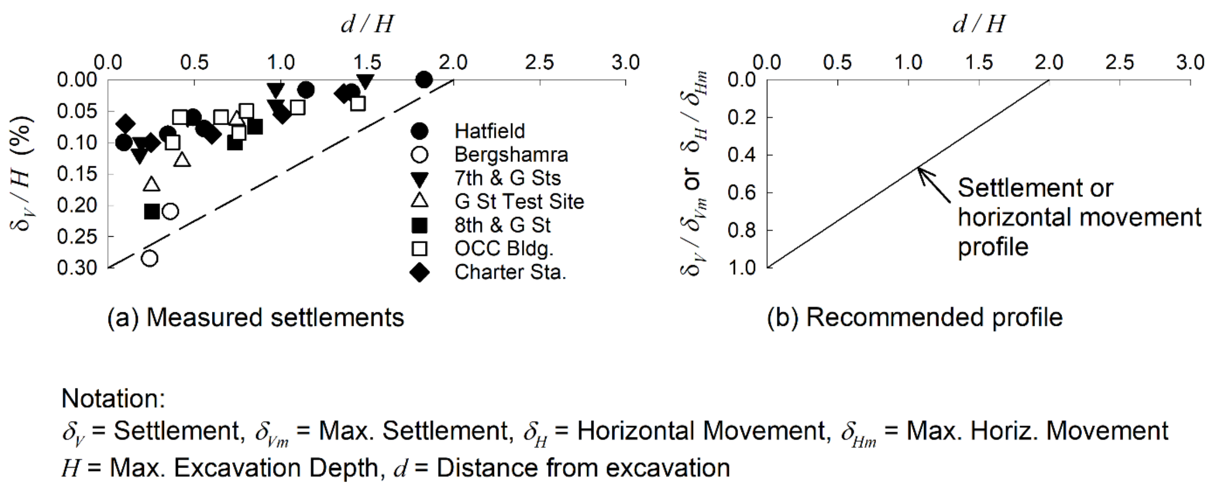


Figure 2-11 Movements Adjacent to Excavations in Sand – (a) Measured Settlement and (b) Recommended Dimensionless Movement Profiles (after Clough and O'Rourke 1990)

Settlements: The maximum settlement tends to be less than $0.3\%\cdot H$ in sand and decreases to a negligible value at $d/H = 2.0$. In the majority of cases, the range of δ_{Vm} was about $0.1\%\cdot H$ to $0.2\%\cdot H$ and averaged about $0.15\% H$, which may be used to estimate the maximum settlement. The dimensionless settlement profile in Figure 2-11(b) may be used to estimate the vertical movement pattern adjacent to an excavation in sand.

Horizontal Movements: Clough and O'Rourke (1990) do not give specific recommendations for horizontal movement in excavations made in sand. For sand, the average value of δ_{Hm} = $0.2\%\cdot H$ can be used from Figure 2-9(b). Horizontal movements are expected to decrease to negligible values at $d/H = 2.0$ with a horizontal movement profile similar to the settlement profile in Figure 2-11(b).

2-4.4.2 Movements in Soft to Medium Clays.

Figure 2-12 summarizes case histories of wall movements in soft to medium clays (Mana and Clough 1981, Clough et al. 1989, Clough and O'Rourke 1990). The types of wall and bracing systems were sheet piling with cross lot struts, soldier piles and lagging with cross lot struts, and concrete diaphragm walls with cross lot struts. On some projects, berms and rakers were used as full or supplemental support. The Peck (1969) zones are included on Figure 2-12(a) for reference.

Settlements: The maximum settlements are limited to about $2\%\cdot H$ and have a trapezoidal profile behind the wall as shown in Figure 2-12(a). The trapezoidal profile extends at $\delta_{Vm} = 2\%\cdot H$ from the wall to $d/H = 0.75$ and then slopes up to $\delta_V = 0.0$ at $d/H = 1.5$ where settlements decreased to negligible values. In most cases, the settlement was less than $1\%\cdot H$. When reasonable care is used during constuction and the factor of safety against basal heave is about 2, $\delta_{Vm} = 1\%\cdot H$ may be assumed. This is true for either flexible or stiff excavation support walls, provided large cantilever movements are limited. When excavation support walls are flexible and the factor of safety against basal heave is less than 1.5, $\delta_{Vm} = 2\%\cdot H$ is a reasonable assumption.

The settlements are normalized by δ_{Vm} in Figure 2-12(b). The settlements fall within a trapezoidal region that extends to zero at d/H of about 1.5 or can conservatively be extended to $d/H = 2$ as proposed by Clough and O'Rourke.

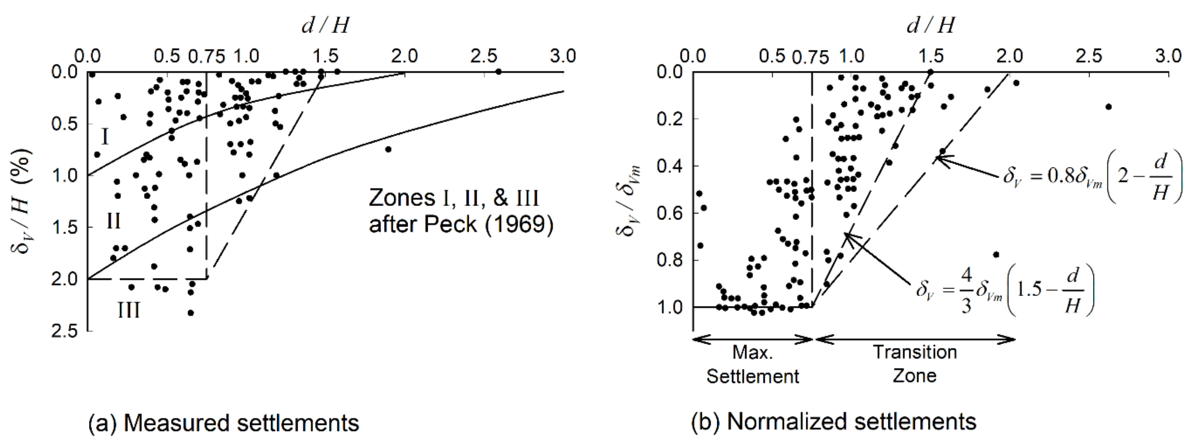


Figure 2-12 Settlement Adjacent to Excavations in Soft to Medium Clays – (a) Measured Settlement and (b) Normalized Settlements with Recommended Settlement Profile (after Clough and O'Rourke 1990)

Horizontal Movements: The case history data of δ_{Hm} / H for soft to medium clays are plotted against normalized wall stiffness in Figure 2-13 for sheet piling and slurry concrete diaphragm walls. The overall wall stability increased as the basal factor of safety is increased as shown in Figure 2-13. For soft to medium clays, horizontal movements are highly dependent on the factor of safety against basal heave. The stiff diaphragm walls generally had a factor of safety greater than 2. The more flexible sheet piling walls had a factor of safety generally less than 1.5 except where the subsurface conditions were favorable to a stable base.

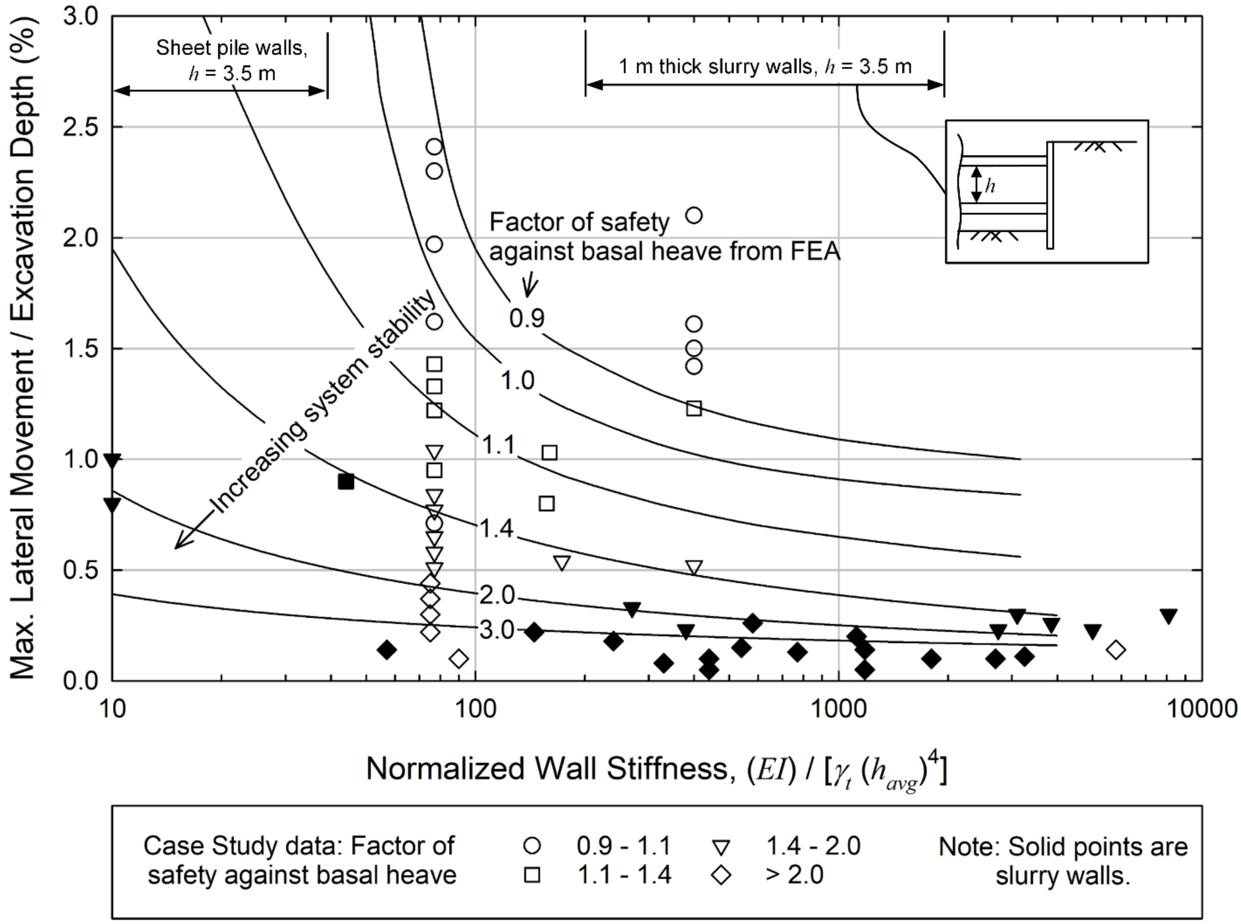


Figure 2-13 Maximum Horizontal Wall Deflection for Soft to Medium Clays (after Clough et al. 1989 and Clough and O’Rourke 1990)

Figure 2-13 also presents the results of finite element analyses by Clough and O’Rourke (1990), which match the case history data well. The finite element curves can be used to select δ_{Hm} / H based on normalized wall stiffness and factor of safety against basal heave for excavations in soft to medium clays. Note that the normalized wall stiffness is greatly influenced by spacing of the bracing or anchors (h). The range of normalized wall stiffness used in the finite element analyses are shown at the top of the Figure 2-13 where the bracing was set at h = 3.5 m or about 12 feet, which is a typical design spacing.

The profile of horizontal movements for soft clays is likely similar to that observed for settlements. Thus, a dimensionless horizontal movement profile similar to that shown in Figure 2-12 for settlement may be assumed for soft to medium clays.

2-4.4.3 Prediction of Damage to Adjacent Structures.

The movements of braced or anchored deep excavation support systems should be evaluated to determine if adjacent structures supported by shallow foundations require underpinning. The distance of existing structures from the excavation support system should be compared to the movement profiles in Figure 2-10 to Figure 2-12. Tolerance of structures to movement is discussed in Chapter 5 of DM 7.1. Other factors that influence the need for underpinning include:

- Lowering groundwater by dewatering may cause soil consolidation and settlement.
- Soldier piles and lagging, sheet piling, and tangent piles all leak to various degrees, and this will lower groundwater.
- Leaks in the excavation support system can also cause loss of fines, piping, and settlement if not properly filtered.

The predicted angular distortion, β, and the horizontal strain, ε_h, across the building can be used to assess damage potential. Angular distortion is the differential vertical movement between two points divided by distance separating the points:

$$\beta = \frac{\delta_{Vi} - \delta_{Vj}}{d_b} \tag{2-3}$$

where:
δ_{Vi}, δ_{Vj} = estimated settlements at two points, i and j, on the building and
d_b = distance separating the points (likely the width of the building).

Similary, the horizontal strain (ε_h) between two points is:

$$\varepsilon_b = \frac{\delta_{Hi} - \delta_{Hj}}{d_b} \tag{2-4}$$

where:
δ_{Hi}, δ_{Hj} = estimated settlements at two points on the building and
d_b = distance separating the points (likely the width of the building).

In most cases, β and ε_h will be measured across the whole building width. In this case, the movements would be estimated at the front and back of the building (compared to the excavation), and d_b would equal the building width. The movements may be estimated from δ_{Vm}, δ_{Hm}, and the movement profile behind the wall, which are found using the methods in Sections 2-4.4.1 and 2-4.4.2.

For stiff to hard clays and sands, the movements can be estimated as:

$$\delta_i = \delta_m \left(\frac{d_0 - d_i}{d_0} \right) \tag{2-5}$$

where:
δ_i = desired horizontal (δ_{Hi}) or vertical (δ_{Vi}) movement at the point of interest,
δ_m = maximum horizontal (δ_{Hm}) or vertical movement (δ_{Vm}) at the wall,
d_i = distance from wall to a point of interest and
d_0 = $3H$ for stiff to hard clays, and $2H$ for sand.

For soft to medium clays, movements can be estimated as:

$$\delta_i = \begin{cases} \delta_m \text{ for } 0 \le d_i \le 0.75H \\ \delta_m \left(\dfrac{1.5H - d_i}{0.75H} \right) \text{ for } 0.75H \le d_i \le 1.5H \end{cases} \quad \text{(2-6)},$$

A method to evaluate the severity of damage from excavations to adjacent structures based on β and ε_h is presented in Figure 2-14 (Clough and O'Rourke 1990). Figure 2-14 maps damage categories for masonry load-bearing wall structures to predicted values of horizontal strain and angular distortion (Boscardin and Cording 1989). The damage categories are negligible, very slight, slight, moderate to severe, and severe to very severe. This damage mapping is based on theoretical structural response to deformation, field observations of building damage, and measurement of building horizontal and vertical displacements. When $\beta \approx 0$, the boundaries for the categories are nearly horizontal and represent horizontal tensile strains that equal the critical tensile strains. When $\varepsilon_h \approx 0$, the boundaries are inclined at about 45° and represent diagonal tensile strains that equal the critical tensile strains.

The estimated ratio of horizontal to vertical movements at the edge of the excavation may be estimated from δ_{Hm} and δ_{Vm}. These ratios are expected to be uniform from the wall to a distance of $d = 0.5\ H$. Ratios of δ_{Hm} / δ_{Vm} are superimposed for stiff soil types in Figure 2-14(a) and for soft to medium clays in Figure 2-14(b) (Clough and O'Rourke 1990, O'Rourke 1981). The ratios are based on the data analyzed in Figure 2-10 to Figure 2-13. In sands and stiff to hard clays, damage typically is bounded by the moderate to severe level, and construction controls can diminish the severity of movement. In soft to medium clays, damage typically is bounded by severe to very severe level, and insufficiently stiff bracing can result in additional movement.

If estimated movements are too large as indicated by Figure 2-14 for the existing structure to tolerate, underpinning will be required. Underpinning methods are described in FHWA (1978). Since underpinning may be required for adjacent buildings when considering deep excavation support systems, underpinning methods are discussed in Table 2-9. Example problems considering the topic of deep excavation support systems are presented in Figure 2-15 for stiff to hard clay and in Figure 2-16 for soft to medium clay.

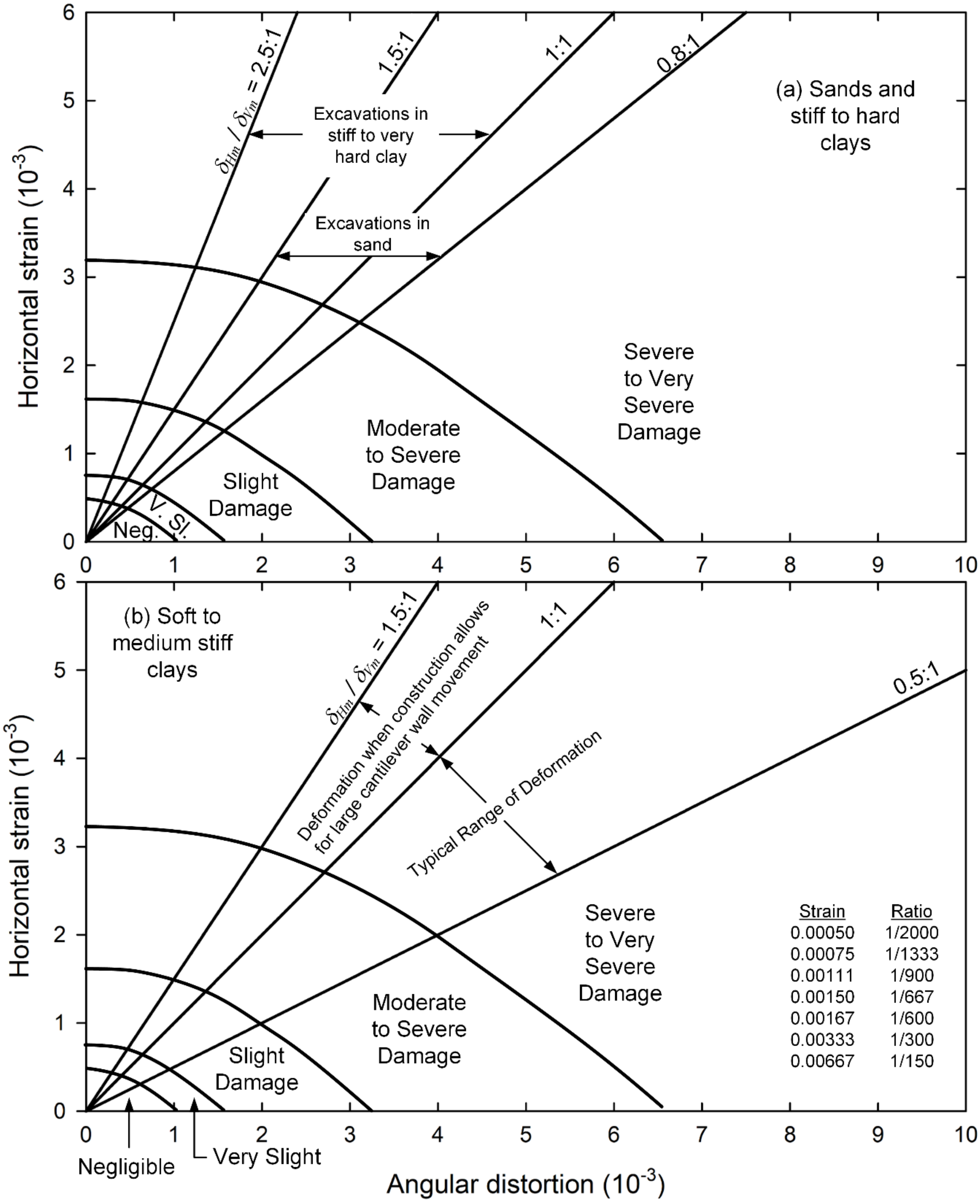


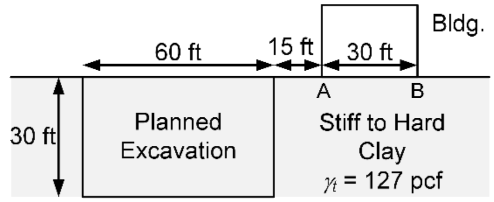
Figure 2-14 Range of Deformations Typical of Excavations in Various Soils Relative to Building Damage Potential (after Clough and O'Rourke 1990)

Table 2-9 Some Common Methods of Underpinning

Type of Underpinning	Comments
Micropiles	• Micropiles are often the method of choice. • Small diameter (3- to 10-inch) piles installed through footings. • Connection to footing is made by high strength grout.
Piles (H-piles, open-ended pipe piles)	• Piles are jacked into position in sections within a shored pit using footing as reaction. • When in final position, wedges are installed, jacks removed, and head of pile encased in concrete. • Piles may be driven on both sides of footing with beams placed across piles and a plate added under footing. • Space between footing and plate is then dry packed. • A footing bracket can be welded to piles if access is available only on one side of footing. • Piles can also be placed in an auger hole and moved into position under footing. • Piles are load tested to greater than anticipated load.
Helical Piers	• Elements are screwed into position. • A bracket is placed under footing and connected to pier.
Underpinning Pits	• Pits are an old and effective procedure, may be expensive if depth is too great. • Concrete is placed in pit, and a dry pack sand and cement mixture is used to assure contact with base of footing.

PROBLEM STATEMENT

- Tolerable angular distortion is 0.005 for existing 3-story building
- Excavation support will be H-piles with wood lagging and prestressed anchors with stiffness = 70
- Factor of safety against basal heave is found to be greater than 2
- Good construction practices are anticipated
- Groundwater is deeper than the excavation



(1) Estimate horizontal and vertical movements at front and back of building.
(2) Determine if underpinning is required.

<u>Horizontal and Vertical Movements</u>

- From Fig. 2-10: δ_{Hm} = 0.2%H and δ_{Vm} = 0.15%H

$$\delta_{Hm} = 0.002(30\,ft) = 0.06\,ft = 0.72\,in$$
$$\delta_{Vm} = 0.0015(30\,ft) = 0.045\,ft = 0.54\,in$$

- Settlement and horizontal movement at front (A):
  (d/H = 15/30 = 0.5)
  From Fig. 2-10: δ_V / δ_{Vm} = δ_H / δ_{Hm} = 0.83

$$\delta_{HA} = 0.83 \cdot \delta_{Hm} = 0.83(0.72\,in) = 0.60\,in$$
$$\delta_{HB} = 0.50 \cdot \delta_{Hm} = 0.50(0.72\,in) = 0.36\,in$$

- Settlement and horizontal movement at back (B):
  (d/H = 45/30 = 1.5)
  From Fig. 2-10: δ_V / δ_{Vm} = δ_H / δ_{Hm} = 0.50

$$\delta_{VA} = 0.83 \cdot \delta_{Vm} = 0.83(0.54\,in) = 0.45\,in$$
$$\delta_{VB} = 0.50 \cdot \delta_{Vm} = 0.50(0.54\,in) = 0.27\,in$$

<u>Is Underpinning Required?</u>

- Estimate Angular Distortion, β

$$\beta_b = \frac{\delta_{VA} - \delta_{VB}}{d_b} = \frac{0.45 - 0.27\,in}{(30\,ft)(12\,in/ft)} = 0.0005$$

- Estimate Horizontal Strain, ε_h

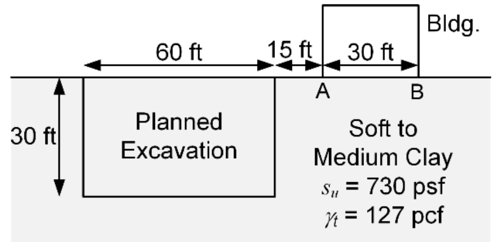
$$\varepsilon_h = \frac{\delta_{HA} - \delta_{HB}}{d_b} = \frac{0.60 - 0.36\,in}{360\,in} = 0.0007$$

Conclusion: Plotting ε_B and β on Fig. 2-14 indicates that the damage potential is **Very Slight**. The ratio of horizontal to vertical deflection is 1.33, which places the deflection within the stiff to hard clay zone on Fig. 2-14(a). Underpinning is not required because of the predicted damage, and the angular distortion is less than the tolerable level.

Figure 2-15 Estimation of Movements and Evaluation of Underpinning Requirements Adjacent to an Excavation Supported by a Deep Excavation Support System - Stiff to Hard Clay

Problem Statement

- Tolerable angular distortion is 0.005 for existing 3-story building
- Support will be H-piles with wood lagging and prestressed anchors with wall stiffness of 70
- Good construction practices are anticipated
- Groundwater is deeper than the excavation



1) Estimate factor of safety against basal heave
2) Estimate horizontal and vertical movements at front and back of building.
3) Determine if underpinning is required.

Factor of Safety Against Basal Heave

- No surcharge and adhesion of 0.6
  - Use approach in Figure 2-7
  - $B_1 = 0.7B$ = 42 ft, d = 15 ft
  - Use F = 1.2

$$F = \frac{5.7(730\ psf)(42\ ft)+(730\ psf)(30\ ft)}{(127\ pcf)(30\ ft)(42\ ft)} = \frac{196700}{160000} = 1.2$$

Horizontal and Vertical Movements

- From Fig. 2-12, use δ_{Vm} = 2%H for Zone II (1 < F < 2)
- From Fig. 2-13, use δ_{Hm} = 1.1%H for F = 1.2 and wall stiffness of 70.

$$\delta_{Vm} = 0.02(30\ ft) = 0.6\ ft$$
$$\delta_{Hm} = 0.011(30\ ft) = 0.33\ ft$$

- Vertical and horizontal movement at front (A) (d/H = 15/30 = 0.5): From Fig. 2-12: $\delta_V / \delta_{Vm} = \delta_H / \delta_{Hm}$ = 1.0

$$\delta_{VA} = 1.0\delta_{Vm} = 1.0(0.6\ ft) = 0.6\ ft$$
$$\delta_{VB} = 0.0\delta_{Vm} = 0.0(0.6\ ft) = 0\ ft$$

- Vertical and horizontal movement at back (B) (d/H = 45/30 = 1.5): From Fig. 2-12: $\delta_V / \delta_{Vm} = \delta_H / \delta_{Hm}$ = 0.0

$$\delta_{HA} = 1.0\delta_{Hm} = 1.0(0.33\ ft) = 0.33\ ft$$
$$\delta_{HB} = 0.0\delta_{Hm} = 0.0(0.33\ ft) = 0\ ft$$

Is Underpinning Required?

- Estimate Angular Distortion, β

$$\beta_b = \frac{\delta_{VA} - \delta_{VB}}{d_b} = \frac{0.6 - 0.0\ ft}{30\ ft} = 0.02 \quad \text{> limit of 0.005}$$

- Estimate Horizontal Strain, ε_h

$$\varepsilon_b = \frac{\delta_{HA} - \delta_{HB}}{d_b} = \frac{0.22\ ft}{30\ ft} = 0.0073$$

Conclusion: If ε_h and β are plotted on Fig. 2-14, the damage potential is **Severe to Very Severe**. Underpinning is required because of the predicted damage and because the angular distortion exceeds the tolerable level.

Figure 2-16 Estimation of Movements and Evaluation of Underpinning Requirements Adjacent to an Excavation Supported by a Deep Excavation Support System - Soft to Medium Clay

2-4.5 Construction Considerations.

Construction procedures can have an impact on deep excavation support system movements. Table 2-10 lists many of the construction considerations for various wall and support system features. FHWA (2008) provides additional guidance.

Table 2-10 Construction Considerations for Deep Excavation Support Systems

Wall or Support System Element	Construction Considerations and Comments
Sheet Pile	• The ball end of the sheets should lead when driving to reduce interlock separation. • Hard driving can be overcome by using spud piles, preaugering, or using a different type of wall. • Interlock separation is the greatest cause of seepage and piping of soil. • Lowering the groundwater by pumping or seepage through the sheeting can cause settlement. • When sheets are removed, care must be used to not remove soil which could cause settlement. Coat sheets in bitumen in plastic clays. • Vibratory hammers can cause settlement in loose to medium sands.
Soldier Piles (H-Piles) and Lagging	• Driven piles can cause: o Noise and vibration. o Settlement behind wall - consider single acting hammers. o Alignment concerns due to obstructions - use heavy section and pile points for hard driving. o Piles should only be removed if soil remains in place. • Predrilled holes for piles: o Reduce noise and vibration. o Use percussion or rotary drill to fracture boulders and rock. o Provide for precise location of piles. o Backfill with lean concrete so that it can be shaved for tiebacks or internal bracing. • Lagging: o Most of earth pressure arches to soldier piles. o Usually placed behind front flange of soldier pile. o Over-excavation should be backfilled with soil for intimate contact. o Lagging is typically 3 inches thick, unless a very deep excavation. o Soft clay or loose sand below water table can exert stress on lagging. o Straw or geotextile is used between lagging to prevent ground loss from drainage of groundwater. o Lowering the groundwater by pumping or seepage through lagging can cause settlement. o Lagging should be removed after construction if above the water table.
Combined Sheet Pile	• Special interlocks required between sheet piles and king piles can cause problems if not properly aligned. • Vertical alignment of piles is critical. • Comments on sheet piling and soldier piles placed in predrilled holes are also applicable.
Secant and Tangent Piles	• A reinforced concrete guide wall (3 to 5 ft deep) is required for proper wall alignment and to provide stability at the top of the trench. • Concrete piles are constructed using slurry, continuous hollow stem augers, or open hole. o Concrete should have a slump of 7 to 8 inches. o For slurry and open holes, concrete is tremied to bottom of pile under positive concrete head (8 to 10 ft). o For hollow stem augers, concrete is pumped to the bottom in the auger as the auger is withdrawn. o Open holes require test piles to verify holes will remain open at desired diameter. • Reinforcing cages or H-beams installed in primary piles for reinforcement. • Alternating piles constructed to avoid damaging fresh concrete. • Secant pile wall requires unreinforced piles to be constructed with lean concrete so that alternating piles can be cut into concrete. • Vertical tolerances can be an issue when hard drilling or cobbles or boulders are present. • Tangent piles are drilled adjacent and have the potential for more leakage of groundwater. • Grouting may be required between tangent piles to prevent leaks if vertical alignment cannot be maintained.
Deep Soil Mixing	• Wall relies on use of *in situ* soil as a construction material thus cobbles, boulders, and obstructions must be removed and replaced with suitable soil. • Monitoring of equipment and operational procedures required. o Revolutions of mixing paddles per unit volume of *in situ* soil. o Grout injection rate varies with soil type encountered. • Test columns are required. • Extraneous material (water, debris, or spoil material) is not allowed to enter production columns.

Wall or Support System Element	Construction Considerations and Comments
Concrete Diaphragm	• A reinforced concrete guide wall (3 to 5 ft deep) is required for proper wall alignment and to provide stability at the top of the trench. • Alternating panels are constructed to avoid damaging concrete. • Excavation is typically made in three steps (a.k.a., bites): left, right, and middle. • Trench stability during excavation is maintained by a bentonite-water slurry and arching to the end points of each panel. • The slurry should be: o Kept above the groundwater level and perhaps part way up the guide wall. o Checked for design properties (new and returned slurry). • Hard soils or boulders can be broken by chisels or percussion tools. • A hydromill, or similar device, should be used to remove rock. • Potential problem soils are: o Clean sands and gravels – consider higher bentonite concentration and fine sand to plug pore space. o Very soft clays (s_u < 500 psf) – squeezing and surface settlement can occur. Test panels required to evaluate. o Stiff fissured clays – overbreak and collapse can occur. Test panels required to evaluate. • Stop ends should be placed to define the ends of the panel. • The trench must be checked for verticality and required dimensions before lowering the reinforcing cage. • Concrete should: o Have a slump of 7 to 8 inches. o Placed by tremie to the bottom of the trench with a positive head of concrete (8 to 10 ft).
Internal Bracing	• Prestress to about 50% of the anticipated load to avoid overstressing if load increases. • Temperature changes can cause strain, and stresses in bracing should be monitored. • Movement of deep excavation walls should be monitored throughout construction. • Excavation below support level should not be allowed. • Slow construction can allow clays to creep.
Tieback Anchors	• Stiff to hard clays and medium to dense granular soils and rock are preferred. • Soft clays may not suitable, and loose coarse-grained soils may be a concern. • Inclined anchors cause a vertical component of load on the wall. Significant vertical movement will cause a reduction in anchor stress and wall movement. • Each anchor should be tested to beyond its anchor load (usually 115% to 125% and then locked off at 75% to 100% of design load). • Slow construction can allow clays to creep.

2-5 ROCK EXCAVATIONS.

2-5.1 Preliminary Considerations.

Rock excavation planning and design must be based on detailed field investigations including: 1) review of available data for the site, 2) geological mapping of any exposed rock, and 3) test borings sufficient to define the stratigraphy. To the extent possible, infrastructure constructed in rock should be oriented favorably with the geological structure. For example, tunnels should be aligned with axis perpendicular to the strike of faults or major fracture zones. Downslope dip of discontinuities into open excavations should be avoided.

In general, factors that must be considered in planning, designing, and constructing a rock excavation are as follows:

- Presence and orientation of faults, folds, fractures, and previous sliding surfaces;
- *In situ* stresses;
- Groundwater conditions;
- Nature of material filling joints;
- Depth and slope of cut surfaces;
- Direction of potential sliding surfaces;
- Dynamic loading;
- Design life of cut as compared to weathering or deterioration rate of rock face;
- Rippability and/or the need for blasting; and
- Effect of excavation and/or blasting on adjacent structures.

The influence of most of these factors on excavations in rock is similar to that of excavations in soil.

More information on the description, classification, and testing of rock can be found in Chapters 1 to 3 of DM 7.1. In addition, DM 7.1 contains pertinent discussion of stress distributions (Chapter 4), seepage and drainage (Chapter 6), and rock slope stability (Chapter 7).

2-5.2 Assessment of Rock Excavation Methods.

Rock excavation can be accomplished by excavators, rippers, hoe rams, and blasting. The following paragraphs discuss how to evaluate which of these methods are most appropriate.

2-5.2.1 Rock Excavatability Based on Rock Test Sections.

The field observation of a rock test section is helpful during the design phase of a project. Various types of equipment, such as excavators, rippers, and hoe rams, can be tested to evaluate which type of equipment would be most effective during construction. The size and shape of the area to be excavated is a significant factor in estimating the ability to rip rock. This exploration technique will provide valuable data on the depth that can be ripped or excavated with each type of equipment and will also define where and at what depth blasting will be required.

2-5.2.2 Rock Excavatability Based on Correlations with GSI.

The excavatability of rock by various methods can be related to Geologic Strength Index (GSI) (Hoek et al. 1992, Marinos and Hoek 2000). The GSI is assigned based on the rock mass structure and the surface condition as shown by the numbered contours in Figure 2-17. Tsiambaos and Saroglou (2010) split sedimentary and metamorphic rock masses ranging from blocky to disintegrated into two groups by point load strength index ($I_{s(50)}$). The region corresponding to the rock's structure and surface conditions can be determined. The shaded areas indicate different levels of excavatability. Digging means the rock can be excavated with power excavators. Ripping indicates excavation with D8 and D9 type tractors. Hammer (and blasting) means that breaking with a hoe or hydraulic ram will likely be required. Blasting indicates the need for blasting.

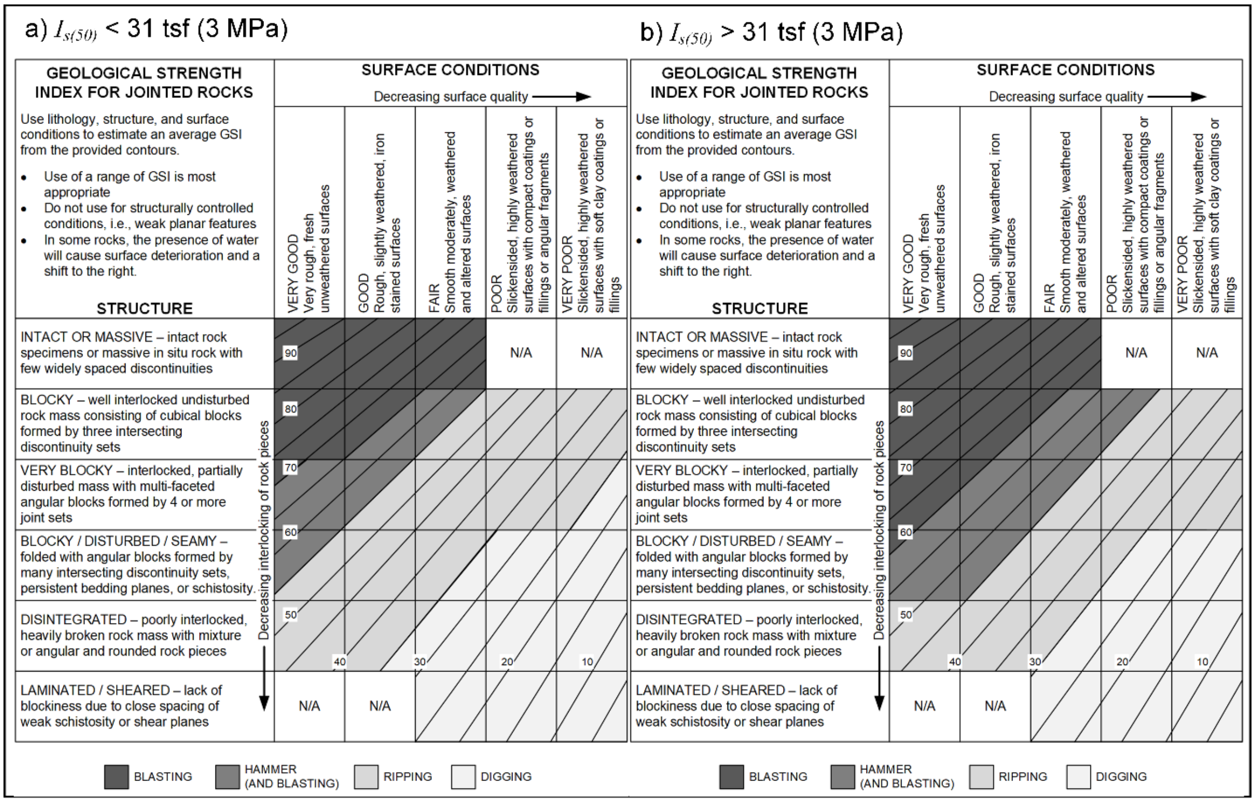


Figure 2-17 Excavatability of Rock Masses: a) $I_{s(50)}$ < 31 tsf (3 MPa) and b) $I_{s(50)}$ > 31 tsf (3 MPa) (after Tsiambaos and Saroglou 2010)

2-5.2.3 Rippability Based on Correlations with Compression Wave Velocity.

Ripping of rock materials is governed by many factors: 1) rock mass lithology including strata, fracture condition, and orientation; 2) rock weathering; 3) rock strength; and 4) rock ripper equipment size and condition. Rock rippability can be assessed from field observation and correlations with the GSI as discussed above or by using correlations with seismic wave velocity.

The most common rock rippability correlation is based on compression wave velocity, or P-wave velocity, obtained from seismic refraction studies. The velocity is based on the fracture condition of the rock. Figure 2-18 illustrates example charts for the performance of rippers mounted on medium (Caterpillar D-8 tractor), heavy (D-9 tractor), and very heavy-duty (D-11 tractor) tractors related to seismic compression wave velocity of various rock materials (Caterpillar 2000). These types of charts are available from equipment manufacturers.

2-5.3 Blasting.

Once it has been determined that blasting is required, a pre-blasting survey should be performed. As a minimum, this should include: 1) examination of the site, 2) detailed examination and a photographic record of adjacent structures, and 3) establishment of horizontal and vertical survey control points.

2-5.3.1 Blasting Design.

Design of blasting for a project can be estimated by considering the maximum particle velocity. The *peak* (or *maximum*) *particle velocity* (PPV) is the longitudinal velocity of a particle in the direction of the wave that is generated by blasting. The major concern in blasting is the influence of the blasting on adjacent structures. PPV is an accepted criterion for evaluating the potential for structural damage induced by blasting vibration. The critical level of the particle velocity depends on the rock properties, the nature of the overburden, the frequency characteristics of the structure, and the capability of the structure to withstand dynamic stresses.

The effects of a blast on a structure can be evaluated by the scaled distance (USBM 1971, Oriard 1987). The *scaled distance* (SD) is the true distance from the charge to the structure corrected by the weight of the charge and can be calculated as:

$$SD = \frac{D}{W^{\beta}} \tag{2-7}$$

where:
D = true distance from charge to structure (ft),
W = weight of charge (lb), and
β = 0.33 for near field structures (i.e., <20 ft from charge) or 0.5 further from charge.

The scaled distance is not correct dimensionally and requires use of the indicated units.

Using SD, the PPV can be estimated using:

$$PPV = K \cdot SD^{-1.6} \tag{2-8}$$

where:
K = confinement factor (lower bound = 20, upper bound = 242, average = 150).

The values of K are empirical and require the use of the indicated units. K may be calculated from blast data as follows:

$$K = \frac{PPV}{SD^{-1.6}} \tag{2-9}$$

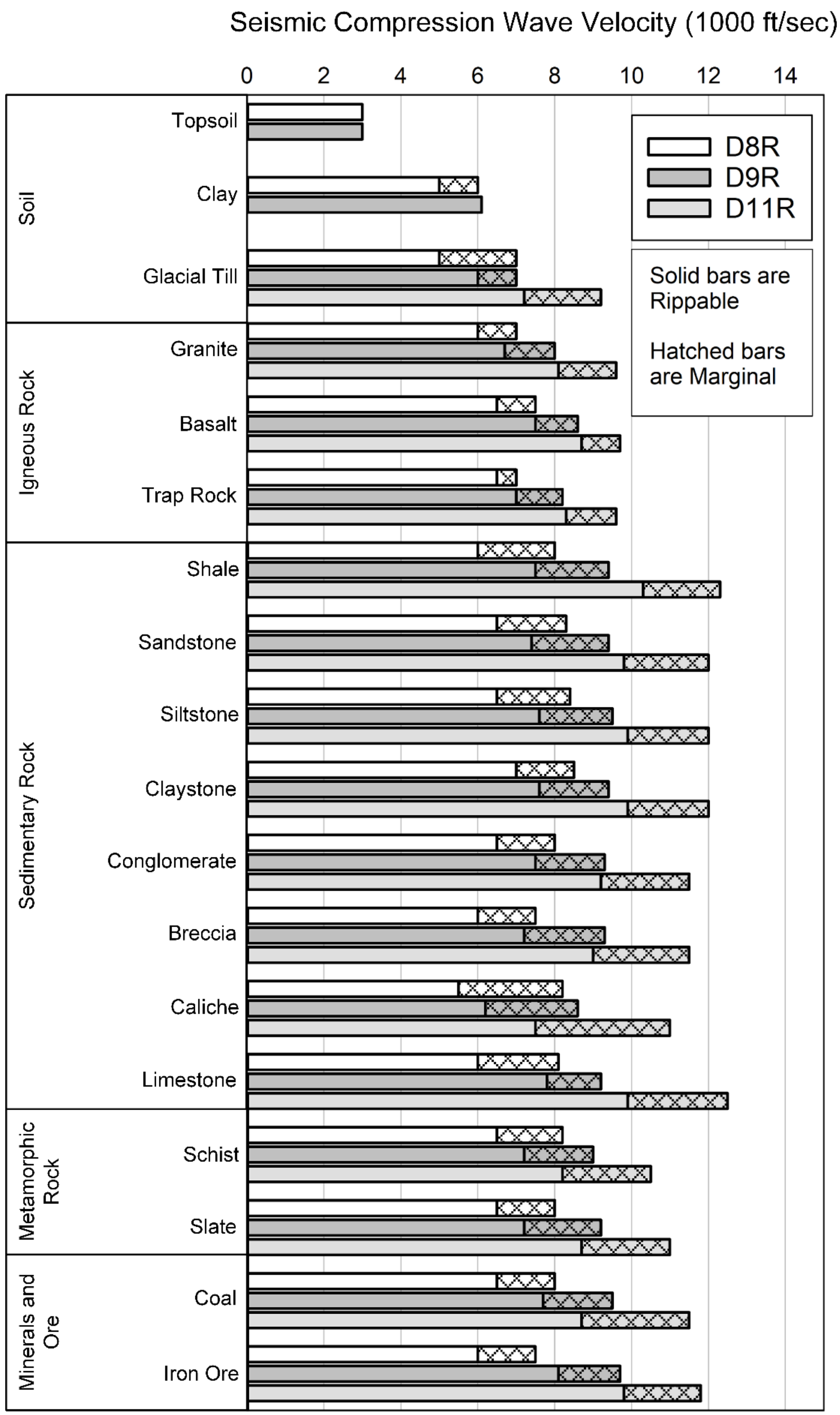


Figure 2-18 Ripper Performance: a) Medium Tractor, b) Heavy-Duty Tractor, and c) Very Heavy Tractors (after Caterpillar 2000)

Figure 2-19 can then be used to estimate potential damage to structures based on the estimated PPV. Human response to vibrations is given in Figure 2-20.

2-5.3.2 Monitoring Blasting.

During construction, vibration monitoring stations should be established, and monitoring should be performed. Detailed records should be kept of charge weight, location of blast point, distance from blast point to existing structures, delays, and response as indicated by vibration monitoring. For safety, small charges should be used initially to establish a site-specific relationship between charge weight, distance, and peak particle velocity along with the associated structural response.

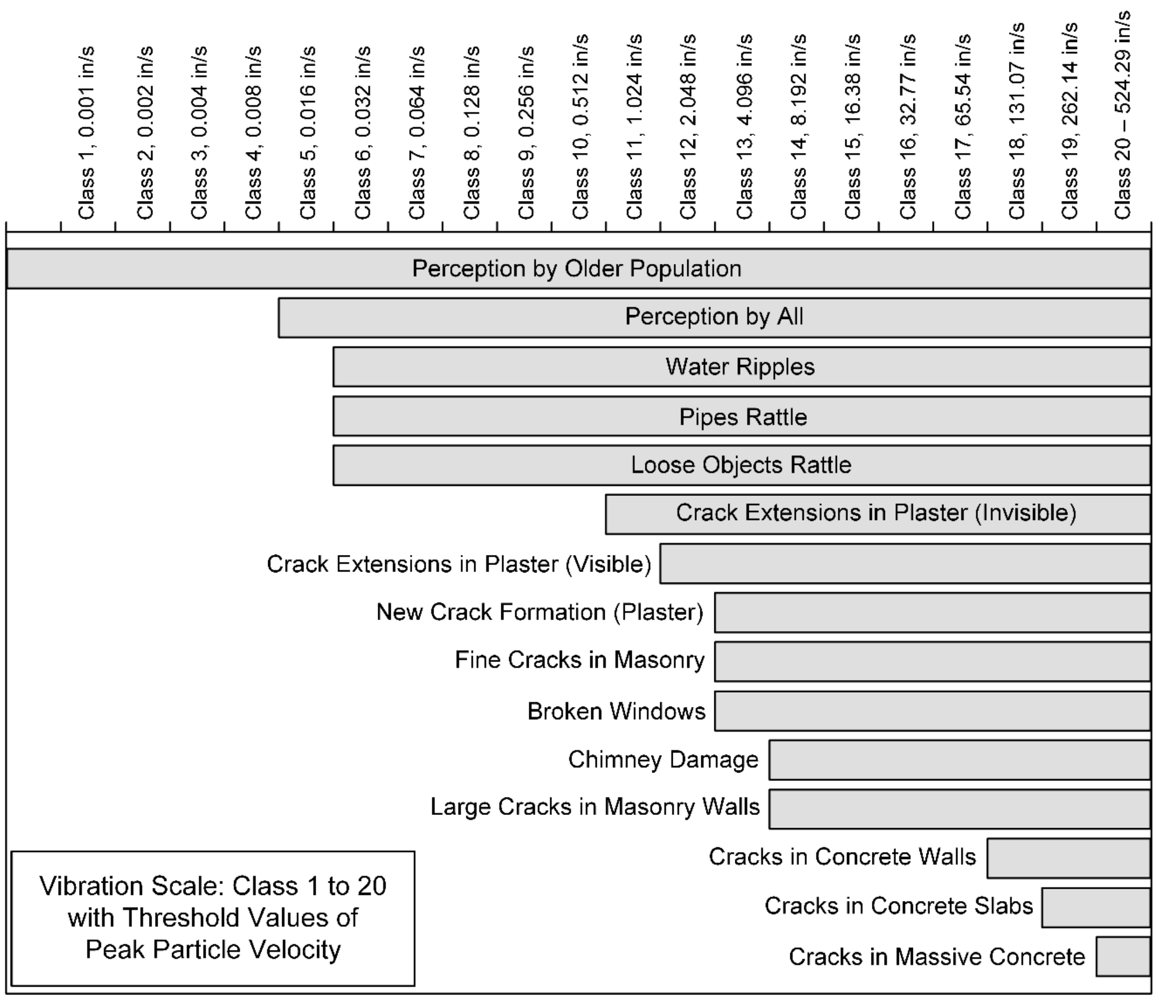


Figure 2-19 Blast Effects Scale (after Konya and Walter 2006)

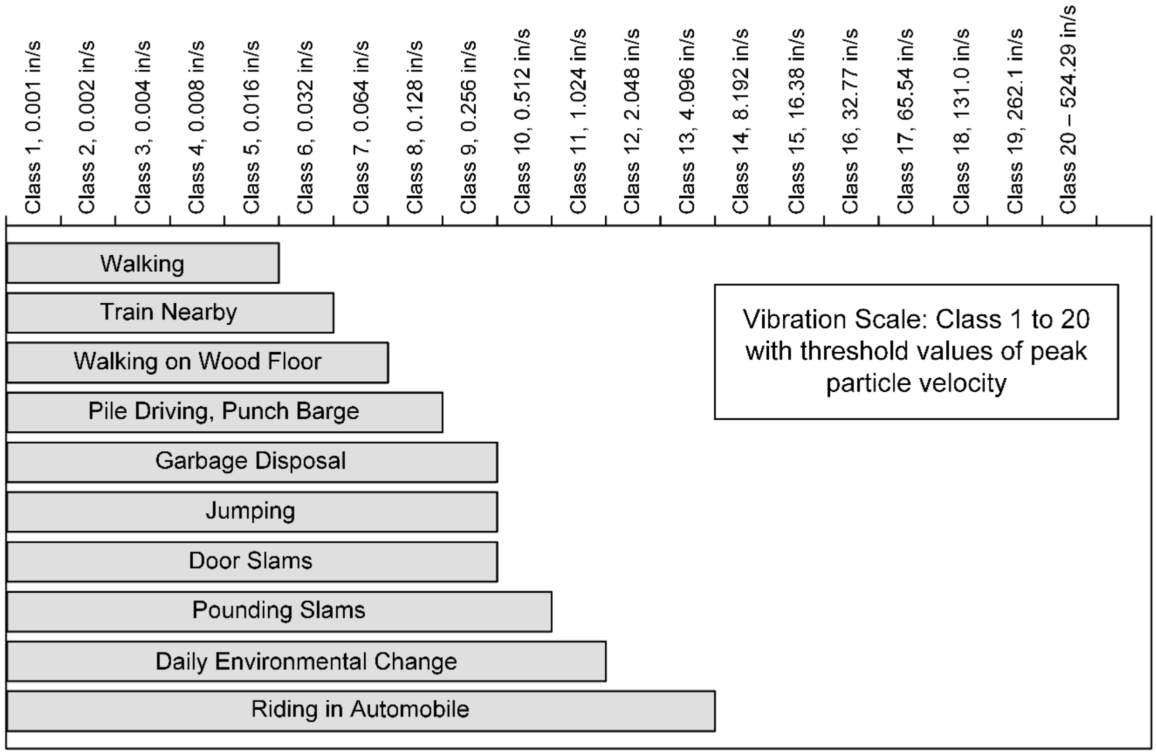


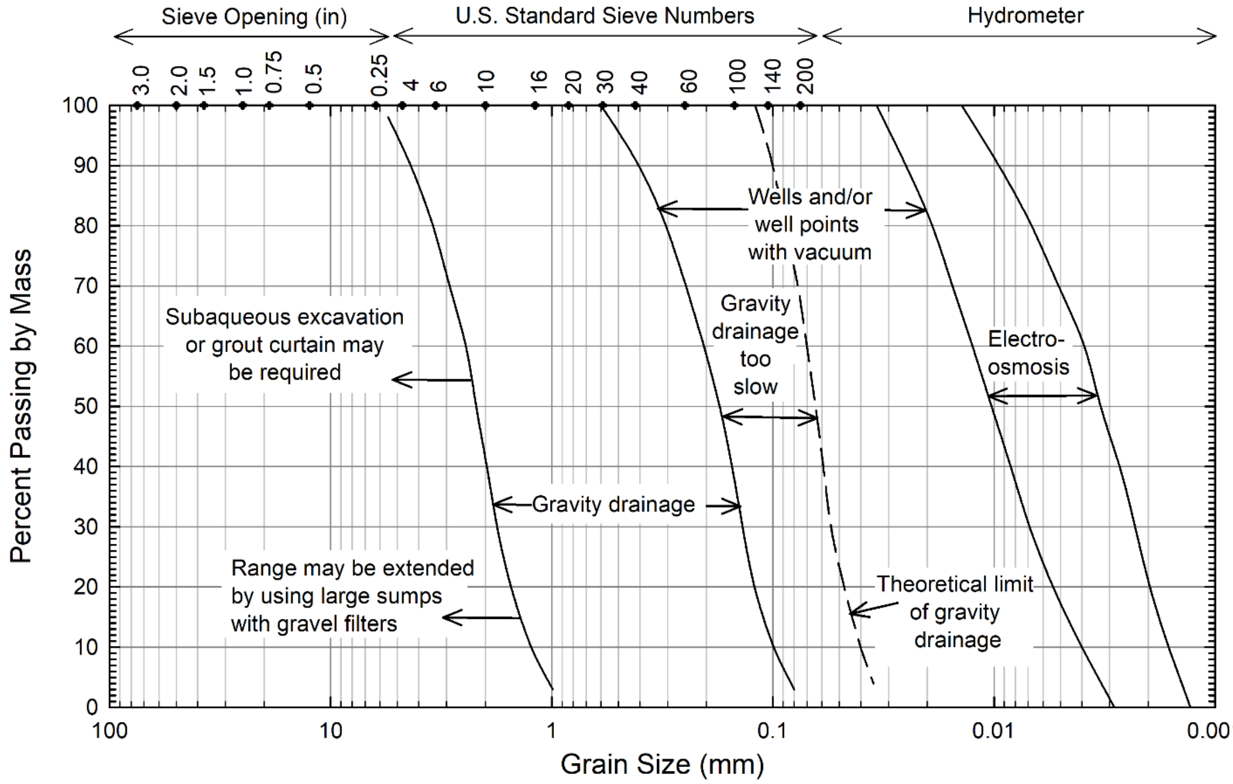
Figure 2-20 Human Response to Vibrations (after Konya and Walter 2006)

2-6 GROUNDWATER CONTROL.

2-6.1 Preliminary Considerations.

Excavations below the groundwater table require groundwater control. This typically consists of controlling seepage into the excavation and controlling excess pore water pressures below the bottom of the excavation. Sumps, wellpoints, and deep wells are most commonly used to lower groundwater in excavations. Figure 2-21 illustrates applicable limits of these dewatering methods for different soil gradations.

Slurry cutoff walls (soil-bentonite or cement-soil-bentonite), concrete diaphragm walls, secant pile walls, and deep soil mix walls are the most effective walls for reducing seepage into an excavation. Concrete diaphragm walls may become part of the final structure. Sheet piling is often considered impervious but seepage occurs through the interlocks. If interlocks split due to hard driving, the rate of seepage can increase greatly. Special waterstops are available.



	Gravel		Sand			Silt or Clay
	Coarse	Fine	Coarse	Medium	Fine	

Figure 2-21 Limits of Dewatering Methods Applicable to different Soils (after Keller Moretrench American Corporation 1954)

2-6.2 Permeability of Sheet Piling.

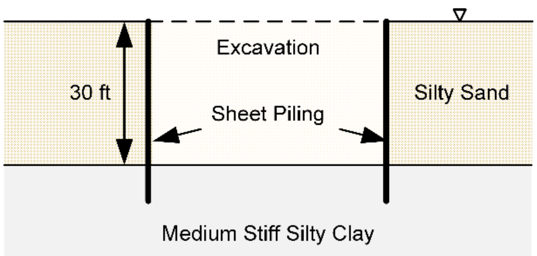
The permeability of sheet pile walls, which occurs only through the interlocks, is usually expressed in terms of the inverse specific resistance, ρ, explained in European Standard EN 12063 (1999) which is defined as follows:

$$\rho = \frac{q\gamma_w}{\Delta p} \qquad (2\text{-}10)$$

where:
q = discharge or flow rate per unit height along the interlock,
γ_w = unit weight of water, and
Δp = differential pressure.

Seepage can be reduced by maintaining tension in the interlocks and/or by sealing the joints. Test sections have been performed on sheet piling sealed with various bitumen and swelling fillers (Sellmeijer et al. 1995). These tests indicate that ρ ranges from about 10^{-3} cm/sec for unsealed joints to about 10^{-9} cm/sec for sealed joints without tension in the joint. Bitumen sealants are slightly less effective than swelling sealants. Tests on vinyl sheet piling indicate ρ ranging from 10^{-5} cm/sec for unsealed joints in tension to about 10^{-10} cm/sec for sealed joints.

If ρ is known or assumed, Equation 2-10 can be rearranged to calculate the flow rate per unit length of interlock. This allows the flow rate through a section of sheet piling to be calculated. An example problem for leakage through sheet piling is shown in Figure 2-22.



Cross-Section of Excavation

Problem Requirements

- Perimeter of Excavation = 800 ft
- Estimated Specific Resistance of Untreated Sheet Pile Joints, $\rho = 1\text{x}10^{-3}$ cm/s = $2\text{x}10^{-3}$ ft/min
- Estimated Specific Resistance of Joints Treated with Bitumen sealant, $\rho = 1\text{x}10^{-7}$ cm/s = $2\text{x}10^{-7}$ ft/min
- Width of Sheet Piling is 1.8 ft
- Maximum Allowable inflow is 20 gal/min

Find leakage into the excavation with and without sealant.
Is the sealant required?

- Calculate the number of interlocks, N, around the perimeter of the excavation

$$N = \frac{800\,ft}{1.8\,ft\,/\,pile} = 444\text{ piles}$$

- Average pressure difference (at midheight)

$$\Delta p = (15\,ft)(62.4\,psf) = 936\text{ psf}$$

Solution Without Interlock Sealant

- Calculate discharge per unit height along the interlock

$$q = \frac{\rho \cdot \Delta p}{\gamma_w} = 2\times10^{-3}\frac{ft}{\min}\left(\frac{936\,psf}{62.4\,pcf}\right) = 0.03\frac{ft^3}{\min\cdot ft}$$

- Calculate the total flow into the excavation

$$Q = \text{q}\cdot\text{H}\cdot\text{N} = \left(0.03\frac{ft^3}{\min\cdot ft}\right)(30\,ft)(444) = 400\frac{ft^3}{\min} = 3000\frac{gal}{\min}$$

Solution with Interlock Sealant

- Calculate discharge per interlock per unit length of wall

$$q = \frac{\rho \cdot \Delta p}{\gamma_w} = 2\times10^{-7}\frac{ft}{\min}\left(\frac{936\,psf}{62.4\,pcf}\right) = 3\times10^{-6}\frac{ft^3}{\min\cdot ft}$$

- Calculate the total flow into the excavation

$$Q = \text{q}\cdot\text{H}\cdot\text{N} = \left(3\times10^{-6}\frac{ft^3}{\min\cdot ft}\right)(30\,ft)(444) = 0.04\frac{ft^3}{\min} = 0.3\frac{gal}{\min}$$

Conclusion: Without the sealant, the inflow is too high. Sealant is required.

Figure 2-22 Example Problem for Flow into an Excavation Through Sheet Piling

2-6.3 Methods of Controlling Groundwater.

Table 2-11 lists methods of controlling groundwater, their applicability, and limitations. The methods represent groundwater lowering techniques including sumps, wellpoints, deep wells, and jet-eductor wells. Cutoff walls include sheet piling, slurry walls, concrete diaphragm walls, secant pile walls, and mix-in-place walls.

Table 2-11 Methods of Groundwater Control

Method	Suitable Soils	Use	Comments
Sumps	Sands and gravels	Shallow localized dewatering	• Pumping from perforated drum or casing. • Geotextile should be used to prevent movement of fines.
Wellpoint Systems with Suction Pumps	Sands, silty sands, and silts	Open excavations including pipe trenches	• Easy to install. • Limited to about 18 ft lift. • Multi-stage wells at 15 ft vertical intervals required to dewater greater depth.
Deep Wells with Submersible Pumps	Sands, silty sands, and silts; fractured rock	Deep excavations	• No limitation of depth of drawdown. • Design of screen openings and filter pack required. • Can be sited clear of excavation area.
Jet-eductor Wells	Sands, silty sands, and silts	In limited space and when well point systems not possible	• No limitation of depth of drawdown. • Design complex. • Low efficiency.
Sheet Pile Cutoff Walls	All soils except dense sand and gravel, glacial till, and boulder soils	Unrestricted use except for hard driving conditions; can be permanent	• Hard driving and boulders can cause interlock failure. • Can be recovered. • Hot rolled sheets have lower permeability. • Decrease interlock leakage with bitumen, water swelling filler, or bentonite. • Sealable joint sheet piling is available. • With proper sealing of interlocks, can be as effective as slurry trench, concrete diaphragm, secant piles, and deep soil mix.
Slurry Trench Cutoff Walls	Silt, sand, gravel and cobbles, and boulders	Unrestricted	• Needs to be keyed into less permeable stratum to reduce seepage. • Can be keyed into rock.
Concrete Diaphragm Cutoff and Foundation Wall	Silt, sand, gravel, cobbles, and boulders	Basement, excavation support, and shafts	• Needs to be keyed into less permeable stratum to reduce seepage. • Can be keyed into rock. • Consider bearing and settlement.
Secant and Tangent Pile Cutoff and Foundation Walls	Silt, sand, gravel and cobbles	Basement, excavation support, and shafts	• Needs to be keyed into less permeable stratum to reduce seepage. • Can be keyed into soft rock. • Consider bearing and settlement. • Tangent piles leak more because piles do not overlap.
Mix-In-Place Walls	Sands, silty sands, and silts	Excavation support and shafts	• Needs to be keyed into less permeable stratum to reduce seepage. • Consider bearing and settlement.
Freezing: Ammonium/ brine refrigerant	All types of saturated soils and rock	Formation of ice in voids prevents water movement	• Better for large areas of long duration. • Takes long time to develop.
Freezing: Liquid nitrogen refrigerant			• Better for small areas of short duration where quick freezing is required. • Expensive and requires strict site controls. • Some ground heave will occur.

Figure 2-23 shows details of a wellpoint system and a deep well with a submersible pump. Figure 2-24 illustrates an example of a two stage well point system and a dewatering system using deep wells.

Design procedures related to seepage analysis and dewatering control are included in Chapter 6 of DM 7.1. Other good references include Mansur and Kaufman (1961) and Cedergren (1997).

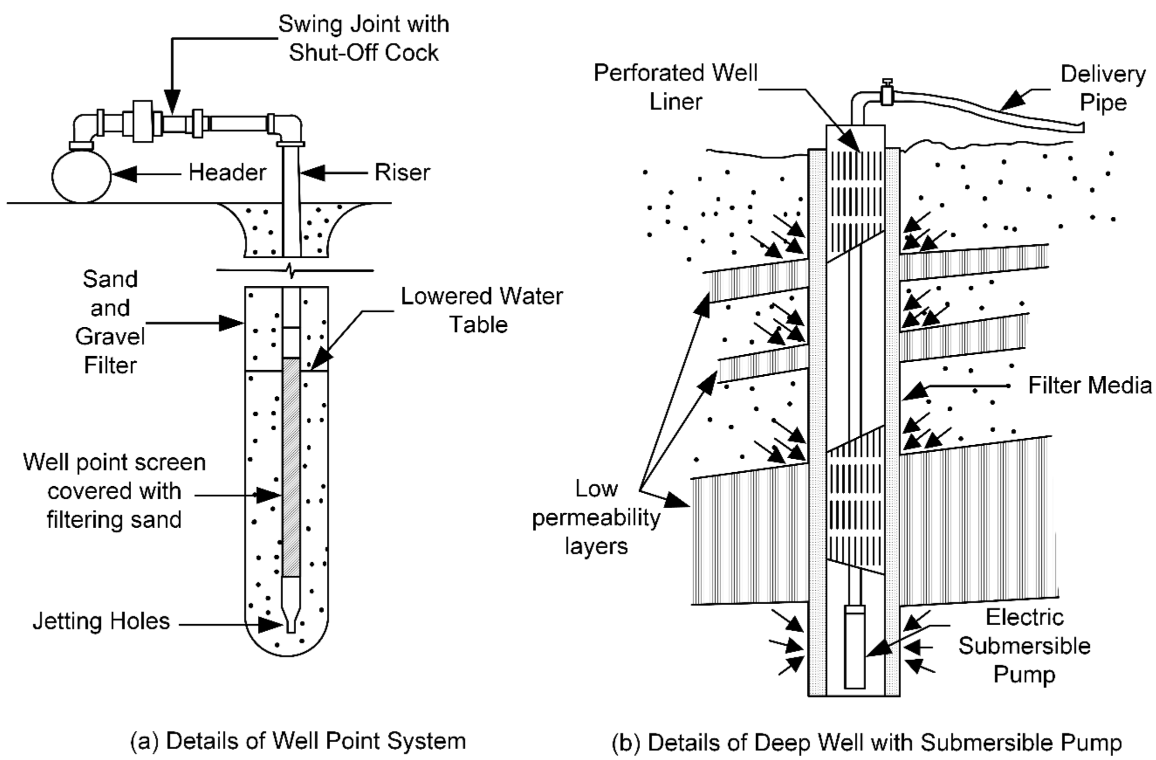


Figure 2-23 Methods of Construction Dewatering a) Details of Wellpoint System and b) Details of Deep Well with Submersible Pump (after Mazurkiewicz 1980)

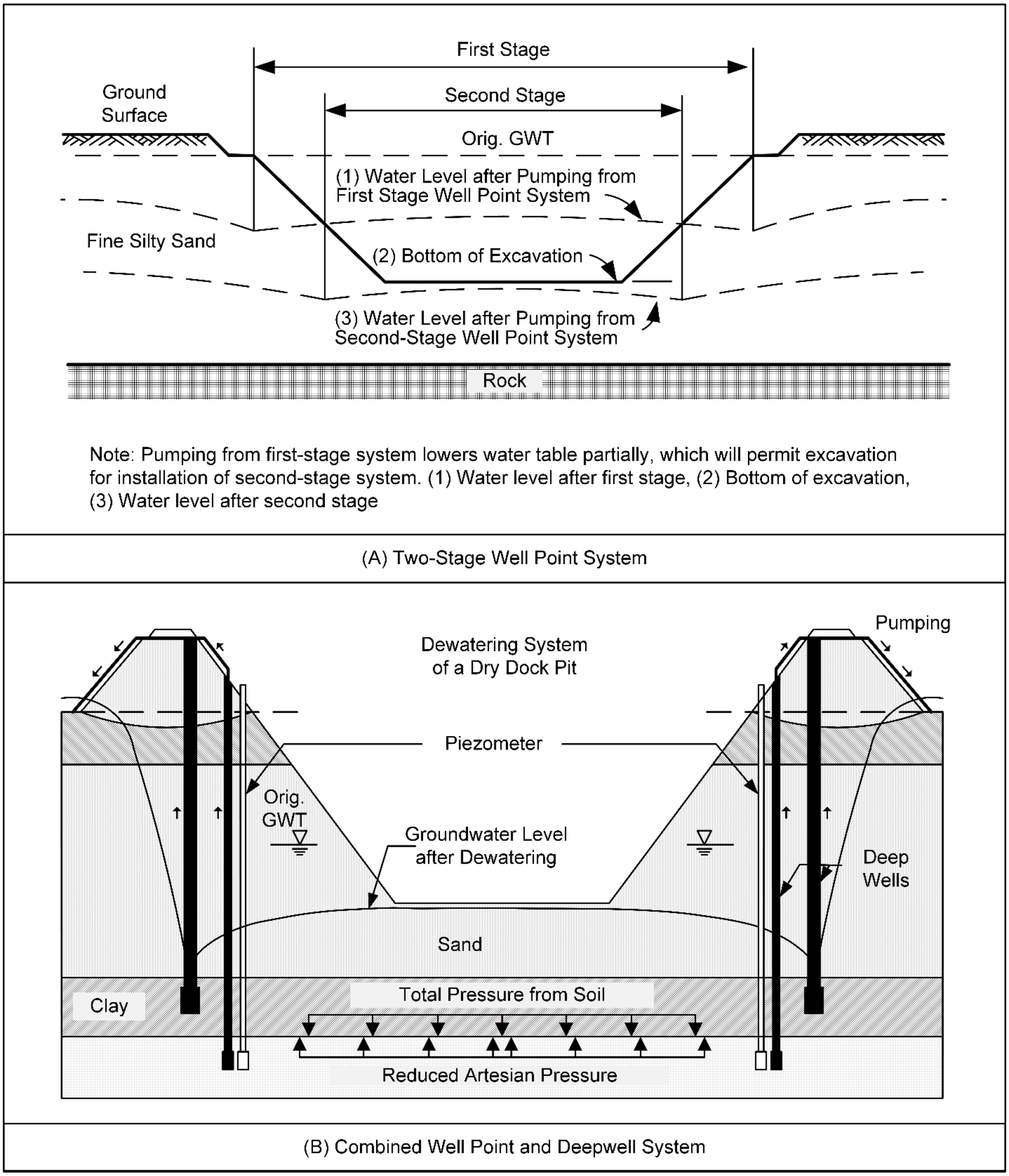


Figure 2-24 Methods of Construction Dewatering a) Two Stage Well Point System (after Mazurkiewicz 1980) and b) Combined Well Point and Deep Well System (after USACE 1983a)

2-7 PROBLEM SOILS AND EXCAVATIONS.

Chapter 1 provides a summary of many types of problem soil conditions that can affect the design of foundations and earth structures. Table 2-12 and Table 2-13 summarize important conditions for the design of excavations in problem soils.

Table 2-12 Problem Soil Considerations for Sloped Open Cut Excavations (after Clough and Davidson 1977)

Soil Type	Primary Considerations for Slope Design

Fissured Stiff Highly Plastic Clays and Soft Shales	• Field shear resistance may be less than laboratory tests.
	• First time slope failures may occur progressively due to:
	  ○ Stress relief,
	  ○ An increase in void ratio,
	  ○ Softening due to surface water seeping into fissures, and
	  ○ Variation of displacements along the failure surface.
	• Fully softened drained shear strength should be used for analysis of first-time slides. See Chapter 3 of DM 7.1 for testing procedures.
	• Residual shear strength should be used when previous failure surfaces are present.
	• Residual friction angles of shale may be as low as 7 to 12 degrees.

Stiff Desiccated Highly Plastic Clays	• Depth of softening and reduced strength is related to the depth of desiccation cracking. • Desiccation cracks have been reported up to 8 ft deep. • Fully softened drained strengths should be used to analyze the stability of these soils which typically have shallow failure surfaces.

Loess and Other Collapsible Soils	• Potential for collapse/erosion of relatively dry material upon wetting.
	• Loess slopes are more stable when cut near vertical.
	  ○ To prevent infiltration, and
	  ○ Benches may be used for high slopes.
	• See Chapter 1 of DM 7.1.

Sensitive Clays	• Considerable loss of strength can occur upon remolding. • Estimate sensitivity from unconfined compression tests, or alternatively, field or laboratory vane tests. • Marine clays can have a high sensitivity because of structure (flocculated) and leaching of salts by freshwater (clay deposits uplifted or sea level lowering during past geologic history). • A Liquidity Index > 1 ($w > LL$) is an indication of a sensitive clay. • See Section 1-2.4 for further description of sensitive clays.
Residual Soils	• Significant local variations in properties should be expected. • Variation occurs due to the weathering profile which is developed from parent rock. • The properties of these soils are unrelated to stress history. • Few reliable correlations are available.
Talus	• Talus is characterized by a loose aggregation of rock that accumulates at the base of rock cliffs. • Stable slopes are commonly 1-1/4 to 1-3/4 horizontal to 1 vertical. • Instability is associated with abundance of water.
Loose Sands	• May settle under blasting vibration. • When saturated under earthquake loading, may liquify and lose strength. • Static liquefaction is also possible in loose contractive sands. • Prone to erosion and piping.
Rock with Weak Planes	• Planar or wedge failures on discontinuities dippin toward excavation and daylighting on the slope. • Toppling of slabs of rock that dip steeply into the excavation face

Table 2-13 Problem Soil Considerations for Deep, Supported Excavations

Soil Type	Primary Considerations for Deep, Supported Excavation Design
Soft Clays	• Basal heave • Large wall movements • High apparent earth pressures
Fissured Stiff Highly Plastic Clays and Soft Shales	• May need to consider the effects of softening for permanent or semi-permanent structures • High earth pressures should be anticipated depending on the K_0 value before excavation. • Water should be diverted away from the soil retained by thet support system.
Loess and Other Collapsible Soils	• Metastable structure of the soil can collapse under loading, especially wetting. • Lower earth pressures should be expected because of the structure of the soil.
Sensitive Clays	• Areas susceptible to vibration may cause sensitive clays to lose strength. • Sensitivity above 4 should be given special consideration. • Impervious walls are suggested. • Keep shear stresses below the peak undrained shear strength throughout the sensitive soil. Use high F_{BH} or consider numerical analysis.
Residual and Lateritic Soils	• Most of these soils will behave similar to stiff clays. • Lateritic soils may have higher permeability.
Loose Sands	• May require extensive dewatering system if saturated. • Internal erosion of particles through the wall or at the base may be a concern.
Glacial Till	• Boulders may complicate some types of excavation and wall systems.
Organic Soils, Peat, and Muskeg	• Low undrained shear strength may be present. • Passive resistance will be low because of low unit weight. • Wall settlement may be a concern.

2-8 NOTATION.

Variable	Definition
B	Excavation or trench width
B_1	Width of zone adjacent to excavation in clay that contributes to basal instability
B_s	Width of surcharge adjacent to excavation
D	Embedded depth of wall below base of excavation
d, d_i	Distance from excavation to a point of interest
d_0	Typical distance from excavation at which no movement occurs
d_b	Distance separating two points on a structure for calculation of distortion or strain
E	Young’s modulus
E_s	Elastic modulus of soil
F_{BH}	Factor of safety against basal heave

Variable	Definition
GSI	Geological strength index
h, h_{avg}	Vertical spacing of support system braces or anchors
H	Excavation depth
H_{crit}	Critical vertical excavation depth in clay for undrained conditions
I	Second moment of inertia
$I_{s(50)}$	Point load strength index of rock
K	Confinement factor for blasting calculations
K_A	Lateral earth pressure coefficient for active conditions
K_0	Lateral earth pressure coefficient for at-rest conditions
K_{wall}	Normalized wall stiffness
N	Number of interlocks in a sheet pile retaining wall
$N\gamma$	Bearing capacity factor
P_A	Active earth pressure force
P'_H	Unbalanced earth force on embedded section of excavation retaining wall
PPV	Peak particle velocity
q	Discharge or flow rate of water per unit height along a sheet pile interlock
Q	Total water flow into an excavation
S	Spacing of structural elements for combined sheet pile walls
SD	Scaled distance for blasting calculations
s_u	Undrained shear strength
$s_{u,b}$	Undrained shear strength below base of excavation
$s_{u,d}$	Undrained shear strength along embedded section of wall
$s_{u,h}$	Undrained shear strength above base of excavation
W	Weight of blasting charge
w	Gravimetric water content
α	Adhesion factor between fine-grained soil and retaining structure
β	Angular distortion of a structure caused by differential movement
δ_H, δ_{Hi}, δ_{Hm}	Horizontal movement of the ground adjacent to an excavation; m indicates maximum

Variable	Definition
Δp	Differential water pressure between the excavation and retained soil for sheet pile seepage
δ_V, δ_{Vi}, δ_{Vm}	Vertical movement of the ground adjacent to an excavation; m indicates maximum
ε_b	Horizontal strain of a structure caused by differential movement
γ, γ_t	Moist or total unit weight
γ_w	Unit weight of water
ϕ'	Drained or effective stress friction angle
ρ	Specific resistance of sheet pile interlocks to seepage
σ'_h	Effective horizontal stress

2-9 SUGGESTED READING.

Topic	Reference
Excavation Safety and Shoring	Occupational Safety and Health Administration (OSHA). 2020. CFR Part 1926, Subpart P, Excavations, with Appendices A - F. https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926SubpartP.
Deep Excavations	FHWA. 2008. *Earth Retaining Structures, FHWA NHI-07-071*. U.S. Department of Transportation, Federal Highway Administration, Washington, DC.
	Clough, G. W., and O'Rourke, T. D. 1990. "Construction Induced Movements of *In situ* Walls." *Proc. of Conf. on Design and Performance of Earth Retaining Structures. ASCE Geotechnical Special Publication No. 25.*
Dry Docks and Groundwater Control	Mazurkiewicz, B.K. 1980. *Design and Construction of Dry Docks*. Trans Tech Publications, Rockport, MA.
	USACE. 1983. *Dewatering and Groundwater Control, TM 5/818-5/AFM 88-5*. Department of the Army, Washington, DC.
Dewatering	Mansur, C. and Kaufman, R. 1961. "Dewatering." *Foundation Engineering*, Ed. Leonards, McGraw Hill, 514 pp.
	Cedergren, H. 1997. *Seepage, Drainage, and Flow Nets*, 3rd Ed., Wiley-Interscience, 496 pp.

CHAPTER 3. EARTHWORK, HYDRAULIC, AND UNDERWATER FILLS

3-1 INTRODUCTION.

3-1.1 Scope.

This chapter summarizes the design and construction of compacted earth, hydraulic fill, and underwater fill. It explains the theory of compaction and the engineering behavior of fill materials. Guidelines for the construction process and control of compacted fills are provided, along with compaction requirements for various applications and equipment. General requirements for the design of various types of embankments are included. The construction and control of hydraulic fills, both on land and underwater, are discussed.

3-1.2 Earthwork Process and Purpose of Compaction.

Earthwork is the process of changing the topography to accommodate construction and to provide drainage. As illustrated in Figure 3-1, earthwork is a manufacturing process using soil or rock, and includes excavation, transport, placement, and amendment. The final step of the process is *compaction*, which refers to the removal of air from the soil by the temporary application of a mechanical load, such as rolling, tamping, or vibration.

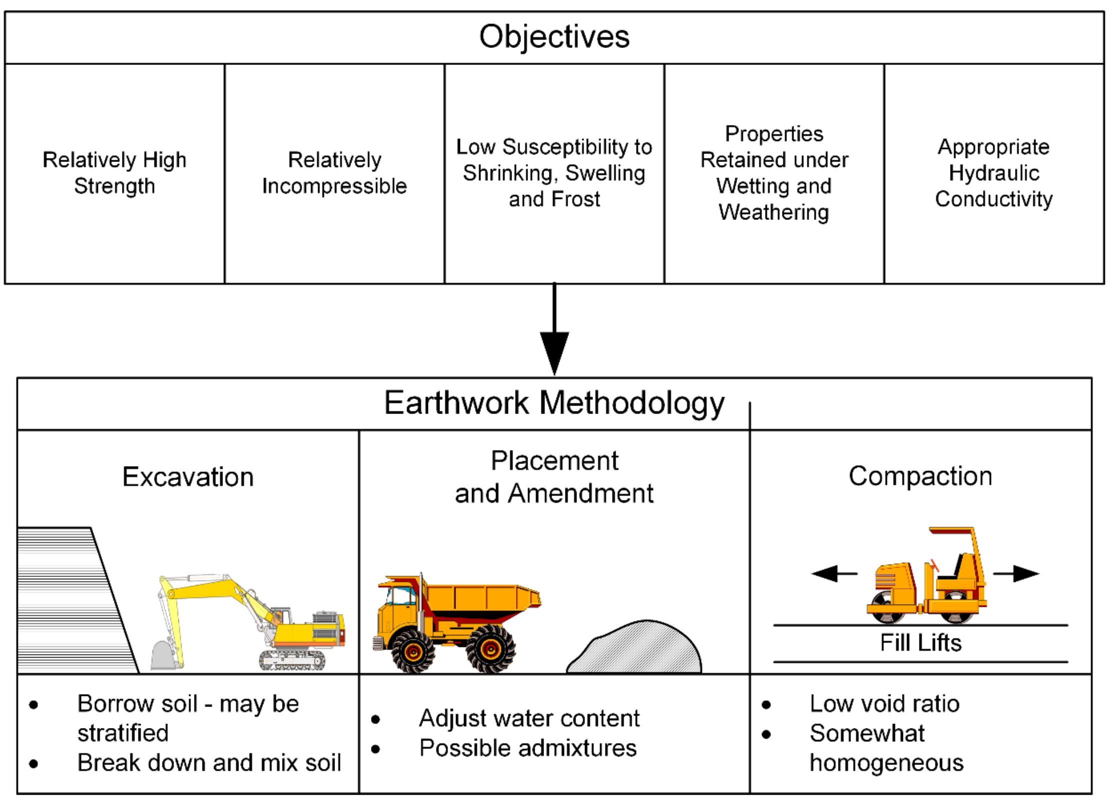


Figure 3-1 Earthwork Objectives and Methodology

As noted by Sowers (1979), the engineer has more control over some aspects of the earthwork process than others. For example, the water content of a fill can be controlled during but not after construction. Similarly, sources of suitable fill material typically depend on local availability, but careful excavation or processing can be used to create select soil or rock materials.

3-1.3 Types of Fills and Applications.

Fills can be grouped into three major categories based on the method of placement. *Controlled compacted fill* is created using a process similar to that shown in Figure 3-1. This process creates compacted fill that is more rigid and uniform than most natural soils. Properly compacted fill also tends to have higher shear strength and lower compressibility. *Hydraulic fill* is placed using flowing water and cannot be compacted during placement. For this reason, the type of soil used for hydraulic fill must be selected carefully. Hydraulic fills tend to be weaker and more compressible than compacted fills. *Uncontrolled fills* consist of soil, rock, or other materials that are placed without control of one or any of the factors discussed in this chapter, including material type, lift thickness, and compaction energy. Uncontrolled fills may contain industrial and domestic wastes, ash, slag, chemical wastes, building rubble, and refuse. An important distinction should be made between uncontrolled fills and fills that intentionally use recycled or waste materials in a controlled manner. The use of ash, slag, and chemical waste is regulated, and current Environmental Protection Agency (EPA) and other appropriate regulations must be considered.

The principal uses of controlled compacted fill include support of structures or pavements, embankments for water retention or for lining reservoirs and canals, and backfill surrounding structures or buried utilities. Hydraulic fill was historically used in dam and levee construction where large quantities of fill were transported long distances. While now less common, hydraulic fill is still used in select cases for the creation of dam and levee structures. Both controlled and hydraulic fills should be created in a such a manner as to maintain slope stability. Uncontrolled fills should not be created or used for engineering purposes without modification.

3-2 COMPACTION THEORY.

This section summarizes the weight volume relationships involved in the process of compaction and how those relationships are represented graphically. Methods for characterizing the level of compaction are discussed for soils both with and without appreciable amounts of fines. Finally, this section explores the effect of compaction on the engineering properties of soil.

3-2.1 Process of Compaction.

Compaction focuses on changing the dry unit weight (γ_d) of soil (and rock) which is defined as:

$$\gamma_d = \frac{W_s}{V_t} = \frac{\gamma_t}{\left(1 + {}^{w}\!/_{100}\right)} \qquad (3\text{-}1)$$

where:
W_s = weight of solids,
V_t = total volume,
γ_t = total unit weight, and
w = water content (percentage).

The degree of saturation (S), which is the percentage of the void space filled with water, is also important to understanding the behavior and construction of controlled fill. The dry unit weight is related to S by:

$$\gamma_d = \frac{\gamma_w S}{\left(\frac{w}{100} + \frac{S}{G_s}\right)} \qquad (3\text{-}2)$$

where:
γ_w = unit weight of water = 62.4 pcf,
w = water content (percentage), and
G_s = specific gravity of solids.

To illustrate the compaction process, phase diagrams are shown in Figure 3-2 for different points on the *compaction plane*, which plots dry unit weight against water content. Moving from left to right on the compaction plane (A→C→E), the dry unit weight stays constant but the amount of water in the voids increases with the water content. In other words, the degree of saturation (S) increases. In order to compact the soil, a compactive effort must be applied to the soil to remove void space in the form of air, following paths similar to A→B or C→D. Further compaction of the soil at Points D or E is not possible unless water is removed, and the water content is decreased.

3-2.2 Characterizing Compaction.

3-2.2.1 Soils with Appreciable Fines.

For soils with more than about 5% to 15% fines (i.e., particles passing the #200 sieve), compacted soil behavior is often idealized using the concave-down *compaction curves* shown in Figure 3-3. These curves were first explained by Proctor (1933) in an effort to improve the quality of fill for earth dam construction. A compaction curve is obtained when soil is compacted using a constant *compactive effort*, which is the amount of work performed on the soil per unit volume during compaction. Hogentogler (1936) further explained compaction in terms of lubrication and particle hydration and noted that air becomes trapped at water contents higher than optimum. Barden and Sides (1970) later confirmed that the peak in the compaction curve occurs at the degree of saturation where air is no longer able to flow freely from the soil during compaction. The compaction process has also been explained in terms of the effective stresses that develop during compaction (Olson 1963) and capillary pressures in the unsaturated state (Hilf 1956).

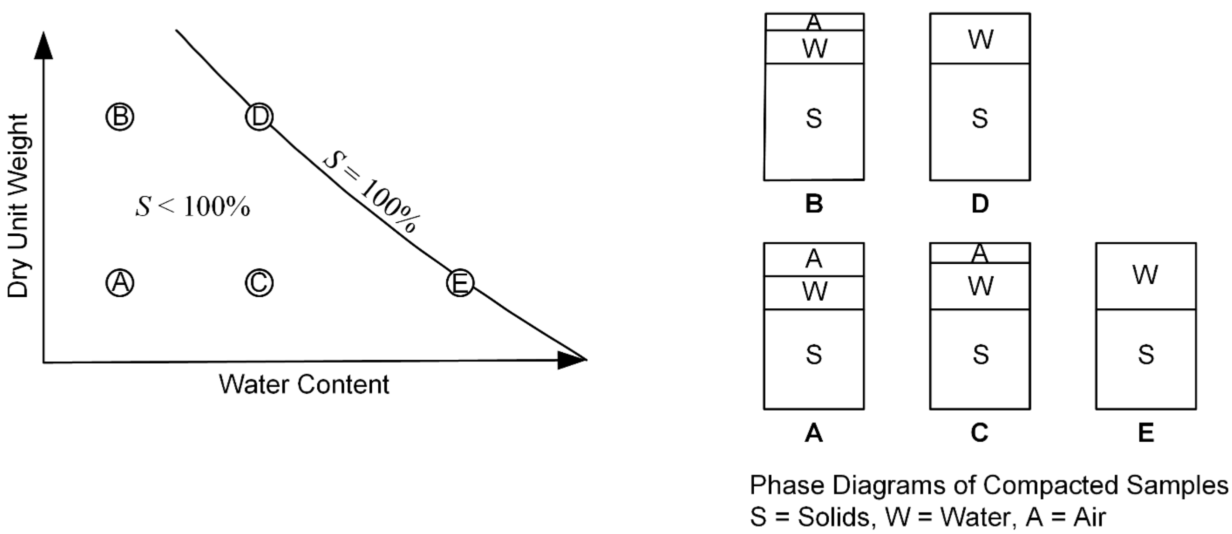


Figure 3-2 Changes in Weight-Volume Relationships from Compaction and Changes in Water Content

All of these theories provide valuable insight into the behavior of compacted soil. As the water content increases, less compactive effort is required to break up the lumps of soil. However, once air can no longer easily leave the soil, additional water simply takes up space and prevents higher levels of compaction. This creates a peak in the compaction curve. The dry unit weight at the peak of a particular compaction curve is referred to as the *maximum dry unit weight* ($\gamma_{d,max}$) for the corresponding compactive effort. The water content corresponding to the peak of a compaction curve is called the *optimum water content* (w_{opt}). If the compaction energy is increased, the compaction curve shifts toward lower water contents and higher dry unit weights. The relationship between the change in compactive effort and the shift of compaction curve is highly nonlinear.

The two most common levels of compactive effort are standard Proctor (ASTM D698) and modified Proctor (ASTM D1557). Standard Proctor is more often used as the reference energy for compaction control. The compactive effort for standard Proctor is 12,400 lbf-ft/ft^3. Modified Proctor was originally developed for compaction of airfield pavement subgrades. The compactive effort for modified Proctor is 56,000 lbf-ft/ft^3.

Modified Proctor is sometimes used as the reference standard for compaction of the upper few feet of a heavily loaded fill.

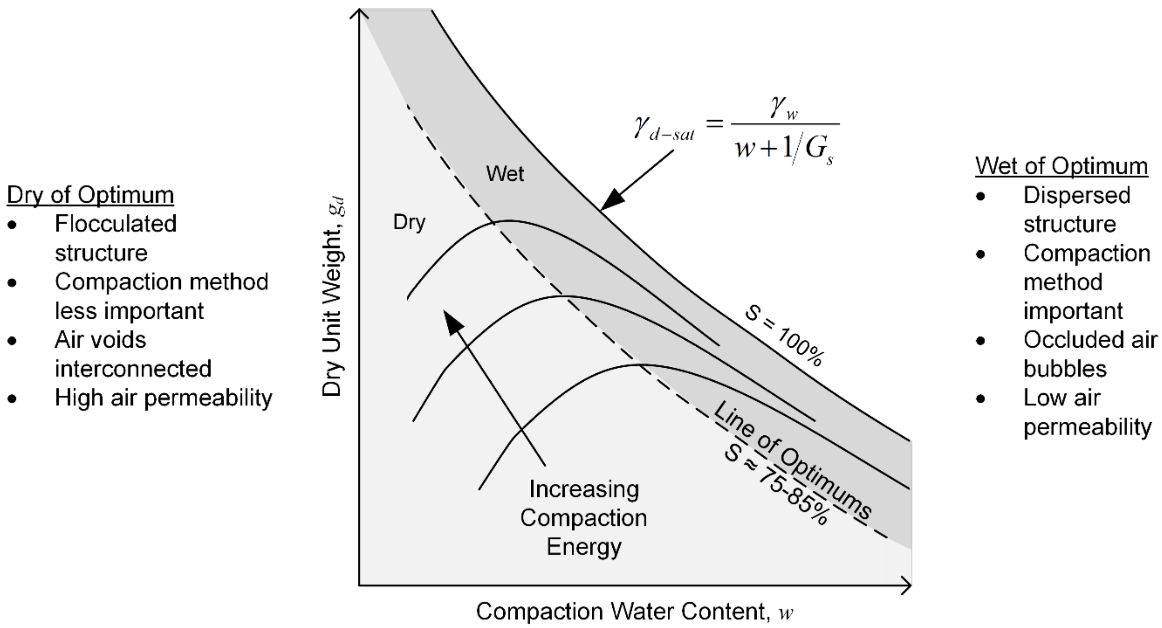


Figure 3-3 Effects of Compactive Effort and Water Content on Compacted Soil Properties

The peaks of a series of compaction curves can be connected to form a *line of optimums*, which often corresponds to S in the range of 75 to 85%. Compaction to a state to the left of this curve is referred to as *dry of optimum* while compaction states to the right are termed *wet of optimum*. All possible compaction states for a particular soil are bounded on the right side by the $S = 100\%$ curve (a.k.a., *zero air voids curve*). Properties typically associated with “dry” and “wet” compaction are summarized in Figure 3-3.

The dry unit weight and water content of a compacted soil can be compared to the conditions at the peak of a compaction curve for the same soil. *Relative compaction* ($R.C.$) is used for soils with appreciable fines and is defined as:

$$R.C. = \frac{\gamma_{d,field}}{\gamma_{d,\max}} \times 100\% \quad (3\text{-}3)$$

where:
$\gamma_{d,field}$ = dry unit weight of compacted fill and
$\gamma_{d,max}$ = maximum dry unit weight for a specified compactive effort.

The *relative water content* (Δw) of the compacted fill is:

$$\Delta w = w_{opt} - w_{field} \tag{3-4}$$

where:
w_{field} = water content of the compacted fill.

The position and shape of the compaction curve can be affected by variables other than compactive effort. For example, different methods of applying the compactive effort, such as kneading compaction, impact compaction, and static compaction, result in different soil structure and change the compaction curves. Similarly, different types of field compaction equipment result in different compaction behavior.

Some soils and rocks undergo irreversible changes during drying and compaction, and they may exhibit drastically different compaction curves in the field compared to those created in the laboratory unless special care is taken. These materials include clays containing halloysite or allophane minerals, which are chemically altered when dried (Hilf 1991). Some weak rocks may degrade differently during field and laboratory compaction. Very dense glacial till clays can have field compacted dry unit weights much higher than the laboratory $\gamma_{d,max}$ because of the extensive loosening required to perform the laboratory compaction tests.

3-2.2.2 Compaction of Soils with Little Fines.

For soils without an appreciable fines content (i.e., $F < 5$ to 15%), compaction behavior is much less sensitive to water content. In some cases, the compaction curve is poorly defined below optimum (Sowers 1979). In other soils, a minimum value of γ_d may be reached at a midrange water content because the bulking of sand or gravel grains inhibits compaction (Hilf 1991).

For these materials, characterization in terms of void ratio can be more appropriate. The loosest state that the soil can sustain with a regular structure is referred to as the *maximum void ratio* (e_{max}) and can be found using ASTM D4254. The densest configuration of the soil is called the *minimum void ratio* (e_{min}) and can be found using a vibratory table as described in ASTM D4253. The value of e_{min} depends on particle shape and size. Some compaction methods and levels of compactive effort may break particles, which can lower e_{min} (Sowers 1979). Corresponding values of minimum dry unit weight ($\gamma_{d,min}$) and maximum dry unit weight ($\gamma_{d,max}$) can be calculated. The value of e_{min} determined by ASTM D4253 corresponds to approximately 100% of $\gamma_{d,max}$ determined by ASTM D698 or 95% of $\gamma_{d,max}$ determined by ASTM D1557.

For coarse-grained soils without appreciable fines, *relative density* (D_r) is sometimes used for determining the level of compaction and assessing the influence of compaction on the engineering properties. Relative density is defined as:

$$D_r = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \times 100\% = \frac{\gamma_{d,field} - \gamma_{d,\min}}{\gamma_{d,\max} - \gamma_{d,\min}} \left(\frac{\gamma_{d,\max}}{\gamma_{d,field}} \right) \times 100\% \qquad (3\text{-}5)$$

where:
e = compacted void ratio ($\gamma_{d,field}$ = corresponding dry unit weight),
e_{max} = maximum void ratio ($\gamma_{d,min}$ = corrsponding dry unit weight), and
e_{min} = minimum void ratio ($\gamma_{d,max}$ = corrsponding dry unit weight).

3-2.3 Influence of Compaction on Engineering Parameters.

Compaction produces an engineered fill with relatively high dry unit weight or low void ratio. Compaction changes the strength, compressibility, and hydraulic conductivity of the fill, fulfilling three of the objectives in Figure 3-1.

3-2.3.1 Engineering Parameters of Compacted Coarse-Grained Soils.

Coarse-grained soils, especially those with little fines, are often characterized in terms of relative density (D_r). Coarse-grained soils will have a low relative density (0 to 20%) when placed loosely. Satisfactory compaction will tend to increase D_r to the range of 75 to 100%. The trends described in this section can be used to set appropriate compaction control requirements.

The shear strength of compacted coarse-grained soils is typically quantified in terms of an effective stress friction angle (ϕ'), which increases as D_r increases. As D_r increases from 0% to 100%, the friction angle increases by about 8 to 12 degrees (Hilf 1991, Duncan et al. 2014) as shown in Figure 3-4(a). This increase is also reflected in correlations between ϕ' and D_r presented in Duncan et al. (2014) and Chapter 8 of DM 7.1 (NAVFAC 2021). The compaction water content tends to have a minor effect on the shear strength of coarse-grained soils and should usually be as high as possible.

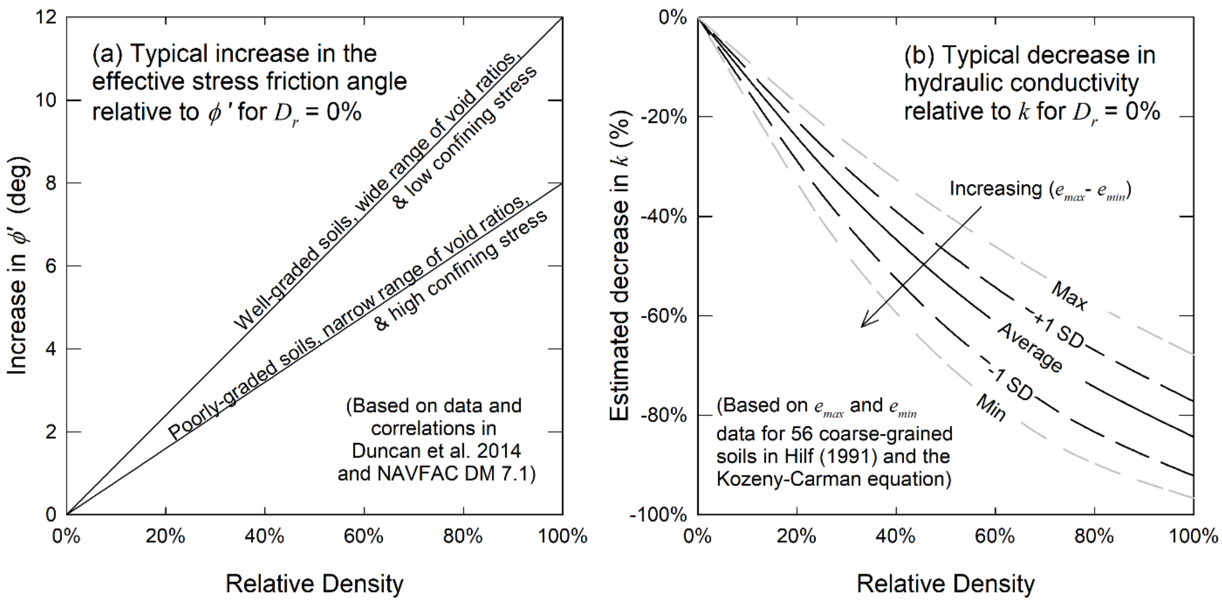


Figure 3-4 Effect of Compaction on (a) Shear Strength and (b) Hydraulic Conductivity of Coarse-Grained Soils

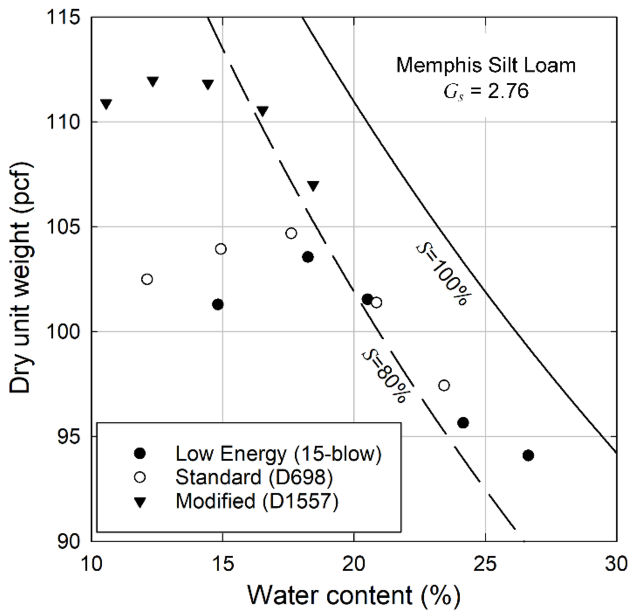
As soil is compacted and D_r increases, coarse-grained soils become stiffer or less compressible. Based on typical values of the elastic modulus, sands and gravels become about four times stiffer when D_r is increased from 0% to 100%.

The hydraulic conductivity (k_{sat}) of coarse-grained soils is inversely related to void ratio and will decrease as D_r increases. In Figure 3-4(b), the approximate percent decrease in k_{sat} is estimated using the Kozeny-Carman equation. A greater reduction in k_{sat} occurs when the soil has a wide range of possible void ratios (i.e., e_{max} - e_{min} is larger).

3-2.3.2 Engineering Parameters of Compacted Fine-Grained Soils.

The engineering parameters of compacted fine-grained soil, particularly clay, depend on the initial compaction conditions, the stress history following compaction, and the time of the design condition with respect to compaction. In particular, the effects of volume change caused by collapse or swelling must be considered. Clays which become saturated after compaction will tend to swell unless subjected to confining pressure. Swelling reduces the dry unit weight of the compacted clay and may reduce shear strength and increase compressibility. Laboratory tests used to measure the parameters of compacted clays should match field conditions to the extent possible.

As illustrated in Figure 3-3, both the water content and the compacted unit weight will affect the structure of the clay. In order to comprehensively determine the effect of compaction on fine-grained soil parameters, the 15-point method can be used as illustrated in Figure 3-5. In this method, three levels of compaction energy are selected, and five specimens are compacted at each energy, resulting in 15 combinations of compacted water content and dry unit weight. The appropriate test (shear strength, compressibility, hydraulic conductivity, etc.) is conducted on each specimen, which allows the variation in this parameter to be assessed across the compaction plane.



<u>15-Point Method</u>

1) Split soil sample into three sub-samples.
2) Mix specimens from each sub-sample to five water contents.
3) Compact specimens using a constant compaction energy for each sub-sample.
4) Plot compaction curves as shown in the example to the left.
5) Perform engineering property test(s), such as shear strength or hydraulic conductivity, at each compaction condition.
6) Plot results from Step 5 on the compaction plane. For example, see Figure 3-6.

Figure 3-5 15-Point Method for Determining Engineering Parameters of Compacted Soil

The 15-point method is appropriate mostly for large projects or research efforts. For smaller projects, it is often necessary to pick a particular $R.C.$ and water content at which to perform tests to determine engineering parameters. If this approach is taken, care must be used to choose a conservative compaction state. VandenBerge et al. (2017) provide guidance on the selection of compaction conditions for shear strength tests on compacted clays.

Within practical levels of compaction, compacted clays are heavily overconsolidated. For both consolidation and axial compression, compaction dry of optimum tends to produce a more brittle response. Compaction wet of optimum tends to produce ductile soil behavior. Clays compacted dry of optimum will exhibit an apparent yield stress as shown in Figure 3-6(a). In contrast, a more gradual stress-strain behavior is observed in clays compacted wet of optimum. Under low stress levels, dry compaction will usually result in less strain or settlement. At higher stress levels, the strains tend to become similar regardless of the initial compaction state. Compression indices for compacted soil can be measured in one-dimensional consolidation tests provided the initial saturation condition in the laboratory appropriately matches the field conditions. The behavior of saturated specimens of compacted clay tested in consolidated-undrained (CU) triaxial compression is shown in Figure 3-6(b). Compaction dry of optimum will tend to create a stiffer initial response. The strength of compacted clay is about equal at high axial strain, regardless of the compaction condition. These observations apply to specimens with the same dry unit weight after consolidation.

The effective stress shear strength of compacted clay is not substantially affected by the compaction state (Johnson and Lovell 1979, VandenBerge et al. 2015). However, the pore pressure response of compacted clay varies widely by compaction state, which in turn impacts the undrained shear strength. Trends in behavior for as-compacted (UU) conditions are illustrated in Figure 3-6(c) and (d). Total stress cohesion increases with increasing compaction, while the total stress friction angle decreases with increasing water content or degree of saturation. For saturated, consolidated undrained conditions, VandenBerge et al. (2015) found that the undrained strength ratio is approximately constant up to about 70% saturation, as shown in Figure 3-7, and increases for clay compacted to higher degrees of saturation. Consolidated undrained strengths are heavily influenced by the amount of swelling that occurs during saturation.

The saturated hydraulic conductivity (k_{sat}) of laboratory specimens of compacted clay is affected by the initial compaction state. As shown in Figure 3-8(a), k_{sat} can vary three or four orders of magnitude within the range of typical compaction. Benson and Trast (1995) studied the hydraulic conductivity of 13 compacted clays and found an inverse relationship between k_{sat} and initial saturation (Figure 3-8(b)). Daniel (1994) stressed the importance of field-scale considerations, such as cracking and defects, on the acting hydraulic conductivity of compacted clay liners. Tinjum et al. (1997) discusses the unsaturated properties of compacted clays.

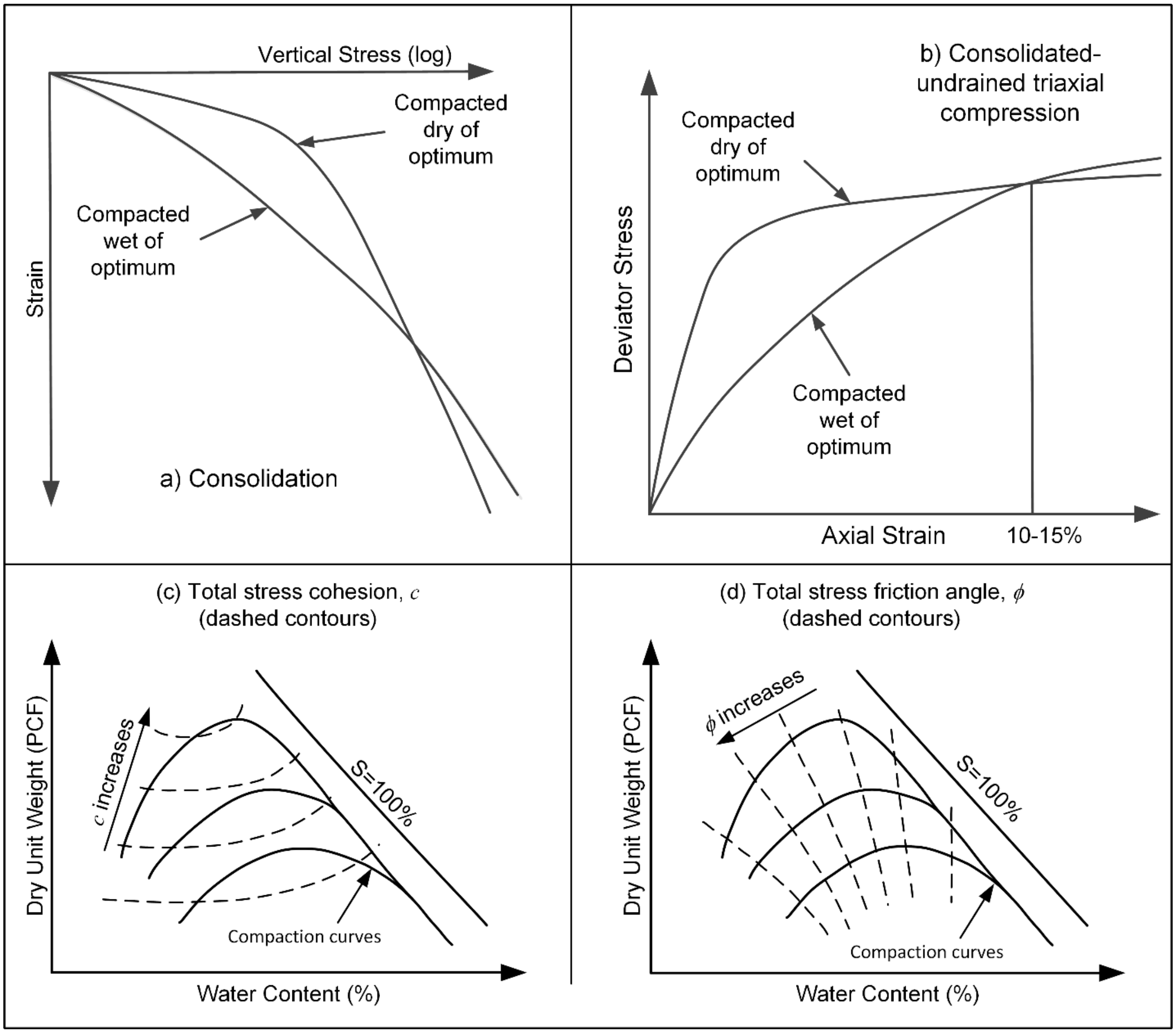


Figure 3-6 Engineering behavior of compacted clay – (a) consolidation, (b) stress-strain, (c) total stress cohesion, and (d) total stress friction angle (after DiBernardo and Lovell 1979, Seed et al. 1960, and Kulhawy et al. 1969)

In most cases, specimens of candidate fill materials should be compacted and tested in the laboratory to directly measure the desired engineering parameters. The trends presented in this section can help to guide the laboratory testing program. For example, clay soils will tend to have the lowest unconsolidated, undrained shear strength at high water content and low relative compaction. Thus, UU tests should be conducted at the highest water content allowed by the specification and lowest specified R.C. Similarly, k_{sat} is highest for low initial saturation. For this reason, laboratory specimens should use the lowest specified water content to obtain a conservative measure of k_{sat}, provided low k_{sat} is desired.

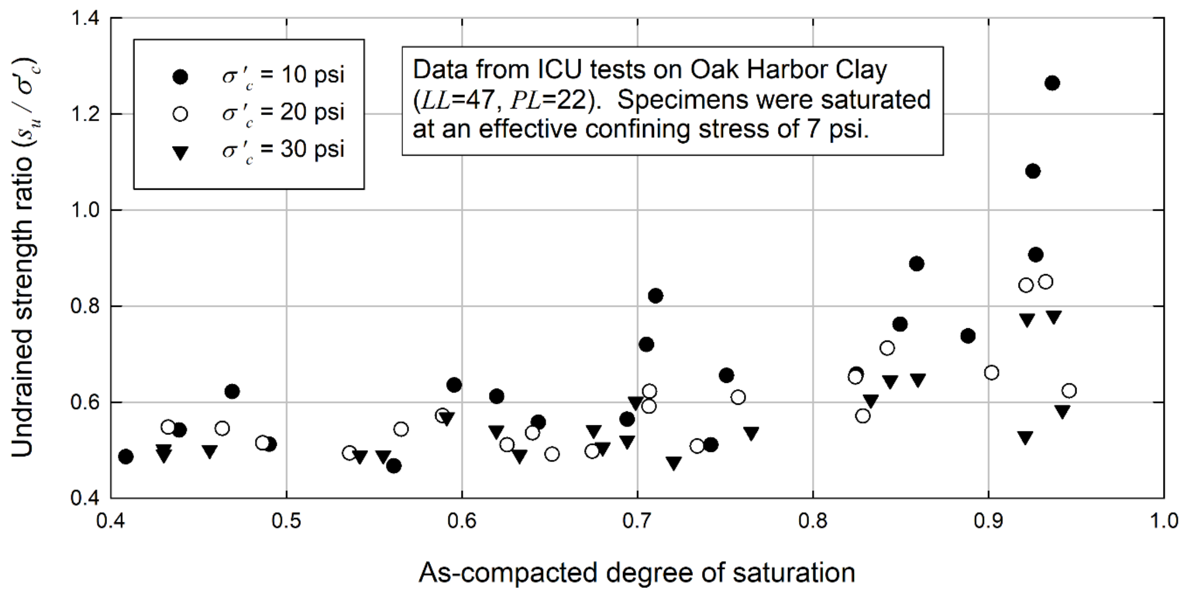


Figure 3-7 Variation in consolidated undrained shear strength ratio with as-compacted degree of saturation (after VandenBerge et al. 2015)

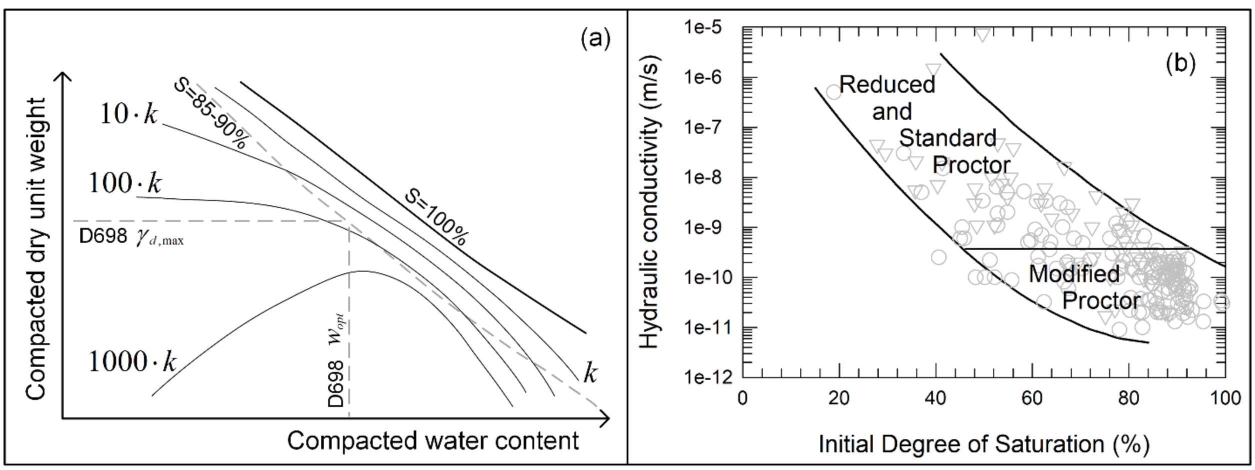


Figure 3-8 Saturated hydraulic conductivity of laboratory compacted clay – (a) typical variation (based on Mitchell et al. 1965, Garcia-Bengochea 1978) and (b) variation with initial saturation (after Benson and Trast 1995)

3-3 FILL MATERIALS.

The selection of fill material for a particular engineering application must consider both the purpose and the availability of fill materials. The selection process may include the following steps: (1) gather samples of all the available and viable fill sources, (2) perform classification tests (i.e., Atterberg limits and grain-size analysis), (3) use soil classification to determine typical properties of the available fill materials based on Table 3-1, Figure 3-9, Figure 3-10, and Figure 3-11, (4) select a small number of soils to obtain larger samples, (5) perform tests to determine appropriate engineering parameters at representative compaction levels (i.e., compaction, strength, shrink/swell, hydraulic conductivity), and (6) select an appropriate soil for the application (Sowers 1979). This type of selection process may be appropriate on large projects. However, on many smaller projects, the engineer specifies the type of material, and the contractor submits particular materials for the engineer's approval, limiting this type of detailed involvement in the selection process.

3-3.1 Borrow Exploration.

The source of the fill material is referred to as the *borrow*. Sufficient borings or test pits should be performed to determine the approximate quantity and quality of construction materials within an economical haul distance from the project. For mass earthwork, initial exploration should be on a 200-foot grid. If variable conditions are found during the initial exploration, intermediate borings or test pits should be completed.

One purpose of the borrow exploration is to determine a reasonably accurate subsurface profile to the anticipated depth of excavation, including the groundwater level. The approximate volume and engineering parameters should be determined for each material considered for use as fill. The other purpose of the borrow exploration is to obtain samples that can be used for classification testing as well as to ascertain the presence of salts, gypsums, or undesirable minerals, and the extent of organic or contaminated soils, if encountered.

3-3.2 Preliminary Selection based on Classification.

Typical properties of compacted soils are summarized by USCS classification in Table 3-1, Figure 3-9, Figure 3-10, and Figure 3-11, which may be used for preliminary selection and analysis. For final analysis, tests should be completed on compacted soil samples to determine engineering parameters.

The ranges of hydraulic conductivity provided for clay soils in Table 3-1 correspond to laboratory compacted specimens. However, a compacted clay mass will contain cracks and discontinuities. For this reason, the mass value of k is typically about two orders of magnitude higher than the laboratory value (Daniel 1984).

Table 3-2 summarizes the relative desirability of various soil types in earth fill dams, canals, roadways, and foundations. Practically any inorganic, insoluble soil may be incorporated in an embankment when modern compaction equipment and control standards are employed. However, some soils may be difficult to use economically. For some embankment zones, fine-grained soils may have insufficient shear strength or excessive compressibility. Clays of medium to high plasticity ($PI > 20$ and/or $LL > 40$) tend to expand if placed at low water content and exposed to low confining pressures for long periods of time. Identification of soils susceptible to volume expansion is discussed in Chapter 1 of DM 7.1. High plasticity soils with high natural moisture are difficult to process for proper moisture for compaction. Stratified soils may require extensive mixing in order to produce a homogeneous fill.

Table 3-1 Typical Compaction Properties and Hydraulic Conductivity based on USCS (after USACE 1960)

USCS Group Symbol	Soil Type	ASTM D698		Typical Hydraulic Conductivity, k (ft/s)[A]
		Maximum Dry Unit Weight (pcf)	Optimum Moisture, Percent	
GW	Well graded clean gravels, gravel-sand mixture	125 to 135	11 to 8	10^{-3} to 10^{-5}
GP	Poorly graded clean gravels, gravel-sand mix	115 to 125	14 to 11	10^{-2} to 10^{-4}
GM	Silty gravels, poorly graded gravel-sand-silt	120 to 135	12 to 8	10^{-5} to 10^{-7}
GC	Clayey gravels, poorly graded gravel-sand-clay	115 to 130	14 to 9	$< 10^{-8}$
SW	Well graded clean sands, gravelly-sands	110 to 130	16 to 9	10^{-3} to 10^{-5}
SP	Poorly graded clean sands, sand-gravel mix	100 to 120	21 to 12	10^{-2} to 10^{-4}
SM	Silty sands, poorly graded sand-silt mix	110 to 125	16 to 11	10^{-5} to 10^{-7}
SM-SC	Sand-Silt clay mix with slightly plastic fines	110 to 130	15 to 11	10^{-7} to 10^{-9}
SC	Clayey sands, poorly graded sand-clay-mix	105 to 125	19 to 11	$< 10^{-8}$
ML	Inorganic silts and clayey silts	95 to 120	24 to 12	10^{-7} to 10^{-9}
CL-ML	Mixture of inorganic silt and clay	100 to 120	22 to 12	$< 10^{-9}$
CL	Inorganic clays of low to medium plasticity	95 to120	24 to 12	$< 10^{-9}$
OL	Organic silts and silt-clays, low plasticity	80 to 100	33 to 21	$< 10^{-9}$
MH	Inorganic clayey silts, elastic silts	70 to 95	40 to 24	$< 10^{-10}$
CH	Inorganic clays of high plasticity	75 to105	36 to 19	$< 10^{-10}$
OH	Organic clays and silty clays	65 to 100	45 to 12	$< 10^{-10}$

[A] Hydraulic conductivity ranges for clay soils are typical of laboratory compacted specimens. The hydraulic conductivity of a compacted clay mass is typically about two orders of magnitude higher than the laboratory value.

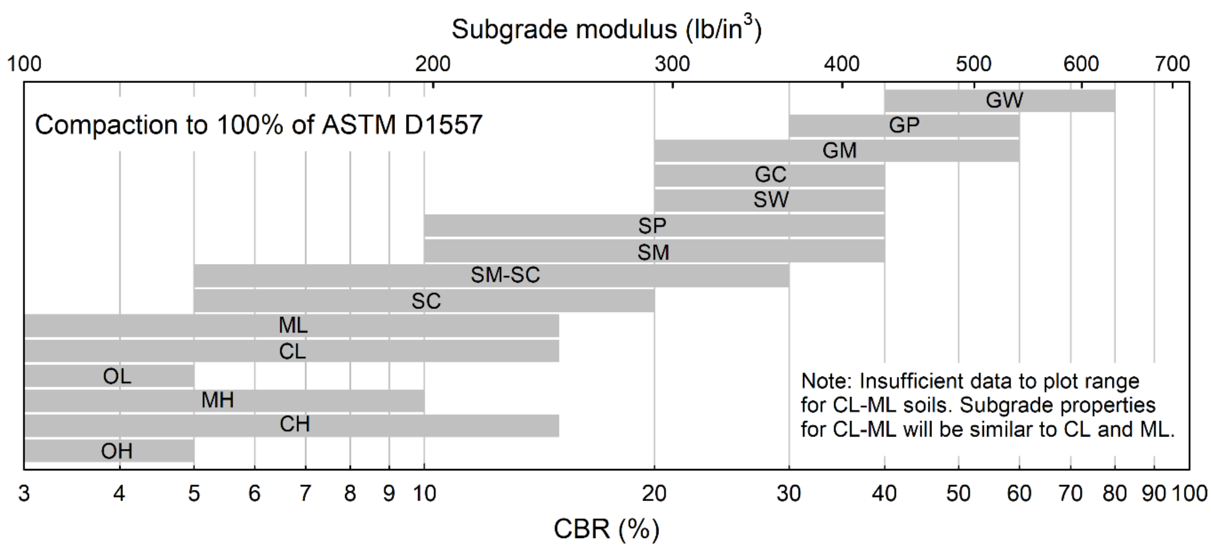


Figure 3-9 Typical Subgrade Modulus and California Bearing Ratio by USCS (after Porter 1943, USACE 1960, PCA 1992)

Fill Compression Parameters by USCS		
Classification Group	a_Δ	b_Δ
1: GM-GP, GM, GM/SM	0.30 - 0.41	0.64
2: SM	0.32 – 0.58	0.80 – 0.58
3: ML	0.28 – 0.53	0.76 – 0.72
4: SC/GC, SC-SM	0.43 – 0.51	0.81 – 0.75
5: SC	0.54 – 1.00	0.66 – 0.61
6: CL-ML, CL/SC, CL/GC	0.33 – 1.35	1.08 – 0.60
7: CL (PI = 8 – 15)	0.28 – 0.92	1.17 – 0.66
8: CL (PI = 10 – 21)	0.22 – 0.68	1.15 – 0.94

Parameters for estimating fill compression based on data from 25 USBR dams. Higher values of a_Δ tend to correspond to lower values of b_Δ.

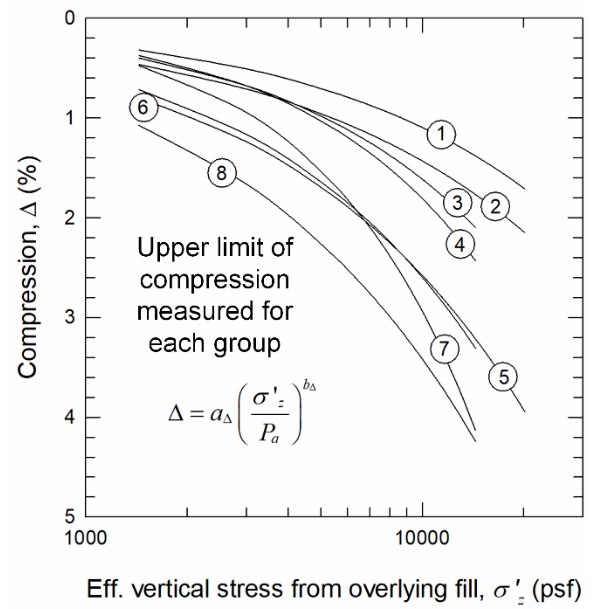


Figure 3-10 Vertical Compression of Compacted Fill by USCS (after Gould 1954)

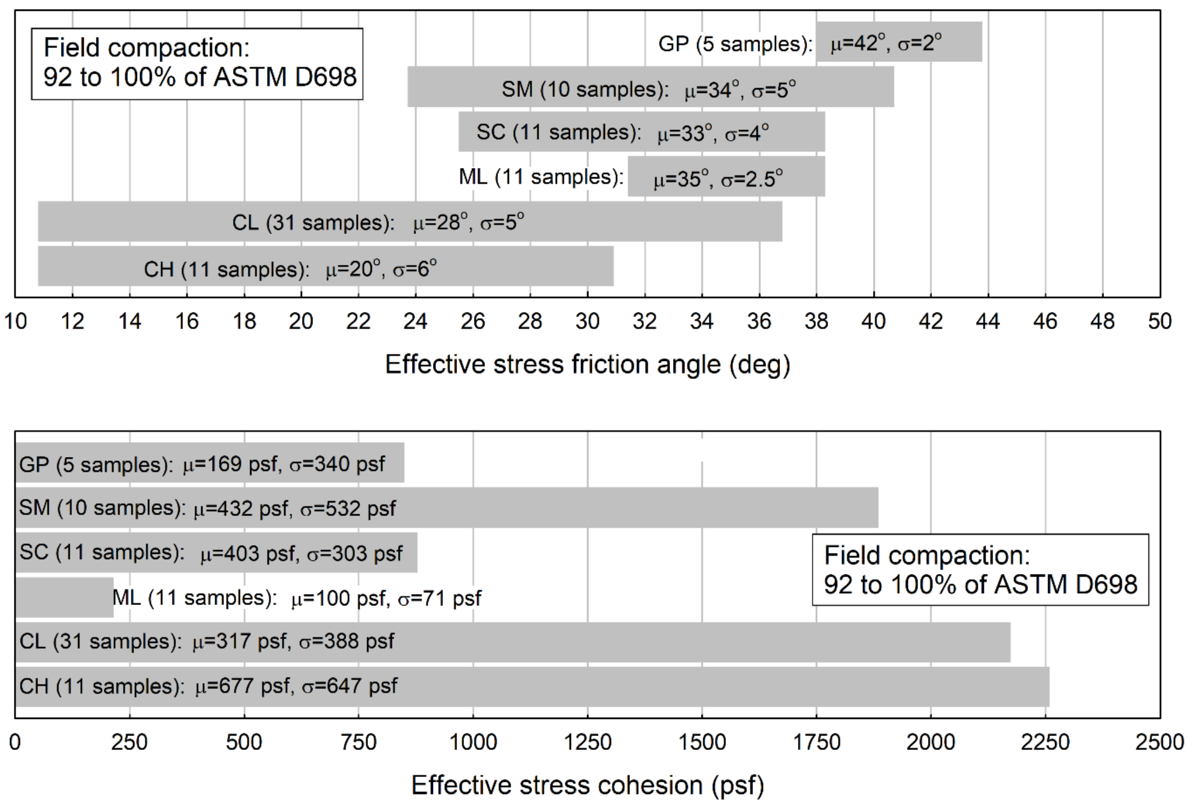


Figure 3-11 Typical Drained Shear Strength Parameters of Compacted Fill – μ Indicates Mean Value and σ Indicates Standard Deviation (after USBR 1998)

Table 3-2 Relative Desirability of Soils for Compacted Fill based on USCS Classification (after USBR 1998)

USCS Group Symbol	Soil Type	Earth Fill Dams: Homogeneous Embankment	Earth Fill Dams: Core	Earth Fill Dams: Shell	Canal Sections: Erosion Resistance	Canal Sections: Compacted Earth Lining	Foundation: Seepage Important	Foundation: Seepage Not Important	Roadway: Fill: Frost Heave Not Possible	Roadway: Fill: Frost Heave Possible	Roadway: Surfacing
		Relative Desirability for Various Uses (1 = very suitable, 2 = suitable, 3 = somewhat suitable, 4 = marginally suitable, 5 = unsuitable)									
GW	Well graded gravels, gravel-sand mixtures, little or no fines	5	5	1	1	5	5	1	1	1	2
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	5	5	2	1	5	5	2	2	1	5
GM	Silty gravels, poorly graded gravel-sand-silt mixtures	1	2	5	2	2	1	2	2	3	3
GC	Clayey gravels, poorly graded gravel-sand-clay mixtures	1	1	5	2	1	1	2	2	2	1
SW	Well graded sands, gravelly-sands, little or no fines	5	5	3[A]	3	5	5	1	1	1	2
SP	Poorly graded sands, gravelly sands, little or no fines	5	5	3[A]	3[A]	5	5	2	2	2	5
SM	Silty sands, poorly graded sand-silt mixtures	2	3	5	3[A]	3[B]	2	3	3	3	3
SC	Clayey sands, poorly graded sand-clay mixtures	2	1	5	2	1	2	3	3	2	1
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	3	3	5	5	3[B]	3	3	3	3	5
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	2	2	5	4	2	2	3	3	2	4
OL[D]	Organic silts and silt-clays, low plasticity	4	4	5	5	3[B]	3	4	4	4	5
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	4	4	5	5	5	3	4	4	4	5
CH	Inorganic clays of high plasticity, fat clays	3	3	5	4	4[C]	4	4	4	4	5
OH[D]	Organic clays of medium high plasticity	4	4	5	5	5	4	4	4	4	5

[A] Suitable if gravelly
[B] Consideration of erosion is critical
[C] Consideration of volume change is critical
[D] USACE experience has shown that organic soils can be incorporated in embankments if necessary. See Chapter 1 for more information.

For normal embankment construction, the maximum particle sizes should not exceed 3 inches (i.e., gravel-sized or smaller) or 50 percent of the compacted layer thickness. Where economic borrow sources contain larger particles, compaction trials should be performed before approval.

3-3.3 Laboratory Characterization of Fill Materials.

3-3.3.1 Reference Compaction Tests.

In order to guide both fill placement and the selection of engineering parameters for compacted fill, tests must be completed to define compaction behavior under a specified compactive effort. For soils containing appreciable fines, the standard Proctor (ASTM D698) and modified Proctor (ASTM D1557) tests are used. These tests are described in more detail in Chapter 3 of DM 7.1. The compactibility of clean soil and rock may alternatively be characterized using e_{min} and e_{max} (ASTM D4253 and D4254). When multiple different soils will be used as fill, a family of compaction curves should be obtained to represent the typical fill materials for the project.

Many soils contain some percentage of particles that are larger than the maximum size allowed using a given compaction mold (e.g., larger than 4.75 mm for 4-inch mold or ¾-inch for 6-inch mold). These particles are referred to as *oversize* and interfere with compaction of the finer soil fraction in the mold. However, in the field, these particles will be present in the field compacted fill and will influence the compacted dry unit weight.

For soils with more than 5% oversize particles, corrections can be made to the water content and dry unit weight measured on the soil without the oversize particles.[13] The corrected water content is found as:

$$w_T = P_C w_C + P_F w_F \tag{3-6}$$

where:
w_T = combined water content of the finer and oversize fractions (decimal),
P_C = percent oversize fraction (decimal),
w_C = water content of the oversize fraction (decimal),
P_F = percent finer fraction (decimal), and
w_F = water content of the finer fraction (decimal).

[13] These corrections are typically limited to 40% oversize for 4.75 mm particles and 30% oversize for ¾-inch particles.

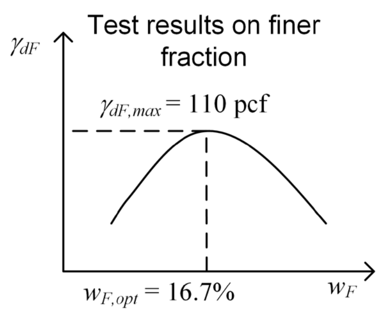
The corrected dry unit weight is found as:

$$\gamma_{dT} = \frac{\gamma_{dF} G_{sC} \gamma_w}{\gamma_{dF} P_C + G_{sC} \gamma_w P_F} \tag{3-7}$$

where:
γ_{dT} = combined dry unit weight of the finer and oversize fractions,
γ_{dF} = dry unit weight of the finer fraction,
G_{sC} = specific gravity of solids of the oversize fraction, and
γ_w = unit weight of water (62.4 pcf, 9.81 kN/m^3).

In addition to correcting laboratory results for oversize as in the previous equations, ASTM D4718 allows the influence of the oversize fraction to be corrected out of the field results by solving Equations 3-6 and 3-7 for w_F and γ_{dF}. An example of the two types of oversize correction is provided in Figure 3-12. The two methods do not give, exactly, the same results, and the method desired for each project should be clearly specified.

Laboratory Results



10% oversize

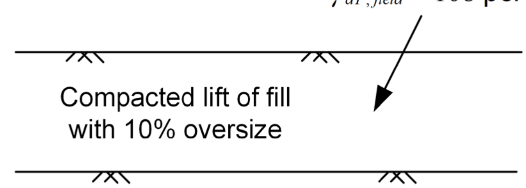
$w_C = 12\%$

$G_{sC} = 2.8$

Field Results

$P_F = 0.9$
$P_C = 0.1$

$w_{T,field} = 11\%$
$\gamma_{dT,field} = 108$ pcf



Option 1: Correct laboratory results for oversize fraction

$$\gamma_{dT,\max} = \frac{(110\ pcf)(2.8)(62.4\ pcf)}{(110\ pcf)(0.1)+(2.8)(62.4\ pcf)(0.9)}$$

$$\gamma_{dT,\max} = 114.2\ pcf$$

$$w_{T,opt} = (0.167)(0.9)+(0.12)(0.1) = 0.162$$

$$w_{T,opt} = 16.2\%$$

$$R.C. = \frac{\gamma_{dT,field}}{\gamma_{dT,\max}} = \frac{108\ pcf}{114.2\ pcf} \times 100\% = 94.6\%$$

$$\Delta w = w_{T,field} - w_{T,opt} = 11\% - 16.2\% = -5.2\%$$

Option 2: Correct field results for oversize fraction

$$\gamma_{dT,field} = 108\ pcf$$

$$108\ pcf = \frac{\gamma_{dF,field}(2.8)(62.4\ pcf)}{\gamma_{dF,field}(0.1)+(2.8)(62.4\ pcf)(0.9)}$$

$$\gamma_{dF,field} = 103.6\ pcf$$

$$w_{T,field} = 11\% = (w_{F,field})(0.9)+(0.12)(0.1)$$

$$w_{F,field} = 0.109 = 10.9\%$$

$$R.C. = \frac{\gamma_{dF,field}}{\gamma_{dF,\max}} = \frac{103.6\ pcf}{110\ pcf} \times 100\% = 94.2\%$$

$$\Delta w = w_{F,field} - w_{F,opt} = 10.9\% - 16.7\% = -5.8\%$$

Figure 3-12 Oversize Correction Example Calculations

3-3.3.2 Engineering Parameter Testing.

In addition to reference compaction tests, engineered fill materials are often tested to verify adherence to material specifications and to determine soil-specific values of shear strength, compressibility, and hydraulic conductivity. While project conditions will dictate the specific types of information that are required, the applicable test methods for various fill materials are summarized in Table 3-3. Further description of these test methods can be found in Chapter 3 of DM 7.1 (NAVFAC 2021).

Table 3-3 Applicability of Testing Methods by USCS Classification

USCS Group Symbol	Test Methods (ASTM method)												
	Atterberg Limits (D4318)	Grain size distribution (D6913, D7928)	Moisture-Unit Weight (Proctor) (D698, D1557)	Maximum and Minimum Index Density (D4253, D4254)	California Bearing Ratio (D1883)	Direct shear (D3080)	Unconsolidated Undrained Triaxial Compression (D2850)	Consolidated Undrained Triaxial Compression (D4767)	Consolidated Drained Triaxial Compression (D7181)	Torsional Ring Shear (Residual Shear Strength) (D6467)	Hydraulic Conductivity (D5084)	One-Dimensional consolidation (D2435)	One Dimensional Swell or Collapse (D4546)
GW		A	A	A	A	S		A	A		A		
GP		A		A	A	S			A				
GM	A	A	A		A	S		A	A		A		
GC	A	A	A		A	S	M	A	M		A		A
SW		A	A	A	A	A		A	A		A		
SP		A		A	A	A			A				
SM	A	A	A		A	A	A	A	A		A	A	A
SC	A	A	A		A	A	A	A	M		A	A	A
ML	A	A	A		A	A	A	A			A	A	A
CL	A	A	A		A	A	A	A		A	A	A	A
MH	A	A	A		A	A	A	A		A	A	A	A
CH	A	A	A		A	A	A	A		A	A	A	A

A = test is applicable, M = test is marginally applicable, S = test is applicable with specialized equipment
Note: D3080 was officially withdrawn by ASTM in 2020 but remains an applicable method for testing many soils.

3-3.3.3 Rock Fill.

Rock fill can be defined as containing at least 30% clean rock with a grain size greater than ¾-inch and containing less than 15% fines (Breitenbach 1993). Rock fill is often placed with the major objective of creating a free-draining fill with rock-to-rock contacts throughout.

As discussed for the oversize portion of compaction test, laboratory characterization of rock fill materials is challenging because of the constraints on particle size imposed by laboratory testing equipment and standards. For example, the maximum particle size is limited to one-tenth of the specimen height for direct shear tests and one-sixth of the specimen diameter for triaxial tests. These constraints effectively limit laboratory shear strength testing to materials with particles no larger than 1 inch diameter, even for the most well-equipped commercial geotechnical laboratories. Most rock fills have a substantial fraction larger than 1 inch. Specialized large scale testing devices have been developed but are not commonly available.

The two primary alternatives for shear strength testing of rock fill with large particles are scalping and parallel gradations (Marachi et al. 1972). A *scalped* gradation refers to the complete removal of all particles larger than a particular grain size. The grain size distribution coefficients, C_c and C_u, of the scalped gradation will be lower than those of the parent rock fill. The scalped gradation is more poorly-graded than the rock fill. A *parallel* gradation is created by shifting the grain-size distribution to have 100% passing the largest allowable particle size but maintaining the shape of the distribution and the values of C_c and C_u. Creation of a parallel distribution requires a substantially larger initial soil sample and causes a more drastic change in the overall classification of the soil. Because of the level of effort and the size of the sample required, scalped gradations are typically preferred.

The shear strength of rock fill is affected by the stress level, roughness, and size of the particles as summarized in Table 3-4. Leps (1970) and others have described nonlinearity in the shear strength or friction angle of rock fill using a variety of equations. Larger particles are more likely to have defects and tend to break more easily. This effect can be considered through the parameters S or m described in Table 3-4. Marachi et al. (1972) found that increasing the particle size by a factor of four (i.e., $D_B/D_A = 4$) produced a 2 to 3.5 degrees decrease in ϕ', while the reduction in ϕ' was in the range of 3 to 5 degrees for $D_B/D_A = 12$. The Frossard et al. (2012) approach predicts similar reduction in ϕ'. The effect of particle size is most pronounced for rock fill with a wide range of particle strength or low m. The value of m for a rock fill can be measured using a large number of laboratory crushing tests (Marsal 1967, Lee 1992).

Two additional factors must be considered for rock fill but are difficult to quantify: (1) changes in the rock fill gradation during excavation and placement and (2) deterioration after placement (Sowers 1979). The first can be evaluated using a test embankment section and grain size analysis of samples of the fill following compaction. Potential for deterioration is especially important for shales, or sedimentary rocks composed primarily of clay and silt. These rocks have a wide range of hardness and can degrade substantially through wetting and drying, which is referred to as *slaking*. The most problematic shales for use as engineered fill are those which are initially hard but do not retain their properties after excavation and placement.

Where fill materials will contain shale, an appropriate system must be selected to determine the durability of the shale as well as its susceptibility to chemical degradation. Huber (1997) reviewed the available systems for classifying shale durability and recommended those proposed by FHWA (1978), Franklin (1981), and Wiles (1988). These systems use the jar slake test (Deo 1972), the slake durability test (ASTM D4644), the point load strength test (ASTM D5731), and Atterberg limits (ASTM D4318). The FHWA (1978) system divides shales into two major categories: soil-like and rock-like. The former require compaction similar to soil, while the latter are durable and can be treated as rock fill. Franklin's (1981) system provides a shale rating that has been correlated to various shale fill parameters. Wiles (1988) devised a durability rating system based on the loss of shear strength caused by wetting in triaxial tests. Susceptibility to chemical weathering is indicated by a pH less than 6 in the slake durability water as well as dark gray, green, or black color.

Table 3-4 Stress and Particle Effects on the Shear Strength of Rock Fill

Effect	Description	Applicable Equations	References
Nonlinearity	The shear strength envelope for rock fill is distinctly curved. The friction angle decreases with increasing effective normal stress.	$\phi' = \phi'_0 - \Delta\phi' \log\left(\frac{\sigma'_f}{P_a}\right)$ $\tau_f = a \cdot P_a \left(\frac{\sigma'_f}{P_a}\right)^b$	Leps (1970) Charles and Soares (1984) Lade (2010) Duncan et al. (2014) VandenBerge et al. (2018)
Particle strength and roughness	Frictional resistance is affected by rock fill roughness (related to relative density, origin, roundness, and smoothness) and particle strength, which tends to decrease with particle size.	$\phi' = R \cdot \log\left(\frac{S}{\sigma'_f}\right) + \phi'_b$	Barton and Kjaernsli (1981)
Particle diameter	As particle size increases, the likelihood of breakage increases. This can be described by a material parameter, m, which for rock fill varies from 4 for a wide range of particle strength to about 15 for uniform particle strength.	$a_B = a_A \left(\frac{D_B}{D_A}\right)^{\frac{-3\cdot(1-b_A)}{m}}$	Marsal (1967) Marachi et al. (1972) Frossard et al. (2012)
Notation: ϕ'_0 and $\Delta\phi'$ = parameters describing the change in friction angle with normal stress , P_a = atmospheric pressure (used for normalization), σ'_f = effective normal stress at failure (plane or orientation depends on usage), a and b = power function parameters describing nonlinearity (also a_A, a_B, b_A, and b_B), R = roughness factor, S = particle compressive strength, ϕ'_b = base friction angle, D_B/D_A = ratio of sizes between two parallel gradations, and m = Weibull distribution parameter for particle strength (mean value of 6 in data by Marsal 1967).			

3-3.4 Alternative Fill Materials.

Materials other than natural soil can be used as fill. These materials include recycled products from construction or other industry as well as lightweight products manufactured for use as fill. Motivations for the use of alternative fill include concerns about sustainability, economics, lack of availability of appropriate natural materials, and efforts to reduce vertical or horizontal earth pressures.

Selection of alternative fill materials should consider multiple costs, including basic material cost, transportation cost, and placement costs. The quantity of required fill, availability of the alternative material, and local experience with construction methods also must be considered. Finally, special concerns, such as fill durability requirements, environmental concerns, and fill thermal parameters, must be addressed. Some of the intangible benefits of alternative materials may be reduced installation time leading to accelerated construction, lower weather sensitivity compared to natural soil, and reduced requirements for field quality control (FHWA 2017, Arellano 2019).

3-3.4.1 Recycled Fill Materials.

Typical properties of recycled fill materials are summarized in Table 3-5. Recycled fill materials are used as a replacement for natural soil in order to reduce disposal impacts and prevent disturbance of natural ground to obtain fill. In many cases, the recycled materials have more favorable engineering properties than natural soils.

Table 3-5 Typical Properties of Common Recycled Fill Materials (after Soleimanbeigi et al. 2014, Soleimanbeigi and Edil 2015, DiGioia and Nuzzo 1972, Masad et al. 1996).

Material	Typical properties or ranges					
	USCS	G_s	w_{opt} (%)	$\gamma_{d,max}$ (pcf)	k (cm/s)	ϕ' (deg)
Recycled asphalt pavement	SP, GW	2.45	5 to 10	120 to 125	10^{-3} to 10^{-2}	42
Recycled concrete aggregate	GW	2.7	5 to 10	120 to 125	10^{-4} to 10^{-3}	46
Recycled pavement material	GW	2.39	< 5	120 to 125	10^{-4} to 10^{-3}	44
Bottom ash	SP	2.67	< 5	95 to 100	10^{-3} to 10^{-2}	44
Recycled asphalt shingles	SW	1.74	5 to 10	70 to 75	10^{-4} to 10^{-3}	33
Foundry sand	SW	2.36	< 5	70 to 75	10^{-3} to 10^{-2}	36
Fly ash	ML	2.39	15 to 20	50 to 80	10^{-9} to 10^{-6}	33 to 40
Tire derived aggregate	SP and GP sized	1.07	NA	25 to 30	10^{-4} to 10^{-3}	NA

An important environmental consideration for recycled materials is that the fill does not contaminate groundwater or surface water through leaching or runoff. It is also important to note that the use of recycled materials does not necessarily lead to a more sustainable project. For example, long transportation can offset the benefits of using a recycled material. The most beneficial recycled materials are those which are available locally, improve the engineering properties of the fill, and are environmentally benign (VandenBerge et al. 2015).

3-3.4.2 Lightweight Fill Materials.

Engineered fill increases the stresses in the underlying ground. This can cause settlement, an increase in the stress on existing structures or walls, and a decrease in the stability of slopes. Lightweight fill materials, such as those listed in Table 3-6, can substantially reduce the stresses applied by a fill or embankment. Lightweight fill is commonly used for soft ground conditions and is often combined with ground improvement methods such as prefabricated vertical drains, deep mixing, and column-supported embankments (FHWA 2017).

Table 3-6 Common Lightweight Fill Materials (after FHWA 2017, Arulrajah et al. 2015)

Material	Unit weight (pcf)	k (cm/s)	Lateral earth pressure, K	Shear strength	Comments
Geofoam	0.7 to 3	10^{-6} to 10^{-2}	0.1	6 to 14 psi	Manufactured from expanded polystyrene (EPS) or extruded polystyrene (XPS), typically installed in large blocks, stability analyses must consider interface properties with soil and between blocks, unit weight increases with time when saturated, provides thermal insulation
Foamed glass aggregate (FGA)	15 to 20	High	Use ϕ' to estimate	ϕ' = 36 to 54°	Synthetic aggregate produced by heating recycled glass, closed and open cell available, provides thermal insulation, used in drainage blankets and green roofs, higher CBR than most lightweight materials
Cellular concrete	20 to 80	10^{-1}	Negligible for self-weight or vertical loads	10 to 300 psi	Manufactured, preformed foam mixed with cement slurry, pumped into place, can be permeable, generates negligible lateral earth pressure
Tire shreds or tire derived aggregate	30 to 73	0.5 to 60	0.25 to 0.47	ϕ' = 19 to 30°	Tires shredded into chips, can be bound together into bales, can be mixed with natural soil, more guidance can be found in ASTM D6270
Expanded clay shale (ECS)	40 to 65 (dry)	High	Use ϕ' to estimate	ϕ' = 35 to 45°	Synthetic, vitrified aggregate produced by heating clay or claystones, often used as aggregate in lightweight concrete, can degrade under steel-tracked equipment
Wood chips, fiber, and sawdust	45 to 60	≈10^{-5}	Use ϕ' to estimate	ϕ' = 25 to 49°	Friction angle increases as size of the particles increases, volume reduction of 40% on compaction, commonly used in low-volume roads
Blast furnace slag	70 to 94 (total)	10^{-3} to 1	Use ϕ' to estimate	ϕ' = 35 to 40°	By-product of iron production, air-cooled slag solidified under atmospheric conditions and is angular and vesicular, expanded slag is solidified using water which increases cellular nature, granulated slag is chilled quickly forming a glassy product, expanded and granulated slags are lighter but more expensive, pH in range of 8 to 12

Design of lightweight fill should determine which stresses must be reduced to make the design functional in terms of both stability and settlement (Arellano 2019). Once the required amount of stress reduction has been determined, appropriate lightweight fill materials can be considered based on the unit weight, availability, and costs. Lightweight mineral materials achieve low unit weight through a porous particle structure. For this reason, the crush resistance and durability of these materials should be considered (TRB 1990).

3-4 CONSTRUCTION OF COMPACTED FILLS.

Compacted fills are constructed to meet some, or all, of the objectives shown in Figure 3-1 for a particular purpose. In order to create a fill that meets these objectives, the construction process starts with establishing suitable drainage and preparing the fill subgrade. The selected fill material(s) are then excavated, transported, placed, and compacted at the site. Throughout the fill construction process, the engineer has the responsibility of protecting both the project owner and the broader environment. This includes confirming that appropriate materials are used, implementing compaction specifications, and enforcing contractor procedures for the control of runoff and the protection of adjacent bodies of water (TRB 1990).

3-4.1 Drainage.

According to Sowers (1979), drainage is a critical, but often overlooked, component of high quality fill construction. Establishing good drainage may have a high initial cost but tends to save money over the course of most projects. In general, soil becomes weaker and more difficult to compact as its water content increases. Inadequate drainage leads to construction delays and unstable subgrade or fill soils. Where possible, surface water should be kept dispersed rather than concentrated to reduce erosion potential. As needed, surface water should be intercepted by ditches or drains and directed away from the fill area. Prior to excavation, including at borrow areas, slope ditches should be installed near the crest and at midslope to keep water out of the excavation and to keep the fill dry.

Subsurface water should also be considered by observing the site topography and knowledge of groundwater sources. The groundwater control methods described in Chapters 1 and 6 of DM 7.1 (NAVFAC 2021) can be used to lower groundwater below fill areas or in excavations. Surface and subsurface drainage is especially important where the embankment soils are susceptible to deterioration when exposed to water, including high plasticity clays and shale fills.

3-4.2 Subgrade Preparation.

3-4.2.1 Ground Preparation.

After drainage has been established, the subgrade must be prepared for evaluation prior to the placement and compaction of the initial lift of fill. *Clearing*, which refers to removal of vegetation, trash, debris, and topsoil from the ground surface, should be completed within the bounds indicated on the plans. Topsoil is often stockpiled onsite for future use. *Grubbing* refers to deeper removal of stumps, heavy root mats, and buried objects. The extent of grubbing required must be specified. Deeper fills and those with less critical support requirements may not require grubbing (TRB 1990). Subsurface structures or debris that will interfere with compaction or the future construction should be removed. The sides of holes created by grubbing should be flattened, scarified, and compacted to similar unit weight as the foundation soil (USACE 1995a).

Unsuitable subgrade materials should be identified by subsurface exploration and observation after clearing and grubbing. Organically contaminated soils (Pt, OH, and OL) are generally not suitable for embankment support. Because of the detrimental effects of differential frost action, special attention should be given to removing near-surface frost susceptible soils and to limiting the availability of water to backfill.

Sites containing old fill, waste, ashes, sludge, slag, and mining spoils often require special preparation with specifics guided by the composition and past compaction of the old fill. For example, construction on poor quality existing fill will likely require ground improvement using methods described in Chapter 1. When dealing with mine waste, variable conditions can be present, including loose dumped materials as well as slurry and tailings deposits.

Special ground preparation is required for fills placed adjacent to existing slopes. If the slope is steeper than 3H:1V, the ground should be benched. Each *bench* consists of a horizontal cut followed by vertical step, typically not more than 4 feet high. The stair-stepped bench pattern prevents a weak zone from being created at the interface between the fill and the existing slope. In addition, slope protection in the form of riprap or drainage blankets may be needed to handle seepage from the fill or existing slope. The slope protection will help to prevent erosion and surficial slope failure (TRB 1990).

Finally, special preparation is required at the transitions between (1) cut and fill and (2) rock cut and soil cut in order to gradually accommodate the change between the differing subgrade support conditions. Material in these transition zones should be uniform without large (diameter greater than 6 inches) particles (TRB 1990). Where water may seep from the cut rock or soil, the transition fill may be used to provide drainage and prevent saturation and instability of the fill.

3-4.2.2 Proof Rolling and Subgrade Stability.

After clearing, grubbing, and other preparation, the relative stability of the fill subgrade is evaluated, often by *proof rolling*. Proof rolling refers to systematic trafficking of the subgrade surface by a loaded dump truck or roller. The purpose of proof rolling is to find instability and inconsistency in the subgrade or fill but not to induce widespread failure. A gross weight of 30 tons with 40 psi tire pressure is typically suitable for proof rolling of cut subgrades (TRB 1990). Once an acceptable proof rolling weight is determined, the proof roller should make two complete coverages of the subgrade and deflecting zones should be highlighted. In road construction, proof rolling can also be completed at the completion of the general earth fill and prior to placement of subbase.

The fill subgrade should be scarified and brought to optimum moisture content with special attention given to deflecting zones identified during proof rolling. The subgrade is then compacted and may be subjected to compaction control tests or further proof rolling prior to the placement of new fill.

3-4.2.3 Methods to Mitigate Subgrade Instability.

Where proof rolling indicates extensive instability or cannot be completed, soft subgrade conditions are present, and an initial thick stabilizing or bridging layer of sand, gravel, or crushed rock is required. Biaxial geogrid can be used below the layer to reduce the thickness of the bridging lift, and separation geotextile may be needed to prevent soft subgrade from pushing into the bridging lift. Gravity drainage should be provided to prevent water from collecting in the bridging lift. Vibrating construction equipment can exacerbate instability and should be limited until a stable working platform is achieved.

Chemical stabilization of the existing soil can also be used to improve subgrade stability. Stabilization is achieved by mixing a drying and/or cementing admixture, such as cement, fly ash, lime, or cement kiln dust, into the unstable soil. Shallow mixing can be accomplished by discing while deeper (up to 24 inches) treatment can be achieved using a specialized soil stabilizing mill. The appropriate percentage of the chemical admixture can be selected based on experience or a formal mix design that uses laboratory testing. Guidance for the selection of admixtures can be found in FHWA (2017).

Unstable soils may present concerns of long-term consolidation or low shear strength below the fill. In this case, vertical drains and/or preloading may be required to accelerate or induce consolidation (see Section 5.7.4 of DM 7.1, NAVFAC 2021) and increase the shear strength. The unstable material may also be improved using ground improvement methods described in Chapter 1.

3-4.3 Excavation, Transport, and Placement.

3-4.3.1 Methods.

Excavation is an important part of the process of manufacturing a quality fill and should be supervised by the engineer. Adequate drainage should be provided in the borrow area in order to maintain the appropriate water content of the fill material for efficient excavation and compaction. In addition, material processing may be required at the borrow, such as scalping oversize or mixing strata to create a homogenous fill.

Selection of appropriate and efficient excavation equipment is typically the decision of the contractor. Excavation methods can include hand tools, excavators, scrapers, graders, and draglines. In some cases, ripping and blasting may be required prior to excavation. More guidance on these can be found in Section 2-5 and FHWA (1991). Because the excavation method can affect the degree of mixing at the borrow, the engineer should be consulted. Blasting also requires consultation with the owner and engineer to determine vibration limitations, inspection requirements, and requirements for the final condition of the borrow area (TRB 1990).

Special care is required where the borrow source contains both durable rock fill and either soil or nondurable rock, such as degradable shale. Mixtures of these two materials should be avoided, because they are very difficult to adequately compact. In particular, nondurable shale should not be mixed with more durable sandstone or limestone in rock fill (FHWA 1978). Where borrow contains both, the durable rock should be separated for use as drainage fill and the outer shell of slopes, while the nondurable rock can be compacted separately as general fill.

An appropriate method must be selected to transport the fill. A variety of transport methods and economical haul distances are summarized in Table 3-7. The transportation and placement of fill can promote either segregation or mixing. If material separation is required, transportation methods should be carefully considered. As fill is dumped and spread, attention should be given to breaking large lumps of soil and removal of deleterious materials. Additional mixing of the fill can be performed at the fill location, if needed.

Table 3-7 Fill Transport Methods and Haul Distances (after Coduto et al. 2011)

Transport Method	Transport Details	Economical Haul Distance (ft)
Bulldozer	Fill pushed over ground surface, off-road only	< 300
Wheel loader	Fill carried in loader bucket (up to about 15 C.Y.), off-road only	150 to 500
Scraper	Fill excavated, hauled, and placed with one machine, about 25 to 35 C.Y. capacity, off-road only	1000 to 8000
Dump truck	Fill loaded into truck, hauled, and end-dumped at site, capacity ranges from 15-25 ton (on-road) to 42 ton (off-road articulating) up to 400 ton (mining)	1100 to 21,000 (4 miles)
Conveyor belt	Move large quantities over rough terrain, can be used with automated processing facilities	100 to 36,000 (7 miles)
Semi-Tractor Wagon	Fill end, side, or bottom-dumped at site, can be towed on or off-road, up to 120 ton capacity	> 10,000 (2 miles)

In many cases, the water content of the fill must be adjusted to meet the compaction specifications. Depending on the soil type as well as the method and distance of transport, this may be accomplished at the borrow area or at the fill. Coarse-grained soils with little fines often require additional water for compaction, and water trucks or hoses are used to increase the water content immediately prior to or during compaction. While water can be added and mixed into fine-grained soils, it is more common that the water content of these materials is too high. Drying can be accomplished by evaporation over time and accelerated by mixing the soil with a disk, harrow, or tiller. Chemical admixtures, such as cement, fly ash, lime, or cement kiln dust, are also drying agents and can be used when weather or time do not allow air drying.

3-4.3.2 Borrow and Fill Quantities.

Calculation of fill volumes at the borrow site, during transportation, and after compaction is an important aspect of earthwork planning. In the borrow, the soil has an average dry unit weight ($\gamma_{d,B}$). As the soil or rock is excavated for transport, *bulking*[14] will occur, which is a decrease in dry unit weight caused by an increase in the overall volume. Coarse-grained soils tend to bulk about 10% when excavated while fine-grained soils may bulk 30% to 40% (Coduto et al. 2011). Once the soil is placed and compacted, the dry unit weight of the fill ($\gamma_{d,F}$) may be either greater or less than $\gamma_{d,B}$. An average value of $\gamma_{d,F}$ can be estimated using the laboratory compaction curve and assuming an average relative compaction about 2% higher than the minimum specified value (Coduto et al. 2011).

Some fill material will be lost in the earthwork process, which is referred to as *waste*. Waste can be intentional, such as the removal of oversize material, or unintentional.

[14] This increase in volume is also referred to as *swelling*. However, bulking will be used in this manual to distinguish from the volume expansion that occurs when clay minerals are hydrated.

For example, a borrow with a large percentage of cobbles (diameter > 3 inches) may have a large amount of waste if the cobbles are excluded from the fill.

Comparison of total borrow and fill volumes must consider both changes in unit weight and waste. *Shrinkage* occurs when the earthwork process causes a reduction of volume. Bulking can occur overall if $\gamma_{d,F}$ is less than $\gamma_{d,B}$ and the amount of waste is low. The total weight of solids remains constant through the calculations even though the total volume changes.

If the fill volume (V_F) is known and the total waste (W_L) can be estimated, the total borrow volume can be calculated as:

$$V_B = V_F \frac{\gamma_{d,F}}{\gamma_{d,B}} + \frac{W_L}{\gamma_{d,B}} \quad (3\text{-}8)$$

where:
V_B = total borrow volume required,
$\gamma_{d,F}$ = average dry unit weight of the fill,
$\gamma_{d,B}$ = average dry unit weight of the borrow, and
W_L = total weight of waste.

In some cases, the waste must be estimated as loss percentage (X_L) and the total borrow volume is:

$$V_B = V_F \frac{\gamma_{d,F}}{\gamma_{d,B}} \left(1 + X_L\right) \quad (3\text{-}9).$$

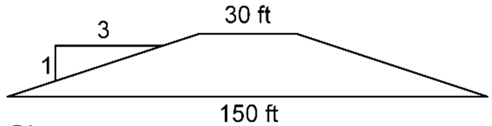
The overall *shrinkage factor* can be defined as:

$$\frac{\Delta V}{V_F} = \frac{\gamma_{d,F}}{\gamma_{d,B}} \left(1 + X_L\right) - 1 \quad (3\text{-}10)$$

where:
ΔV = change in total volume = V_B - V_F.

If more detailed unit weight information is not available, a shrinkage factor of 10% to 15% of V_F can be used for estimating purposes. If required, transportation volumes can also be calculated by replacing $\gamma_{d,B}$ in the preceding equations with the dry unit weight during transport, ($\gamma_{d,trans}$). An example of borrow and fill calculations is provided in Figure 3-13.

Embankment Borrow Calculations



Cross-Sectional Area: $A = \frac{150\,ft + 30\,ft}{2} \cdot 20\,ft = 1800\,ft^2$

Volume of Fill (per foot): $V_F = 1800\,ft^3$

<u>Given:</u>
Soil Properties: G_s = 2.7, $\gamma_{d,max}$ = 115 pcf, w_{opt} = 14% (ASTM D698), and $\gamma_{d,borrow}$ = 102 pcf
Compaction: Average $R.C.$ = 98% at w = 14%,

<u>Assume:</u>
Void ratio in truck e_{truck} = 1 and Loss Factor = 2% by dry weight

<u>Find (Per Foot of Embankment):</u>
- Trucking Volume
- Volume of Borrow
- Waste

<u>Fill Volume</u>

$$\gamma_d = \frac{\gamma_w G_s}{1 + e_{truck}} = \frac{(62.4\,pcf) \cdot 2.7}{1+1} = 84.2\,pcf \qquad \gamma_{d,f} = \frac{RC}{100} \cdot \gamma_{max} = \frac{98\%}{100} \cdot 115\,pcf = 112.7\,pcf$$

$$V_{truck} = V_F \cdot \left(\frac{\gamma_{d,f}}{\gamma_{\gamma,truck}} \right) = 1800\,ft^3 \cdot \left(\frac{112.7\,pcf}{84.2\,pcf} \right) = 2409 \frac{ft^3}{ft} = 89 \frac{CY}{ft}$$

<u>Volume of Borrow</u>

$$V_{borrow} = V_F \cdot \frac{\gamma_{d,f}}{\gamma_{\gamma,truck}} (1 + X_c) = 1800\,ft^3 \cdot \left(\frac{112.7\,pcf}{102\,pcf} \right) (1 + 0.02) = 2029 \frac{ft^3}{ft} = 75 \frac{CY}{ft}$$

<u>Waste</u>

$$W_L = V_F \cdot \gamma_{d,f} \cdot X_c = (1800\,ft^2)(112.7\,pcf)(2\%) = 4057 \frac{lb}{ft} = 2 \frac{tons}{ft}$$

Figure 3-13 Borrow Excavation Example

Because of its dense state *in situ*, rock fill will experience bulking from the borrow to the fill state. Maximum bulking will tend to occur for borrow consisting of dense, hard rock with fine fracture systems that breaks into uniform sizes. In this case, the shrinkage factor may be -50% (i.e., unit volume in the borrow will produce approximately 1.5 volumes in the fill). A minimum bulking (a.k.a., minimum expansion) condition occurs in porous, friable rock that breaks into broadly-graded pieces with numerous spalls and fines. In this case, the shrinkage factor may be as low as -10%.

3-4.4 Compaction.

After soil is transported to the project site, it is spread and compacted in layers or lifts of relatively uniform thickness by consistent coverage of the compaction equipment. This aspect of earthwork involves control of the major factors that influence soil compaction behavior (Section 3-2), including soil type, water content, compactive effort, and type of compaction. Efforts should also be made to route equipment, such as dozers and dump trucks, uniformly across the surface of the fill. This will provide some compactive effort and will minimize the effort required from other equipment. In addition, it will reduce the potential for rutting and overloading the fill.

3-4.4.1 Influence of Soil Type and Water Content.

Most soils used as fill are at least somewhat sensitive to the water content during compaction. For example, silts and some silty sands have steep compaction curves, and field moisture must be controlled within narrow limits for effective compaction. Clays are sensitive to moisture. If they are too wet, they are difficult to dry to optimum moisture, and if they are dry, it is difficult to mix the water in uniformly. An extreme example is sensitive clays, which do not respond to compaction because they lose strength upon remolding or manipulation. Soils in this category tend to compact more effectively using impact, static, and kneading compaction.

Coarse-grained soils with less than 5% to 15% fines are relatively insensitive to the compaction water content. The lower limit applies to well-graded soils while poorly-graded soils can contain more fines and still be insensitive to compaction moisture. These soils tend to have a hydraulic conductivity greater than 0.001 cm/s. These materials can be placed at the highest practical moisture content, preferably close to 100% saturation. Vibratory compaction generally is the most effective procedure. In these materials, a relative density of 70 to 75 percent can be obtained with proper compaction procedure, and relative density should be used for compaction control.

Gravel, cobbles, and boulders are also insensitive to compaction moisture. Compaction with smooth wheel vibrating rollers is the most effective procedure.

3-4.4.2 Types of Equipment.

The four major methods of compaction are (1) pressure; (2) impact; (3) vibration; and (4) manipulation, kneading, or shearing. With the exception of small equipment, most compaction equipment possesses significant weight. However, the contact pressure can vary widely from high pressures under tamping foot (a.k.a., sheepsfoot) rollers[15] to low pressures under smooth-drum rollers. While impact compaction is the primary method of laboratory compaction, it is primarily used in the field by power tampers and some operation modes of tamping and grid rollers. Vibration applies dynamic forces to soil particles that promote compaction and is used by vibratory tamping foot and

[15] While the term *sheepsfoot* is commonly used, rollers which use true sheepsfoot tines are rare in current earthwork practice.

smooth-drum rollers, vibratory base plate compactors, and grid compactors. Kneading compaction manipulates and shears the soil and is applied by tamping foot and rubber-tired rollers.

Table 3-8 lists commonly used compaction equipment with typical sizes and weights. In general, the compaction equipment should exert the highest contact pressure that does not result in rutting (i.e., bearing capacity failure) or failure to *walk out* of the fill (Sowers 1979). Walking out refers to the ability of tamping foot rollers to penetrate less and less into the fill as the fill becomes well-compacted.

The appropriate lift thickness will depend on the combination of the soil type, equipment, and fill purpose. Table 3-9 provides guidance on the applicability of different equipment to various soil conditions along with typical compacted lift thickness and number of passes. In general, the thicknesses in Table 3-9 are a satisfactory starting point. Thicker lifts may be appropriate for general purpose fills, if adequate compaction is still achieved. For water retaining fills, thinner lifts may be required to produce the desired hydraulic conductivity throughout the fill.

Selection of appropriate compaction equipment continues through the earthwork process by observation of the fill performance. When fill that is wet of optimum is compacted excessively, it deforms and deflects in an elastic manner, which is referred to as *weaving* or *pumping*. In this state, the fill is nearly saturated, and application of compactive effort is ineffective at removing further air from the fill. Further compaction can lower the dry unit weight. When the compaction equipment is too heavy for the fill or the fill is too wet, the equipment will sink into the fill causing *rutting*, which is a bearing capacity failure that must be fixed before earthwork can continue (TRB 1990).

Table 3-8 Equipment Type Summary

Equipment	Dimensions and Weight			Possible Variations in Equipment
Tamping Foot Roller	Soil Type	Contact area	Foot contact pressure	For earth dam, highway and airfield work, articulated self-propelled rollers are commonly used. For smaller projects, towed 40 to 60 inch drums are used. Foot contact pressure should be regulated to avoid shearing the soil on the third or fourth pass. Tamping foot rollers must penetrate a loose lift (too light otherwise) and should walk out as compaction proceeds (too heavy otherwise or soil too wet).
	Fine, PI > 30	5 to 12 ft^2	250-500 psi	
	Fine, PI < 30	7 to 14 ft^2	200-400 psi	
	Coarse	10 to 14 ft^2	150-250 psi	
	Efficient compaction wet of optimum requires less contact pressure than that required for the same soil at lower moisture contents.			
Rubber Tire Roller	Tire inflation pressures of 35 to 130 psi for clean granular material of base course and subgrade compaction. Wheel load of 18,000 to 25,000 lbs.			A wide variety of rubber tire compaction equipment is available. For fine-grained soils, light-wheel loads, such as provided by wobble-wheel equipment, may be substituted for heavy-wheel load if lift thickness is decreased. For granular soils, large-size tires are desirable to avoid shear and rutting. In general, higher tire pressure is more effective than higher wheel load. Increased tire size with same pressure results in deeper compaction.
	Tire inflation pressures in excess of 65 psi, for fine-grained soils of high plasticity. For uniform clean sands or silty fine sands, use large size tires with pressures of 40 to 50 psi.			
Smooth Wheel Rollers	Tandem type rollers for base course or subgrade compaction; 10 to 15-ton weight or 300 to 500 lb per inch of rear roller width.			Three-wheel rollers are obtainable in wide range of sizes. Two-wheel tandem rollers are available in the weight range of 1 to 20 tons. Three-axle tandem rollers are generally used in the weight range of 10 to 20 tons.
	Three-wheel roller for compaction of fine-grained soil; weights from 5 to 6 tons for materials of low plasticity to 10 tons for materials of high plasticity.			
Vibrating Tamping Foot Rollers	1 to 20-ton ballasted weight. Dynamic force up to 20 tons.			May have either fixed or variable cyclic frequency.
Vibrating Smooth Drum Rollers	1 to 20-ton ballasted weight. Dynamic force up to 20 tons.			May have either fixed or variable cyclic frequency. Heavy roller with low frequency for rockfill and clays. Lighter and high frequency for sand. Best performance for soil at, or slightly above, optimum.
Vibrating Baseplate Compactors	Single pads or plates should weigh no less than 200 lb. May be used in tandem where working space is available. For clean coarse-grained soil, vibration frequency should be no less than 1,600 cycles per minute.			Vibrating pads or plates are available, hand-propelled, single or in gangs, with width of coverage from 1.5 to 15 ft. Various types of vibrating-drum equipment should be considered for compaction in large areas.
Grid Pattern Roller	Towed by a tractor or dozer. Contact pressure between 200 and 900 psi with 50% coverage.			Generates vibration, crushing, and impact when towed at high speeds.
Crawler Tractor or Dozer	Vehicle with standard tracks having contact pressure not less than 10 psi.			Tractor weight up to 85 tons.
Power Tamper or Rammer	30-lb minimum weight. Considerable range is tolerable, depending on materials and conditions.			Weights up to 250 lb, foot diameter 4 to 10 in.

Table 3-9 Applicability of Compaction Equipment to Different Soil Types

Type of Fill Material		Typical compacted lift thickness (inches) for different compaction equipment (compaction method indicated in parentheses)									# of passes or coverages
		Tamping foot (kneading)	Pneumatic / rubber tired (kneading)	Smooth wheel (static only)	Vibrating tamping foot (kneading, vibration)	Vibrating smooth drum (vibration)	Vibratory baseplate compactor (vibration)	Grid (vibration, impact)	Crawler tractor	Power tamper or rammer (impact)	
Fine-grained	General fine-grained	6 to 12	6 to 8	6 to 8							4 to 8
Fine-grained	Water retaining fills	6 to 12	6 to 8								4 to 6
Coarse-grained	General coarse-grained	6 to 12	6 to 8	6 to 8	8 to 12	6 to 12	8 to 10	6 to 12	6 to 10		3 to 5
Coarse-grained	Dirty, $P_{\#200}$ > 8%	6 to 12	6 to 8	6 to 8	8 to 12	6 to 12		6 to 12			6 to 8
Coarse-grained	GW base or subbase			8 to 12		6 to 12		6 to 12			4
Coarse-grained	Clean, $P_{\#200}$ =4-8%		10	8 to 12		6 to 12	8 to 10	6 to 12	6 to 10		3 to 5
Coarse-grained	Gravel			8 to 12		6 to 12		6 to 12			3 to 5
Coarse-grained	Durable rock fill					up to 36					4 to 6
All soils, difficult access such as trench backfill										4 to 6	2

3-4.5 Special Construction Conditions.

3-4.5.1 Rock Fill.

Rock fill should be placed and compacted to a dense state without large voids so that overlying material will not settle or migrate into the rock fill. Rock fill can be placed in compacted lifts up to 3 feet thick. In general, the compacted lift thickness should be at least 1.5 times the largest particle diameter (TRB 1990). Dozers can be used to crush oversized particles or rake them from the fill. Compaction should be performed with 10 to 20-ton vibratory rollers operating at about 20 to 25 Hz. Appropriate compaction is typically achieved with about four to six roller passes, while additional passes pulverize the surface without increasing compaction. The rock fill fraction smaller than ¾-inch diameter should be near its optimum moisture content for best compaction (Breitenbach 1993).

Special attention should be given to the durability of rock fill as discussed in Section 3-3.3.3. Nondurable rock should be treated similar to soil when used as fill. It should be broken down during compaction such that the large voids are filled and particle migration will be prevented if slaking occurs. This can be difficult if the shale is hard but nondurable. Problematic shales often require use of a tamping foot roller to break the particles followed by a large rubber-tired roller to compact the fill. Experience has shown that good compaction with a lift thickness of 8 inches will result in no major problems and few minor problems, regardless of the durability of the fill (FHWA 1978).

3-4.5.2 Retaining Wall Backfill.

As described in TRB (1990), lateral earth pressures on fill-type retaining walls depend heavily on the type of soil used as backfill, the placement conditions, and compaction methods. Prediction of these pressures is discussed in more detail in Chapter 4. If possible, clean, free-draining soil should be used as retaining wall backfill. Material substitutions should not be allowed for retaining wall backfill without approval of the engineer. Frozen material should not be used as backfill.

Retaining wall backfill should be spread evenly in lifts of 6 to 8 inches or less, depending on the size of the compaction equipment. The water content should be controlled closely and kept near optimum to minimize the required compactive effort and loading on the wall.

3-4.5.3 Cold Weather Considerations.

Experience and research have shown that adequate compaction of moist soil is very difficult in freezing temperatures. The water in the soil has higher viscosity at low temperature. Even coarse-grained soils require much higher compactive effort when compacted near or below freezing. For example, Modified effort at 30° Fahrenheit produces a lower dry unit weight than Standard effort at 74 deg Fahrenheit (TRB 1990). In addition to difficulty compacting the soil, frozen soil may contain substantial moisture in the form of ice. When this ice eventually thaws, the fill may be softened by the additional moisture, leading to poor performance.

3-4.5.4 Trench Backfill.

Backfill within trenches (depth greater than width and width less than about 15 feet) must be adequately compacted, even when poorly graded gravel, such as a #57 gradation, is used. Compaction in trenches can be difficult and requires special and/or small equipment. In addition, OSHA safety considerations apply as described in

Chapter 2. While sometimes it may be necessary to jet sand backfill into place around utility pipes (Coduto et al. 2011), flooding of fill into trenches is not recommended (Holtz et al. 2011). In trenches less than 3 to 4 feet wide, the backfill should be a clean sand or gravel that can be easily placed in 6 to 12-inch thick compacted lifts at a high water content. USACE (1995b) provides guidance on compaction in confined areas for water retaining structures.

3-5 CONTROL OF COMPACTED FILLS.

Compaction improves all or most of the engineering parameters of a soil or rock fill (see Figure 3-1) but is expensive both economically and environmentally. Thus, the decision whether an adequate level of compaction has been achieved is a critical step in the earthwork process (Coduto et al. 2011). This decision-making process is referred to as *quality assurance* (QA) when completed by an entity other than the contractor and *quality control* (QC) when completed by the contractor. *Compaction control* refers to the QA process coupled with in-depth regulation of the earthwork process appropriate to an owner's representative.

Most of this section focuses on the quantitative aspects of field testing for compaction control. However, the visual observations and simple measurements summarized in Table 3-10 are just as critical to good compaction control. Field engineers monitoring earthwork using these methods will stay active throughout the earthwork process regardless of the number of compaction control tests performed.

3-5.1 Compaction Requirements.

The target level of compaction is typically defined using either end-result or method specifications. The number and size of QA tests performed on an earthwork project is always small with respect to the size of the fill (USBR 1987). For this reason, a well-defined compaction procedure is required for adequate compaction control, regardless of the type of specification used.

End-result specifications require that the fill be compacted to a minimum and/or average dry unit weight and may include a limitation on the compaction water content. End-result specifications may include a maximum lift thickness but allow the contractor freedom in the selection of compaction methods and equipment. Because of soil variability and the uncertainties in the construction process, the specified dry unit weight is typically stated in terms of relative compaction or relative density as compared to an applicable standard. Most often, compaction specifications use relative compaction (Equation 3-3), which is applicable to soils with appreciable fines. For these soil types, an acceptable range of relative water content (Equation 3-4) may also be specified.

Relative density (Equation 3-5) is sometimes used to determine the compaction of clean coarse-grained soils. However, D_r ranges from 0% to 100% over approximately the range of dry unit weights corresponding to $R.C.$ of 80% to 100%. For this reason, D_r is much more sensitive to small changes in the field dry unit weight, and more variation should be expected in the compaction control tests, if D_r is used. A useful alternative for clean coarse-grained soils is to use the relative compaction concept along with ASTM D4253 as means of determining the maximum dry unit weight rather than the Proctor compaction test.

Table 3-10 Simple Compaction Control Methods for Field Engineers (after TRB 1990, USACE 1995a)

Compaction Variable to Monitor	Simple Control Method
Compaction method	Record equipment used to place and compact the soil, including equipment model or weight.
Compactive effort	Count and record number of passes of compactor.
Compacted lift thickness	Elevation of each test via global positioning system (GPS), conventional surveying, or hand level and benchmark.
Soil type	Regularly record visual soil description and classification (ASTM D2488). If possible, have the field engineer help with laboratory characterization of fill materials (i.e., Atterberg limits and Proctor tests).
Soil moisture (soil with appreciable fines)	Use Visual-Manual tests to assess proximity to Plastic Limit and optimum water content (typically $w_{opt} = PL$ - 2%±).
	Excessively wet soil: Rubber-tired equipment will sink up to 50% of tire width. Fill surface weaves or pumps in response to compaction equipment. Fill remains stuck to the roller.
	Appropriate moisture: Rollers track in 3 to 4 inches on first pass but progressively penetrates less deeply with each pass (i.e., *walks out*). Feet of tamping foot rollers become clean after a few passes.
	Excessively dry soil: Fill surface becomes hard and dry after a few passes. Fill shows little or no response to weight of compaction equipment.
Soil response to hauling and compaction equipment	Soil with appreciable fines: Weaving and rutting indicates excessively wet soil or excessively heavy compaction equipment. Some springing or deformation immediately under the equipment is expected.
	Clean coarse-grained soils: Vibratory rollers should only push a small amount of soil in front of the roller, otherwise the vibration frequency is incorrect, or the material has too high of a fines percentage.
Penetration resistance	Soil with appreciable fines: Use T-Probe, Proctor needle, or pocket penetrometer to obtain a semi-quantitative assessment of compacted fill. The feel of the probe or measured values provide a site-specific correlation to level of compaction.
	Clean coarse-grained soils: Press a boot heel into the compacted soil. The heel will create a rotational general shear type of bearing capacity failure in well-compacted soil. The heel will simply sink into poorly compacted soil.

Table 3-11 summarizes typical end-result compaction specifications in terms of relative compaction for various purposes. These specifications can be modified to meet site-specific conditions and materials. USBR (1987) requirements for earth dams are summarized in Table 3-12 in terms of both relative compaction and relative density.

Table 3-11 Typical Compaction Specifications for Soil with Appreciable Fines

Fill Used for:	Typical Min. *R.C.*	Δw^A	Compacted Lift Thick.	Special Requirements
Structural Support	100% (D698) 95% (D1557)	-2% to +2%	Up to 12 inches	Fill should be uniform. Blending or processing of borrow may be required. For plastic clays, investigate expansion induced by saturation for various compaction moisture and densities at loads equal to those applied by structure, to determine condition to minimize expansion. Clays that show expansive tendencies generally should be compacted at or above optimum moisture to a unit weight consistent with strength and low compressibility required of the fill.
Lining for canal or small reservoir	95% (D698) 90% (D1557)	-2% to +2%	Up to 6 inches	For thick linings, GW-GC, GC, and SC are preferable for stability and to resist erosive forces. Single size silty sands with PI less than five generally are not suitable. Remove fragments larger than 6 inches before compaction.
Support of pavements	100% (D698) 95% (D1557)	-2% to +2%	---	Place coarsest borrow materials at top of fill. Investigate expansion of plastic clays placed near pavement subgrade to determine compaction moisture and unit weight that will minimize expansion and provide required soaked CBR values.
Backfill surrounding structure	95% (D698) 90% (D1557)	-2% to +2%	Up to 8 inches	Where backfill is to be drained, provide pervious coarse-grained soils. For low walls, do not permit heavy rolling compaction equipment to operate closer to the wall than a distance equal to about two-thirds of the unbalanced height of fill at any time. For highwalls or walls of special design, evaluate the surcharge produced by heavy compaction equipment by the methods of Chapter 4 and specify safe distances back of the wall for its operations.
Backfill in pipe or utility trenches	95% (D698) 90% (D1557)	-2% to +2%	Up to 8 inches for general sitework; 12 inches or more for pipelines	Material excavated from the trench generally is suitable for general trench backfill if it does not contain organic matter or refuse. The excavated material is typically unsuitable for pipe bedding. Instead bedding material is typically coarse-grained soil or controlled low-strength material (flowable fill). Where free draining sand and gravel is utilized, the trench bottom may be finished flat and the granular material placed saturated under and around the pipe and compacted by vibration. More stringent compaction requirements may be appropriate in the upper foot of trenches, especially in pavement areas. Special backfilling procedures may be required in seismic zones.
Drainage blanket or filter	95% (D698) 90% (D1557)	Wet	Up 8 inches	Ordinarily, vibratory compaction equipment is utilized. Blending of materials may be required for homogeneity. Segregation must be prevented in placing and compaction. For compaction adjacent to and above drainage pipe, use hand tamping or light travelling vibrators.
Structure subgrade excavation	100% (D698) 95% (D1557)	-2 to +2	---	For uniform bearing or to break up pockets of frost susceptible material, scarify the upper 8 to 12 inches of the subgrade, dry or moisten as necessary and recompact. Certain materials, such as heavily preconsolidated clays, which will not benefit by compaction, or saturated silts and silty fine sands that become quick during compaction, should be blanketed with a working mat of lean concrete or coarse-grained material to prevent disturbance or softening. Depending on foundation conditions revealed in exploration, a substantial thickness of loose soils may have to be removed below subgrade and recompacted, or compacted in place by vibration, or pile driving.
Water retaining structures	See Table 2-12		Up to 12 inches	Core material and other impervious zones should be placed and compacted to create a homogeneous fill without horizontal stratification. The compacted surface of each lift should be heavily scarified prior to the placement of the next lift.

[A] Relative water content, $\Delta w = w_{field} - w_{opt}$

Table 3-12 Compaction Control Criteria for Compacted Earth Dams (after USBR 1987)

Material	Fraction of soil passing #4 sieve ($P_{\#4}$)	Compaction Control Criteria (based on $P_{\#4}$ fraction)					
		Height less than 50 ft			Height greater than 50 ft		
		Minimum	Average	Δw^A	Minimum	Average	Δw^A
Soil with appreciable fines	$P_{\#4}$ > 75%	$R.C. \geq 95\%$	$R.C. \geq 98\%$	-2% to +2%	$R.C. \geq 98\%$	$R.C. \geq 100\%$	-2% to 0%
	$P_{\#4}$ = 75% to 50%	$R.C. \geq 93\%$	$R.C. \geq 95\%$		$R.C. \geq 95\%$	$R.C. \geq 98\%$	
	$P_{\#4}$ < 50%	$R.C. \geq 90\%$	$R.C. \geq 93\%$		$R.C. \geq 93\%$	$R.C. \geq 95\%$	
Soil without appreciable fines	Fine sand, $P_{\#4}$ > 75%	$D_r \geq 75\%$	$D_r \geq 90\%$	Soil should be very wet	$D_r \geq 75\%$	$D_r \geq 90\%$	Soil should be very wet
	Medium sand $P_{\#4}$ > 75%	$D_r \geq 70\%$	$D_r \geq 85\%$		$D_r \geq 70\%$	$D_r \geq 85\%$	
	Coarse sand and gravel	$D_r \geq 65\%$	$D_r \geq 80\%$		$D_r \geq 65\%$	$D_r \geq 80\%$	

[A] Relative water content, $\Delta w = w_{field} - w_{opt}$

Method specifications require the contractor to use a particular earthwork process (i.e., placement, lift thickness, equipment type, water content, number of passes, etc.) that is known to produce the desired result in the compacted fill. Method specifications are most common for large projects and for locations or materials where the determination of $\gamma_{d,field}$ is difficult, such as confined spaces or rock fills. The earthwork process in a method specification is typically determined using a field test section, which is a smaller scale embankment compacted using a variety of means and methods (see Section 3-5.2). In some cases, special equipment can be specified based on experience with local conditions and available fill materials.

3-5.2 Field Test Sections.

A field test section can be used to define a definite and appropriate compaction procedure for a particular combination of site conditions and fill material. In some cases, the field test section is used to develop a method specification. In other cases, a test section may be used to refine the compaction procedure. An example of the field test section process is shown in Figure 3-14. Combinations of the compaction variables, such as water content, compaction equipment, lift thickness, and equipment passes, are varied systematically. The results are typically plotted in terms of dry unit weight and number of passes.

Test sections provide an opportunity for field-scale testing of the engineering parameters of the fill material. Shelby tubes or block samples can be obtained from the compacted fill for laboratory shear strength, compressibility, or hydraulic conductivity testing. Any differences in the field compacted parameters can be used to refine the project design. Large double-ring infiltrometer tests (ASTM D3385) can be performed to evaluate the field hydraulic conductivity of compacted fine-grained soils used as seepage barriers. The results from these field tests can be used to select the appropriate compaction procedure or can be correlated to laboratory tests, which can be more easily performed.

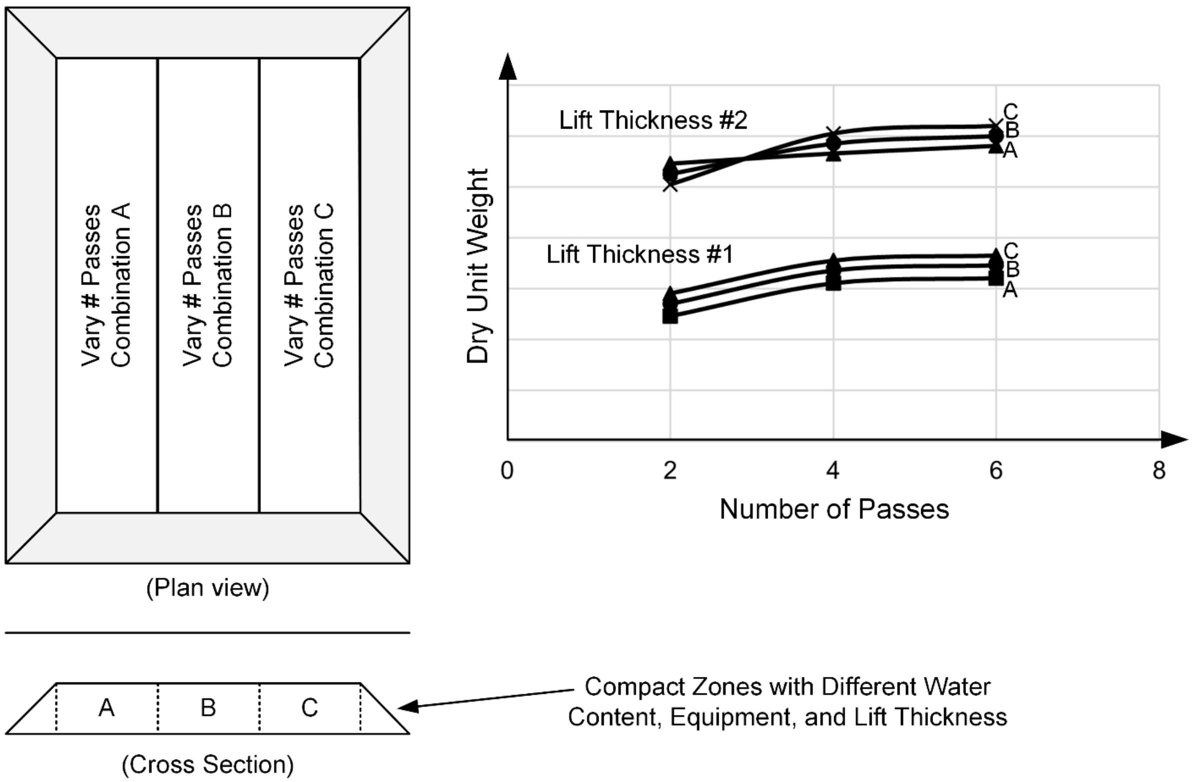


Figure 3-14 Schematic of Field Test Section Process

Field test sections are particularly important for rock fills (USACE 1994b), especially those constructed with nondurable rock, such as shale. The compacted dry unit weight of rock fill is time-consuming and expensive to determine and is often impractical to regularly measure during earthwork. In addition, the engineering parameters of rock fill are difficult to measure in the laboratory without altering the grain-size distribution. A field test section allows some parameters, such as compacted hydraulic conductivity, to be measured directly. It is not feasible to determine reference unit weights or void ratios in the laboratory. The test section provides a quantitative basis for proper compaction procedures in rock fill. While gradation tests are sometimes required before and after compaction of a rock test fill to evaluate particle breakage (USACE 1994b), a field test section combined with a performance specification may eliminate the need for this testing.

Detailed guidance and examples of field test sections are provided in USACE (1994b). The field test section should preferably be located near the quarry or borrow area for economic reasons and should have a similar foundation as the planned fill. An effort should be made to use similar means and methods to those anticipated in construction. For example, fill material should only be temporarily stockpiled for the test section if such stockpiling will occur during production. The geometry of the test section should be carefully planned to include sufficient space for the various combinations of compaction equipment, layer thickness, and water content. Space for traffic lanes and side slopes must also be considered. Multiple side-by-side test sections have been used successfully to reduce side slope requirements. At a minimum, settlement measurements should be obtained using surveying after each roller pass. For rock fill test sections, the dry unit weight of the fill may be measured occasionally. For soil test sections, a combination of conventional field dry unit weight tests and intact samples can be used to evaluate the compaction process and the properties of the compacted fill.

3-5.3 Compaction Control Tests.

Compaction control tests are used directly with end-result specifications. In general, a field measurement is made of the compacted dry unit weight ($\gamma_{d,field}$) and water content (w_{field}) of the fill. The available methods for determining these values are discussed in Chapter 2 of DM 7.1 (NAVFAC 2021). Some of the common methods are compared in Table 3-13, especially focusing on the typical variability of each method. In all of the studies used to collect this data, it is difficult to separate the effects of variability in the compacted fill itself from variability in the measurement of $\gamma_{d,field}$ and w_{field}.

3-5.3.1 Control Test Methods.

The common methods for determining field dry unit weight or relative compaction tend to have standard deviations of 1 to 2 pcf or 1% to 2%, respectively. This indicates that the range in measured γ_d may be as high as 5 to 10 pcf, simply due to measurement error. As noted in DM 7.1, the sand cone test is still regarded as the most accurate method, provided the sand is new, dry, and well-calibrated and the technician is experienced. However, McCook and Shanklin (2000) found that under field conditions the sand cone has similar variability as the nuclear gauge, which was attributed to the difficulty of calibrating the sand cone properly.

The time required to complete a compaction control test (summarized in Table 3-13) is an important consideration in the selection of a method. The nuclear gauge is the quickest method, being about six times faster than the sand cone. Because of its relative speed, a larger number of nuclear gauge control tests can be performed in a reasonable time period. Assuming the nuclear gauge is correctly calibrated, the use of multiple nuclear gauge tests will substantially reduce the uncertainty in the measured values of $\gamma_{d,field}$ and w_{field} that results from either actual fill variability or the variability of the test method. Unfortunately, this perspective is not always appreciated, and the speed of the test is simply used to permit faster construction.

Table 3-13 Comparison of Common Compaction Control Test Methods

Method (ASTM)	Comments	Time Required per Test	Variability in Measurement	
			Unit Weight or *R.C.*	Water Content
Sand cone (D1556)	Noorany et al. (2000) found this method to be more accurate than drive cylinder or nuclear gauge but still with an *R.C.* range of 5%±. McCook and Shanklin (2000) found the method to be more variable and to require more careful calibration.	30 to 45 minutes	Reported variability differs by study. Noorany et al.): $SD(R.C.)$=1.5 to 2% McCook and Shanklin: $SD(\gamma_d)$=1.4 to 5.8 pcf	These methods use oven drying (ASTM D2216) of field samples. Reported variability differs by study. Noorany et al.: $SD(w)$=0.1 to 0.5% McCook and Shanklin: $SD(w)$=1.3 to 3.6%
Rubber balloon (D2167)	Tends to compress soft soils (may not be an issue in well-compacted fill) leading to low unit weight.	15 to 30 minutes	ASTM 2167 indicates that two tests by same operator shouldn't vary by more than 1 pcf.	
Drive cylinder (D2937)	Tends to be less accurate than sand cone or nuclear density gauge. Some soils may loosen during driving while others may compress.	10 to 15 minutes	ASTM 2937: $SD(\gamma_d)$=2 pcf Noorany et al.: $SD(R.C.)$=1.5 to 2.5% McCook and Shanklin: $SD(\gamma_d)$=1.6 to 2.1 pcf	
Nuclear gauge (D6938)	Direct transmission method is more accurate than backscatter mode. Noorany et al. (2000) found higher variability and up to 10% difference in *R.C.* compared to the as-compacted value. McCook and Shanklin (2000) found the method to be just as or more accurate than the sand cone, provided a water content correction is performed. Can have good repeatability but lack accuracy because of incorrect calibration.	5 to 10 minutes	Reported variability differs by study. Noorany et al.: $SD(R.C.)$=1 to 3% ASTM D6938: $SD(\gamma_t)$=0.3 to 1.2 pcf for direct transmission $SD(\gamma_t)$ = 2 pcf for backscatter McCook and Shanklin: $SD(\gamma_d)$=0.5 to 3.9 pcf	$SD(w)$=0.3 to 1.0% Higher values may be observed if soil is variable. Variability between two gauges and operators is about twice as large as variability between tests for the same operator and equipment.
Calcium Carbide (a.k.a. Speedy) (D4944)	Commonly used as an alternative to oven-drying with displacement methods or as a field check to the nuclear gauge.	5 to 10 minutes	NA	McCook and Shanklin: $SD(w)$=1.6 to 2.1% Sotelo et al. (2014): $COV(w)$ = 5%
eGauge (D8167)	License exempt nuclear device. Measures moisture content using an electronic probe, which is less accurate than the nuclear gauge. No backscatter option. Requires site-specific background radiation calibration. Bursey et al. (2016) found good relationship between unit weights measured by the eGauge and nuclear gauge.	5 to 10 minutes	Troxler (2019) $SD(\gamma_t)$=0.3 pcf	Variability data not available. Accuracy is greatly improved through use of soil-specific calibration or moisture offset.
Notes: *SD*(●) indicates the standard deviation of the variable, *COV*(●) indicates the coefficient of variation of the variable				

3-5.3.2 Control Test Frequency.

Minimum testing frequencies for different types of fill are summarized in Table 3-14. Where the earthwork operation is large and employs a consistent procedure, the testing frequency is low. In contrast, more frequent testing is required for small areas where the compaction procedure is less regular. Multiple lifts should not be placed without control testing. More frequent testing is also required at the beginning of the project as the compaction procedure is becoming established (USACE 1995a). Some agencies also require that *record samples* be obtained on a less frequent basis than the routine control tests. Record samples are block or other intact samples of the fill that can be used for laboratory shear strength or consolidation testing. For example, USACE (1995a) requires record samples every 30,000 to 50,000 C.Y.

Table 3-14 Control Testing Requirements for Different Types of Fill (after Hilf 1991, USBR 1998, USACE 1995a, Sowers 1979)

Type of Compacted Fill	Minimum Testing Frequency
Mass earthwork / embankment	1 test / 2000 C.Y.
Relatively thin sections, canals, and reservoir linings	1 test / 1000 C.Y.
Pervious materials	1 test / 1000 C.Y.
Large fill areas	1 test / lift / 10,000 to 20,000 ft^2
Trench backfill and around structures	1 test / 200 C.Y. to 1 test / 500 C.Y.
Small fill areas	2 to 3 tests / lift / area
Minimum for mass earthwork	1 test / shift
Areas of doubtful quality	1 test / area
Instrumentation locations	1 test / instrument

Compaction control tests should be made at regions of doubtful quality, including transitions between materials, areas where rollers turn, lifts that may be too thick, lifts with improper water content, lifts compacted with insufficient roller passes or too light of rollers, fill compacted with clogged rollers, fill containing oversize rock or minor frost, and fill that is different from the average material. Such tests should be distinctly labeled as different from the routine spot tests. Proof rolling can also be used to identify doubtful regions but may be practical only for the final lift of an earthwork project or below pavements.

3-5.3.3 Control Test Comparison to Reference Values.

The results of field spot tests are compared to reference values of $\gamma_{d,max}$ and w_{opt}, or minimum and maximum void ratios. The reference values can come from laboratory compaction tests on the same soil or field test sections. More details on laboratory compaction testing procedures are found in Chapter 3 of DM 7.1. It is common to perform a series of these tests on the soils that are planned for use as fill, forming a set of standard compaction curves for the project. An appropriate compaction curve is selected for each lift of fill by the field engineer based on visual classification and either the relative compaction or relative density is calculated. During construction, additional laboratory compaction tests should be performed on samples of the fill, depending on the variability of materials.

Laboratory compaction tests can be supplemented by rapid, one-point compaction tests that are performed in the field. A variety of procedures have been proposed (e.g., Hilf 1991, AASHTO T272). As shown in Figure 3-15, the compaction curves for a range of soils tend to fall along a line of optimums for a particular compactive effort.

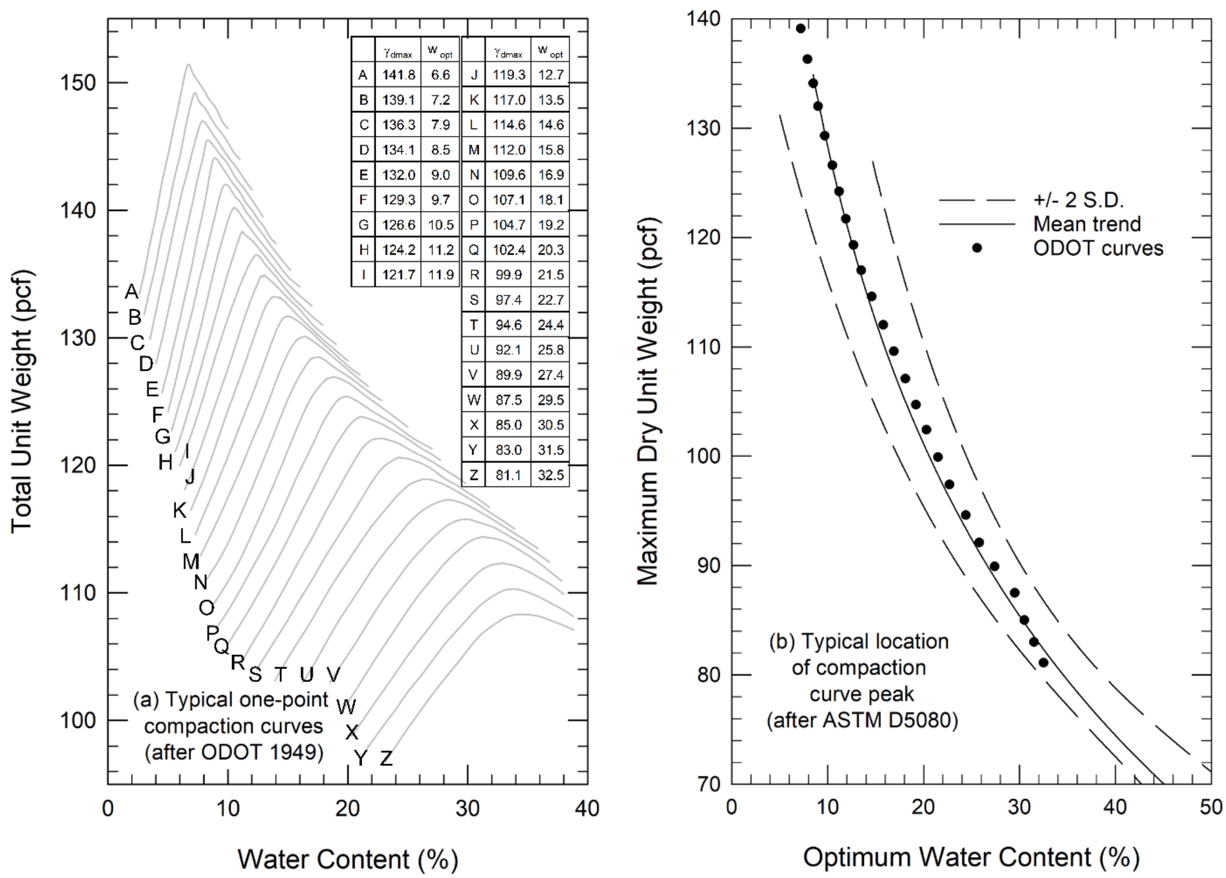


Figure 3-15 Typical Soil Compaction for Field Verification – (a) One-Point Method (after ODOT 2010) and (b) Typical Range of Compaction Curve Peak (after ASTM D5080)

After performing a field compaction control test, the field engineer excavates soil from the field test location. The excavated soil is compacted in accordance with the appropriate test procedure (e.g., ASTM D698 or ASTM D1557), which results in a total unit weight and water content. The γ_t and w point is plotted on a family of typical compaction curves (e.g., Figure 3-15a). The nearest typical curve is selected, or a similarly shaped compaction curve can be interpolated. The values of $\gamma_{d,max}$ and w_{opt} are provided for the typical curves because these values do not correspond directly to the peaks of the total unit weight curves. In order for the rapid compaction method to work, the soil must be dry of optimum because the compaction curves merge together at water contents above optimum. If it is necessary to provide clarity, a second specimen can be compacted by wetting or drying another sample of the soil. Because compaction characteristics depend on local geology and mineralogy, the families of typical compaction curves are best obtained from the local experience of geotechnical laboratories or from regional agencies, such as state departments of transportation. The typical range of compaction curve peak values is provided in Figure 3-15b. When using reference compaction values, field engineers must be careful to avoid choosing a reference curve on the basis of allowing the field control test to pass.

In some cases, field determination of the minimum and maximum void ratios may be required for evaluation of relative density. USACE (1995a) indicates that correlations have successfully been developed based on the percent passing the #16 sieve.

3-5.4 Analysis of Compaction Control Test Data.

A regular, consistent procedure should be selected to report the results of compaction control tests. At a minimum, the soil description, reference compaction curve, test location and elevation, $R.C.$ (or D_r), and Δw should be reported along with the test results. Each test result should be evaluated with respect to the project end-result specification. Where a minimum average $R.C.$ is specified, average values should also be calculated for the interval specified or requested by the project engineer.

In addition to the evaluation of individual test results, analysis of the entire compaction control data set will reveal general trends in compaction and may suggest the need to alter compaction methods. Two simple methods can be used by the field or project engineer: (1) plot the test results on the compaction plane with the reference compaction curve and (2) tabulate the frequency of γ_d and w (or $R.C.$ and Δw). An example of how these two methods can be combined is provided in Figure 3-16. The results can be plotted in this manner either by hand or electronically.

Control tests plotted on the compaction plane should also include the $S = 100\%$ curve and the specification limits. Test points that are grouped near the edge of the limits indicate a need to adjust either the water content, the compactive effort, or both. If test results are grouped near the $S = 100\%$ curve, the fill may be overcompacted and have lower shear strength, even if the $R.C.$ and water content meet the specification. This is of particular concern for high embankments and earth dams (Turnbull and Foster 1956). Test results that plot above the $S = 100\%$ curve are theoretically impossible and indicate uncertainty in the control testing method, error in the compaction control test, or a change in soil type and G_s value used to plot the $S = 100\%$ curve. Control tests with calculated $S > 100\%$ should not be discarded categorically but should be evaluated carefully (Schmertmann 1989).

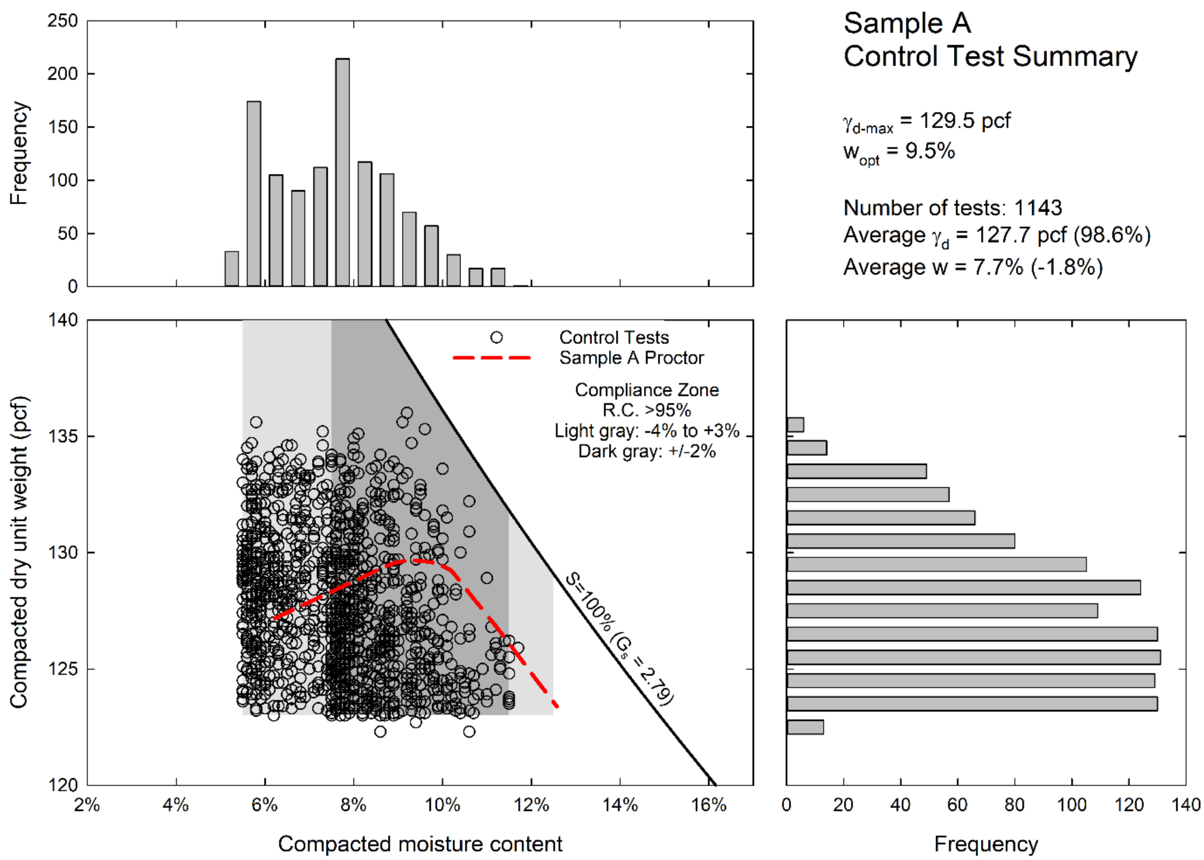


Figure 3-16 Graphical Analysis of Control Test Data

Tables or histograms of the frequency of γ_d and w can be used to understand the distribution of the compacted properties. Once an adequate number of test results is available (40 or more), the mean and standard deviation of γ_d and w (or $R.C.$ and Δw) can begin to be estimated from these distributions (see Chapter 7 for calculations). Simple tabulation methods provided in Davis (1953) and USBR (1998) can be used to create field histograms and cumulative distribution plots similar to those in Figure 3-16. The standard deviation can be estimated knowing that about two-thirds of the data falls within one standard deviation of the mean and 95% of the data falls within two standard deviations of the mean (for a normal distribution).

The mean and standard deviation of $R.C.$ help to evaluate the compactive effort being used. Because a compacted fill will have variable compacted dry unit weight, the mean or average $R.C.$ must be above the minimum specified $R.C.$ in order for all of the fill to meet the specification. Standard deviations of $R.C.$ for well-controlled compaction are typically less than about 3%. Higher standard deviation indicates insufficient or erratic compaction and improvement is required in the uniformity of moisture control, compaction equipment weights and pressures, or level of equipment coverage.

The mean and standard deviation of Δw help to evaluate moisture control. The mean Δw should be close to the midpoint of the specified range of water contents. A standard deviation of Δw of 1.5% or less is evidence of good moisture control. If the standard deviation of Δw is more than 3%, the moisture control is erratic, and the borrow materials may need to be better blended and moisture conditioned.

Variation in the $\gamma_{d,max}$ and w_{opt} of the borrow may also lead to apparent variation in the $R.C.$ and Δw. For example, Hilf (1991) considers two soils with similar mean properties, a uniform aeolian soil and a more variable alluvial soil. The standard deviation of $\gamma_{d,max}$ was 1.5 pcf for the aeolian soil and about 2.8 pcf for the alluvial soil. If this variation in the reference compaction curve is ignored, the reported $R.C.$ may have a larger standard deviation than is actually present in the fill. This further emphasizes the importance of obtaining regular samples for laboratory compaction testing and checking with rapid compaction tests.

Some portion of the compaction control results will fall outside the specification limits. Hilf (1991) presents a decision-making approach for determining if such tests indicate an unacceptable compacted lift, which depends on the specification limits. An example set of compaction specifications is plotted in Figure 3-17. In Hilf's approach, the first control test is compared to the outer bounds of the specification. Tests are accepted if the γ_d and w are both in the specified range and rejected if both γ_d and w are insufficient. In regions with tests that indicate insufficient water content or γ_d, a retest is performed. The retest may be compared to a tighter specification because the two control tests provide a stronger statistical case for acceptance or rejection.

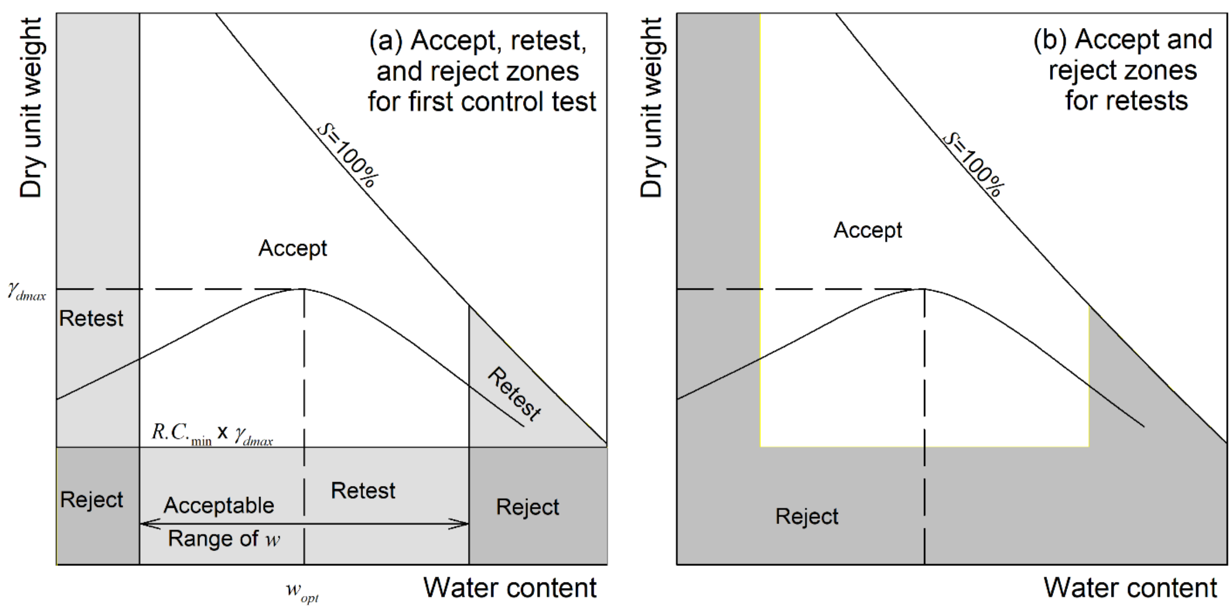


Figure 3-17 Two-Step Interpretation of Control Test Results (after Hilf 1991)

In some cases, compaction control specifications include a mean relative compaction that must be met or exceeded. This approach recognizes that some variability will always exist within the compacted fill. It may be desirable to specify the mean $R.C.$ such that only a certain percentage of the fill will have a $R.C.$ below a lower threshold. In Table 3-15, the lower threshold is referred to as $R.C._{10}$ for which only 10% of the $R.C.$ values will be lower. Based on the selected value of $R.C._{10}$ and the estimated variability of the fill, a mean relative compaction can be selected. For example, if it is desired to have only 10% of the fill with $R.C.$ less than 95%, the mean $R.C.$ should be 100% for a fill with medium variability.

Table 3-15 Statistical Approach to the Selection of Mean Relative Compaction Requirements

Fill Variability	**Required Mean $R.C.$ to Achieve Indicated Value of $R.C._{10}$**			
	$R.C._{10}$ = 90%	**$R.C._{10}$ = 93%**	**$R.C._{10}$ = 95%**	**$R.C._{10}$ = 98%**
Low $COV(R.C.)$ = 2%	92%	95%	97%	101%
Medium $COV(R.C.)$ = 4%	95%	98%	100%	103%
High $COV(R.C.)$ = 6%	97%	101%	103%	106%

Notes: $R.C._{10}$ = relative compaction for which only 10% of the values are lower. A sufficient number of compaction control tests must be performed to adequately determine the mean $R.C.$ A normal distribution has been assumed for $R.C.$ $COV(R.C.)$ = coefficient of variation of relative compaction (see Chapter 7).

3-5.5 Compaction Control of Rock Fill.

In most cases, field test sections and method specifications should be used for the primary control of rock fill (Breitenbach 1993). The test section establishes the number of passes and particular equipment required to achieve suitable compaction of the rock fill. Large-scale unit weight tests should be performed occasionally to verify the compaction procedure. Such tests require an excavation with a diameter at least four times greater than the maximum particle size and the removal of about 1000 to 2000 pounds of rock fill (Breitenbach 1993, Holtz et al. 2011).

3-5.6 Intelligent Compaction Systems.

Intelligent compaction (IC) systems are those which continuously monitor soil properties from roller vibrations, provide automatic feedback to the roller vibration, and use GPS to map the measurements to a GIS model of the site (NCHRP 2010). The rollers record a measurement value (MV), which is an indicator of compaction to a depth of about 3 to 4 feet. Depending on the system and manufacturer, the MV may indicate soil stiffness, modulus, or roller vibration characteristics.

NCHRP (2010) summarizes the interaction between the MV and soil/subgrade conditions. The response of the soil below the roller is highly nonlinear. The MVs for thin layers are substantially affected by different stiffness of the underlying soil. Many correlations between MV and soil parameters, such as dry unit weight and plate load test moduli, are available.

Figure 3-18 illustrates the simplest manner in which intelligent compaction can be used to monitor compaction. The MVs are plotted in plan view to identify weak or soft regions in the fill based on low MV. Compaction control tests are performed on those regions. A more advanced approach to IC monitors the change in the MV with subsequent passes of the roller and compares this change to a specified threshold. Other methods correlate the MV to field compaction control tests or laboratory tests in order to determine threshold values of MV.

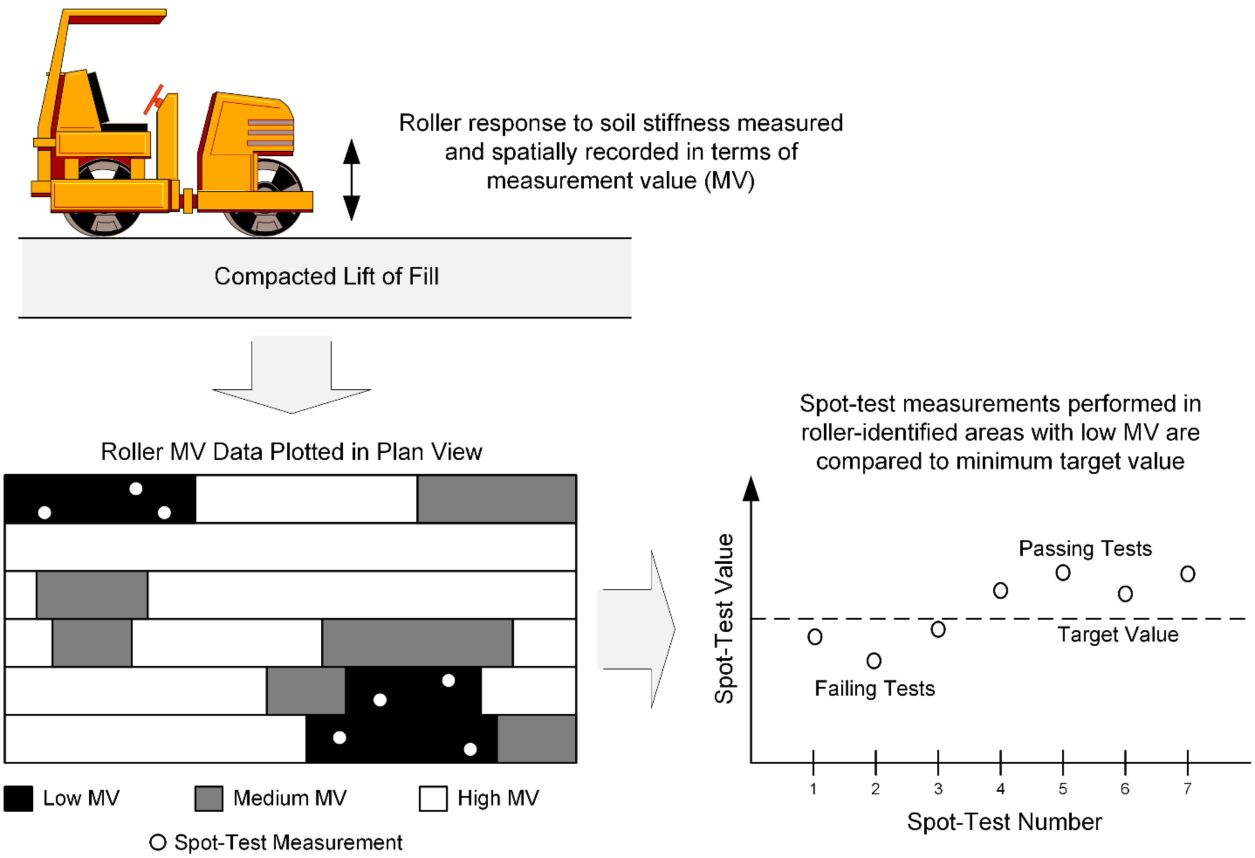


Figure 3-18 Compaction Control Guided by Intelligent Compaction (after NCHRP 2010)

3-5.7 Indirect Evaluation of Deep Fills.

Deep fills can be evaluated using subsurface exploration techniques as discussed in Chapter 2 of DM 7.1 (NAVFAC 2021). In particular, soil borings with SPT, CPT soundings, and geophysical surveys are useful to assess previously placed fills. In fill constructed from fine-grained soil, Shelby tube samples can be obtained to measure the dry unit weight of the fill. The water content of a fill can change after compaction, and samples obtained a significant time after compaction should be used with caution. A major concern in the evaluation of deep fills is the ability to evaluate the uniformity of compaction using widely spaced *in situ* testing.

Ground improvement can be used to densify deep fill (see Chapter 1 for specific methods). *In situ* testing performed both before and after the ground improvement can be used to measure its effect.

3-6 DESIGN OF EMBANKMENTS.

Proper design and satisfactory performance of embankments depend on a high-quality subsurface exploration and laboratory characterization program. Chapter 2 of DM 7.1 and NCHRP (2018) provide in depth guidance on these topics. The major types of embankments are illustrated in Figure 3-19 and are discussed in the following sections.

3-6.1 Primary Design Conditions.

3-6.1.1 Slope Stability.

The stability of embankment slopes is controlled primarily by the shear strength of the fill and supporting foundation, the groundwater conditions, and the geometry of the slope. Some soils are susceptible to softening from weathering, climatic effects, and progressive failure. Changes in the properties of these soils with time must be considered. Procedures for calculating slope stability can be found in Chapter 7 of DM 7.1. Guidance for the selection of appropriate shear strength parameters can be found in Chapter 1.

3-6.1.2 Settlement.

Settlement of an embankment is caused by foundation consolidation, consolidation of the embankment material itself, and secondary compression in the embankment after its completion. Foundation consolidation occurs as a result of the weight of the embankment fill. Chapter 5 of DM 7.1 summarizes methods to calculate foundation settlement as well as procedures to decrease foundation settlement and/or accelerate consolidation.

The compacted embankment may also experience consolidation. Significant excess pore pressures can develop during construction of fills exceeding about 80 feet in height or for lower fills of clays compacted wet of optimum. As these excess pore pressures dissipate after construction, the embankment will settle. Settlements of about 1% to 2% of the fill height are commonly experienced. Estimates based on past experience can be made using the data in Figure 3-10. For earth dams and other high fills where settlement is critical, construction pore pressures should be monitored by the methods described in Chapter 2 of DM 7.1.

Even for well-compacted embankments, secondary compression and shear strain can cause slight settlements after completion. Normally, this is only of significance in high embankments. This secondary compression typically is between 0.1% and 0.2% of the fill height after three to four years and increases to 0.3% and 0.6% after 15 to 20 years. The larger values are for clay soils.

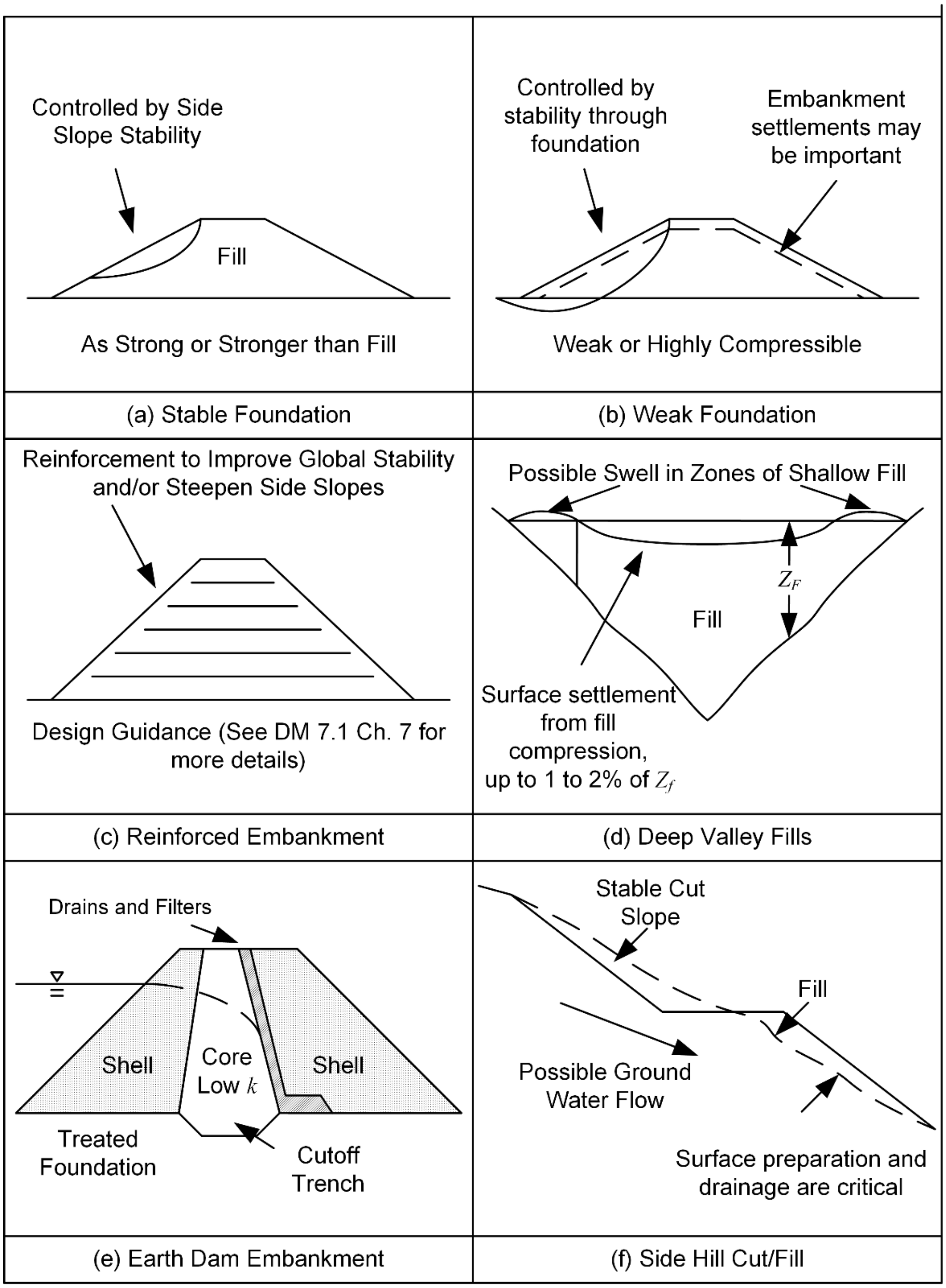


Figure 3-19. Schematics of Typical Embankment Design Sections (not to scale)

3-6.2 Embankments on Stable Foundations.

A stable foundation for an embankment has low compressibility and is as strong or stronger than the planned fill as shown in Figure 3-19(a). In this case, the stability of the side slopes controls the design, which will be affected by the type of soil used to build the fill and the seepage conditions. For slopes without significant seepage forces, the appropriate side slope angle varies between 1.5H:1V and 3H:1V. Steeper slopes are appropriate for compacted coarse-grained soils while flatter slopes may be required for compacted clays. The geometry of slopes and berms is also controlled by requirements for erosion control, maintenance, and mowing.

Special caution is required when constructing embankments from high plasticity clays. These soils experience the detrimental effects of shrink-swell due to weathering and moisture content changes, which leads to progressive failure and the development of fully softened conditions. Appropriate side slope design for these soils depends on selection of applicable fully softened shear strength parameters (Duncan et al. 2011, Castellanos et al. 2015).

3-6.3 Embankments on Weak Foundations.

Embankments built over weak foundations must consider settlement and instability through the foundation soil as indicated in Figure 3-19(b). Weak foundation soils may need to be partially or completely removed or densified *in situ*.

A range of methods for addressing embankment foundation instability is illustrated in Figure 3-20. Some approaches, such as slope reinforcement and flattening of side slopes, will only improve slope stability but will not reduce settlement. Other methods will improve both slope stability and settlement and include reducing the embankment weight using lightweight fill, transferring the load to deeper strata, removing and replacing problem materials, and implementing ground improvement. For cases where settlement is primary concern, preloading methods with surcharges and vertical drains are appropriate. Chapter 1 summarizes methods for addressing problem soils with ground improvement. More comprehensive guidance can be found in FHWA (2017).

3-6.4 Reinforced Embankments.

Reinforced embankments are constructed by incorporating tensile reinforcement horizontally between layers of compacted fill (Figure 3-19(c)). Most often, reinforced soil slopes (RSS) use geosynthetic reinforcement. For embankments on stable foundation, reinforcement improves stability within the embankment and allows steeper side slopes. Over a weak foundation, reinforcement can be used to prevent instability through the embankment and into the foundation soil. The reinforcement requires the RSS embankment to act as a unit and effectively reduces the bearing pressure on the weak foundation. Many column-supported embankments contain partial reinforcement in the lower lifts to help transfer load to the columns. Chapter 7 of DM 7.1 contains a summary of RSS design, and a comprehensive coverage of the topic is found in FHWA (2009). Where reinforcement is required in fill that is used as seepage barrier (i.e., earth dams), special compaction techniques are required for the layers adjacent to the reinforcement (Gregory 1993)[16]. Fiber admixtures can be used to repair shallow slope failures and reinforce slopes (Gregory 2006, Hatami et al. 2018).

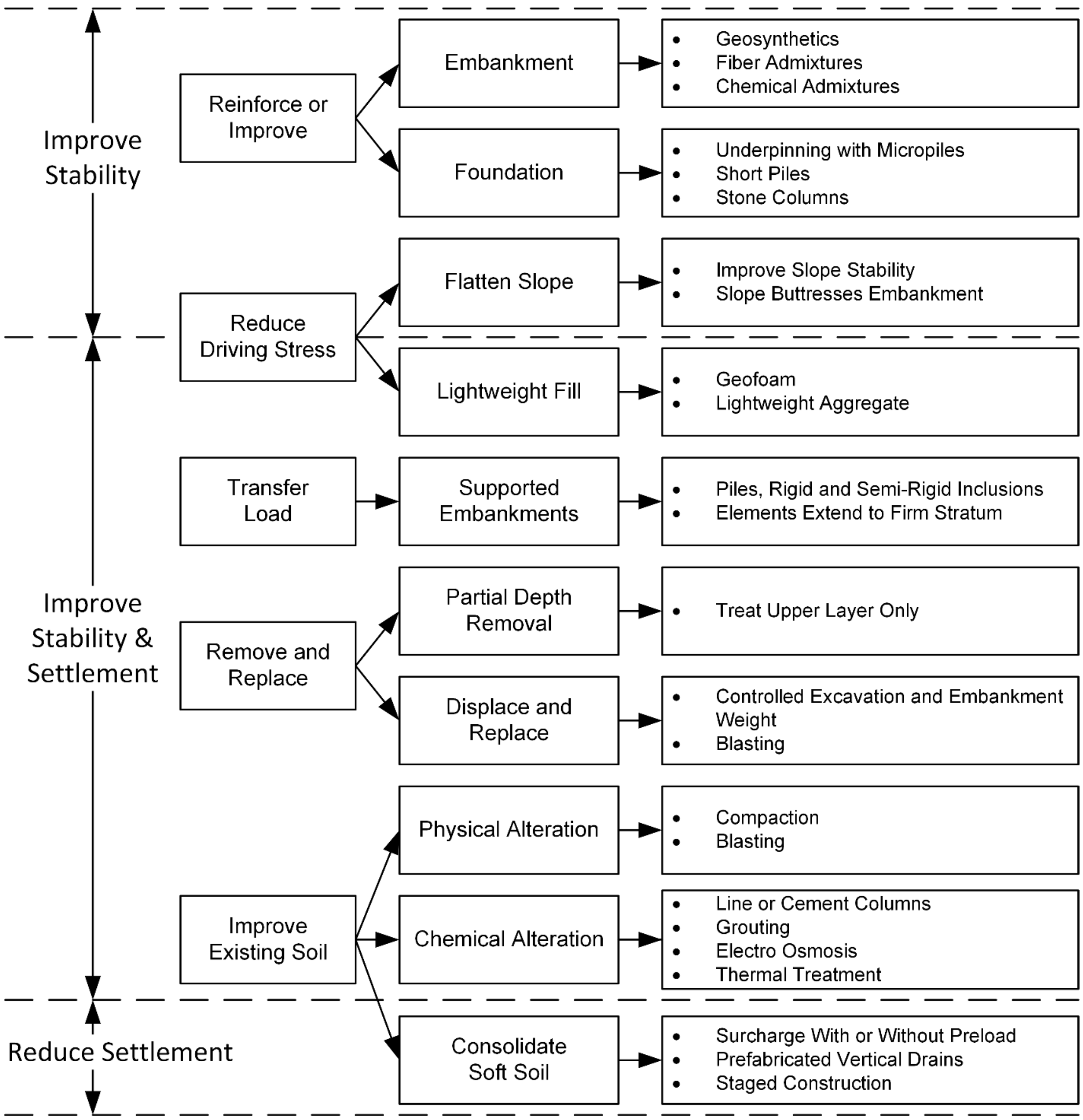


Figure 3-20 Methods to Address Foundation Instability (after TRB 1990 and Holtz 1989)

[16] Local regulations should be checked. Some jurisdictions do not allow reinforcement in earth dams and other seepage barriers.

Suitable performance of RSS depends on the performance of the reinforcement, which in turn is related to the selection of appropriate fill material, installation of the reinforcement, and careful earthwork practice. In general, fill for RSS should be coarse-grained (less than 50% fines), and the fines should have a PI not exceeding 20. Coarse-grained fill provides the relatively high shear strength desired for an RSS and the high level of soil-reinforcement interaction required to develop the reinforcement capacity. In order to prevent damage during earthwork, reinforcement should be installed and fill should be placed according to the manufacturer's specifications, at a minimum. These specifications will include limitations on the types of equipment that can operate on or near the reinforcement as well as appropriate lift thicknesses above the reinforcement. Construction restrictions may also prevent turning and sudden starts or stops of compaction equipment above the reinforcement. The manufacturer's specifications will also provide information about seams or overlap requirements. Special care should be taken to align the reinforcement in the proper direction because the properties are often direction dependent.

3-6.5 Deep and/or Valley Fills.

Relatively deep fills, as illustrated in Figure 3-19(d), experience settlement over time. Settlement can be the result of consolidation of both the foundation and the embankment fill itself. It can also be related to secondary compression over time. This behavior is especially important for dams because the long-term crest elevation is a key design consideration and for valley fills where the depth of the embankment varies greatly through the cross-section. Duncan and Bursey (2006) found that valley fills tend to experience 0.1% to 2% settlement in 50 years. Because the settlement is relative to the thickness of the embankment, valley fills may experience significant differential movement.

Over time, deep fills will experience changes in water content in response to the surrounding climate and human activity such as irrigation. In the case of earth dams, inundation will saturate some portion of the embankment. Shallow layers of compacted fill may swell while deeper layers consolidate or collapse when wetted (Brandon et al. 1990). Thus, swelling behavior can further exacerbate differential movement.

Some amount of compression and differential movement is inevitable in deep fills. Appropriate construction practice is the primary means of design to counteract these effects (Coduto et al. 2011). The lower portions of deep fills should be built with a higher specified relative compaction, which reduces the potential for further consolidation. The compaction water content may also need to be varied with lower water contents being more appropriate near the bottom of the fill. In shallower zones of deep or valley fills, expansive fill should not be used, if at all possible. In all cases, deep fills should be designed for some degree of wetting using methods such as those proposed by Brandon et al. (1990) or Noorany and Stanley (1994).

3-6.6 Earth Dam Embankments.

USACE (2004), USBR (2012), and Chapters 6 and 7 of DM 7.1 provide guidance on the design of earth dams for stability and seepage under a variety of conditions, including end of construction, steady state seepage, rapid drawdown, and seismic loading. Earth dams may be homogeneous or zoned as illustrated in Figure 3-19(e). Considerations of shear strength and hydraulic conductivity will control the both the cross-sectional geometry of an earth dam embankment as well as the parameters required of the engineered fill in each zone of the dam. This section focuses on the general properties required of fill materials used for dams. The shear strength of compacted fill should be characterized using laboratory testing on compacted specimens. The influence of compaction on shear strength of compacted soil and rock is summarized in Section 3-2.3.

With the exception of homogeneous dams, most earth dams have zones of both free-draining soil with very high hydraulic conductivity (k) and nearly impervious soil with very low k. Filter and drain zones with high k are used to intercept seepage through dams and consist of sands and gravels with little fines. These zones should be kept free of contamination with fines or the core soil during construction. Methods to estimate the hydraulic conductivity of different types of soil and to design filters between zones can be found in Chapter 6 of DM 7.1. In contrast, compacted fine-grained soils with low k are used to retain water. Compacted fill for a dam core should be free of lenses, pockets, or layers of pervious material, and successive lifts should be well bonded to each other. If a borrow source contains more than 1% oversize by mass, it should be removed prior to arrival on the earth dam embankment.

The soils selected for the zones of an earth dam must not erode under the seepage forces to which they are subjected. This includes both external erosion at the surface of the compacted fill as well as internal erosion of particles. The critical location for seepage-induced external erosion is the downstream face of a homogenous embankment. Internal erosion occurs as finer particles move into larger void spaces and can be subdivided into scour, backward erosion piping (BEP), internal migration, and internal instability (USBR and USACE 2019).

In the context of earth dams, *scour* refers to movement of soil particles by water flowing along an unprotected interface, most often by concentrated leak erosion (CLE). Concentrated leaks can occur through cracks or defects in fill and along unprotected discontinuities, such as conduits through the fill and foundation defects or joints. Selection of fill to resist CLE can be guided by the categories in Table 3-16. Figure 3-21(a) presents the typical gradation ranges of soils in the more resistant categories. Soils that are susceptible to CLE include gap-graded soils and soils with a well-graded flat tail, as shown Figure 3-21(b). Because CLE can occur at cracks within the fill itself, the cracking resistance of fill should be considered for earth dams. Figure 3-21(c) can be used to evaluate the likelihood of cracking.

Table 3-16 Erosion Resistance Categories (after USBR and USACE 2019)

Erosion Resistance Category	Applicable Soil Types
1 (best)	CL, CH, and well-graded SC with $PI > 15$, any compaction level
2	Well-graded with clay binder, $15 > PI > 6$, any compaction level
	Well-graded, coarse-grained, $PI < 6$, well compacted
3 (worst)	Well-graded, coarse-grained, $PI < 6$, poorly compacted
	Very uniform, fine sands, $PI < 6$, any compaction level
	Gap-graded soils, any compaction level

The mechanics of BEP and internal instability are discussed in detail in Chapter 6 of DM 7.1 along with guidance on the selection of fill materials for filters. In addition, the diagonal lines shown on Figure 3-21 can be used as a preliminary assessment for internal instability. If the grain size distribution curve of a soil has sections flatter than the diagonal lines, the soil may be internally unstable. A summary of other methods for evaluating the internal instability potential of soils can be found in USBR and USACE (2019).

Dispersive clays are clay minerals that contain a high percentage of dissolved sodium in the pore water and are very susceptible to erosion. Water flowing through holes and cracks will quickly erode these clays. Dispersive clays can be identified using laboratory methods, such as the double hydrometer (ASTM D4221), the analysis of pore water extract (ASTM D4542), the pinhole test (ASTM D4647), or the crumb test (ASTM D6572). Dispersive clays should not be used as fill in dam embankments because they are very susceptible to internal erosion. Categories of dispersive tendency and associated laboratory test procedures are summarized in Table 3-17.

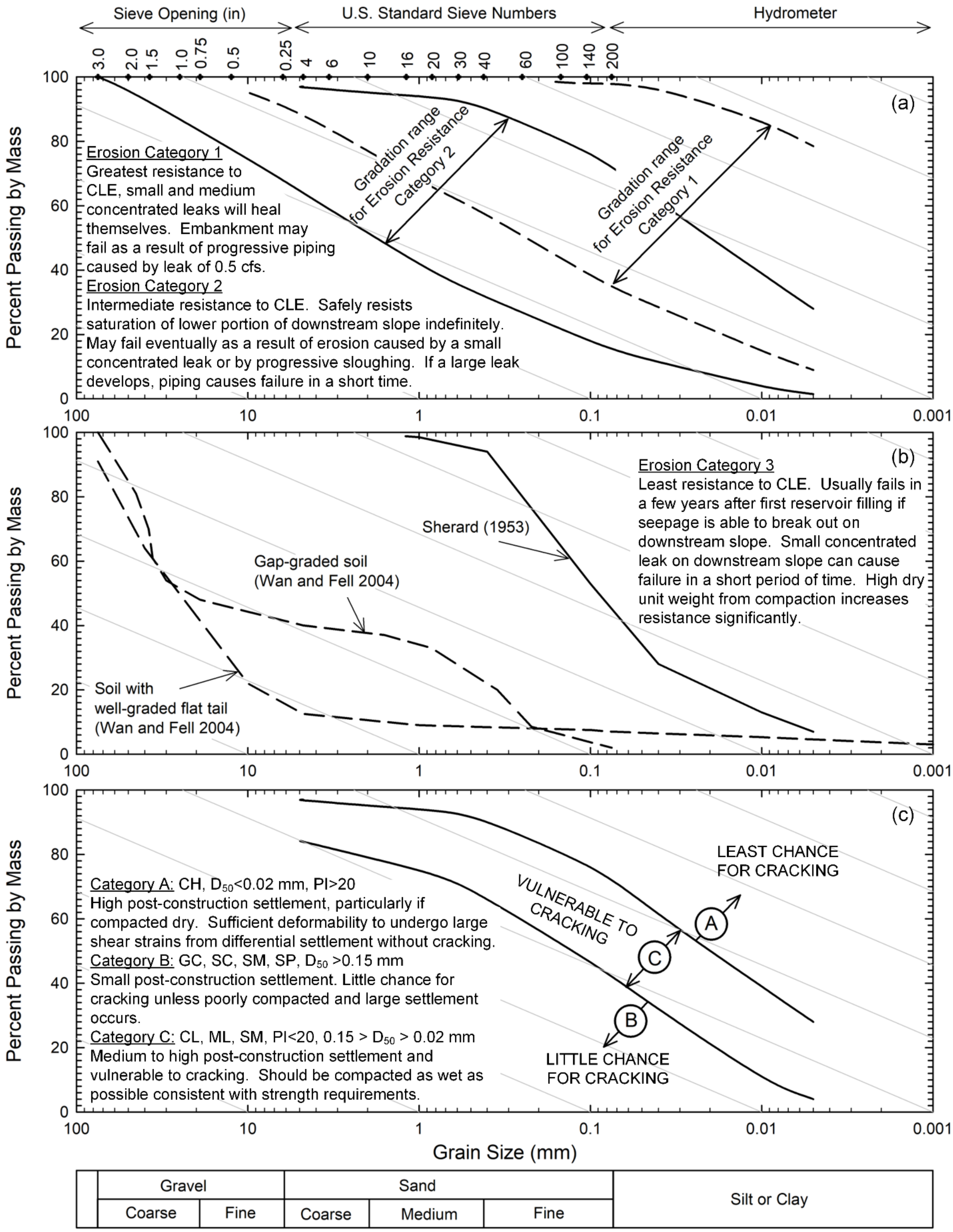


Figure 3-21 Concentrated Leak Erosion and Cracking Resistance of Fill Materials (after Sherard 1953, Wan and Fell 2004)

Table 3-17 Dispersive Tendency from Double Hydrometer, Pinhole and Crumb Tests (after ASTM D4221, D4647, D 6572)

<table>
<tr><th rowspan="2">Dispersive Tendency</th><th rowspan="2">Percent Dispersion by Double Hydrometer (ASTM D4221, 2018)</th><th colspan="4">Dispersive Classification by Pinhole Test (ASTM D4647 Method B)</th><th rowspan="2">Dispersive Grade by Crumb Test (ASTM D6572)</th></tr>
<tr><th>Class</th><th>Applied Head (mm)</th><th>Cloudiness from side</th><th>Hole size after test (mm)</th></tr>
<tr><td rowspan="2">Dispersive</td><td rowspan="2">$\frac{P_{2\mu m,nd}}{P_{2\mu m,d}} > 50\%$</td><td rowspan="2">D</td><td rowspan="2">50</td><td rowspan="2">Dark to slightly dark</td><td rowspan="2">≥ 1.5</td><td>Grade 4 – dense cloud of colloids appears in water</td></tr>
<tr><td rowspan="2">Grade 3 – visible cloud of colloids appears in water</td></tr>
<tr><td rowspan="2">Moderate to slightly dispersive</td><td rowspan="2">$30\% \le \frac{P_{2\mu m,nd}}{P_{2\mu m,d}} \le 50\%$</td><td rowspan="2">SD</td><td rowspan="2">180 to 380</td><td rowspan="2">Barely visible</td><td rowspan="2">≥ 1.5</td></tr>
<tr><td rowspan="2">Grade 2 – faint cloud of colloids appears around soil in water</td></tr>
<tr><td rowspan="2">Nondispersive</td><td rowspan="2">$\frac{P_{2\mu m,nd}}{P_{2\mu m,d}} < 30\%$</td><td rowspan="2">ND</td><td rowspan="2">380</td><td rowspan="2">Clear</td><td rowspan="2">< 1.5</td></tr>
<tr><td>Grade 1 – no reaction to water, soil may slake or crumble, but no turbidity</td></tr>
<tr><td colspan="7">$P_{2\mu m,nd}$ = percent passing 2 μm in soil-water suspension with no dispersant and minimal agitation.
$P_{2\mu m,d}$ = percent passing 2 μm in soil-water suspension with dispersant in regular hydrometer

Note: Dispersive tendency was previously measured using the 5-micron particle size. The engineer should take care comparing test results using the newer standard to historical guidelines and experience.</td></tr>
</table>

3-6.7 Side Hill Fills.

In areas with hilly or mountainous terrain, side hill fills are a commonly used method to create level space for roads and structures. As shown in Figure 3-19(f), a *side hill fill* is created by compacting fill on an existing slope with some of the fill material often coming from an adjacent cut. Side hill fills are often prone to instability even when the fill is appropriately compacted, leading to regular or seasonal slippage. While many of these landslides are a maintenance nuisance, some cause serious damage or loss of life. Conditions in the natural slope that typically lead to these problems include high or fluctuating groundwater and relatively weak foundation materials, such as colluvial or residual soils or degradable rock.

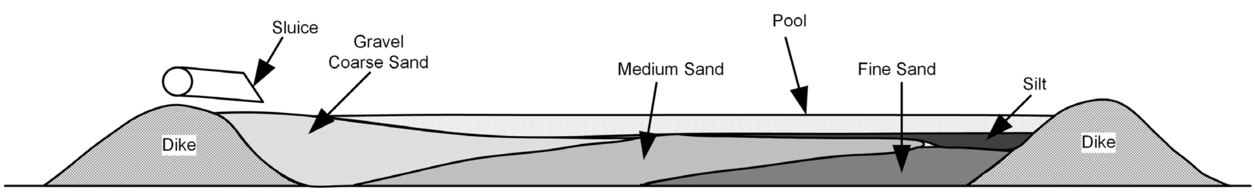
Although side hill fills can be problematic, they are often unavoidable, and appropriate design guidelines are required. The typical problems suggest the primary design considerations, and the side hill fill should be treated as a transition zone (TRB 1990). First, groundwater control is essential. Drainage systems should be designed to intercept groundwater seeping from the natural slope and to route surface water off the fill (see Chapter 6 of DM 7.1). The drainage should prevent both the fill and the natural soil below the fill from becoming saturated. Conservative groundwater levels, including seasonal fluctuations, should be used in slope stability calculations. Second, the interface between the compacted fill and natural slopes steeper than 3H:1V should be benched prior to compaction. Benching allows all fill to be placed horizontally. More importantly, the inclined interface between the new fill and the natural slope is removed, which reduces the potential for the fill to simply slide down the slope. This is especially important for slopes where a thin layer of weak soil is present at the surface.

3-7 HYDRAULIC AND UNDERWATER FILLS.

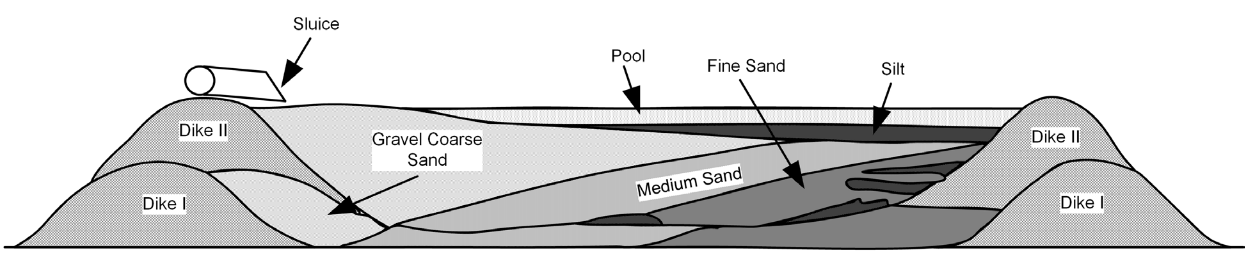
3-7.1 Purpose and Use of Hydraulic Fill.

Since the advent of modern methods of excavation, transportation, and compaction in the 1930s, hydraulic fill is used mostly in particular situations, such as underwater fill and land reclamation. However, understanding the hydraulic fill process may prove helpful for interpreting the behavior of existing structures, particularly old dams, built with this method.

Hydraulic fill is a method of earthwork that uses water to excavate, transport, and place fill. Soil can be excavated hydraulically with jets, dredging, or cutter heads. The soil-water slurry is then pumped by pipe from the excavation site to the fill. Where ample water is available and large fill quantities are required, the ability to economically transport soil long distances is the main advantage of hydraulic fill. The slurry is discharged from the transport pipe as illustrated in Figure 3-22, and the soil is deposited at the hydraulic fill site, creating a fan with significant segregation and difference in the slope of the fill (Sowers 1979). Removal or placement of soil by hydraulic methods must conform to applicable water pollution control regulations. Fills that are excavated conventionally and placed using water, such as puddled clay cores or sluiced rock fill, can be classified as semi-hydraulic fill (USBR 1998).



(a) Stage I – Low Dikes and Initial Pool



(b) Stage II – Dikes Built up from Stage I Filling, Followed by More Fill

Figure 3-22 Hydraulic Fill Illustration (after Sowers 1979)

3-7.2 Placement of Hydraulic Fill.

Hydraulic fill can be placed either on land or underwater. When used, hydraulic fill should be placed in a manner that produces the required usable area while minimizing environmental impact.

On land, hydraulic fills are commonly placed by pipeline but can also be created using clam shells or draglines. When hydraulic fill is discharged from a pipe, it creates a fan as the soil-water slurry spreads. The particles will segregate by size with the largest particle settling first. The fill will be wide with slopes ranging from 5H:1V to 40H:1V. Similar to underwater, dikes are required to create steeper slopes. The rate of flow can be used to control the gradation of the fill. The fine particles will remain in suspension for longer periods of time and can be removed if short sedimentation times are used (Sowers 1979).

Hydraulic fill with steeper side slopes requires the use of a mixed sand and gravel fill material or a control method during placement. Underwater slopes as steep as 3H:1V or 2.75H:1V may be achieved by careful placement of fill containing about equal amounts of sand and gravel. Berms or dikes of the coarse fill or large rock can be created around the perimeter of the fill to confine it laterally. The voids in rock placed underwater are filled with sand by sluicing to reduce compressibility and possible loss of hydraulic fill into the rock.

3-7.3 Performance of Hydraulic Fills.

Coarse-grained soils with less than 15% non-plastic fines or less than 10% plastic fines create the most satisfactory hydraulic fills. They cause the least turbidity during placement, drain faster, and are more suitable for structural support than fine-grained material. Relative densities of 50% to 60% can be obtained without compaction with a coefficient of variation of about 25%. Allowable bearing pressures are in the range of 500 to 2000 psf depending on the level of permissible settlement. Coarse-grained hydraulic fill may be variable and may contain zones of low permeability that develop high pore water pressures under seismic loading (USBR 1998). Relative density, allowable bearing pressure, and resistance to seismic liquefaction may be increased substantially by the ground improvement methods described in Chapter 1.

Hydraulic fills constructed from soft fine-grained soils, such as bottom silts and clays produced by maintenance dredging, will initially be placed at very high-water contents. Depending on measures taken to induce surface drainage, it will take approximately 2 years before a crust sufficient to support light equipment is formed and the water content of the underlying materials approaches the liquid limit. In order to allow more rapid use, a 1 to 3 feet thick layer of coarse-grained fill can be spread above the fine-grained hydraulic fill. This layer will improve the surface conditions rapidly so that they can support surcharge fills, with or without vertical drains to accelerate consolidation.

Care must be exercised in applying the surcharge so that the shear strength of the soil is not exceeded.

Experience has been gained on existing hydraulic fill dams via field tests. At one dam which was constructed by discharging slurry from pipes along the sides of the dam, the resulting hydraulic fill consisted of a free-draining coarse-grained shell of gravelly silty sand with a core of silty sand and sandy non-plastic silt.[17] The shell was generally loose to medium dense ($N_{1,60}$ of 5 to 30 with mean of 17) with isolated zones of $N_{1,60}$ below 5. Effective stress friction angles were determined to be in the range of 31° to 34°. The loose zones in the shell were determined to have undrained steady state shear strengths in the range of 150 to 500 psf. The hydraulic fill core was very loose to loose ($N_{1,60}$ below 5 with mean of 3), and the effective stress friction angle was estimated and measured in the range of 29° to 32°. For undrained conditions, the core behaved as a normally consolidated, fine-grained soil. Shear wave velocities from seismic CPT mostly ranged from 400 ft/s to 800 ft/s and increased with depth (i.e., increased effective vertical stress). Based on these observations, new or existing hydraulic fill can be evaluated using conventional *in situ* testing techniques provided the engineer anticipates the spatial distribution of soil composition and relative density that results from hydraulic fill placement.

3-7.4 Consolidation of Hydraulic Fills.

Coarse-grained hydraulic fills with high permeability and high coefficient of consolidation will consolidate quickly and will gain shear strength as excess pore pressures dissipate. Reasonable estimates of shear strength can be made based on estimated relative density. Hydraulic fills with k < 0.001 cm/s (fine sands and fine-grained soils) will take a long time to consolidate, and prediction of the behavior of the completed fill will be difficult. Settlement and pore pressure monitoring can be used to assess the state of consolidation of the hydraulic fill under its own weight and that of any surcharge. Settlement plates can be placed both on top of the underlying soil and within the hydraulic fill to observe settlement rates and amounts.

After self-weight consolidation, a hydraulic fill will be normally consolidated and further consolidation may be desirable. As noted by Sowers (1979), this compression can be completed by various ground improvement methods. For coarse-grained soils, vibro-compaction, pile driving, and blast densification can be used to increase relative density. Vibration at the surface of the fill can be effective to depths of about 10 feet. Silty hydraulic fills can be consolidated using well points.

[17] Confidential location (personal communication)

The consolidation of fine-grained hydraulic fills will depend on the properties of the borrow material. Those derived from stiff clays will have a structure consisting of hard clumps in a matrix of soft clay, making laboratory tests inapplicable. Hydraulic fills derived from soft clays can be evaluated using one-dimensional consolidation tests. The coefficient of compressibility (m_v) of fine-grained hydraulic fills ranges from 3×10^{-6} to 5×10^{-5} 1/psf. In both cases, preloading of fine-grained hydraulic fills is effective to reduce settlements. Pore pressure dissipation rates of hydraulic fills range from hours to years depending on the sand content and cannot be estimated from laboratory tests (Whitman 1970).

3-7.5 Underwater Fill.

Some projects require fill to be placed underwater, which poses unique challenges. In most cases, experience with underwater fill placement has been limited to depths of about 100 feet or less. Pollution control, including the use of turbidity curtains, is critical during underwater fill construction.

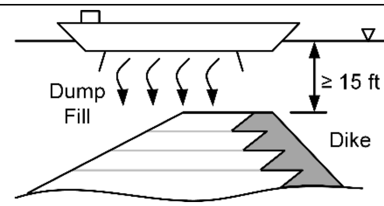
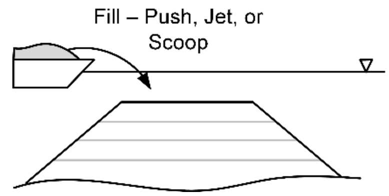
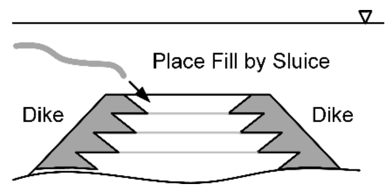
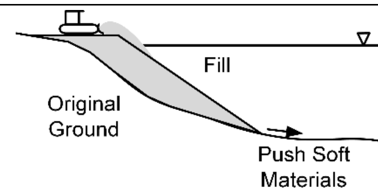
Dredging is an important part of the underwater fill placement process similar to subgrade preparation for conventional fill. Dredging can be used to remove unsuitable soil, cut slopes in existing submerged materials, and clean the fill area. At a minimum, the latter is required to remove settled fine-grained material resulting from the construction activity (Johnson et al. 1972).

The primary methods of placing fill underwater are summarized in Table 3-18. The placement method will be governed by the available equipment, the depth of water, and the required side slopes. Fill quantities are tracked by bathymetric methods. The effects of settlement during construction on the measured fill quantities should be considered.

Control of underwater fill is typically completed using *in situ* testing techniques, such as SPT or CPT. Testing should be completed as placement of the fill progresses, particularly to check for unsuitable materials trapped below or within the fill. Samplers can be used, if necessary, to obtain physical samples of the underwater fill. Experience has shown that large, rugged sampling techniques are more effective than refined, sophisticated ones (Bazett and Foxall 1972).

The relative density of underwater fill is typically up to 50% to 60% and is highly variable. Zones of low relative density may be a concern for settlement under moderate to heavy loads and for liquefaction. Vibro-compaction is the primary method used to densify hydraulic and underwater fills after placement. Examples include dry docks (Zola and Boothe 1960), dams (Hassouna and Shenouda 1970), and man-made islands.

Table 3-18 Methods of Underwater Fill Placement (after Johnson et al. 1972)

Method	Characteristics	Schematic
Bottom-dump scows	• Quick • Relatively flat slopes unless retained by dikes or sheet piles, slope angle flattens as water depth increases • Boat drafts limit to minimum depth of about 15 ft • Discharge of fill entraps air and limits segregation	
Deck scows	• Slower • Fill pushed from deck by dozer, placed by clamshell, or jetted from deck • Steeper sides achievable, slope angle flattens as water depth increase	
Hydraulic fill	• Segregation between coarse and fine materials occurs • Fines may collect in low areas, requiring removal • May cause shear failures in soft foundation soils • More difficult to inspect	
Dump fill on land and push into the water	• Advance the central part of the fill first so that softer bottom materials can be displaced • Bulldozer blades can be used in shallow water to displace soft materials • Fines in fill placed below the water accumulate in front of the advancing fill	

3-8 PROBLEM SOILS AND EARTHWORK.

Chapter 1 provides a summary of many types of problem soil conditions that can affect the design of foundations and earth structures. Table 3-19 summarizes important conditions for the design of earthwork in problem soils.

Table 3-19 Problem Soil Considerations for Earthwork

Soil Type	Primary Considerations for Earthwork Design
Soft Clays	• Soft clays do not provide a stable platform for the compaction of fill. Solutions may include: o Mechanical stabilization with crushed stone, possibly reinforced with geogrid, or o Chemical stabilization of upper layer. • Staged construction may be required to allow strength gain resulting from consolidation.
Highly Plastic Expansive Clays and Shales	• Compacted clay embankment soils may shrink and swell due to seasonal moisture changes, leading to progressive failure. • Slope design should be based on fully-softened shear strength parameters.
Collapsible Soils	• Earthwork loading can cause compression of natural collapsible soils, such as loess, especially if the earthwork is combined with changes in moisture content. • Compacted clays may have a collapsible structure if compacted dry of optimum, which can be reduced by compacting wet of optimum. This consideration is especially important for deep fills.
Sensitive Clays	• Earthwork loading of sensitive clays can cause deformations leading to remolding and catastrophic failure. • Design should maintain a high factor of safety, such that imposed shear stresses remain below the peak shear strength at all points in the sensitive clay.
Residual and Colluvial Soils	• Residual and/or colluvial soils are often problematic if left in place below side hill fills. • May have lower shear strength compared to the compacted fill, creating a weak layer. • Residual materials may have adverse planes of weakness, which can be addressed by proper benching procedures.
Laterites	• Provide poor support for embankments if loaded cyclically or exposed to flowing groundwater
Talus	• Global stability should be considered for design of earthwork over talus deposits
Loose Sands	• Loose sands may not provide a stable platform for compacted fill, particularly if saturated (see soft clays above). • Significant compression should be anticipated due to embankment loading. • In seismic zones, loose sands may present a liquefaction hazard for embankments. • Where fine, loose sands are present in foundation or embankments, erosion potential should be considered.
Glacial Till	• Problematic erosion may occur in sand and silt-sized glacial tills.
Organic Soils, Peat, and Muskeg	• Organic soils do not provide a stable platform for the compaction off fill (see soft clays above). • Organic soils are highly compressible and may experience substantial primary consolidation and secondary compression from earthwork loading. • Organic content of structural fills is often strictly controlled by specifications.
Dispersive Soils	• Dispersive soils are susceptible to internal erosion by flowing water, particularly when used as seepage barriers in earth dams or levees. • Use of dispersive clays in dams should be avoided, because they are very difficult to protect even with well-designed filters.
Dredged Soils	• Most dredged soil deposits will be loose or soft and earthwork construction will require considerations discussed above for soft clays or loose sands. • Dredged material typically has a high water content, which would need to be lowered prior to use as fill.
Low Plasticity Silts and Clays	• Silts can be extremely unstable, both as a working platform for earthwork and within a fill. • Some low plasticity lean clays (PI in range of 9 to 15) have a high percentage (60 to 80%) of silt-sized particles. Fill or subgrades constructed from these soils experience substantial strength loss when wetted and lose ability to support pavements.
Municipal Solid Waste	• Earthwork performed above MSW or in conjunction with landfills must consider the shear strength and compressibility of the waste. Some correlations are available. • Consideration should be given to changes in MSW properties with time.

3-9 NOTATION.

Variable	Definition
a	Power function strength parameter defining the steepness of the curve
b	Power function strength parameter defining the amount of curvature
a_{Δ}	Fill compression parameter controlling magnitude of compression with vertical effective stress
b_{Δ}	Fill compression parameter controlling nonlinearity of compression with vertical effective stress
c	Total stress or undrained cohesion intercept
C_c	Coefficient of curvature from grain size analysis, a.k.a, coefficient of gradation
C_u	Coefficient of uniformity
D_r	Relative density
e_{max}	Maximum void ratio
e_{min}	Minimum void ratio
G_s	Specific gravity of solids
G_{sC}	Specific gravity of oversize fraction (particle size implied by *oversize* depends on the test method)
k	Hydraulic conductivity
k_{sat}	Hydraulic conductivity for saturated conditions
LL	Liquid limit
m	Weibull distribution parameter used for the effects of particle size on shear strength
m_v	Coefficient of compressibility
$N_{1,60}$	Standard Penetration Test blow count corrected for overburden stress and efficiency
P_a	Atmopheric pressure
P_C	Percent oversize fraction (particle size implied by *oversize* depends on the test method)
P_F	Percent finer fraction (particle size implied by *finer* depends on the test method)
pH	Quantitative measure of acidity
PI	Plasticity index
PL	Plastic limit
R	Roughness factor used for operational strength of rockfill
$R.C.$	Relative compaction
S	Degree of saturation

Variable	Definition
s_u/σ'_c	Undrained strength ratio
V_t	Total volume
w	Water content
w_C	Water content of oversize fraction (particle size implied by *oversize* depends on the test method)
w_F	Water content of finer fraction (particle size implied by *finer* depends on the test method)
$w_{F,opt}$	Optimum water content of finer fraction
w_{field}	Water content of field compacted soil
w_{opt}	Optimum water content associated with a particular compactive effort
W_s	Weight of solids
w_T	Water content of the combined finer and oversize fractions
$\Delta\phi'$	Parameter describing the change in effective friction angle with confinings
$\Delta V/V_F$	Overall shrinkage factor
Δw	Relative water content
γ	Total or moist unit weight
$\gamma_{d,B}$	Average dry unit weight of borrow material
$\gamma_{d,F}$	Dry unit weight of finer fraction (particle size implied by *finer* depends on the test method)
$\gamma_{d,field}$	Dry unit weight of field compacted soil
$\gamma_{d,max}$	Maximum dry unit weight associated with minimum void ratio
$\gamma_{d,min}$	Minimum dry unit weight associated with maximum void ratio
γ_{dT}	Dry unit weight of the combined finer and oversize fractions
$\gamma_{dT,field}$	Dry unit weight of the combined finer and oversize fractions as compacted in the field
γ_w	Unit weight of water
ϕ	Total stress friction angle
ϕ'	Effective stress or drained friction angle
ϕ'_0	Effective stress friction at reference stress (typically one atmosphere)
μ	Mean value
σ'_c	Effective consolidation stress
σ'_f	Effective normal stress at failure

Variable	Definition
σ	Standard deviation
σ'_z	Effective vertical stress

3-10 SUGGESTED READING.

Topic	Reference
General Earthwork	TRB 1990. *Guide to Earthwork Construction, State of the Art Report 8*, National Research Council, Washington, D.C.
	Hilf, J. W. 1991. “Compacted fill.” *Foundation Engineering Handbook*, 2nd Edition, Ed. H.-Y. Fang, Springer Nature, 249-316.
Earth Dam Construction	USACE, 2004. *General Design and Construction Considerations for Earth and Rock-Fill Dams, EM 1110-2-2300*, Department of the Army, Washington, D.C.
	USBR, 2012. “Chapter 10: Embankment Construction.” *Design Standards No. 13 Embankment Dams*, Technical Service Center, United States Bureau of Reclamation.
Rock Fill	Breitenbach, A. J. 1993. “Rockfill placement and compaction guidelines.” *Geotechnical Testing Journal*, 16(1), 76-84.
Underwater Fill	*Underwater Soil Sampling, Testing, and Construction Control, ASTM Special Technical Publication 501*, ASTM International.

This Page Intentionally Left Blank

CHAPTER 4. ANALYSIS OF WALLS AND RETAINING STRUCTURES

4-1 INTRODUCTION.

Earth retaining structures are among the oldest built structures in the history of civilization. They are necessary to accommodate a change in grade or ground surface elevation over a short distance. Earth retaining structures are also necessary in harbors, shores, and riverbanks to allow easy access to water. Some of the first technical papers in geotechnical engineering concerned theories for calculating earth pressures for retaining structures (Coulomb 1776; Rankine 1857).

Although a myriad of types of earth retaining structures are part of 21st century civil engineering construction, the basic earth pressure theories and major design elements of these structures share common links.

This chapter presents the basic theories and principles behind the calculation of earth pressure. The application of these theories and principles is illustrated for a variety of retaining structures encountered in civil engineering construction.

4-2 DEVELOPMENT OF EARTH PRESSURES AND LOADS.

The earth pressures acting on buried structures, such as retaining walls, basement walls, ground anchors, etc., are dependent on the relative movement between the structure and the surrounding soil. In the simplest form, this is often shown as a buried plate within a soil mass (Figure 4-1). If the plate or structure does not move, then the pressures on the right side and left side of the structure are equal, and this is called an *at-rest earth pressure* condition.[18] In the at-rest earth pressure condition, the soil *is not* in a condition of failure.

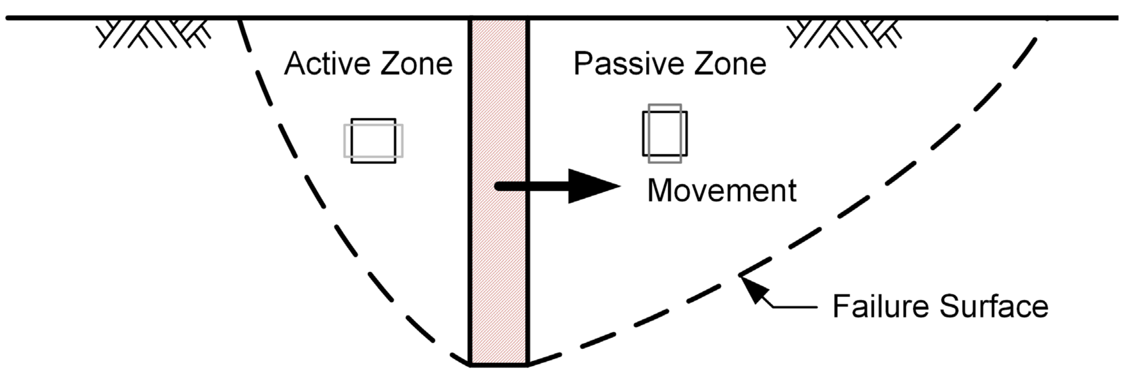


Figure 4-1 Influence of Movement on Active and Passive Earth Pressure Zones

[18] This is also called a K_o condition or *zero lateral strain* condition.

If a load is applied to the plate to move it toward the right, the soil to the right of the structure is compressed horizontally, and the shear resistance of the soil is mobilized. A *passive earth pressure* condition develops on the right side. On the left side of the structure, the horizontal stress is decreased, and the soil is extended or stretched until the shear resistance of the soil is mobilized. This is called an *active earth pressure* condition. The figure also shows how a square element of soil would deform for each of the cases. In the passive zone, the square element is compressed laterally, and in the active zone, the square element is extended laterally. Provided the active and passive conditions are fully developed, the soil is in a condition of failure in both the active and passive zones.

A common parameter used in earth pressure calculations is the *earth pressure coefficient*, K. The earth pressure coefficient is normally defined as the ratio of the horizontal *effective* stress to the vertical *effective* stress at a point within the soil mass. The earth pressure coefficient is occasionally assumed to be the ratio of the horizontal total stress to the vertical total stress.[19] In this chapter, K is defined as the ratio of the effective stresses unless specifically stated otherwise.

4-2.1 At-Rest Earth Pressure.

For at-rest conditions, the earth pressure coefficient is defined as:

$$K_0 = \frac{\sigma'_h}{\sigma'_z} \qquad (4\text{-}1)$$

where:
K_0 = at-rest earth pressure coefficient,
σ'_h = horizontal effective stress, and
σ'_z = vertical effective stress.

For this equation to be valid, the soil mass must be in a state of zero lateral strain. Within a soil mass, at-rest conditions normally require a horizontal ground surface and the absence of surface loads of limited areal extent. At-rest conditions can exist when there is a rigid boundary, such as a basement wall, that will satisfy the condition of zero lateral or horizontal strain. For most applications, the horizontal and vertical stresses are the major and minor principal stresses with the relative directions depending on the value of K_0 (i.e., $\sigma'_h = \sigma'_1$ if $K_0 > 1$ and $\sigma'_h = \sigma'_3$ if $K_0 < 1$).

Standardized laboratory tests are not available to measure the value of K_0. Some special tests apparatuses have been developed to measure K_0 (Filz 1992; Sehn 1990),

[19] Total stress earth pressure coefficients can be useful for specifying earth pressures in numerical analyses concerned only with total stresses.

but these are not used in conventional engineering practice. The Menard pressuremeter, the self-boring pressuremeter, and the Marchetti dilatometer have been used to obtain an *in situ* measurement of K_0, but these devices are not in common use for the design of earth retaining structures.

The most common method used to determine K_0 is based on a correlation presented by Mayne and Kulhawy (1982):

$$K_0 = (1 - \sin\phi') \cdot OCR^{\sin\phi'} \tag{4-2}$$

where:
K_0 = at-rest earth pressure coefficient,
ϕ'= effective stress friction angle for normally consolidated conditions, and
OCR = overconsolidation ratio.

K_0 values are less than one for normally consolidated soils, and can range from about 0.3 to 0.8. For simple calculations, K_0 is often assumed to be equal to 0.5. In overconsolidated soils, it is common for the value of K_0 to be greater than one, indicating that the horizontal effective stress is greater than the vertical effective stress.

4-2.2 Rankine Active and Passive Earth Pressures.

Both the active and passive earth pressure coefficients represent the effective stress ratio for a failure condition in the soil. The earth pressure coefficients K_A and K_P are best explained using Rankine's (1857) earth pressure theory. Mohr circles representing at-rest, active, and passive conditions are shown in Figure 4-2.

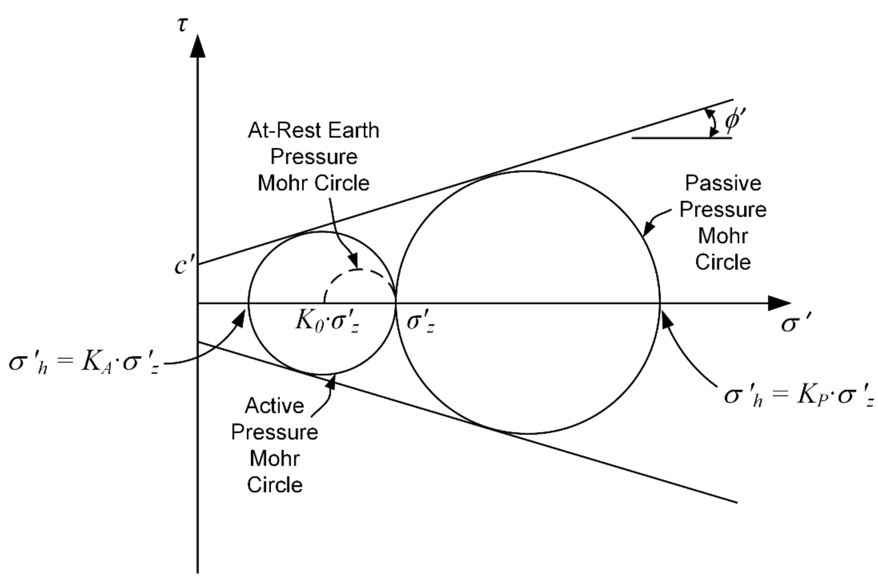


Figure 4-2 Mohr Circles for At-Rest, Rankine Active, and Rankine Passive Stress States

For the at-rest conditions, the Mohr circle is not tangent to the envelope; therefore, it does not represent a condition of failure. The circle representing an active failure shows that the horizontal stress is equal to K_A multiplied by the vertical stress, and the Mohr circle is tangent to the envelope. The circle representing the passive failure condition shows that the horizontal stress is equal to K_P multiplied by the vertical stress. In the active condition, the major principal stress (σ'_1) is vertical and the minor principal stress (σ'_3) is horizontal. For the passive condition, the major principal stress (σ'_1) is horizontal and the minor principal stress (σ'_3) is vertical. For both of these cases, the horizontal stress is the earth pressure.

Rankine's theory and the geometry of the Mohr circles shown in Figure 4-2 result in the following equations for the active and passive earth pressure coefficients:

$$\textit{Active:}\ K_A = \frac{1-\sin\phi'}{1+\sin\phi'} = \tan^2(45-\frac{\phi'}{2}) \qquad (4\text{-}3),$$

$$\textit{Passive:}\ K_P = \frac{1+\sin\phi'}{1-\sin\phi'} = \tan^2(45+\frac{\phi'}{2}) \qquad (4\text{-}4),$$

and

$$K_A = \frac{1}{K_P} \qquad (4\text{-}5)$$

where:
K_A = coefficient of active earth pressure,
K_P = coefficient of passive earth pressure, and
ϕ'= effective stress friction angle.

The Mohr circles in Figure 4-2 allow the horizontal effective stress to be predicted for both active and passive conditions for the stresses at any point within the failure zone. The horizontal pressures are calculated as:

$$\textit{Active:}\ \sigma'_h = K_A \cdot \sigma'_z - 2 \cdot c' \cdot \sqrt{K_A} \qquad (4\text{-}6)$$

and

$$\textit{Passive:}\ \sigma'_h = K_P \cdot \sigma'_z + 2 \cdot c' \cdot \sqrt{K_P} \qquad (4\text{-}7)$$

where:
K_A = coefficient of active earth pressure,
K_P = coefficient of passive earth pressure,
σ'_h = horizontal effective stress (earth pressure),
σ'_z = vertical effective stress, and
c' = effective stress cohesion intercept.

From Equations 4-6 and 4-7, the effective cohesion intercept theoretically decreases the active earth pressure and increases the passive earth pressure. The value of c' is usually assumed to be zero for coarse-grained soils. Fine-grained soils that are represented by a linear failure envelope may have a value of c', which is associated with overconsolidation or compaction. These soils creep, shrink, and swell with time, and the operating value of c' can decrease or reach zero. For this reason, the changes to the earth pressures caused by c' are usually neglected for fine-grained soils.

4-2.3 Movement Required to Develop Active and Passive States.

An important consideration in earth pressure theory is the amount of movement required to develop the active and passive earth pressure conditions. Much more movement or displacement is required to develop the passive condition than the active condition. This is particularly important in the design of earth retention structures or soil anchors since both active and passive pressures affect the performance of the structure. However, the amount of displacement of the structure might not be an explicit parameter in the calculations.

Figure 4-3(a) illustrates the importance of wall movement on the development of active and passive earth pressures. For active and passive pressures to fully develop, the wall must translate laterally or tilt (rotate). The figure shows general trends developed from experimental data linking the magnitude of the earth pressure coefficient to wall rotation, expressed as the ratio of horizontal displacement (Y) to the wall height (H). Typical magnitudes for different soil types are summarized in Figure 4-3(d). About five to ten times more displacement is required to develop passive pressures than active pressures.

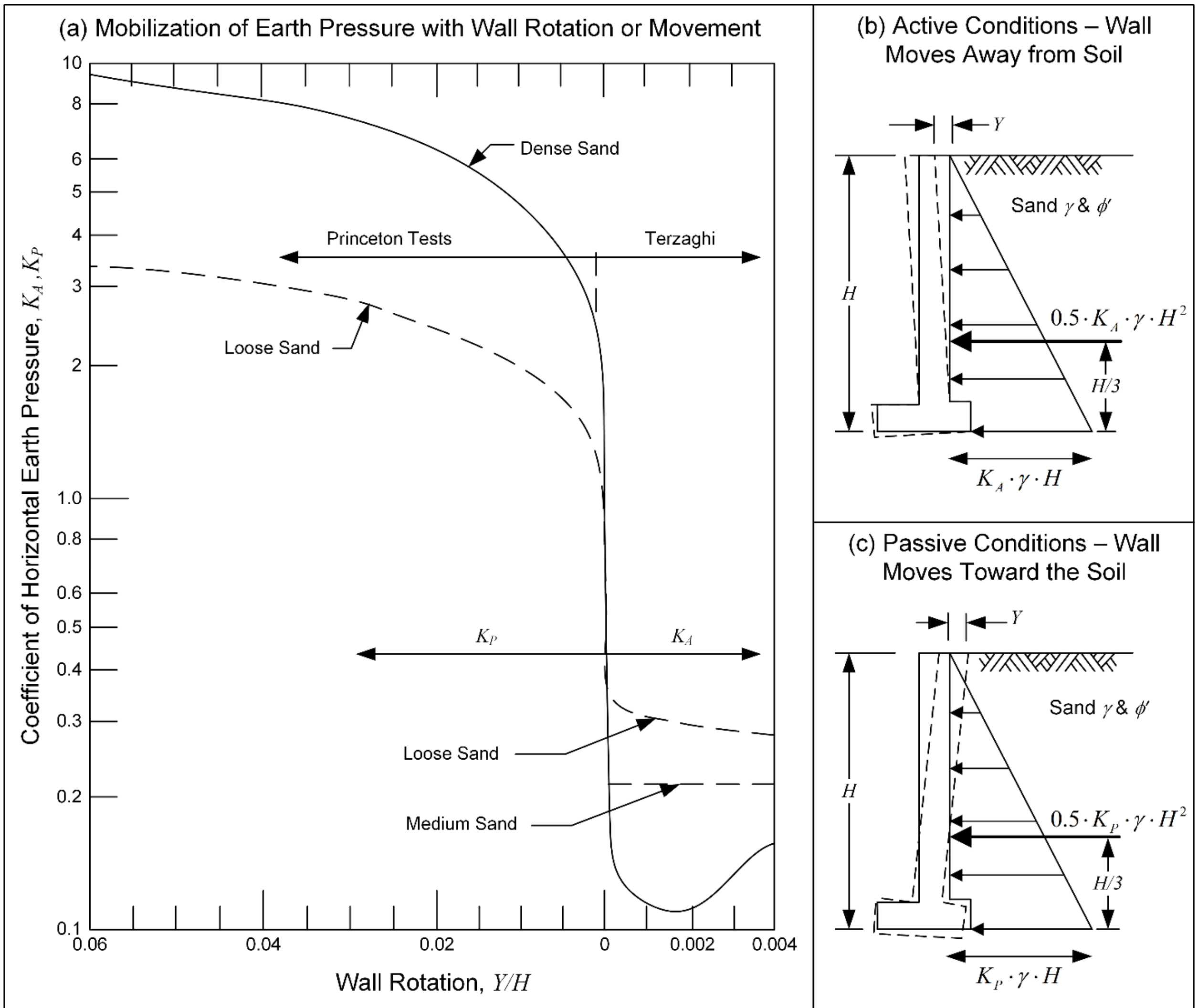
The amount of displacement required to mobilize active and passive states also depends on the soil type and compaction. Dense sands require less displacement than loose sands. Compacted clays require five to ten times more movement than dense sands.[20] As noted in Figure 4-3(d), theoretical values of K_A and K_P can only be sustained for short time periods by clay soils because of creep.

4-2.4 Earth Pressure Distributions and Loads.

Figure 4-3(b) and (c) illustrate the active and passive pressure distributions acting on a retaining wall. The earth pressure is calculated over the depth of the backfill (H). The cases shown have horizontal backfill, no effective stress cohesion, and no friction between the wall and backfill. The active and passive earth pressures result in triangular pressure distributions.

---

[20] The Rankine method for calculating earth pressures is more applicable to coarse-grained soils than fine-grained soils. Other methods are recommended for calculating earth pressures of fine-grained soils.



(d) Magnitudes of Wall Rotation to Fully Mobilize Earth Pressure by Soil Type

Soil Type and Condition	Rotation Y/H	
	Active	Passive
Dense Sand	0.001	0.01
Medium Dense Sand	0.002	0.02
Loose Sand	0.004	0.04
Compacted Silt	0.002	0.02
Compacted Lean Clay**	0.01	0.05
Compacted Fat Clay**	0.01	0.05

Y = Horizontal Displacement and H = Height of the Wall

** Under stress conditions close to the minimum active or maximum passive pressure, clay soils will creep continually. These levels of movement will only temporarily produce active or passive pressure. With time, the active pressure will approach the at-rest value, and the passive pressure will approach about 40% of the passive value.

Figure 4-3 Active and Passive Earth Pressure – (a) Mobilization with respect to Wall Movement, (b) Active Earth Pressure Distribution and Load, (c) Passive Earth Pressure Distribution and Load, and (d) Required Magnitude of Wall Rotation for Various Soil Types (after Kim et al. 1991)

The resultant force of the triangular pressure distribution is determined for the active and passive cases as:

$$\textit{Active: } P_A = K_A \cdot \frac{\gamma \cdot H^2}{2} \tag{4-8}$$

and

$$\textit{Passive: } P_P = K_P \cdot \frac{\gamma \cdot H^2}{2} \tag{4-9}$$

where:
P_A = active earth pressure resultant force,
P_P = passive earth pressure resultant force,
γ = unit weight of backfill soil, and
H = height of wall.

The equations shown above are for effective stress or drained analyses. The same equations can be expressed for undrained or total stress analyses. For this case, total stress strength parameters (c, ϕ, or s_u) are used in the equations, and the calculated earth pressure is the total horizontal stress (σ_h). There are some important issues regarding the application of the Rankine method to undrained or total stress conditions, which are discussed in Section 4-3.3.

Figure 4-4 shows earth pressure distributions for active and passive cases using the Rankine theory. The application of the Rankine theory is generally limited to cases where there is not any friction between the retaining wall and the soil (i.e., smooth wall) and the backfill is horizontal although there are published techniques that can accommodate inclined backfills.

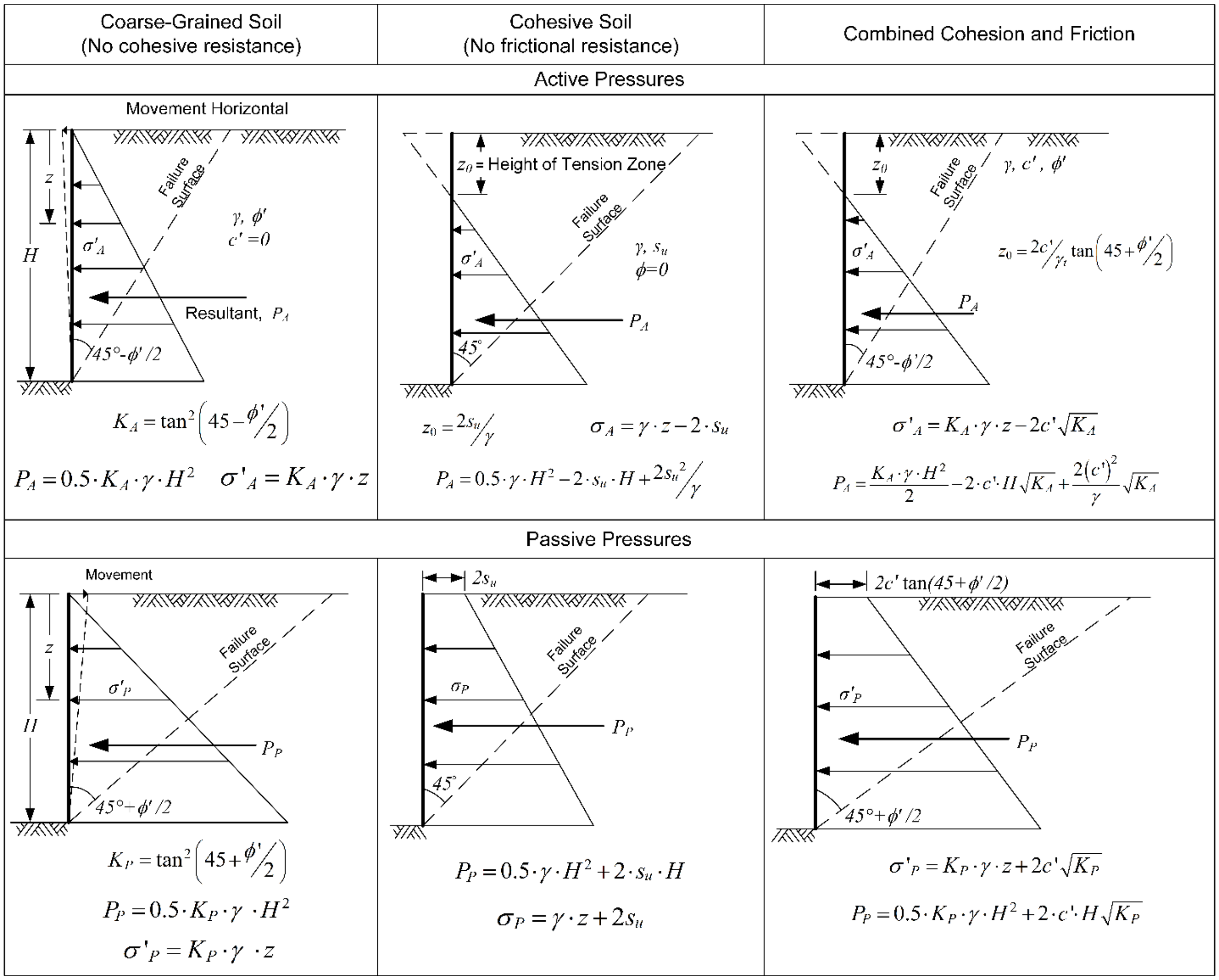


Figure 4-4 Earth Pressure Distributions for Active and Passive Rankine Cases

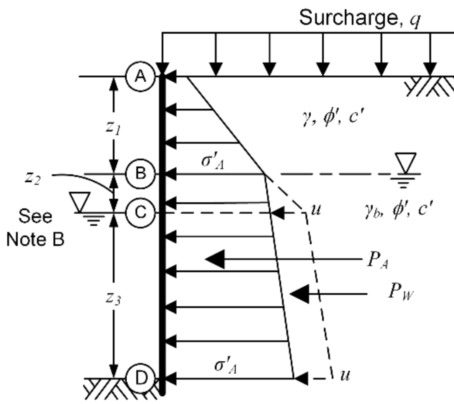
4-2.5 Rankine Method Examples.

Figure 4-5 shows an example for active pressure determination using the Rankine method for the following conditions:

- horizontal backfill,
- uniform surcharge load (q),
- no wall friction,
- horizonal water surfaces on both sides of the wall, and
- homogeneous soil conditions with strength characterized by c' and ϕ'.

For this example, moist unit weights are used above the water table and buoyant unit weights are used below the water table in order to calculate the correct vertical effective stress. In this example, the earth pressure caused by the surcharge is greater than the reduction in earth pressure due to the effects of cohesion, so the earth pressure at the ground surface is greater than zero. It is common to ignore the contribution of the cohesion term in earth pressure calculations for additional conservatism.

Figure 4-6 has the same cross section as Figure 4-5, but the equations for passive earth pressure are shown. The calculations are very similar to the active earth pressure example (Figure 4-5).



Conditions:

- Horizontal backfill
- Uniform surcharge
- Wall friction negligible
- Ground water level horizontal
- Soil is homogeneous

Active earth pressures (σ'_A) can be calculated by formula (See Note A):

At A) $\sigma_A' = q\tan^2\left(45-\phi'/2\right) - 2c'\tan\left(45-\phi'/2\right)$

At B) $\sigma_A' = \left(q+\gamma\cdot z_1\right)\tan^2\left(45-\phi'/2\right) - 2c'\tan\left(45-\phi'/2\right)$

At C) $\sigma_A' = \left(q+\gamma\cdot z_1+\gamma_b\cdot z_2\right)\tan^2\left(45-\phi'/2\right) - 2c'\tan\left(45-\phi'/2\right)$

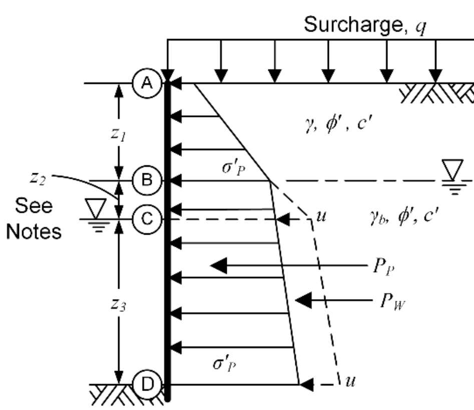
At D) $\sigma_A' = \left(q+\gamma\cdot z_1+\gamma_b\cdot\left(z_2+z_3\right)\right)\tan^2\left(45-\phi'/2\right) - 2c'\tan\left(45-\phi'/2\right)$

In general, active earth pressure at any height = $\sigma_A' = \sigma_z'\tan^2\left(45-\phi'/2\right) - 2c'\tan\left(45-\phi'/2\right)$

Net water pressure = $u = \gamma_w\cdot z_2$

Note A – Cohesion term may be neglected. In no case should negative pressure be considered.
Note B – Inboard and outboard water levels may differ due to pumping, tidal fluctuation and lag, or other reasons.

Figure 4-5 Rankine Active Earth Pressure Calculation for No Wall Friction and Uneven Water Elevations



Conditions:

- Horizontal backfill
- Uniform surcharge
- Wall friction negligible
- Ground water level horizontal
- Soil is homogeneous

Passive earth pressures σ_P' can be calculated as:

At A) $\sigma'_P = q\cdot K_P + 2c'\sqrt{K_P}$ $\qquad K_P = \tan^2\left(45+\phi'/2\right)$

At B) $\sigma'_P = \left(q+\gamma\cdot z_1\right)K_P + 2c'\sqrt{K_P}$

At C) $\sigma'_P = \left(q+\gamma\cdot z_1+\gamma_b\cdot z_2\right)K_P + 2c'\sqrt{K_P}$

At D) $\sigma'_P = \left[q+\gamma\cdot z_1+\gamma_b\left(z_2+z_3\right)\right]K_P + 2c'\sqrt{K_P}$

In general, passive earth pressure at any height = $\sigma'_P = \sigma'_z K_P + 2c'\sqrt{K_P}$ Net water pressure = $u = \gamma_w \cdot z_2$

Inboard and outboard water levels may differ due to pumping, tidal fluctuation and lag, or other reasons.

Figure 4-6 Rankine Passive Earth Pressure Calculation for No Wall Friction and Uneven Water Elevations

4-2.6 Wall/Soil Interface Friction Angle.

The interface friction angle (δ) between the wall and soil backfill can be an important parameter in retaining wall analysis. The angle is equal to that obtained in a direct shear apparatus when the bottom half of the shear box is the wall material (normally concrete or steel) and the top half is soil. Tests can be conducted at pressures in the same range as the earth pressures, and a linear envelope is fit through the data. In geotechnical practice, these special direct shear tests are not often conducted, and the value of δ is most often obtained from published data, such as that presented in Table 4-1. Typical δ values for various combinations of wall materials and soil types are provided. For clayey soils located at an interface, such as the bottom of a wall or adjacent to a sheet pile, the resistance is termed the *adhesion*, C_a.

Table 4-1 Interface Friction Angles and Adhesion Values for Wall/Soil Interfaces

Frictional Interface between Various Materials	Interface friction angle, δ (deg)	Friction Factor (tan δ)
Mass concrete or masonry on the following foundation materials		
Clean sound rock	35	0.7
Clean gravel, gravel-sand mixtures, coarse sand	29 - 31	0.55 – 0.60
Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel	24 - 29	0.45 – 0.55
Clean fine sand, silty or clayey fine to medium sand	19 - 24	0.35 – 0.45
Fine sandy silt, nonplastic silt	17 - 19	0.30 – 0.35
Very stiff and hard residual or overconsolidated clay	22 - 26	0.40 - 0.50
Medium stiff and stiff clay and silty clay	17 - 19	0.30 - 0.35
Steel sheet piles against the following soils		
Clean gravel, gravel-sand mixtures, well-graded rock fill with spalls	22	0.40
Clean sand, silty sand-gravel mixture, single size hard rock fill	17	0.30
Silty sand, gravel or sand mixed with silt or clay	14	0.25
Fine sandy silt, nonplastic silt	11	0.20
Formed concrete or concrete sheet piling against the following soils		
Clean gravel, gravel-sand mixture, well-graded rock fill with spalls	22 - 26	0.40 – 0.50
Clean sand, silty sand-gravel mixture, single size hard rock fill	17 - 22	0.30 – 0.40
Silty sand, gravel or sand mixed with silt or clay	17	0.30
Fine sandy silt, nonplastic silt	14	0.25
Various structural materials		
Masonry on masonry, igneous and metamorphic rocks		
Cleaned and scaled soft rock on cleaned and scaled soft rock	35	0.70
Cleaned and scaled hard rock on cleaned and scaled soft rock	33	0.65
Cleaned and scaled hard rock on cleaned and scaled hard rock	29	0.55
Masonry on wood (cross grain)	26	0.50
Steel on steel at sheet pile interlocks	17	0.30
Interface with Clayey Soils (Undrained shear strength)	**Adhesion C_a (psf)**	
Very soft fine-grained soil (0 - 250 psf)	0 – 250	
Soft fine-grained soil (250 - 500 psf)	250 – 500	
Medium stiff fine-grained soil (500 - 1000 psf)	500 – 750	
Stiff fine-grained soil (1000 - 2000 psf)	750 – 950	
Very stiff fine-grained soil (2000 - 4000 psf)	950 - 1300	

4-3 ACTIVE AND PASSIVE EARTH PRESSURE FROM OTHER METHODS.

The values of K_A and K_P for the Rankine method, as presented in Equations 4-3 and 4-4, are solely a function of the drained friction angle, ϕ'. Other methods of calculating earth pressure coefficients, such as the trial wedge method developed by Coulomb (1776) and the log spiral method summarized by Caquot and Kerisel (1948), are available. With the trial wedge and log spiral methods, the effects of other factors, such as sloping backfills and wall friction, can be accommodated, and these effects are reflected in the values of the earth pressure coefficients. A gravity retaining wall with a sloping backfill (β) and wall (θ) is shown in Figure 4-7 for a case where the wall/soil interface friction angle (δ) is considered.

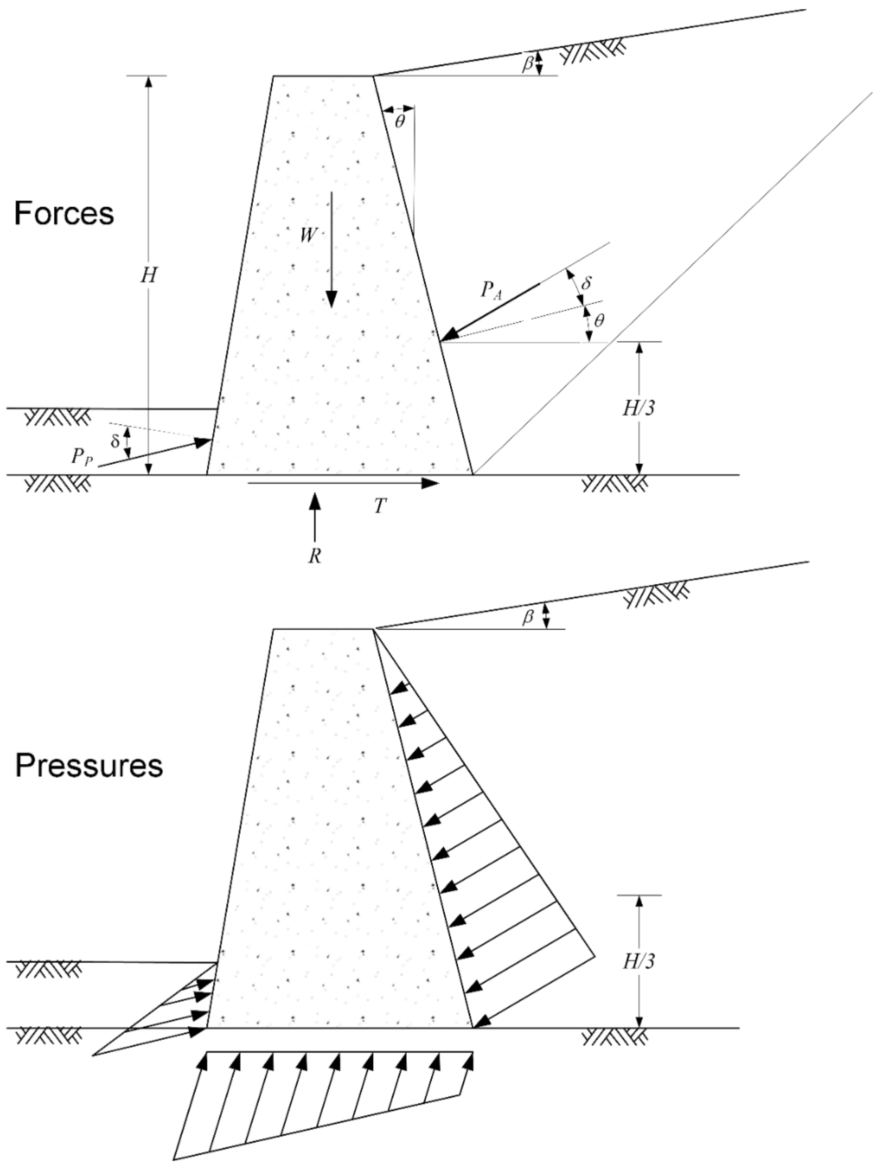


Figure 4-7 Gravity Retaining Wall with Sloping Backfill, Sloping Wall, and Interface Friction Angle

4-3.1 Coulomb Wedge Method.

Coulomb (1776) developed a limit equilibrium method for calculating the force applied to a wall or anchor for the active and passive earth pressure conditions. This method, along with other modifications of the method, analyzes the forces acting on an active or passive failure wedge defined by a linear failure surface. The main differences between the active and passive cases are the angle at which the resultant force acts on the wall and the direction of the shear forces acting on the failure plane, owing to the difference in the direction of movement of the wedge.

The Coulomb method has advantages over the Rankine method in that it can accommodate:

- irregular ground surfaces,
- sloping wall faces,
- irregular surcharge loads on the ground surface, and
- interface friction between the wall and the soil backfill.

A Coulomb analysis can be performed as a graphical solution, chart solution, or equations can be developed for direct calculations. Different failure surfaces are analyzed until the maximum active force or minimum passive force is obtained. The free body diagrams and force polygons for the active and passive conditions for cases with and without wall friction are shown in Figure 4-8.

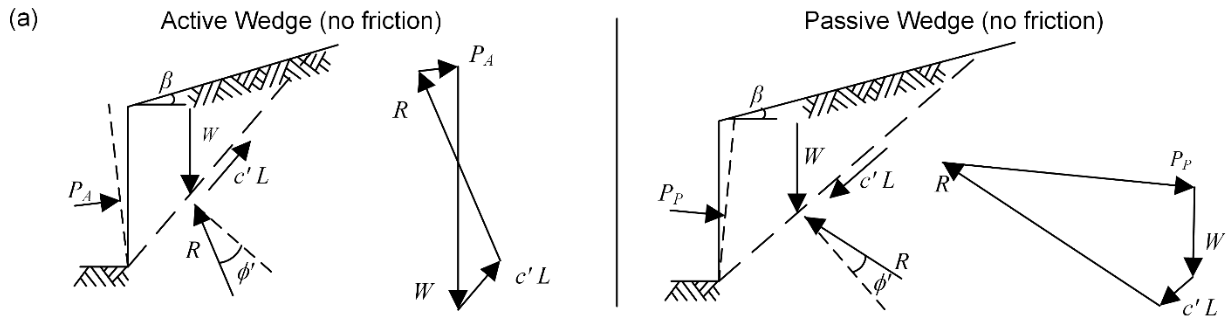
For the conditions given in Figure 4-8(a), Figure 4-9 provides values of K_A and K_P for different friction angles and backfill slopes, assuming c' = 0. Once the earth pressure coefficient has been determined, then a resultant force (P_A or P_P) can be calculated using the same procedure as used for the Rankine method (Equations 4-8 and 4-9). Figure 4-10 allows the determination of the slope of the linear failure surface measured from vertical (α).

The active earth pressure load can be directly calculated for the more complex case of a sloping wall face (θ), sloping backfill (β), and interface friction angle (δ) as:

$$P_A = \frac{1}{2} \cdot \gamma \cdot H^2 \cdot \frac{\cos^2(\phi' - \theta)}{\cos^2\theta \cdot \cos(\theta + \delta)\left[1 + \sqrt{\dfrac{\sin(\phi' + \delta)\sin(\phi' - \beta)}{\cos(\theta + \delta)\cos(\theta - \beta)}}\right]^2} \quad (4\text{-}10)$$

where:
P_A = active earth pressure force,
γ = unit weight of backfill soil,
H = wall height,
ϕ' = effective stress or drained friction angle,
θ = slope angle of the wall face,
δ = interface friction angle between wall and soil, and
β = slope of backfill surface.

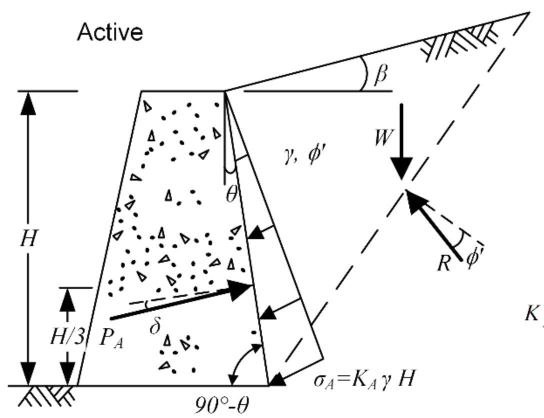
(a)

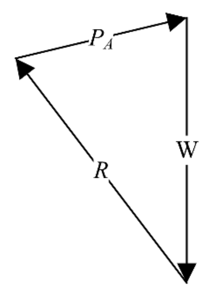


For soil with c' and ϕ', the position of the failure surface is determined by analyzing trial wedges to obtain a maximum value of P_A or minimum value of P_P. The cases shown above involve the following assumptions:

1. Materials are homogeneous.
2. Sufficient movement has occurred so the shear strength on rupture surface is completely mobilized.
3. Wall is vertical. No shear forces are present on back of wall. Resultant forces are horizontal. Under these conditions, resultant pressures are active and passive values, and rupture surface is a straight plane through heel of wall. Effects of surcharge and groundwater pressures are not included.

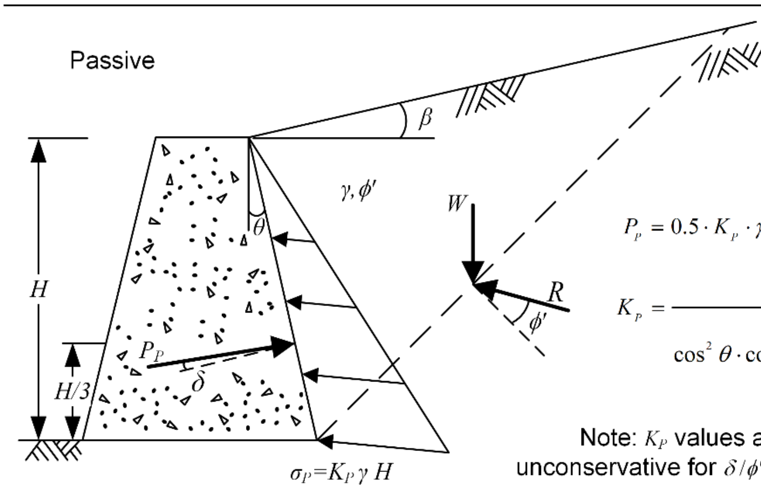
(b) For $c' = 0$ soils with sloping backfill and/or wall, values of K_A and K_P, and conditions of failure are given below.

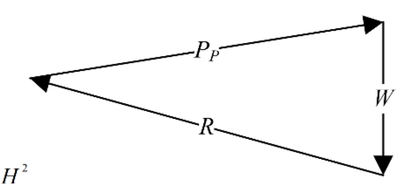




$$P_A = 0.5 \cdot K_A \cdot \gamma \cdot H^2$$

$$K_A = \frac{\cos^2(\phi' - \theta)}{\cos^2\theta \cdot \cos(\theta + \delta)\left[1 + \sqrt{\dfrac{\sin(\phi' + \delta)\sin(\phi' - \beta)}{\cos(\theta + \delta)\cos(\theta - \beta)}}\right]^2}$$





$$P_P = 0.5 \cdot K_P \cdot \gamma \cdot H^2$$

$$K_P = \frac{\cos^2(\phi' + \theta)}{\cos^2\theta \cdot \cos(\theta - \delta)\left[1 - \sqrt{\dfrac{\sin(\phi' + \delta)\sin(\phi' + \beta)}{\cos(\theta - \delta)\cos(\theta - \beta)}}\right]^2}$$

Note: K_P values are satisfactory for $\delta / \phi' \leq 0.4$ but are unconservative for $\delta / \phi' > 0.4$ and, therefore, should not be used.

Figure 4-8 Free Body Diagrams and Force Polygons for Coulomb Method for Various Wall and Backfill Geometries

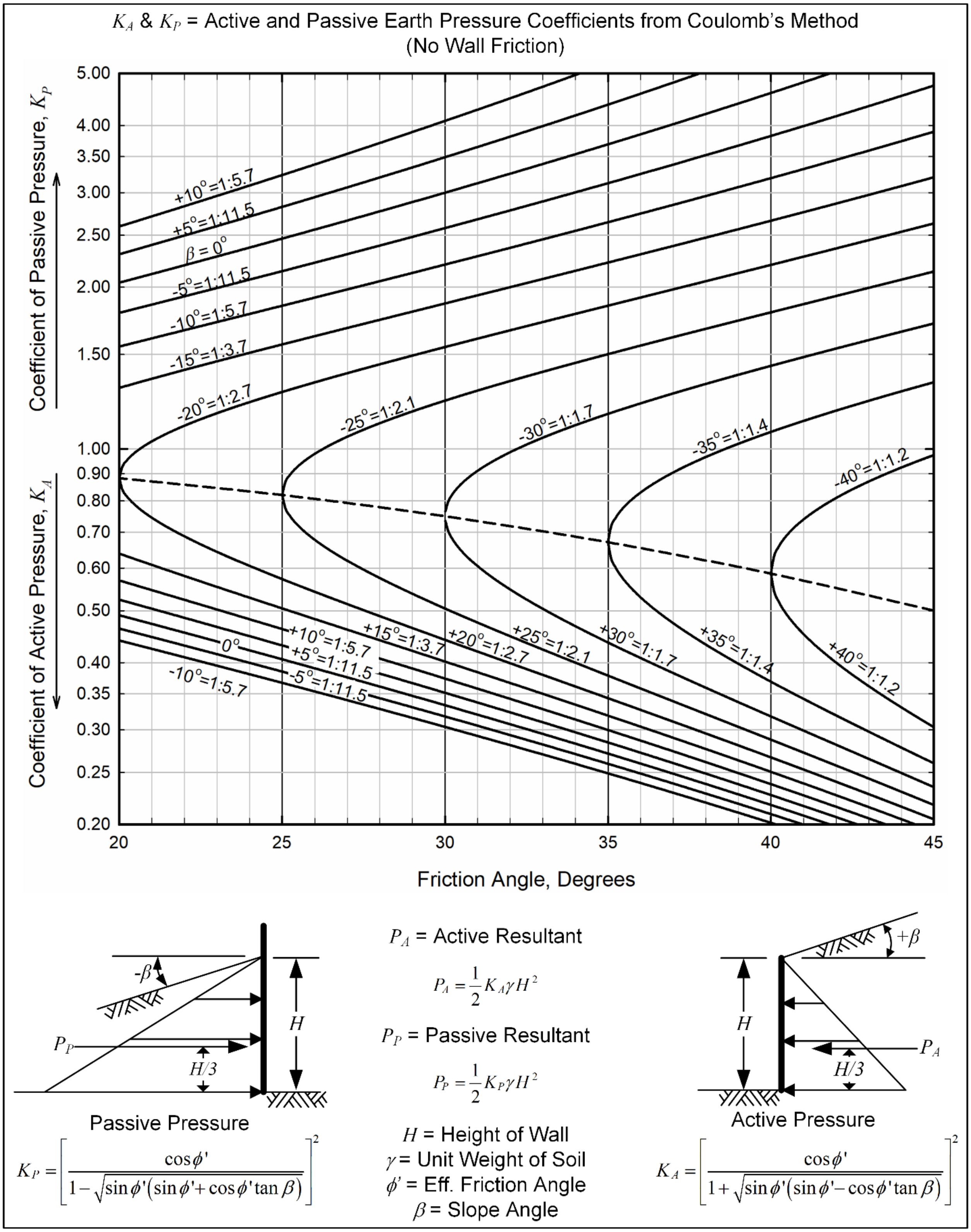


Figure 4-9 Values of K_A and K_P for the Coulomb Method for Vertical Walls with No Wall Friction

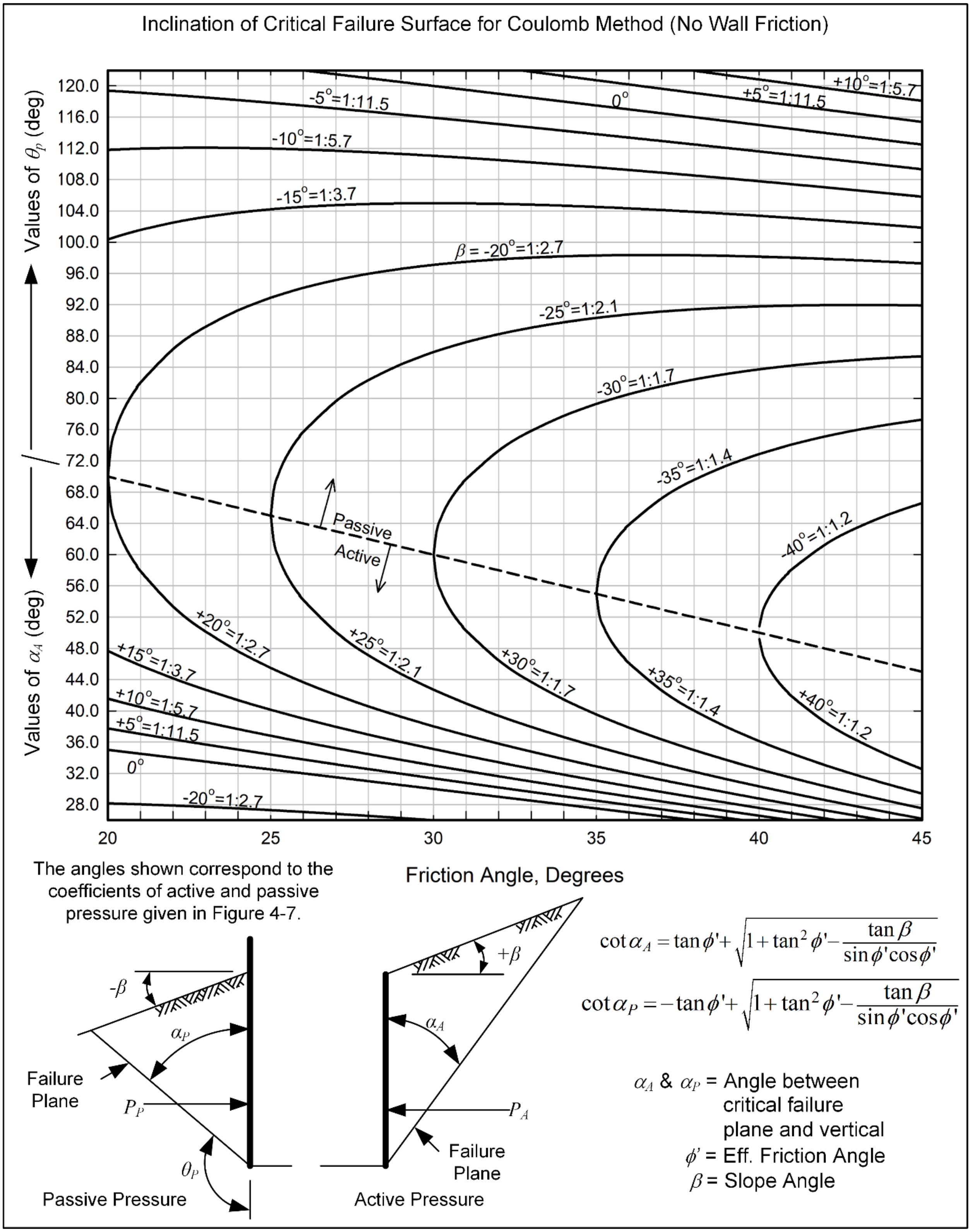


Figure 4-10 Inclination of the Failure Plane for the Coulomb Method for Vertical Walls with No Wall Friction

The passive earth pressure load can be calculated as:

$$P_P = \frac{1}{2} \cdot \gamma \cdot H^2 \cdot \frac{\cos^2(\phi' + \theta)}{\cos^2\theta \cdot \cos(\theta - \delta)\left[1 - \sqrt{\frac{\sin(\phi' + \delta)\sin(\phi' + \beta)}{\cos(\theta - \delta)\cos(\theta - \beta)}}\right]^2} \tag{4-11}$$

where:
K_P = passive earth pressure force.

For cases with surcharge loads, irregular backfill slopes, line loads, etc., the individual forces in the free body diagram (FBD) should be calculated, and force equilibrium should be used to find the values of P_A and P_P for trial failure surfaces. In addition, for active earth pressure cases where the wall is expected to settle a significant amount, it may be necessary to reverse the direction of the shear force on the wall in the FBD. This is called a *negative* δ *case*, and the reversal of the direction of the shear force is detrimental to wall stability.

4-3.2 Log Spiral Method.

One simplification of the Rankine and Coulomb methods is the assumption of a linear failure plane. Experimental and numerical analysis have shown that the true failure surface is curved instead of linear. The surface closely approximates a logarthmic spiral. The linear and log spiral failure surfaces for the active and passive earth pressure cases are shown in Figure 4-11. The difference in the failure planes is not substantial for the active earth pressure case, but there is a considerable difference in the passive case. If the Coulomb method is used to calculate the passive resistance of an earth anchor, the resistance will be greatly overestimated compared to results using the log spiral method. Much less soil is engaged by the true, log spiral surface compared to the linear Coulomb surface. This is especially true as the interface friction angle approaches the friction angle of the soil (i.e., $\delta/\phi' > 0.4$). Therefore, passive pressure should be calculated using the log spiral method and not the Coulomb method.

Unfortunately, the calculations for the log spiral method are not as simple as for the Coulomb method. Caquot and Kerisel (1948) provide tables of values of K_A and K_P for different wall geometries and interface friction angles. Alqarawi et al. (2021) provide the equations for using a spreadsheet to perform log spiral analysis calculations. Alternatively, charts can be used to determine values of K_A and K_P for log spiral solutions.

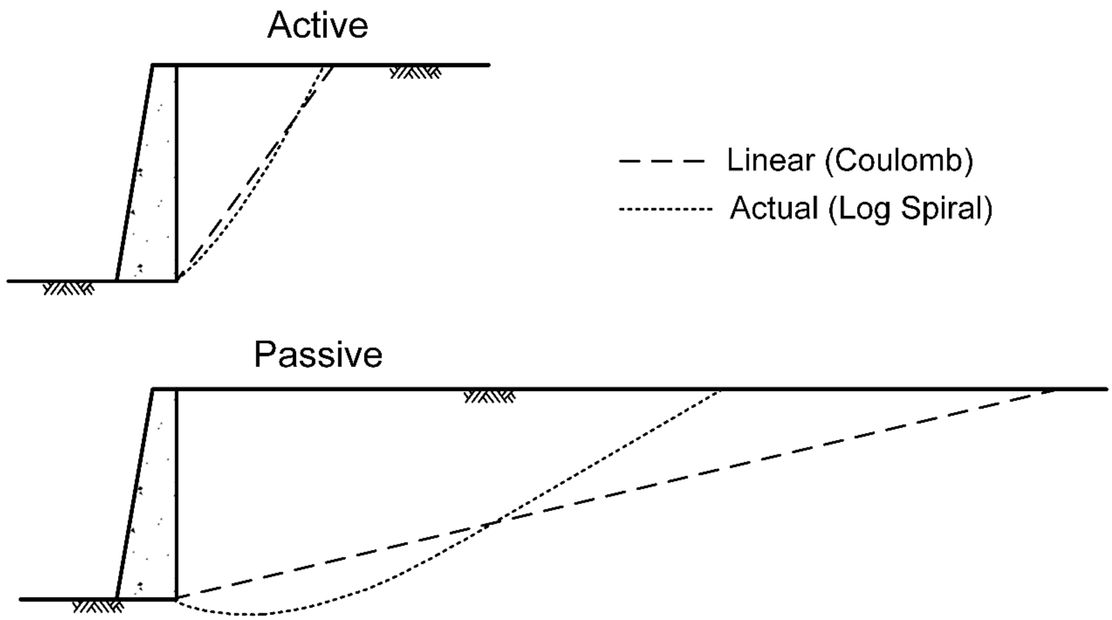


Figure 4-11 "Actual" and Linear Failure Planes for Active and Passive Earth Pressure Cases for $\phi' = \delta = 30°$ (after Perloff and Baron 1976)

Figure 4-12 shows values of K_A and K_P for the log spiral method for walls with a sloping face and δ/ϕ' = 0.66 based on the published data of Kerisel and Absi (1990). Figure 4-13 is a similar chart for vertical-faced walls having a sloping backfill. [21]

The log spiral method is commonly used for cut walls, such as sheet pile or soldier pile and lagging, where both K_A and K_P are required. These walls are vertical and often have no backslope. While δ/ϕ' = 0.66 is a common assumption, this type of design may require K_p for a different value of wall friction. For conditions with θ = 0 deg and β = 0 deg, the value of K_p can be approximated as:

$$\ln\left(K_p\right) = \ln\left(\frac{1+\sin\left(\phi'\right)}{1-\sin\left(\phi'\right)}\right)\left[1.443\left(\frac{\delta}{\phi'}\right)\sin\phi' + 1\right] \qquad (4\text{-}12)$$

where:
K_p = log spiral passive earth pressure coefficient for θ = 0 deg and β = 0 deg,
ϕ' = effective stress friction angle, and
δ = wall-soil interface friction angle.

[21] It is important to note that Figure 4-12 and Figure 4-13 differ significantly from the charts provided in the 1982 version of DM 7.2. Those charts used δ/ϕ' = 1 along with reduction ratios for other values of friction angle and δ/ϕ'. The reduction ratios were averages that introduced substantial inaccuracy for some cases. For this reason, a single value of δ/ϕ' was selected to reproduce the charts.

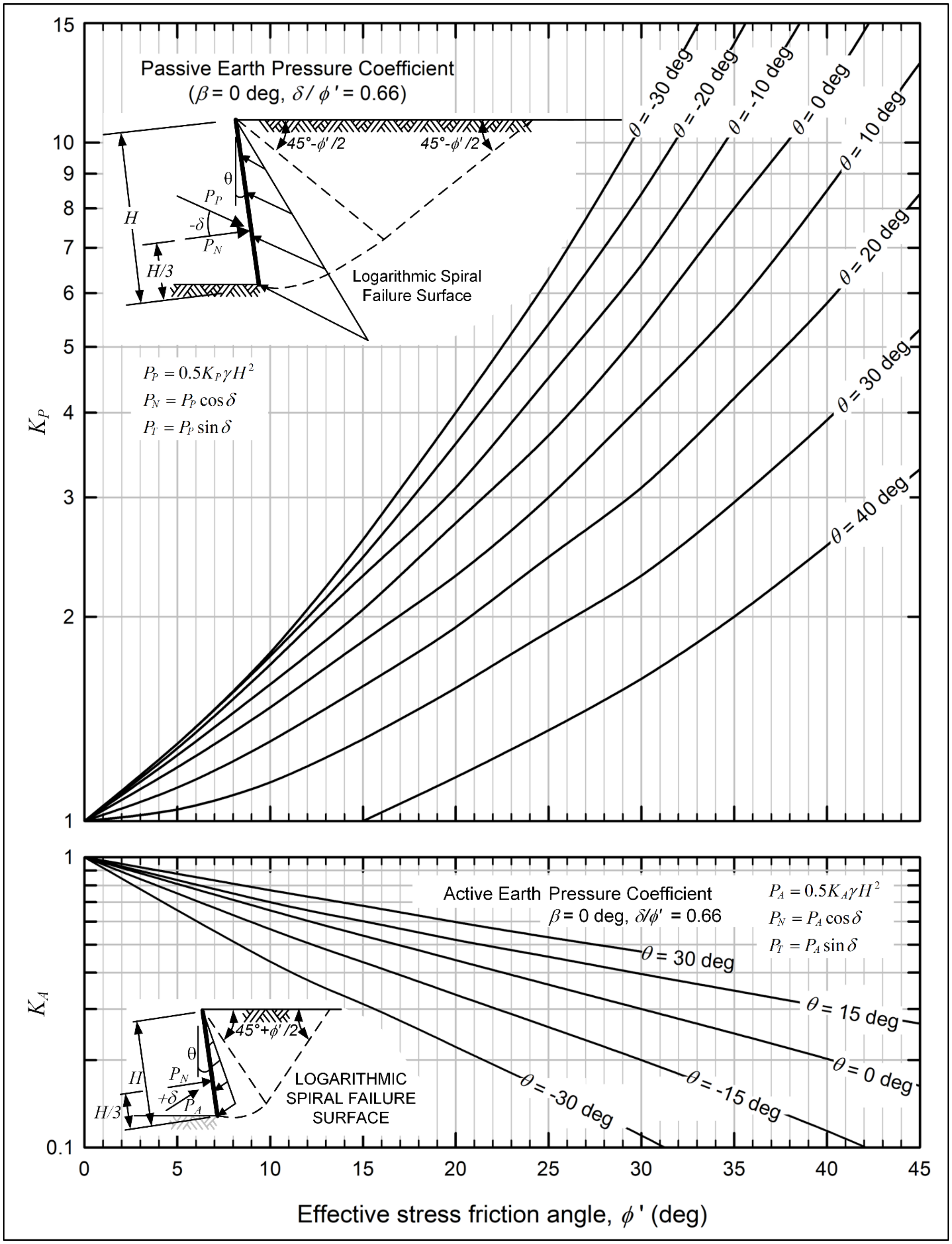


Figure 4-12 Values of K_A and K_P for the Log Spiral Method for a Sloping Wall with a Horizontal Backfill (after Kerisel and Absi 1990)

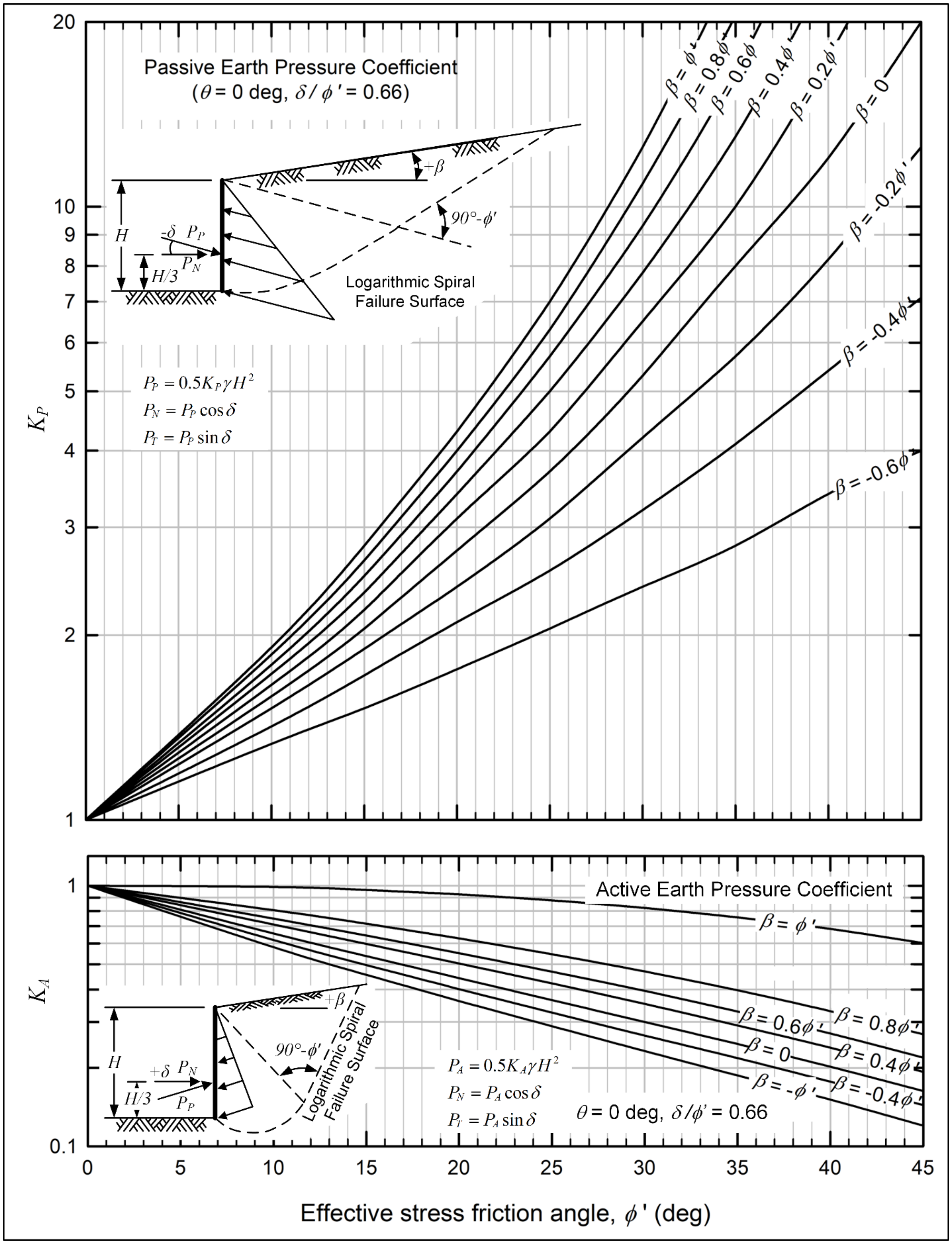


Figure 4-13 Values of K_A and K_P for the Log Spiral Method for a Vertical Wall with a Sloping Backfill (after Kerisel and Absi 1990)

As expected, Equation 4-12 results in the Rankine value of K_p if wall friction is neglected.

Table 4-2 compares K_A and K_P values calculated by the Rankine, Coulomb, and Log Spiral methods for a range of friction angles and δ / ϕ' values. Examining the active case, the method and wall friction have little effect on the predicted K_A. In most cases, the Rankine method is appropriate for active condtions without sloping wall or backfill. For the passive case, the earth pressure theory and wall friction have a large impact on the magnitude of the predicted K_P. The log spiral K_P can be in the range of two to five times higher than the Rankine value. This is especially important for the design of cut-type retaining walls, such as sheet pile and soldier pile, that rely on passive earth pressures for stability.

Table 4-2 Comparison of K_A and K_P Values for Earth Pressure Methods (β=θ=0°)

Friction Angle (deg)	δ / ϕ'	Active			Passive		
		Rankine	Coulomb	Log Spiral	Rankine	Coulomb	Log Spiral
30	0	0.33	0.33	0.33	3.00	3.0	3.0
	0.5	NA	0.30	0.3	NA	(6.1)	5.3
	1	NA	0.30	0.31	NA	(10)	6.5
35	0	0.27	0.27	0.27	3.69	3.7	3.7
	0.5	NA	0.24	0.25	NA	(9.8)	8.0
	1	NA	0.25	0.26	NA	(23)	10.5
40	0	0.22	0.22	0.22	4.60	4.6	4.6
	0.5	NA	0.20	0.2	NA	(18)	12
	1	NA	0.21	0.22	NA	(92)	18
45	0	0.17	0.17	0.17	5.83	5.8	5.8
	0.5	NA	0.16	0.16	NA	(44)	20
	1	NA	0.18	0.19	NA	(∞)	35

Note: Values in parentheses are unconservative applications of Coulomb theory and should not be used.

4-3.3 Presumptive Earth Pressure Coefficients and Equivalent Fluid Pressures.

The earth pressures theories presented within this section are based on the shear strength of the backfill material. Pressures imparted by water and other loads applied to the backfill will be discussed in Section 4-4. A few additional factors that may impact the loads applied to retaining structures are discussed below.

In particular, fine-grained soils can *creep*. There are many definitions for creep in the geotechnical literature, but the term usually refers to a time-dependent deformation of a soil at a constant effective stress. For structures constructed to retain fine-grained soils, the active earth loads applied to the structure can increase over time to values that significantly exceed the loads calculated by earth pressure theory. Similarly, passive earth loads may decrease over time in fine-grained soils. For this reason, presumptive earth pressure coefficients that empirically incorporate the effects of creep are often an appropriate alternative to values based on earth pressure theory.

In addition, the typical design and construction sequence imposes another practical constraint on the calculation of earth pressures and loads. Gravity retaining walls are often designed prior to the selection of a specific backfill material with well-defined properties (e.g., ϕ' and γ). In this case, presumptive earth pressure coefficients will be just as accurate as design based on assumed values of ϕ' and γ.

Presumptive values based on relative density and soil type are provided in Table 4-3 for both at-rest and yielding wall conditions. These values can be used to account for the effects of creep as well as the constraints of the design and construction process.

Table 4-3 Equivalent Fluid Unit Weights for At-Rest and Active Conditions for Horizontal and Sloping Backfills (after Kim et al. 1991)

Type of Soil	Level Backfill				Sloping Backfill (2H:1V)			
	At-Rest		Rotation Y/H = 1/240		At-Rest		Rotation Y/H = 1/240	
	γ_{eq} (pcf)	K_0	γ_{eq} (pcf)	K_A	γ_{eq} (pcf)	K_0	γ_{eq} (pcf)	K_A
Loose sand or gravel	55	0.45	40	0.35	65	0.55	50	0.45
Medium dense sand or gravel	50	0.40	35	0.25	60	0.50	45	0.35
Dense sand or gravel	45	0.35	30	0.20	55	0.45	40	0.30
Compacted silt (ML)	60	0.50	40	0.35	70	0.60	50	0.45
Compacted lean clay (CL)	70	0.60	45	0.40	80	0.70	55	0.50
Compacted fat clay (CH)	80	0.65	55	0.50	90	0.75	65	0.60

For the case of no backfill surcharge, the earth pressure applied to retaining structures has a triangular pressure distribution. For this reason, it is often convenient to use the *equivalent fluid unit weight*, γ_{eq}, to calculate earth pressures using the same methodology as for hydrostatic fluids. The equivalent fluid unit weight is found as:

$$\gamma_{eq} = \gamma \cdot K \qquad (4\text{-}13)$$

where:
γ = the unit weight of the backfill and
K = an appropriate earth pressure coefficient (at-rest or active).

Table 4-3 shows values of γ_{eq} for horizontal and sloped backfills for different backfill soil types. The effects of creep are reflected in the γ_{eq} values for the clay backfill materials. The choice of the value of the equivalent fluid unit weight should consider wall movement and the potential of the backfill soil to creep over time. Since equivalent fluid pressures are only an approximate method to calculate earth pressures, their use should be limited to walls that are less than 20 feet tall.

A uniform surface surcharge (discussed in more detail in Section 4-4.2) can also be considered using presumptive earth pressures. Using the appropriate values listed in

Table 4-3, the horizontal earth pressure at the bottom of the wall, σ_h, can be calculated as:

$$\sigma_h = \gamma_{eq} \cdot z + K \cdot q \tag{4-14}$$

where:
γ_{eq} = equivalent fluid unit weight,
z = depth below ground surface,
K = horizontal earth pressure coefficient, and
q = uniform surcharge pressure.

4-3.4 Earth Pressure Examples for Complex Geometries.

A more complex active pressure problem is shown in Figure 4-14. In this case, the surface of the backfill is uneven, and an irregular surcharge is present. Two different soil types are present, and the contact between these soils is not horizontal. The ground water table is not horizontal, which means it is a hydrodynamic case (e.g. water is flowing). Friction between the wall and backfill will be considered.

The type of problem shown in Figure 4-14 is too complicated for the Rankine method, and the Coulomb method must be used. In addition, the problem is too complex for the Coulomb charts (Figure 4-9 and Figure 4-10), and different trial failure surfaces must be analyzed by hand. The figure shows the FBDs and force polygons for two trial surfaces.

In this example, the moist unit weight should be used above the water table and the saturated unit weight should be used below the water table when calculating the weight of the wedge. The water pressure force, acting normal to the failure surface, must be calculated. Since two soil types are present, the active wedge is subdivided into two free bodies, with the vertical boundary between the free bodies defined by the location where the layer interface crosses the failure plane. The forces acting on the vertical boundary are assumed to be horizontal.

Figure 4-15 shows a passive pressure example with a cross-section very similar to Figure 4-14. Since wall friction is considered in this example, it would be unconservative to use the linear failure surface assumed by the Coulomb method. Ideally, the log spiral method would be used to solve this problem. However, in this example, a simpler procedure is adopted where the portion of the failure surface that would normally be represented by a log spiral has been replaced with a circular arc. Three free bodies are used in the example solution separated by two vertical boundaries. One boundary between the free bodies has been defined where the circular failure surface transitions into the linear failure surface. The second boundary is located where the interface between the two layers intersects the linear failure surface. The passive earth force for this example is determined by resolving the forces for the three force polygons. To determine the vertical location of the passive force on the wall, moments should be summed about the toe of the wall.

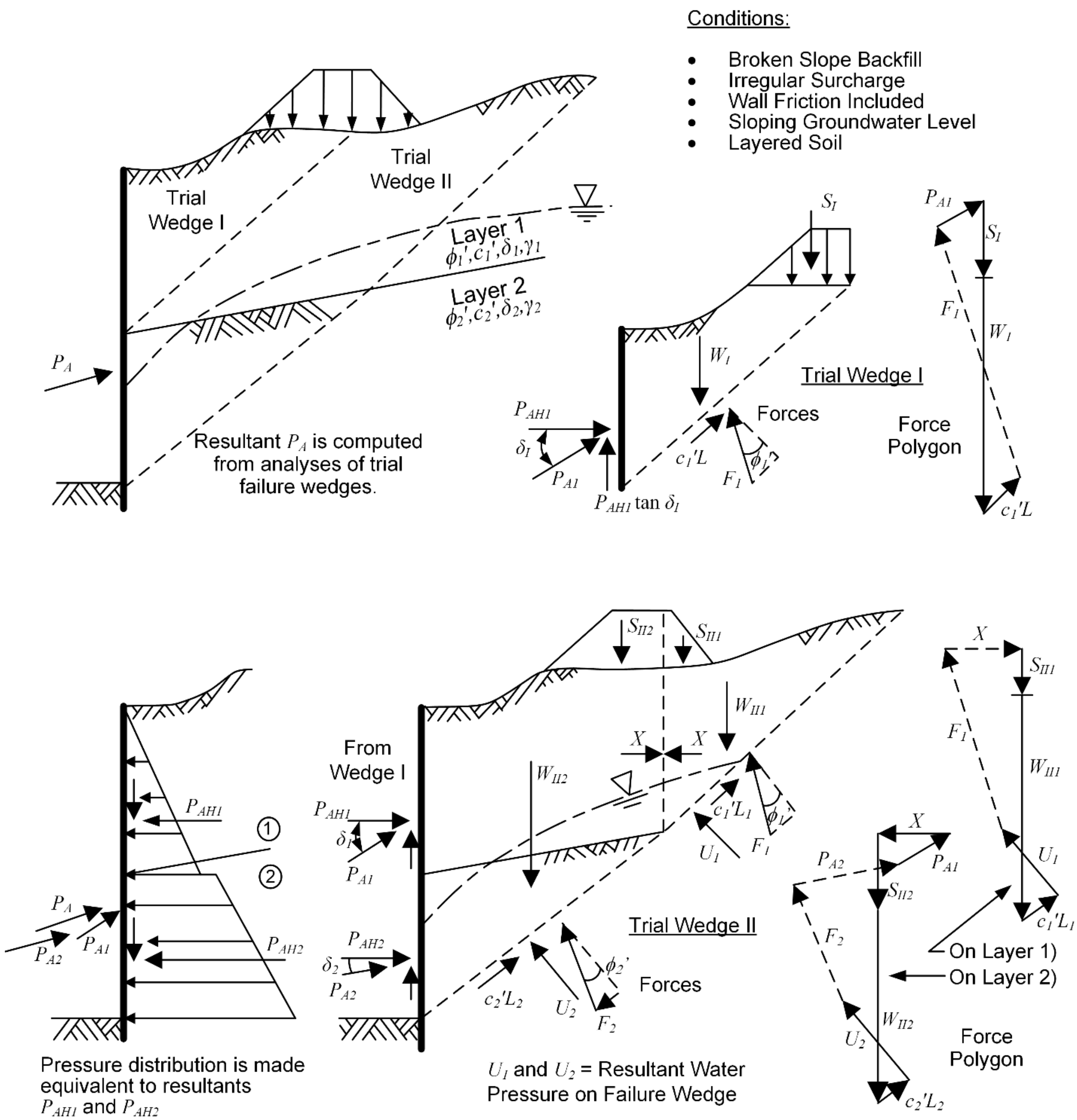


Figure 4-14 Coulomb Method Applied to a Complex Active Earth Pressure Case

For earth pressure problems that exhibit complex cross-sections, such as those in Figure 4-14 and Figure 4-15, other methods can be used to determine the passive earth pressure. Some limit equilibrium slope stability software can be employed to solve earth pressure problems, and these programs can easily accommodate different soil layering and nonhorizontal contact surfaces. However, the results from these programs should be carefully checked against hand calculations for simpler cross-sections to verify that the user is correctly using the computer software. Also, finite element and finite difference soil structure interaction software can be used to solve these types of problems, but considerable skill is required to obtain meaningful results.

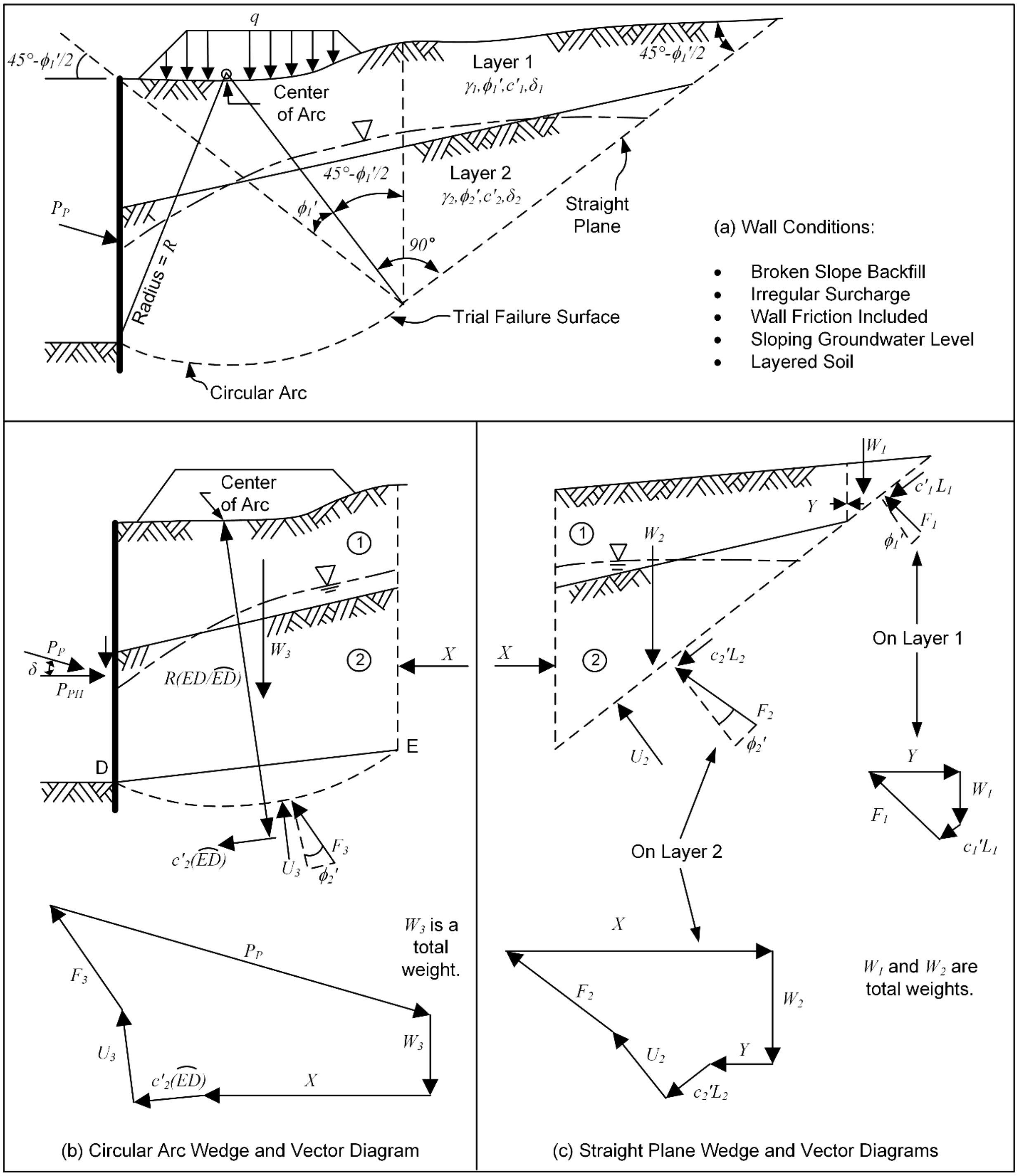


Figure 4-15 Passive Earth Pressure Calculations Similar to the Log-Spiral Method with a Circular Arc Replacing the Log Spiral Portion of the Failure Surface

4-3.5 Use of Slope Stability Software for Earth Pressures.

Many of the procedures outlined thus far in this manual use the limit equilibrium procedure to determine the forces acting on retaining structures. This is the same basic analysis technique used by most slope stability software. In the hands of an engineer skilled in its use, slope stability software can be used to find the earth forces acting on a retaining structure for complex site conditions. This approach can accommodate more scenarios than the equations and chart solutions normally used in engineering practice. Situations where slope stability software can be particularly useful are:

1) The shear strength of the backfill soil is more accurately represented by a nonlinear strength envelope as opposed to a linear failure envelope,
2) Hydrodynamic groundwater conditions (as opposed to hydrostatic conditions),
3) Layered soil stratigraphy,
4) Nonlinear failure surfaces in the backfill, and
5) Presence of tension cracks.

Slope stability software can be used for retaining wall analysis by applying the earth pressure force as a line load on the structure at the approximate vertical location. The trial slip surface can be forced to intersect a point at the heel of the wall. Next, the earth pressure force is varied until a factor of safety of unity is achieved. The slope stability method should solve all conditions of equilibrium, such as Spencer’s method or the Morgenstern and Price method.

Although the software manual may include examples of retaining wall analysis, the user should be confident in their abilities to do this sort of analysis prior to attempting a design. The results of simple example problems using log-spiral solutions should be compared to computer solutions before more complicated strength models and geometries are analyzed.

4-4 EARTH PRESSURES FROM OTHER SOURCES

4-4.1 Water Pressure Effects.

Water ponded on the interior of a retaining structure can apply substantial forces to the structure. Water applies a triangular pressure distribution equivalent to a soil with a unit weight of 62.4 pcf and an earth pressure coefficient of unity. The examples given in Figure 4-5 and Figure 4-6 show the net water pressure distribution when there are unequal water elevations on the front and back of the structure.

Because of the large pressures that water can apply to walls, significant efforts are required to prevent water from collecting behind retaining structures. Wall drainage systems are presented in Section 4-5.2. Although water behind a wall creates additional loading, there are many design cases where water loads on walls are unavoidable. Many walls used in waterfront structures have an elevated water level on the ground side compared to the water side. This is also often the case for lock structures on navigable rivers. Sometimes, the drainage system behind a wall can be overwhelmed by significant rainfall events, and the wall may experience potentially damaging, albeit temporary, water loads. Clogging of drainage systems can also lead to damaging water loads.

When the soil behind a wall becomes saturated, the pressure on the wall is controlled by two factors. First, the earth pressure is reduced since the effective stress is decreased. Instead of the total unit weight (γ), the buoyant or effective unit weight (γ_b) is used in the earth pressure equations for soils below the water table. The second effect is that an additional load, supplied by the water pressure, is applied to the wall. Figure 4-16(a) shows combined influence of these two effects. The consequence of an increasing water level is expressed as a ratio of the height of water (H_w) to the height of the wall (H). When $H_w = H$, the water level is at the ground surface. The relative increase in the pressure applied to the wall is quantified in the upper right inset as the ratio of the sum of the earth pressure and water pressure force divided by the earth pressure force for $H_w = H$. As the friction angle increases, this ratio increases.

Figure 4-16(b) shows an analysis case demonstrating the effects of a large rainfall event on the stability of a retaining wall that contains a drainage layer next to the wall. Even with the drainage system installed, a large rainfall event can still increase the pore pressure in the backfill. The flow net shows the head loss as a function of depth. For a potential failure plane, oriented at the angle α_A (measured from vertical), the pore pressure distribution can be calculated, and the resulting pore pressure force, U, can be determined. The middle inset shows the ratio of the pore pressure force to the force that would be applied for hydrostatic conditions for different failure plane angles. As the angle of the failure plane increases, the relative water pressure force also increases. The right inset shows the increase in the force applied to the wall, expressed as a ratio of the force calculated from both soil and water for the rainfall event to the active earth pressure force for the case of no water pressures. As the friction angle of the soil increases, this ratio also increases.

For waterfront and riverfront earth retaining structures, active seepage can be occurring, and this can compromise stability. Figure 4-16(c) shows a cantilever sheet pile wall installed in a coarse-grained soil. The water levels are higher on the landside of the wall than on the riverside; therefore, water flow is occurring from right to left. As shown on the figure, the active and passive earth and water pressures should first be calculated assuming conditions of “no flow.” Next, corrections to the active and passive pressures can be made to account for the seepage conditions. The correction factors depend on the ratio of the length of the sheeting ($H+D$) to the depth of embedment and the earth pressure coefficient. The development of the passive pressure occurs at a much greater wall displacement than the active pressure. For cantilever walls, which must include passive pressure, this can be accommodated by a reduction in the value of K_P used in the analysis. Cantilever sheet pile design is covered in more detail in Section 4-7.4.

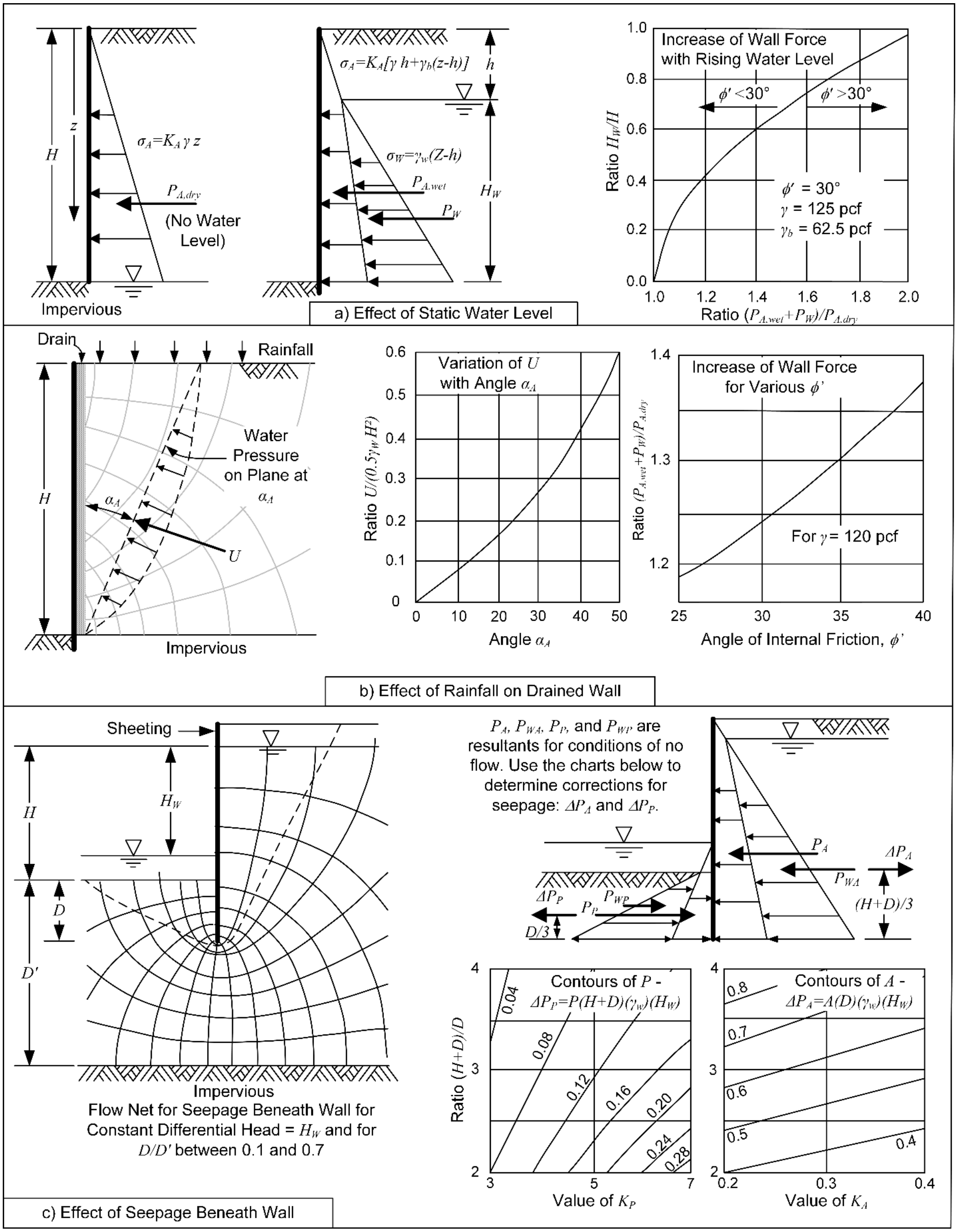


Figure 4-16 Effects of the Presence of Water on the Loads Applied to Walls for Cases of (a) Static Water Pressure, (b) Extreme Rainfall Events on Walls with Drainage Elements, and (c) Seepage Beneath a Cantilever Wall

In some analysis methods, the seepage forces exerted on the soils on both sides of the wall are accommodated. This is particularly an issue if hydrostatic water pressure conditions are assumed to exist when calculating the earth pressures. A simple means to do this involves modifying the unit weight of water based on the hydraulic gradient. On the side of the wall with the highest phreatic surface, the water flow is downward, and the unit weight of water is decreased resulting in higher earth pressures. On the opposite side of the wall, the unit weight of water is increased, resulting in lower earth pressures.

Water pressures can add an uplift force on the base of retaining walls which can be detrimental to the wall stability. These are discussed in the section on overall wall stability (Section 4-5).

4-4.2 Surface Loads Behind Retaining Structures.

Loads applied to the ground surface behind a retaining structure can impose a pressure distribution to the wall. The types of loads considered here are:

1) Surcharge loading (wide extent compared to wall),
2) Rectangular or surcharge loading over limited area,
3) Point loads,
4) Line loads parallel to wall, and
5) Line loads perpendicular to the wall.

Many of these solutions are based on elastic theory, which require the assumption that the wall is rigid and unyielding. This means that the same load would be applied for the active and passive earth pressure cases. The assumption of an unyielding wall would be conservative for the active earth pressure case but may be unconservative for the passive earth pressure case, depending on the specific application.

If the retaining structure is expected to yield or move sufficiently to develop active conditions, then 75% of the load calculated using the following methods can be used. This value will be approximately halfway between the pressures expected for yielding and unyielding walls, and thus, should still be conservative.

It is prudent to include surface loads on the backfill of retaining structures in urban construction since it may not be possible to determine future loads. Construction materials can sometimes be stockpiled on the ground surface near the top of walls, or loads applied by construction equipment may be present. Sometimes, building codes require a specified minimum distributed load be applied to the top of the retaining structure backfill for design calculations.

4-4.2.1 Surcharge Loading.

In many cases, loads behind retaining structures are idealized as a unifom surcharge or uniformly loaded (q) area with large extent compared to the wall size. A surcharge is relatively easy to accommodate in Rankine earth pressure theory because q can directly be added to the vertical effective stress term for all depths. In the Coulomb method, the increase in the weight of the soil wedge can be calculated by multiplying q by the horizontal length of the top boundary of the wedge.

4-4.2.2 Uniform Rectangular Surface Load.

The wall backfill may support a rectangular uniform load that extends a limited distance (L) along the wall and extends a distance (B) perpendicular to the wall. The additional horizontal stress applied to the wall at the corner of this load can be calculated using the influence factors in Figure 4-17. The surcharge load, q, is expressed in units of stress or pressure. The highest horizontal stress will be applied to the wall at the midpoint of the loaded area, corresponding to a load width of $L/2$. Because the chart determines the pressure at the corner of the loaded area, the principle of superposition (NAVFAC DM-7.1 Chapter 4) should be used to determine the horizontal stress at the midpoint.

For design purposes, it is common to consider a distributed surface load surcharge on the order of 300 psf to account for storage of construction materials and equipment. This surcharge is usually applied within a rather limited work area of about 20 feet to 30 feet from the wall and can also be used to account for concentrated loads from heavy equipment (concrete trucks, cranes, etc.) located more than about 20 feet away. If such equipment is anticipated within a few feet of the wall, it must be accounted for separately using the methods described in the following sections.

4-4.2.3 Point Load.

A point load on the backfill of a retaining structure might be the force applied by an outrigger of a crane or other similar condition where a force is applied over a small area. Sometimes, the loads caused by construction traffic are modeled assuming that the tire contact positions are point loads, and the principle of superposition is applied to calculate the load applied by all of the tires.

The modified elastic solution for the pressure distribution and the horizontal resultant force (P_H) from a point load (Q_p) is shown in Figure 4-18. Since a point load is limited in lateral extent, the force applied to the wall is greatest at the minimum perpendicular distance from the point load to the wall.

The individual curves shown on the influence chart are for different values of m, which is the distance to the load divided by the height of the wall. For values of $m \leq 0.4$, the solution is not closely dependent on m, and the same influence curve can be used for all values of $m \leq 0.4$. For values of $m > 0.4$, the proper influence curve should be used corresponding to the value of m.

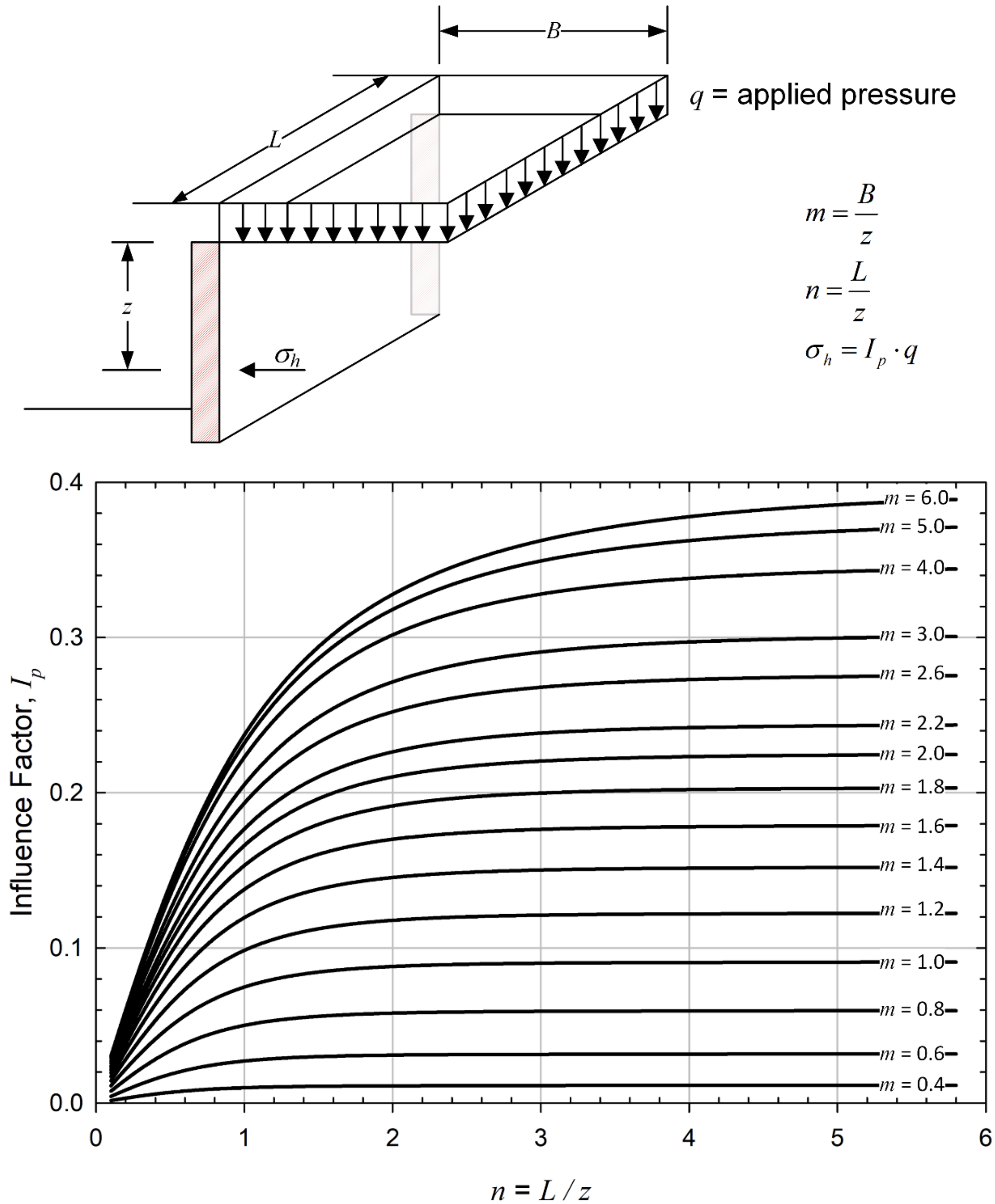


Figure 4-17 Lateral Pressure on an Unyielding Wall at the Corner of a Uniform Rectangular Surface Load

The value of the resultant force (P_H) can be estimated as a function of m from the inset table on the influence chart. The point of application of P_H, located a vertical distance (y) from the ground level on the front of the wall, can be calculated using the table for different values of m. The value of P_H is the maximum force per unit length of wall caused by Q_P, rather than the total horizontal load for the entire length of wall. Thus, P_H occurs at the point where θ is zero degrees.

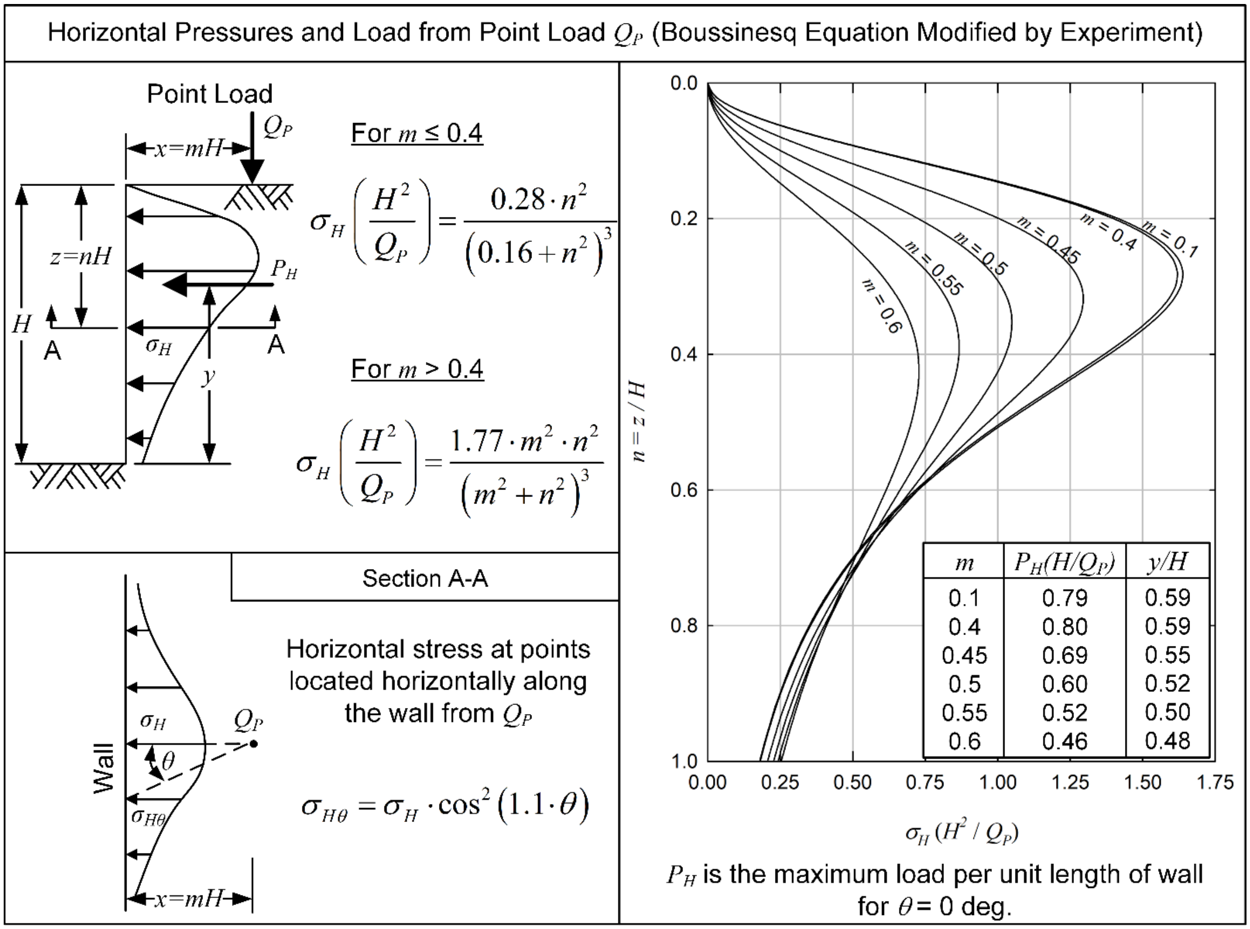


Figure 4-18 Horizontal Pressure and Resultant Force for a Single Point Load Applied at the Surface of the Backfill

The horizontal variation of pressure ($\sigma_{H\theta}$) can be calculated from the maximum pressure exerted by the point load (σ_H) for a given depth based on the angle (θ) between a horizontal line drawn from the point load to the wall and a line drawn from the point load to the point on the wall where $\sigma_{H\theta}$ is to be calculated.

4-4.2.4 Line Load Parallel to the Structure.

A line load on the backfill of a retaining structure can be used to represent a strip footing from a structure or other long, narrow loading. Line loads (Q_L) are considered to be as long as the retaining wall, and the loads are expressed as a force per distance. Since line loads are considered numerically to be of infinite length, the calculated pressures do not vary along the length of the retaining structure.

Similar to the equations for a point load, the influence factors do not vary considerably for values of $m \leq 0.4$, and the curve shown for $m = 0.4$ can be used for m values less than 0.4 as well. For values of m > 0.4, the influence value can read off of the chart if the correct value of m is available, or it can be calculated from the formula indicated in Figure 4-19.

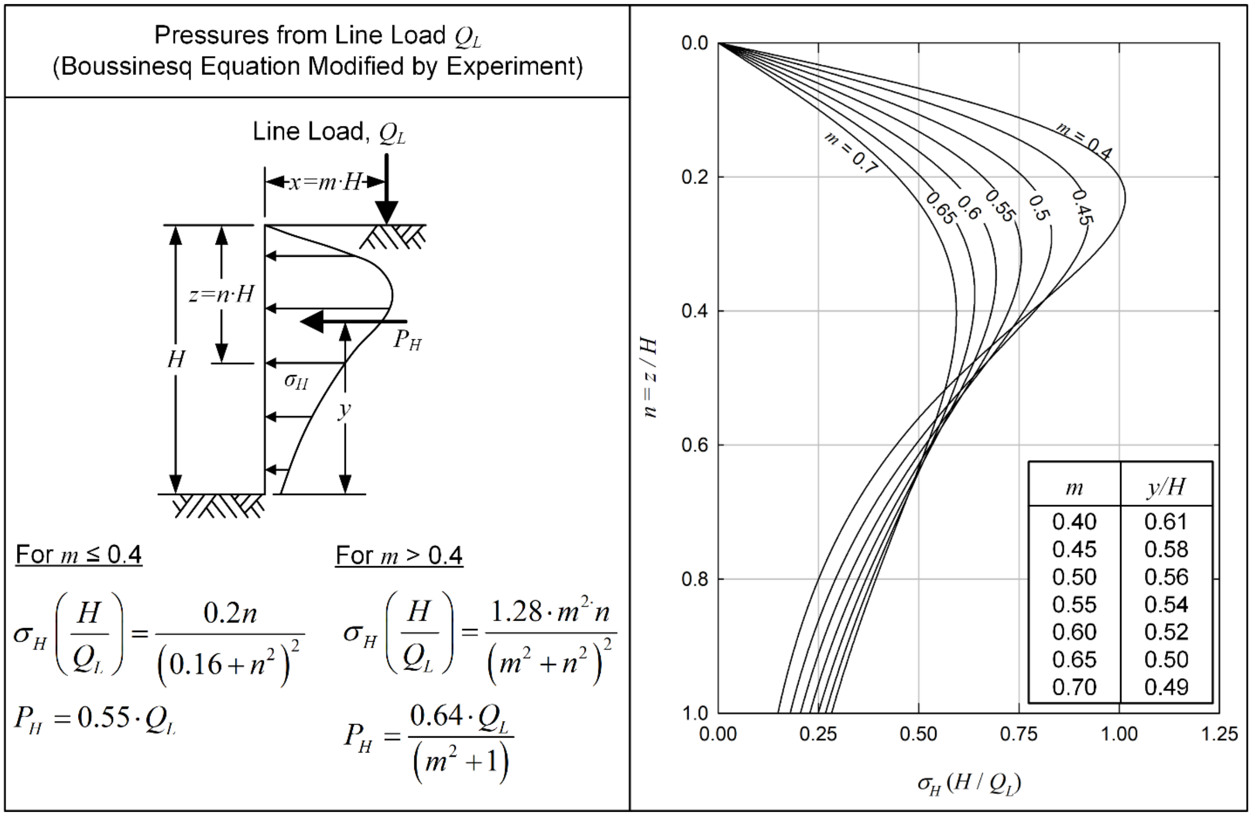


Figure 4-19 Horizontal Pressure and Resultant Force for Line Load Applied at the Surface of the Backfill Parallel to the Retaining Structure

4-4.2.5 Line Load Perpendicular to the Structure.

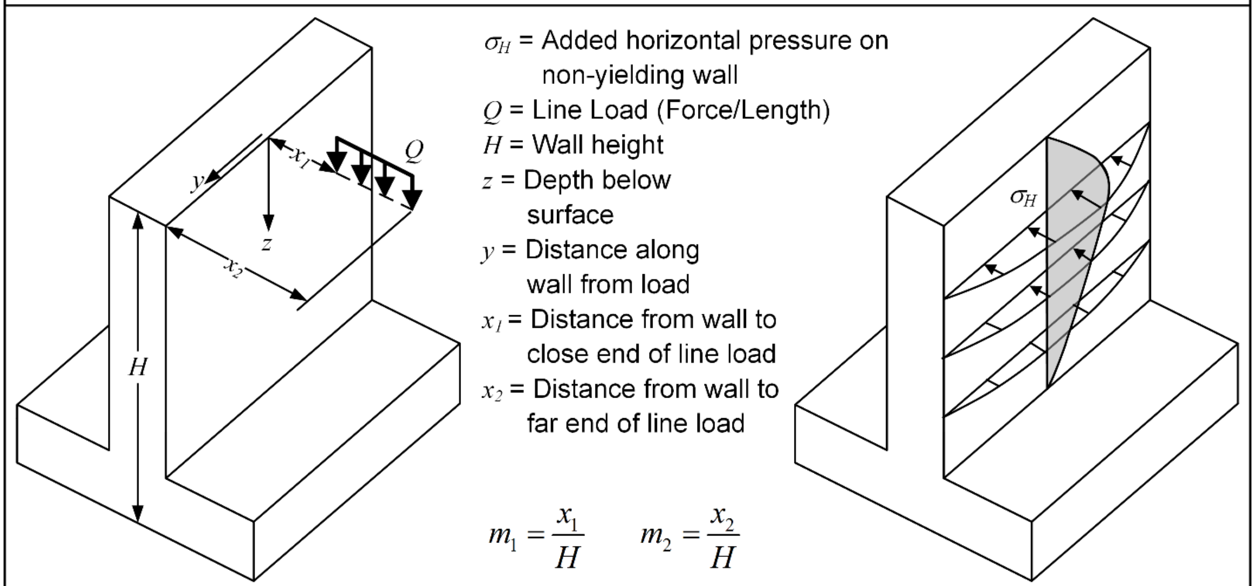
Figure 4-20 and Figure 4-21 show the geometry for a line load (Q) oriented perpendicular to the structure, expressed as a force per unit length. The maximum pressure is applied to the wall at the perpendicular intersection of the line load and the wall. The pressure decreases along the wall in each direction from this point.

Figure 4-20 shows the general form of the solution for a line load parallel to the wall along with the geometric definitions. Figure 4-21 provides influence factors for specific situations.

4-4.3 Earth Pressures Due to Compaction.

The operation of a compactor near a retaining structure can impose two types of loads on the wall. First, a transient load can be applied due to the weight of the compactor and the force applied at the ground surface. Second, horizontal stress can be “locked-in” due to the compaction process, and this increased pressure can remain after the compactor is removed.

Horizontal Stress from a Line Load Perpendicular to the Wall



$$m_1 = \frac{x_1}{H} \qquad m_2 = \frac{x_2}{H}$$

$$\sigma_H = \frac{Qz}{\pi}\left[\frac{x_2^3}{\left(y^2+z^2\right)\left(x_2^2+y^2+z^2\right)^{3/2}} - \frac{x_1^3}{\left(y^2+z^2\right)\left(x_1^2+y^2+z^2\right)^{3/2}}\right]$$

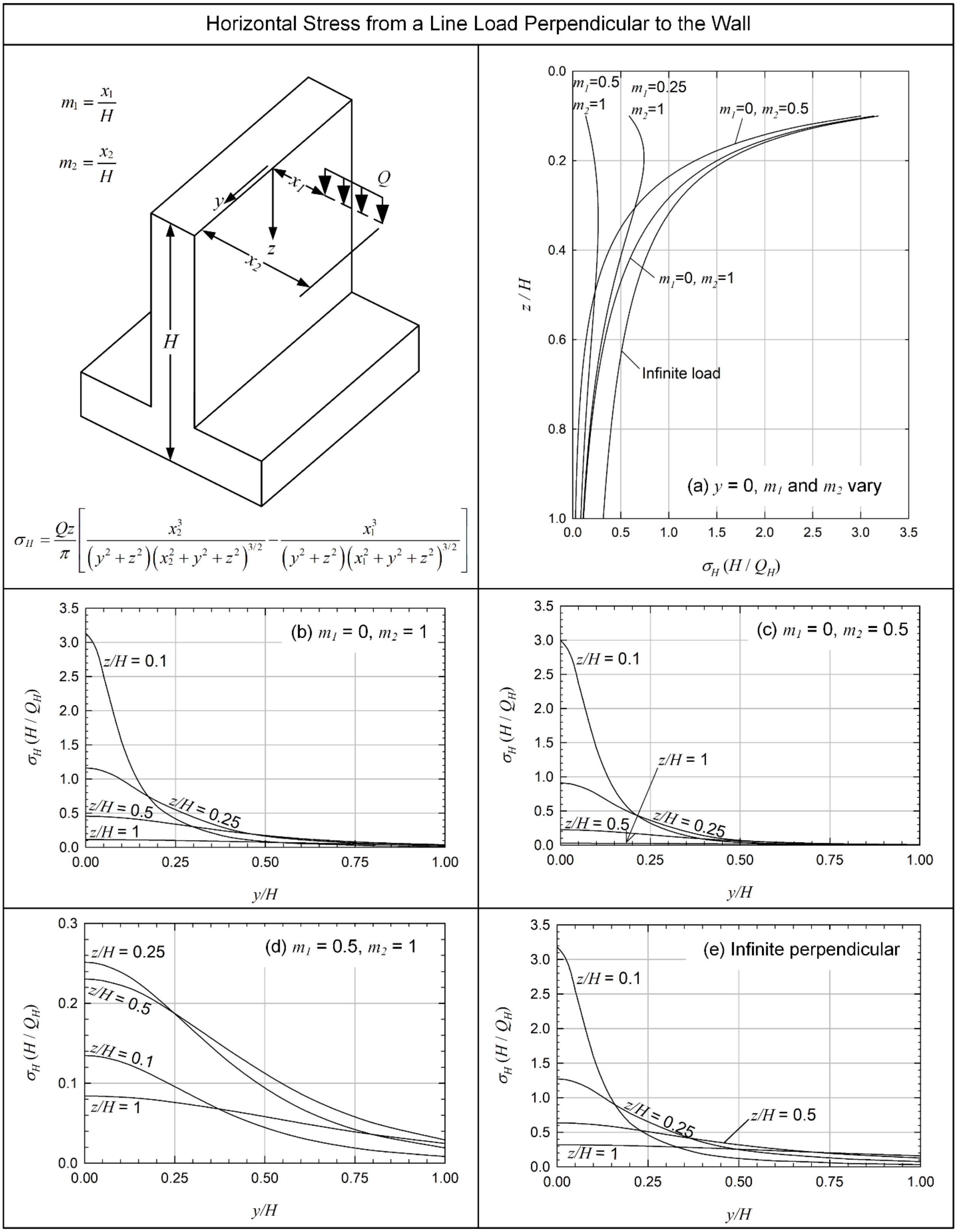
Figure 4-20 Horizontal Pressure from a Line Load Perpendicular to the Retaining Structure

The “locked-in” horizontal pressures from compaction can be calculated using tables and figures from Duncan et al. (1991).[22] In Figure 4-22 to Figure 4-24, the earth pressures due to compaction by rollers are shown by the solid and single-dashed lines. The at-rest earth pressures are shown for comparison using dash-dot lines. The charts were developed from experimental data on rollers, plate compactors, and rammer plates operating 0 to 0.5 feet from the wall. The lift thickness varied from 0.33 to 0.5 feet and the backfill material had a friction angle of 35 degrees. For compaction

[22] The discussions and closure to this paper contain important corrections that are reflected in the figures and tables included here.

conditions that vary from these assumptions, correction factors for the earth pressure are given in Table 4-4 to Table 4-6.

The force imparted by the specific compactor can be found by consulting the manufacturer's information. Duncan et al. (1991) summarized the compactor specifications for many small compactors at the time of publication of the paper. The specifications for current compactors should be checked prior to using these tables and figures.



$$\sigma_H = \frac{Qz}{\pi}\left[\frac{x_2^3}{\left(y^2+z^2\right)\left(x_2^2+y^2+z^2\right)^{3/2}} - \frac{x_1^3}{\left(y^2+z^2\right)\left(x_1^2+y^2+z^2\right)^{3/2}}\right]$$

Figure 4-21 Distribution of Horizontal Pressure from a Line Load Perpendicular to the Retaining Structure for Varying Load Geometries and Depths

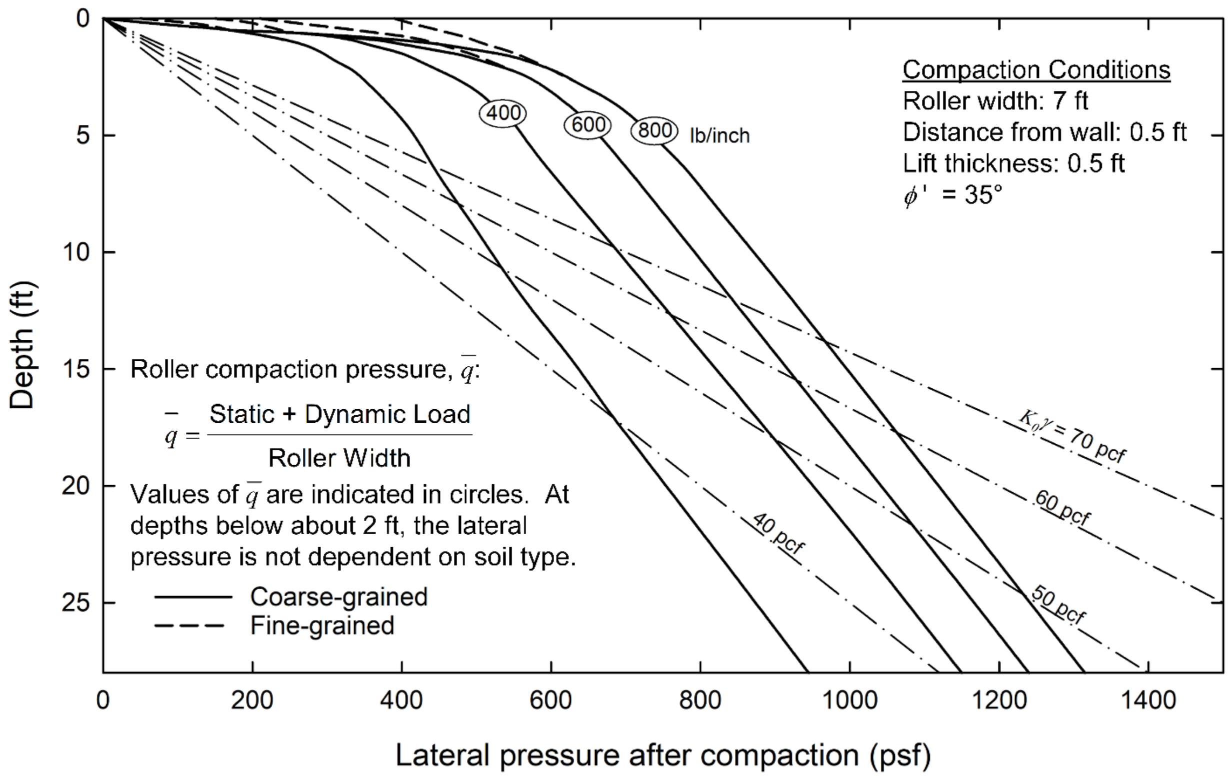


Figure 4-22 Earth Pressures Due to Compaction from Rollers (after Duncan et al. 1991)

Table 4-4 Adjustment Factors for Earth Pressures Induced by Compaction with Rollers (after Duncan et al. 1991)

Variables	**Multiplier factors for z =**			
	2 ft	4 ft	8 ft	16 ft
(a) Distance from Wall (x) and Lift Thickness (t). Adjustment factors are combined				
x = 0.0 ft, t = 0.5 ft	1.00	1.0	1.0	1.0
x = 0.2 ft, t = 0.5 ft	1.00	1.0	1.0	1.0
x = 0.5 ft, t = 0.5 ft	1.00	1.0	1.0	1.0
x = 1.0 ft, t = 0.5 ft	0.87	0.88	0.89	0.90
x = 0.0 ft, t = 1.0 ft	0.94	0.95	0.95	0.96
x = 0.2 ft, t = 1.0 ft	0.94	0.95	0.95	0.96
x = 0.5 ft, t = 1.0 ft	0.94	0.95	0.95	0.96
x = 1.0 ft, t = 1.0 ft	0.83	0.84	0.86	0.88
(b) Roller Width (w)				
w = 1.25 ft	0.80	0.80	0.80	0.88
w = 3.50 ft	0.96	0.94	0.94	0.97
w = 7.00 ft	1.00	1.00	1.00	1.00
w = 10.00 ft	1.00	1.01	1.02	1.04
(c) Friction angle (ϕ')				
ϕ' = 25°	0.59	0.70	0.81	0.96
ϕ' = 30°	0.75	0.83	0.89	0.98
ϕ' = 35°	1.00	1.00	1.00	1.00
ϕ' = 40°	1.23	1.16	1.10	1.03

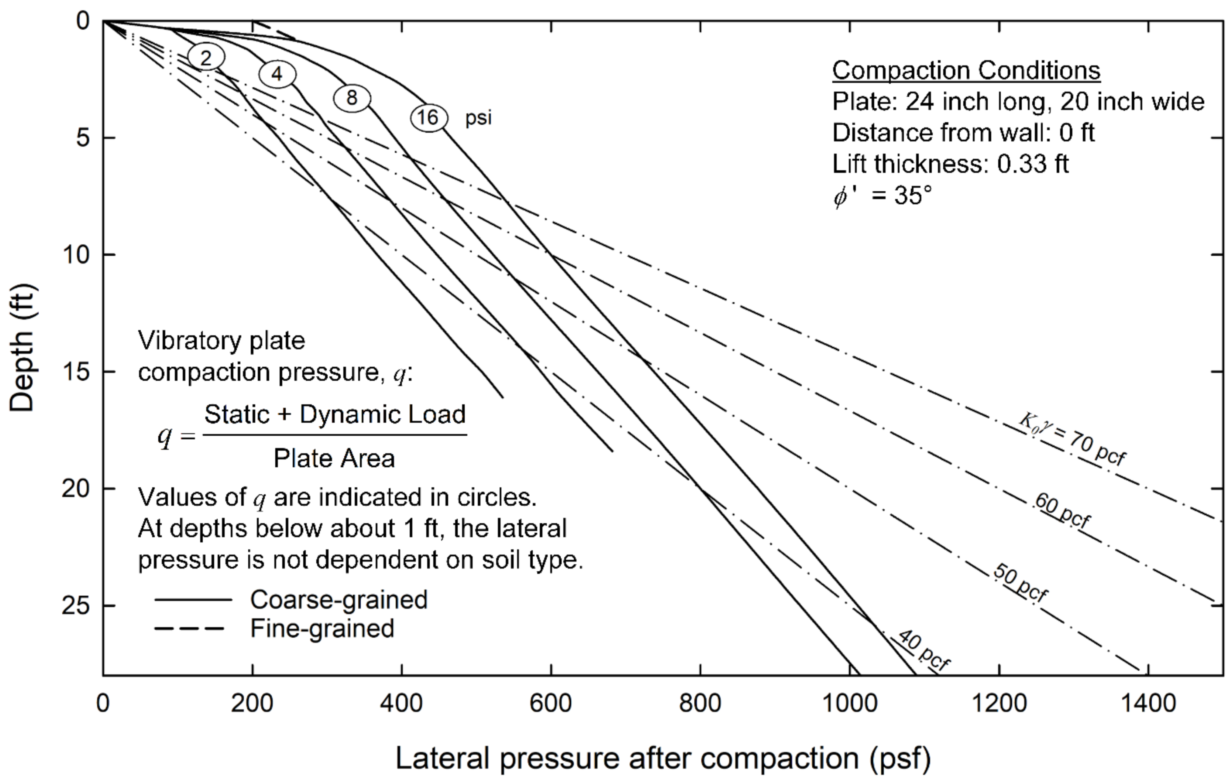


Figure 4-23 Earth Pressures due to Compaction by Vibratory Plates (after Duncan et al. 1991)

Table 4-5 Adjustment Factors for Earth Pressures Induced by Compaction with Vibratory Plates

Variables	**Multiplier factors for z =**			
	2 ft	4 ft	8 ft	16 ft
(a) Distance from Wall (x) and Lift Thickness (t). Adjustment factors are combined.				
x = 0.0 ft, t = 0.33 ft	1.00	1.00	1.00	1.00
x = 0.5 ft, t = 0.33 ft	0.85	0.88	0.88	0.90
x = 0.0 ft, t = 0.5 ft	0.87	0.88	0.91	0.95
x = 0.5 ft, t = 0.5 ft	0.75	0.75	0.88	0.99
(b) Area of Vibratory Plate				
Area = 240 sq. in.	0.85	0.85	0.90	0.95
Area = 480 sq. in.	1.00	1.00	1.00	1.00
Area = 960 sq. in.	1.12	1.15	1.11	1.07
(c) Friction angle (ϕ')				
ϕ' = 25°	0.70	0.82	0.96	1.00
ϕ' = 30°	0.82	0.89	0.98	1.00
ϕ' = 35°	1.00	1.00	1.00	1.00
ϕ' = 40°	1.15	1.08	1.01	1.00

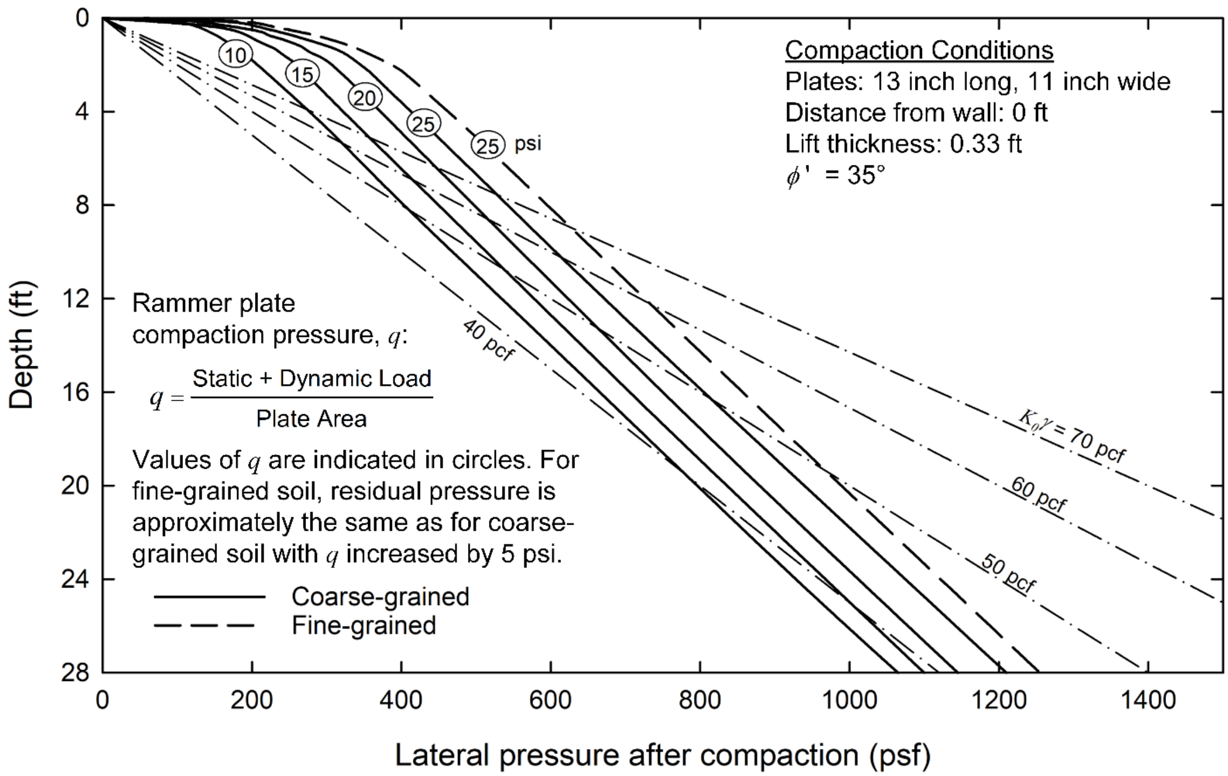


Figure 4-24 Earth Pressures due to Compaction by Rammer Plates (after Duncan et al. 1991)

Table 4-6 Adjustment Factors for Earth Pressures Induced by Compaction with Rammer Plates (after Duncan et al. 1991)

Variables	**Multiplier factors for z =**			
	2 ft	4 ft	8 ft	16 ft
(a) Distance from Wall (x) and Lift Thickness (t). Adjustment factors are combined.				
x = 0.0 ft, t = 0.33 ft	1.00	1.00	1.00	1.00
x = 0.5 ft, t = 0.33 ft	0.81	0.82	0.82	0.82
x = 0.0 ft, t = 0.5 ft	0.86	0.89	0.93	0.97
x = 0.5 ft, t = 0.5 ft	0.72	0.73	0.82	0.90
(b) Area of Rammer Plate				
Area = 72 sq in	0.82	0.86	0.92	0.98
Area = 144 sq in	1.00	1.00	1.00	1.00
Area = 288 sq in	1.18	1.17	1.10	1.05
(c) Friction angle (ϕ')				
ϕ' = 25°	0.68	0.79	0.92	1.00
ϕ' = 30°	0.79	0.87	0.95	1.00
ϕ' = 35°	1.00	1.00	1.00	1.00
ϕ' = 40°	1.18	1.12	1.05	1.00

4-4.4 Seismic Earth Pressures on Retaining Structures.

Earthquakes can increase the loading on retaining structures. In the past, waterfront structures have performed poorly under earthquake loading (FEMA 2009). The methods for calculating the effects of seismic loading are rapidly evolving. The procedures presented in this section are very basic and are based on the 2009 edition of the NEHRP *Recommended Seismic Provisions* (FEMA 2009). Earthquake assessment of retaining structure is an evolving topic, and the users of this manual are encouraged to seek out the most recent design guidance. Seismic effects are quantified in terms of the vertical ground acceleration (k_v) and horizontal ground acceleration (k_h), both in units of gravity.

Retaining structures are separated into two major categories: (1) yielding walls that are free to rotate or laterally translate, and (2) nonyielding walls, such as basement walls that are restrained on the top and bottom.

4-4.4.1 Yielding Walls.

The assessment of yielding walls is based on the Coulomb earth pressure theory presented earlier in this chapter. The wall movement is assumed to be sufficient to allow an active earth pressure condition to develop. The framework that has been adopted for analysis is the Mononobe-Okabe (M-O) seismic coefficient analysis (Mononobe and Matsuo 1929; Okabe 1924).

The seismic active earth pressure coefficient (K_{AE}) considers the normal factors in a Coulomb analysis (i.e., soil strength, backfill slope, interface friction angle, slope of wall face) and also the horizontal and vertical ground acceleration. K_{AE} can be calculated by:

$$K_{AE} = \frac{\cos^2(\phi' - \theta - \psi)}{\cos\psi \cdot \cos^2\theta \cdot \cos(\delta + \theta + \psi) \cdot \left[1 + \sqrt{\frac{\sin(\phi' + \delta) \cdot \sin(\phi' - \beta - \psi)}{\cos(\delta + \theta + \psi) \cdot \cos(\beta - \theta)}}\right]^2} \qquad (4\text{-}15)$$

where:
ϕ' = backfill soil friction angle,
β = slope of backfill,
θ = slope of wall back,
δ = interface friction angle between soil backfill and wall, and
$\psi = \tan^{-1}(k_h / (1 - k_v))$.

The basic equation for calculating the seismic earth pressure assumes that the backfill material is a cohesionless soil and that the phreatic surface is below the base of the wall.

With these assumptions, the seismic earth force is:

$$P_{AE} = \frac{\gamma H^2}{2}(1 - k_v)K_{AE} \tag{4-16}$$

where:
P_{AE} = active earth pressure force including seismic effects,
γ = unit weight of backfill soil,
H = wall height, and
K_{AE} = seismic active earth pressure coefficient.

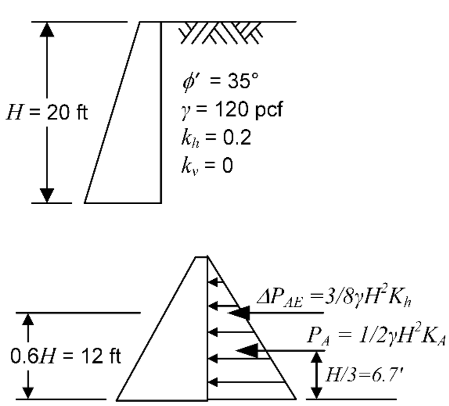
Seed and Whitman (1970) provide a simplified application of Equation 4-16 by separating the total applied earth pressure force (P_{AE}) into static (P_A) and dynamic (ΔP_{AE}) components. The static component is calculated as described in Section 4-3. For the case of a horizontal backfill, vertical wall face, and no wall friction, the dynamic component is calculated as:

$$\Delta P_{AE} = \frac{3}{8} \cdot k_h \cdot \gamma \cdot H^2 \tag{4-17}$$

where:
ΔP_{AE} = dynamic earth pressure force and
k_h = horizontal ground acceleration assumed equal to the maximum ground acceleration.

The dynamic component of the earth pressure force is assumed to act at $0.6H$ above the wall base. This simplified approach is limited to cases where the backfill is horizontal and the wall height is less than 20 feet. An example for calculating the static and dynamic forces acting on a wall is shown in Figure 4-25.

Example: Vertical Wall with Horizontal Backfill



Combined Effect of Static and Dynamic Force.

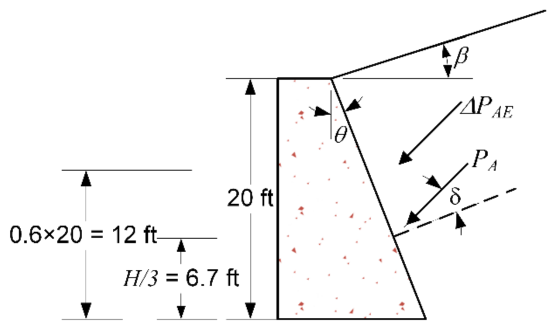
Force	Equations and Values	Resultant Location above Base of the Wall
P_A (Static)	K_A = 0.27 for ϕ' = 35° $P_A = 1/2\gamma H^2 K_A$ $P_A = 1/2(120)(20)^2(0.27)$ = 6480 lb	$H/3$ = 6.7 ft
ΔP_{AE} (Seismic)	$\Delta P_{AE} = 3/8\gamma H^2 k_h$ $\Delta P_{AE} = 3/8(120)(20)^2(0.2)$=3600 lb	$0.6H$ = 12 ft
P_{AE}	$P_{AE} = P_A + \Delta P_{AE}$ P_{AE} = 6480 + 3600 = 10,800 lb	8 ft
Resultant location of P_{AE} found by summing moments about toe.		

Figure 4-25 Application of the Simplified M-O Procedure for a Vertical Gravity Retaining Wall with a Horizontal Backfill

The M-O procedure can also be applied for conditions where the backfill is not horizontal and the wall has a batter. The combined active earth pressure force can be calculated using Equation 4-16. If separate values of the static and dynamic earth pressure forces are desired, the conventional static active earth pressure force, P_A, can be calculated using K_A determined from the values of β and θ. The dynamic component, ΔP_{AE}, can be calculated by subtracting P_A from P_{AE}.

The resultant force for this method can vary in its location depending on wall movement, ground acceleration, and wall batter. For practical purposes, it may be applied at 0.6H above the base of the wall. An example using the M-O method for a wall having a sloping backfill and face is shown in Figure 4-26.

Mononobe-Okabe Method – Sloping wall with sloping backfill



Soil Properties
ϕ' = 35 degrees
γ= 120 pcf
k_h = 0.2
k_v = 0.05

For a wall with θ of 10 degrees and a backslope of 15 degrees, find P_A, P_{AE}, and ΔP_{AE}. Assume the wall is smooth (δ = 0).

Horizontal acceleration angle: $\psi = \tan^{-1}\left(\frac{k_h}{1-k_v}\right) = \tan^{-1}\left(\frac{0.2}{1-0.05}\right) = 12°$

Determine earth pressure coefficient and forces:

Active earth pressure:
K_A from Figure 4-8
K_A = 0.41
K_{AE} from Equation 4-15

$$K_{AE} = \frac{\cos^2(35-10-12)}{\cos(12)\cos^2(10)\cos(22)\left[1+\sqrt{\frac{\sin(35)\sin(35-15-12)}{\cos(10+12)\cos(15-10)}}\right]^2} = 0.64$$

Static earth pressure force: $P_A = 0.5(0.41)(120\ pcf)(20\ ft)^2 = 9840\ lb/ft$

Earth pressure force with seismic effects: $P_{AE} = 0.5\cdot\gamma\cdot K_{AE}(1-k_v)H^2$

$$P_{AE} = 0.5\cdot(120\,pcf)\cdot(0.64)(1-0.05)(20\ ft)^2 = 14592\ lb/ft$$

Dynamic earth pressure force: $\Delta P_{AE} = 14592 - 9840 = 4752\ lb/ft$

Figure 4-26 Example of M-O Method for a Retaining Wall Having a Sloping Face and a Sloping Backfill

The M-O method should not be used for site conditions where there are high ground accelerations and complex soil backfill conditions. For more complex conditions, evaluation of ground motions is often required, and numerical methods assessing wall displacements are employed.

If the wall does not move or rotate sufficient to develop active pressure, the actual applied pressure can be much greater than the pressure calculated using the M-O method. If there is uncertainty about the ability of the wall to displace sufficiently, more advanced numerical methods are warranted. A simplified approach to calculate seismic pressures on nonyielding walls is presented in the next section.

4-4.4.2 Nonyielding Walls.

Walls that are unable to develop seismic active earth pressures are considered to be *nonyielding walls*. Basement walls are often used as a practical example of a nonyielding wall. Very rigid walls founded on rock can classify as nonyielding walls.

Wood (1973) developed a simplified approach to calculate an increase in the earth pressure force (ΔP_E) for nonyielding walls during seismic events. This force would be added to the existing static pressure to determine the total applied force. The earth pressure force can be calculated by:

$$\Delta P_E = k_h \cdot \gamma \cdot H^2 \tag{4-18}$$

The point of application of ΔP_E is normally assumed to be at 0.6H above the base of the wall. Other solutions for nonyielding walls include inertial effects and kinematic soil-structure interaction effects.

4-4.4.3 Dynamic Water Pressure.

Seismic loading also changes the water pressure applied to walls. The solutions presented below assume that the backfill is saturated. Methods for partially submerged conditions can be found in Kramer (1996) and Matsuzawa et al. (1985). Calculation approaches can be separated by the hydraulic conductivity of the soil.

4-4.4.3.1 High Hydraulic Conductivity Soils.

For soil with hydraulic conductivity greater than about 10^{-3} cm/s, the water in the voids will act independently of the soil and will impart a hydrodynamic water pressure (p_w) that can be calculated as:

$$p_w = 0.875 \cdot k_h \cdot \gamma_w \sqrt{H \cdot z} \tag{4-19}$$

where:
γ_w = unit weight of water,
z = depth below the phreatic surface, and
H = total depth of water behind the wall.

This equation can also be used to estimate the hydrodynamic pressure acting on a wall from an impounded reservoir.

The resultant force from the hydrodynamic water pressure is found as (Kramer 1996):

$$P_w = \frac{7}{12} k_h \cdot \gamma_w \cdot H^2 \qquad (4\text{-}20).$$

If the hydrodynamic water pressure is calculated in this manner, the seismic earth force should be calculated using the buoyant unit weight in Equation 4-16.

4-4.4.3.2 Low Hydraulic Conductivity Soils.

For soil with hydraulic conductivity less than about 10^{-3} cm/s, the water will tend to move with the soil, and a separate hydrodynamic water pressure is not required. However, the effect of increased pore pressures on stability must be considered (Kramer 1996).

The seismic earth pressure coefficient should be calculated using Equation 4-15 with:

$$\psi = \tan^{-1}\left[\frac{\gamma_{sat} k_h}{(\gamma_{sat} - \gamma_w)(1 - r_u)(1 - k_v)}\right] \qquad (4\text{-}21)$$

where:
γ_{sat} = saturated total unit weight of soil,
γ_w = unit weight of water,
k_h = horizontal ground acceleration (g),
k_v = vertical ground acceleration (g), and
r_u = pore pressure coefficient.

The seismic earth pressure force can be calculated using Equation 4-16 with an adjusted unit weight to account for seismically induced excess pore pressure is:

$$\gamma = (\gamma_{sat} - \gamma_w)(1 - r_u) \qquad (4\text{-}22)$$

where:
γ_{sat} = saturated total unit weight of soil,
γ_w = unit weight of water, and
r_u = pore pressure coefficient.

4-5 RIGID GRAVITY RETAINING STRUCTURES.

The preceding sections provide the theories for calculating earth and water pressures on retaining structures. A key element in the development of earth pressures is the wall movement or displacement. For design, retaining structures are divided into two basic categories: (1) rigid gravity structures and (2) flexible structures. Alternative forms of gravity structure are presented in Section 4-6. The design of flexible walls is discussed in Section 4-7.

Rigid retaining walls are structures that displace (translation or rotation) monolithically, and for the most part, they develop their lateral resistance from their own weight and the weight of overlying soil. The construction process for rigid walls typically involves construction of the wall followed by the placement of backfill. Examples of rigid retaining structures are concrete gravity walls, concrete cantilever walls, counterfort walls, buttress walls, and gabion walls. The design of rigid retaining structures is discussed in this section.

4-5.1 Design Calculations for Rigid Retaining Walls.

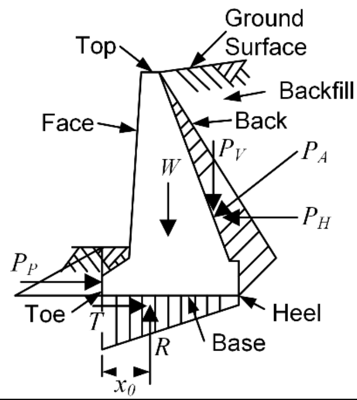
Examples of four rigid retaining walls are shown in Figure 4-27. The pressures acting on the face of rigid walls follow the theory, presented earlier in this chapter, that depends on the displacement or rotation of the wall. Once the earth and water pressures are determined, the forces and pressures acting on the other parts of the wall are assessed so that an entire free-body diagram can be constructed. With a knowledge of the FBD, a variety of modes of failure can be assessed. Figure 4-27 summarizes the calculations for the following modes of failure:

1) Overturning,
2) Sliding,
3) Bearing capacity and settlement, and
4) Global or overall stability.

Passive forces are indicated above the toe of the retaining walls in Figure 4-27. However, the passive pressure on the front of the wall is typically ignored when assessing the stability. As shown in Figure 4-1, there is a marked difference in displacement required for developing passive pressure as compared to active pressure. By the time that full passive pressure has been developed, the wall displacement would be too great for the performance to be considered satisfactory. Also, the soil in front of the wall might be excavated at a later date, so relying on passive pressure often is not warranted.

4-5.1.1 Pressure Distribution at the Base of Walls.

The pressure distribution acting on the base of retaining walls impacts the stability assessment for different failure modes. Using the equations for force equilibrium, the magnitude of the resultant normal force (R) and the shear force (T) can be determined. The location of R can be determined from moment equilibrium about the toe of the wall. The distance that R acts from the centerline or midpoint of the base of the wall is defined as the *eccentricity*, e. Figure 4-27 provides the method for calculating the resultant location and eccentricity.

<table>
<tr><th>Type of Wall</th><th>Load Diagram</th><th>Design Calculations</th></tr>
<tr><td>Gravity</td><td>
</td><td rowspan="4">Location of Resultant
Moment Arm about Toe:
$x_0 = (W \cdot a - P_v \cdot f - P_H \cdot b)/(W + P_v)$
assuming P_P = 0.
Eccentricity can be calculated from x_0 as:
$e = B/2 - x_0$

Overturning
Moment about toe:
$F_{OT} = (W \cdot a)/(P_H \cdot b - P_V \cdot f) \geq 1.5$
Design is safe for overturning if R within middle third for soil or middle half for rock. Check R at different horizontal planes for gravity walls.

Resistance Against Sliding
The resisting force at the base of the wall, T, is:
$T = (W + P_V)\tan\delta + C_a \cdot B_e$
where:
C_a = Adhesion between soil and base
$\tan\delta$ = friction factor between soil and base
W = weight of wall
Weight includes soil in front of gravity and semigravity walls and includes weight of soil above footing for cantilever and counterfort walls. For coefficients of friction between base and soil see Table 4-1.
The factor of safety against sliding is calculated as:
$F_{SL} = T/P_H \geq 1.5$
If passive pressure is considered:
$F_{SL} = (T + P_P)/P_H \geq 2.0$
Contact Pressure on Foundation
For allowable bearing pressure for inclined load on strip foundation, see Section 5-3.3.

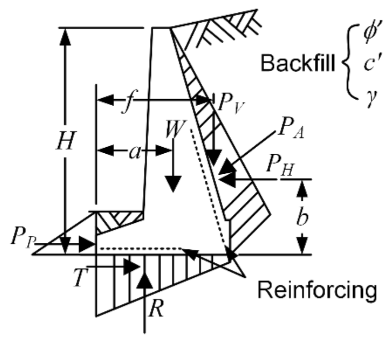
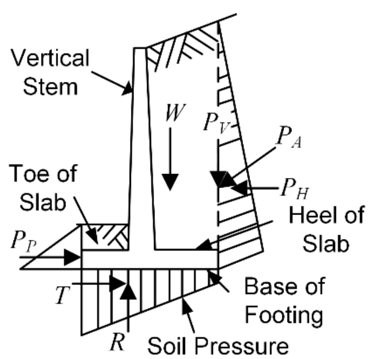
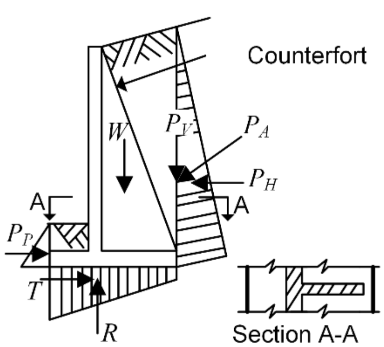
Settlement and Overall (Global) Stability
For analysis of settlement and overall stability, see Chapters 5 and 7 of DM 7.1.
*Variables defined on diagrams.</td></tr>
<tr><td>Semigravity</td><td>
</td></tr>
<tr><td>Cantilever</td><td>
</td></tr>
<tr><td>Counterfort</td><td>
</td></tr>
</table>

Figure 4-27 Analysis Methods for Stability Assessment of Gravity Retaining Walls

Knowledge of the magnitude and position of R allows the pressure distribution on the bottom of the wall to be calculated. Theoretically, the shape of pressure distribution is either triangular or trapezoidal as shown in Figure 4-28. If the resultant acts precisely at the one-third point of the base, a triangular pressure distribution results, with the full base of the wall under compression. If the resultant acts within the middle third of the base, a trapezoidal distribution results, and the maximum pressure, q_{max}, acting at the toe is:

$$q_{\max} = \frac{R}{B} + \frac{6Re}{B^2} \qquad (4\text{-}23).$$

The resultant of the pressure distribution acts at the centroid of the pressure diagram. The minimum pressure, q_{min}, acting on the heel side of the trapezoidal pressure distribution that provides the correct location of the resultant (R) can be calculated by:

$$q_{\min} = \frac{R}{B} - \frac{6Re}{B^2} \qquad (4\text{-}24).$$

If the resultant is located outside of the middle third of the base, the maximum stress can be calculated by:

$$q_{\max} = \frac{2R}{3x_0} \qquad (4\text{-}25)$$

where:
$x_0 = B/2 - e$ = horizontal distance between R and the toe.

When the resultant is outside of the middle third of the base, only a portion of the base is under compression. The amount of base under compression, B_e, can be calculated by:

$$B_e = 3x_0 \qquad (4\text{-}26).$$

As shown at the bottom of Figure 4-28, the pressure distribution can be simplified by assuming that the pressure acts uniformly over a width of $2 \cdot x_0$. If the pressure distribution is assumed to be uniform, its magnitude is:

$$q_{\max} = \frac{R}{2x_0} \qquad (4\text{-}27).$$

For the simplified uniform distribution of pressure, the amount of the base that is under compression is:

$$B_e = 2x_0 \qquad (4\text{-}28).$$

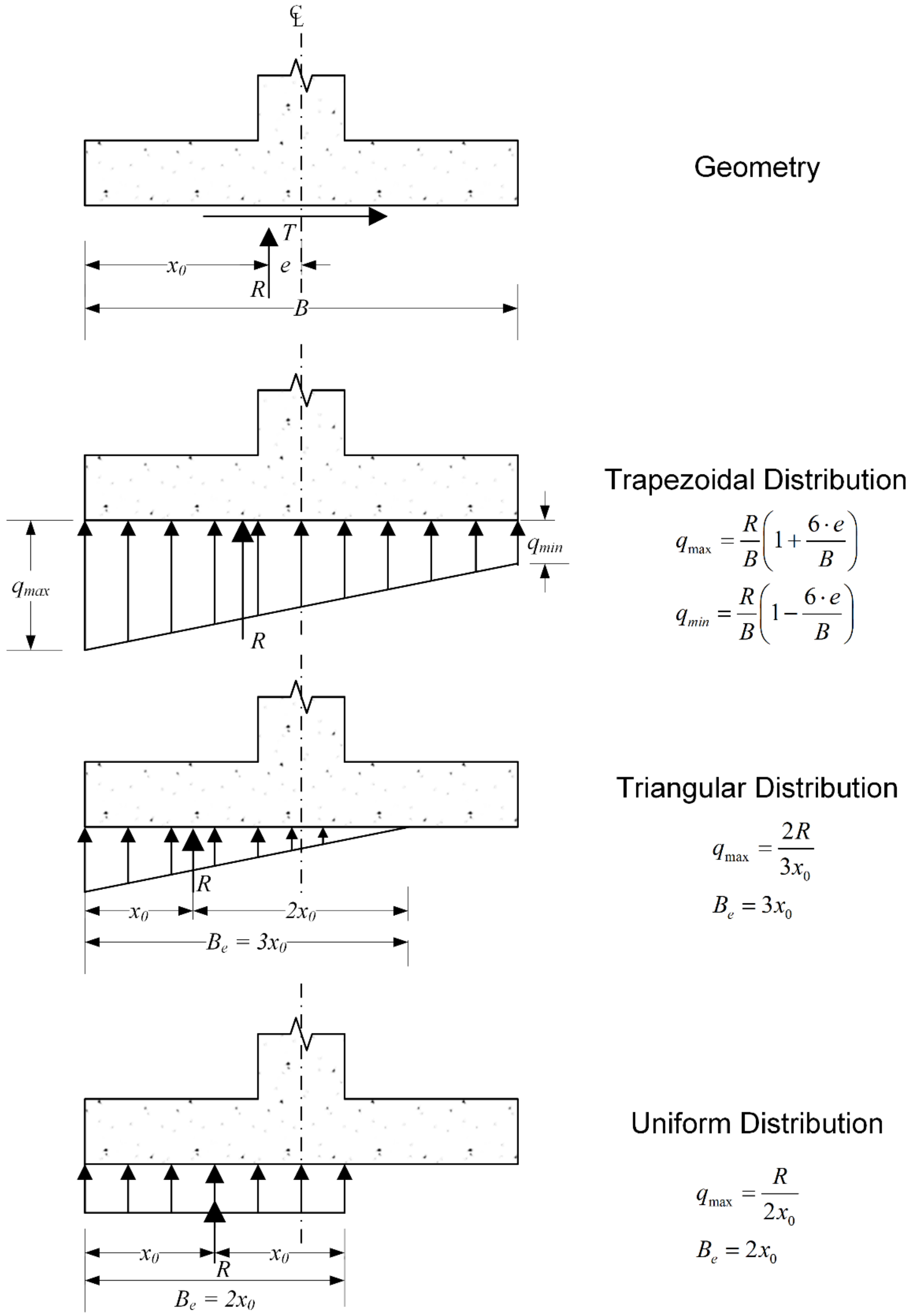


Figure 4-28 Pressure Distributions at the Base of Rigid Retaining Walls (after Kim et al. 1991)

4-5.1.2 Overturning.

The stability of the wall for the failure mode of overturning can be determined by defining a factor of safety equal to the restoring moment divided by the overturning moment. The factor of safety, F_{OT}, should be greater than or equal to 1.5.

An alternative method is to examine the location of the resultant, R, relative to the width of the base of the wall. If R is in the middle one-third of the base for walls founded on soil, the wall is considered safe. For walls founded on rock, R should be located in the middle one-half of the base for the wall to be considered safe.[23]

4-5.1.3 Sliding.

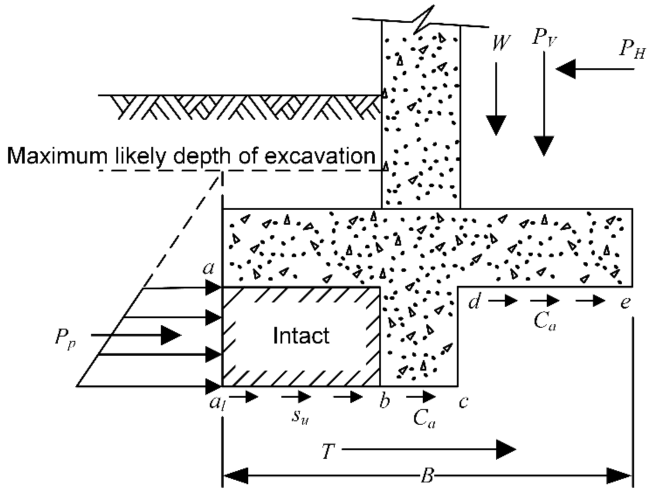
The stability of the wall for the failure mode of sliding is normally determined by using horizontal force equilibrium. The factor of safety against sliding, F_{SL}, is the ratio of the resisting force to the horizontal earth pressure force. The resisting force is a combination of the frictional resistance at the base of the wall and the adhesion between the base of the wall and the soil foundation. For sliding resistance on fine-grained soils, the adhesion should be multiplied by the effective width of the base (B_e) found using the uniform bearing pressure method. The factor of safety should be greater than or equal to 1.5. The parameters used to calculate F_{SL} are shown on Figure 4-27. If passive resistance is included, the minimum F_{SL} should be increased to 2.0. Minimum F_{SL} may also need to be increased when base adhesion is included in the resistance.

In some cases, a layer of coarse-grained soil may be placed below the wall as a bearing material. Sliding should be checked at two locations. The shear resistance, T, should be taken as the lowest of (1) the resistance at the interface between the base of the wall and the bearing material and (2) the resistance within the clay using the full undrained shear strength.

If stability against sliding is an issue, gravity retaining walls can be designed with a *key* to increase the sliding resistance by adding a passive resistance component. Figure 4-29 shows an outline of the analysis method to accommodate a wall base with a key. Note that the passive pressure is applied only along the depth of the key and not along the entire burial depth of the wall. It is also prudent to consider some amount of future excavation in front of the wall that would reduce passive resistance.

---

[23] If LFRD techniques are used for design, there are wider thresholds for the location of the resultant force if factored loads are used.



Resistance Against Sliding on Keyed Foundations

Undrained: $T = C_a \cdot \left(B_e - \overline{a_1 b}\right) + s_u \cdot \overline{a_1 b} + P_p$

Drained: $T = \left(W + P_V\right) \tan \delta + P_p$

Factor of Safety Against Sliding, F_{SL}

$$F_{SL} = \frac{T}{P_H}$$

where:
P_p = Passive resistance
P_V = Vertical earth force
P_H = Horizontal earth force
s_u = Undrained shear strength of foundation soil
C_a = Adhesion for cohesive soil and concrete
δ = Interface friction angle for granular soil & concrete
Note: Values of C_a and δ are given in Table 4-1.

Figure 4-29 Analysis Method for Gravity Retaining Wall Base with a Key

4-5.1.4 Bearing Capacity and Settlement.

The bearing capacity of the soil below a retaining wall is calculated by assuming the wall acts as a conventional strip footing with eccentric, inclined loading, which is discussed in Chapter 5. The depth of embedment is equal to the depth on the toe side of the wall.

The bearing capacity should be compared to the maximum bearing pressure calculated as shown in Figure 4-28. A factor of safety of 2.5 to 3 is typically appropriate. A uniform pressure distribution can be used to determine q_{max} if the soil below the wall is relatively ductile. For more brittle materials, such as rock and sensitive clays, the triangular or trapezoidal pressure distribution should be used to find q_{max}. Because load inclination affects bearing capacity, the factor of safety against bearing capacity failure and sliding are often closely related.

Settlement of retaining walls can be an important factor in overall stability. For the examples shown in Figure 4-27, the backfill places a downward pressure on the retaining wall. This pressure increases the contact stress at the base of the wall, thus increasing the sliding resistance. If the wall settles considerably more than the backfill, then the relative movement between the wall and backfill can be reversed, and the vertical pressure can act up instead of down. This is a destabilizing force on the wall since it decreases the resistance to sliding.

Settlement analyses can be performed using the procedures outlined in Chapter 5 of DM 7.1. Settlement should consider net changes in stress by comparing the conditions before and after the wall was constructed.

4-5.1.5 Overall or Global Stability.

Overall or global stability is assessed using the same tools employed for slope stability analysis. This mechanism of failure considers slip surfaces that extend from the back of the wall to the front of the wall, and the slide mass contains the wall and backfill. Slope stability is discussed in Chapter 7 of DM 7.1.

4-5.1.6 Design of Low Walls.

For low retaining walls (less than 12 feet tall), the retaining wall loads can be calculated based on equivalent fluid pressures, provided the consequences of failure are not significant. Figure 4-30 provides a method for determining the loads on low retaining walls for three different soil categories based on the Unified Soil Classification System. This method accommodates a *broken* backslope, in which the backslope levels are relatively close to the wall. The equivalent fluid unit weights can be used to calculate horizontal and vertical forces applied to the wall.

Figure 4-30 is based on equivalent fluid pressures associated with the different soil types listed above, and similar charts are found in several geotechnical textbooks. However, the specific details on how these charts were created are unclear. If these charts are used, it is prudent to check the results using other methods.

4-5.2 Drainage Behind Rigid Walls.

Water should not be allowed to pond behind retaining structures or within the backfill, if at all possible. The presence of a phreatic surface in the wall backfill decreases the effective stress in the soil, so the earth pressure is reduced. However, as discussed in Section 4-4.1, the water itself applies a pressure to the wall, and the net result is that lateral forces on the wall are increased. Many failures of retaining structures are due to unanticipated or unmitigated water pressures.

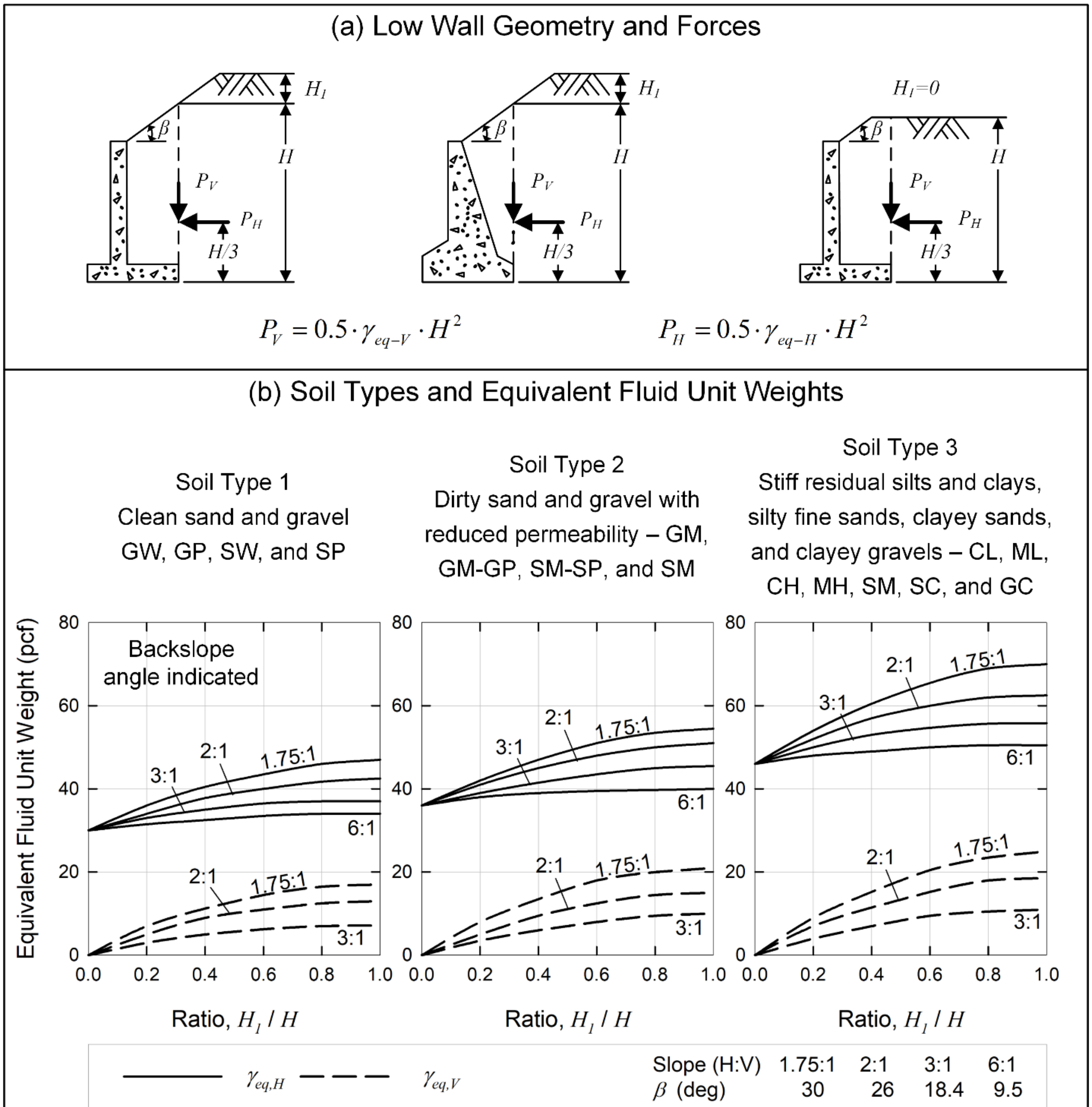
Drainage systems should be incorporated into the design of retaining structures if there is a potential for water pressures to act on the wall. The drainage system design should satisfy several criteria:

1) An elevated water table should not be present behind the wall, even in the case of large rainfall events.

2) Any water that finds its way to the backfill should be safely conveyed away from the wall. The water should be drained laterally down the wall to a safe exit or through weep holes in the face of the wall.

3) The drainage system should not allow erosion of the backfill materials or migrations of fines within the backfill. This may require the use of a graded filter or geosynthetic filter fabric.

Examples of drainage and filter systems that can be incorporated into rigid wall design are shown in Figure 4-31.



Similar charts of equivalent fluid unit weights based on soil type are found in several geotechnical textbooks. However, the specific basis of these charts is unclear. The higher uncertainty associated with these values of γ_{eq} may warrant the use of higher factors of safety. Do not use for walls higher than 12 ft.

Figure 4-30 Low (<12 ft Tall) Retaining Walls – (a) Geometry and Forces and (b) Equivalent Fluid Unit Weights by Soil Type

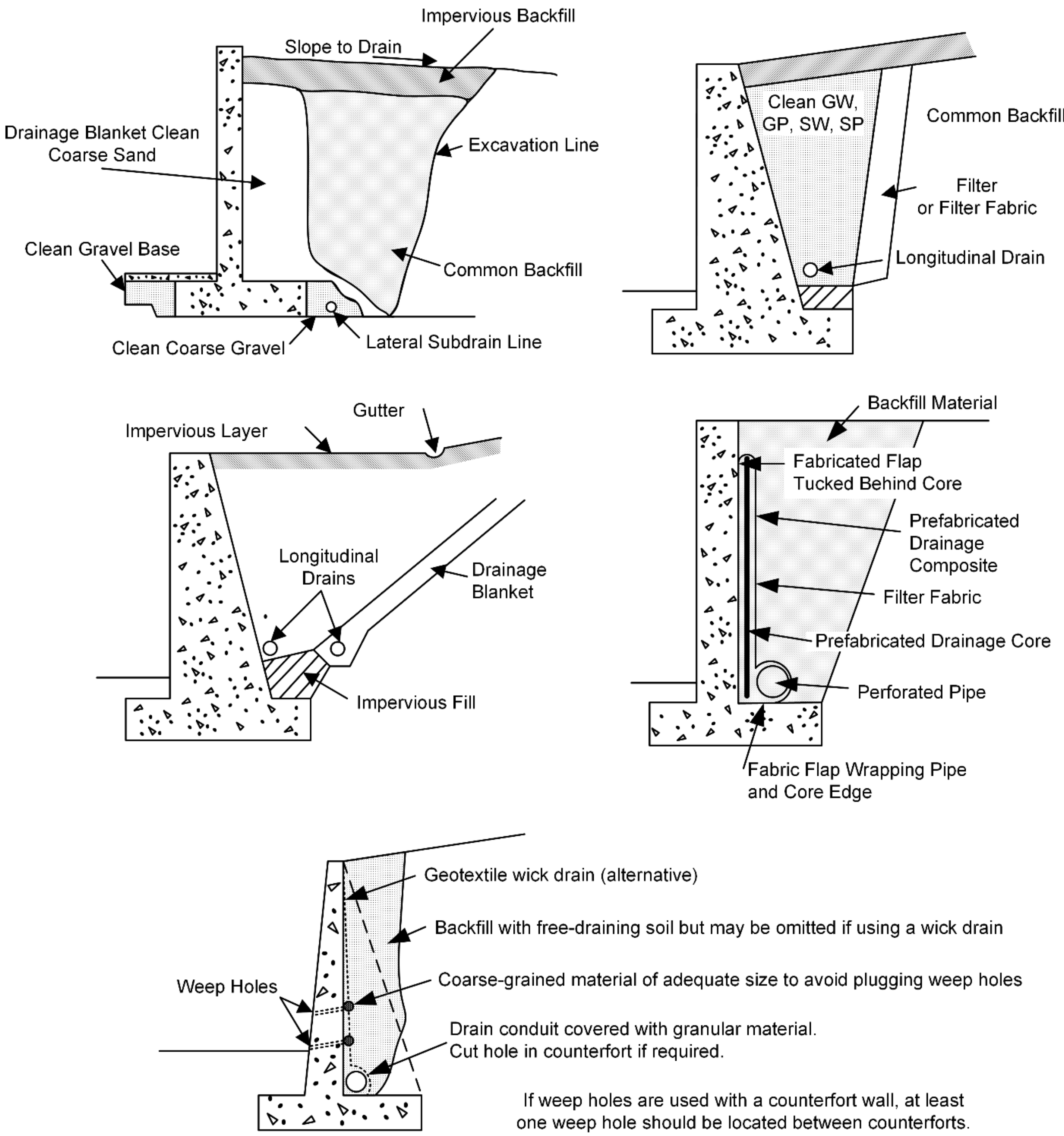


Figure 4-31 Drainage Systems Used for Rigid Retaining Structures (after Kim et al. 1991)

4-6 ALTERNATIVE GRAVITY RETAINING STRUCTURES.

4-6.1 Mechanical Stabilized Earth (MSE) Retaining Structures.

Mechanically stabilized earth (MSE) retaining structures are a popular alternative to rigid retaining structures. The technology and design methods used for MSE walls and slopes are very similar, and they share the same design manuals from the FHWA. If the face angle of the structure is greater than or equal to 70 degrees, then the structure is considered to be a *wall*. If the face angle is less than 70 degrees, then the structure is considered to be a *slope* (FHWA 2009). Walls also have a facing material, while slopes normally do not.

NAVFAC DM-7.1 covers many of the details regarding the internal design of MSE structures in Chapter 7. These details included the backfill materials, reinforcing materials, drainage systems, and the steps for designing MSE structures. These structures must also be designed for overturning, sliding, bearing capacity, settlement, and global stability.

Further discussion of MSE is beyond the scope of this manual. There are several technical reports available from the FHWA that provide design methods for MSE walls and slopes. FHWA (2009) describes Load and Resistance Factor Design (LRFD) for MSE walls. This manual is considered to be an update for the Allowable Stress Design (ASD) manual, FHWA NHI-00-043 (FHWA 2001).

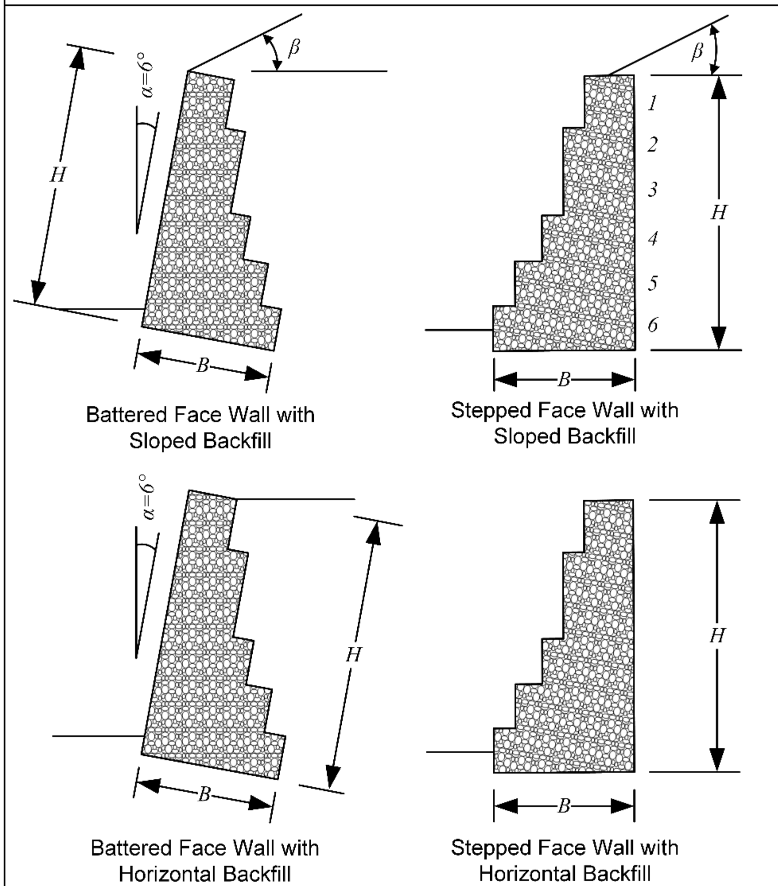
4-6.2 Gabion Walls.

Gabions are compartmented, rectangular containers made of heavily galvanized steel or polyvinylchloride (PVC) coated wire, filled with stone from 4 to 8 inches in size, and are used for control of bank erosion and stabilization as well as earth retaining structures. Design notes for gabion retaining walls are given in Figure 4-32. When the water quality is in doubt (pH > 12 or pH < 6) or where high concentration of organic acid may be present, PVC coated gabions are necessary. At the construction site, the individual gabion units are laced together with wire and filled with stone. Specifications for the gabion baskets are available in the Corps of Engineers CW-02541 (1980).

Gabions are designed as mass gravity structures using the same design procedures as rigid retaining walls that are presented in Figure 4-27. When designing a vertical face wall, it should be battered at an angle of about 6° to keep the resultant force toward the back of the wall. The interface friction angle between the base of a gabion wall and a coarse-grained foundation soil can assumed to be equal to the effective stress friction angle of the foundation. For the back of the wall, the ratio of interface friction to the friction angle of the backfill (δ / ϕ') can be set equal to 0.9. Where the retained material is mostly sand, a geosynthetic filter fabric or granular filter is recommended to prevent any erosion of the backfill soil into the gabions. Along all exposed gabion faces, the outer layer of stones should be hand placed to ensure proper alignment, and to achieve a neat, compact, square appearance.

A system of gabion counterforts is recommended when designing gabion structures to retain clay slopes. They should be used as headers and should extend from the front of the wall to a point at least one gabion length beyond the critical slip circle of the bank. Counterforts may be spaced from 13 feet (very soft clay) to 30 feet (stiff clay). A filter is also required on the back of the wall so that clay will not clog the free-draining gabions.

Gabion Retaining Wall Configurations



<u>Gabion Retaining Wall</u>
The common gabion wall configurations are shown to the left.

The choice of either battered or stepped face rests with designer. A stepped face is recommended, if the gabion wall is more than 10 feet high.

<u>Gabion Fill</u>
Use hard, durable, clean stone 4 to 8 inches in diameter or other approved size

Typical total unit weight:

γ = (44 pcf)×G_s

For common gabion fill, G_s ranges from 2.2 for some sandstone to 3.0 for basalt.

Gabion Wall Design

Design criteria for gravity walls apply. Wall section must resist overturning and sliding. To increase wall stability, it is recommended to tilt the wall at an angle of 6° (i.e. 1:10). On the base of the wall, use tan δ = tan ϕ' between the gabion wall and coarse-grained soil. At the back of the wall, assume tan δ = 0.9 tan ϕ'. For retaining clay slopes, a system of gabion counterforts is recommended.

Compute active soil pressure behind the wall using the Coulomb wedge theory, and design the mass of the wall to balance the force exerted by that soil wedge. Earth pressures higher than active may be used, depending on compactions conditions and limitations on deformations. Maximum pressure at the base of the gabion wall must be less than the allowable bearing capacity of the soil under the wall.

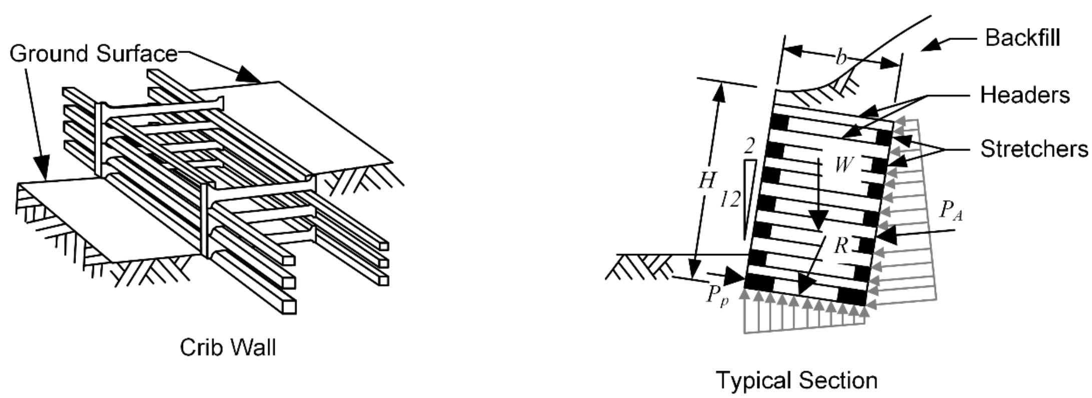
When water quality is in doubt (pH below 6 or greater than 12) or where high concentration of organic acids may be present, the use of PVC (polyvinvlychloride) coated gabions is recommended.

Figure 4-32 Design Notes for Gabion Retaining Walls

Hesco Bastion Concertainers®, commonly referred to as *Hesco baskets*, are similar to gabions in that they are wire baskets or cages that are filled with cobbles or other granular soils. Hesco baskets are normally lined with a non-woven geotextile. Common sizes for Hesco baskets are 3 ft x 3 ft x 15 ft and 4 ft x 3 ft x 15 ft. Hesco baskets have been used for a variety of functions in the Armed Forces. They can be used in lieu of sandbags for erosion and seepage control purposes, particularly at the crest of levees to increase the functional height of the levee. Hesco baskets can also be used to create walls to protect personnel as a force protection barrier system (MIL-DTL-32488 2014).

4-6.3 Earth-Filled Crib Walls and Bin Walls.

Crib walls and *bin walls* can be used as retaining structures when site access is too difficult to use other earth retaining structures. These also are designed as mass gravity structures using the same design methodology presented in Figure 4-27. Examples of the design elements of crib and bin walls are shown in Figure 4-33. The height of crib and bin walls should generally be less than 30 feet. For taller walls, consideration should be given to other wall types that are generally more robust.



<u>Cribbing Materials</u> – Timber, Concrete, and Metal.

<u>Fill</u> – Crushed stone or other coarse grained material, including rock less than 12 inches in diameter.

<u>Design</u> – Design criteria for gravity wall apply. Wall section resisting overturning is taken as a rectangle with dimensions H and b. Weight of crib is equal to that of material with a plumb face. Higher walls are battered on the face at least 2 inches per foot. For high walls (i.e., 12 ft high and greater), the batter is increased or supplemental cribs are added at the back. Such walls are very sensitive to transverse differential settlements. Walls with a convex back are more desirable for greater height. In open-face cribs, the space between stretchers should not exceed 8 inches so as to properly retain the fill. Expansion joints for concrete and metal cribbing are spaced no more than 90 feet.

<u>Filling</u> – The wall should not be laid up higher than 3 feet above the level of the fill within the crib.

<u>Bin Type Retaining Wall</u> – Composed of metal bins or cells joined to special columnar units at the corners. The design requirements are the same as for crib walls except that suitable drainage behind the walls is needed. Internal stresses are investigated in accordance with criteria for cellular walls.

Figure 4-33 Design Elements of Crib Walls and Bin Walls

Crib walls can be constructed of timber or precast concrete beams. Interlocking precast concrete beams are available for rapid wall construction. Crib walls can be constructed with common earth-moving equipment and manual labor. The walls can accommodate changes in alignment and topography better than other types of walls. Crib walls can be more tolerant to differential settlement than other stiffer wall types.

Bin walls are often made of corrugated steel panels that are bolted together and filled with coarse-grained soils. It is important for the backfill of bin walls to be free-draining, and the high permeability of the backfill should be maintained.

4-7 FLEXIBLE RETAINING STRUCTURES.

Flexible retaining structures consist primarily of vertical structural elements that are inserted prior to excavation. The structures may be braced or anchored. Examples include sheet pile, soldier beam and lagging, and concrete diaphragm walls. Flexible structures can exhibit a range of displacements depending on the fixity of the buried parts of the wall and on the location of supports or anchors.

The embedded portion of a flexible structure develops passive resistance resulting from displacement of the structure toward the soil. In addition, flexible structures are often braced or supported as shown in Figure 2-6 because embedment alone is insufficient. *Internally-supported* systems use structural supports that are internal to the excavation. *Externally-supported* systems use anchors or tiebacks within the soil that are external to the excavation.

A variety of flexible retaining structures are used for waterfront structures, excavation bracing, permanent retaining walls, and other support systems. These walls often appear to be quite rigid, but due to the length of the support elements, they deflect under earth and water loads. As described earlier, earth pressures vary according to wall deflections, and the design of flexible retaining structures can be quite involved. Limit equilibrium analyses have been historically used for the design of these structures, and those are the methods that are described in this manual. Numerical methods, such as finite element and finite difference, are often used in geotechnical engineering practice, especially when limiting wall deflections is important or for deep excavations. However, the use of limit equilibrium methods is still widespread in engineering practice.

4-7.1 Factored Passive Resistance.

As noted above, the stability of many flexible structures depends on the passive resistance at the base of the wall and in front of supporting anchors. In the analysis methods that follow, two different methods may be used to provide an adequate factor of safety. Where passive earth pressure forces are directly calculated, the allowable passive force ($P_{P,allow}$) can be found as:

$$P_{P,allow} = \frac{P_P}{F} \tag{4-29}$$

where:
P_P = passive earth pressure force calculated using the shear strength parameters and
F = factor of safety.

As such, the factor of safety is applied to load, which is similar to the approach used in bearing capacity analysis. In this case, the value of F should be 2 to 3 for coarse-grained soils (effective stress design). A value of F = 1.5 to 2.0 can be used for undrained analysis in fine-grained soils. These factors of safety will provide approximately equivalent factors of safety with respect to shear strength.

Alternatively, the value of K_P can be determined from an allowable effective stress friction angle (ϕ'_{allow}) which is found as:

$$\phi'_{allow} = \tan^{-1}\left(\frac{\tan\phi'}{F}\right) \tag{4-30}$$

where:
ϕ' = effective stress friction angle.

The second method (Eqn. 4-30) provides a factor of safety on shear strength, similar to slope stability. In this case, a factor of safety of 1.5 to 2.0 is appropriate, regardless of the soil types or analysis conditions.

4-7.2 Anchored Bulkheads.

Anchored bulkheads are waterfront structures used to allow a change in elevation for access to the water. These structures are often driven sheet piles that are restrained on the landside by some form of anchoring system. Sheet piles are often steel, but can also be made of concrete, wood, vinyl, and plastic.[24] Excavations are made on the waterside down to the *dredge line* to allow sufficient draft for vessels. The dredge line is the lowest depth to which soil is removed in front of the wall.

Several references are available that provide design guidance and construction details for anchored bulkheads. These include:

- USACE (1995b) Design of Coastal Revetments, Seawalls, and Bulkheads, EM 1110-2-1614, CECW-EH-D.

---

[24] Plastic and vinyl sheet piles have exceptional corrosion resistance, but the interlock strength is much less than steel sheet piles. Plastic and vinyl sheet piles should not be used for cases where there are significant consequences of failure, especially loss of life.

- USACE (1994a) Design of Sheet Pile Walls, CECW-ED, EM 1110-2-2504.

- US Steel (1984) Steel Sheet Piling Design Manual, Updated and reprinted by the US Department of Transportation/FHWA.

The earth pressure and water pressure distributions on anchored bulkheads can be quite complex. The ground surface elevation is different on the landside and the waterside. The water level on the landside and waterside is often different as well. In addition to soil and water loads, the anchoring system applies a concentrated force on the wall. Anchored bulkheads are often constructed by excavation and dredging in natural soils or unengineered fills; therefore, the soil properties can vary greatly. An important part of the engineering design of these structures is to accurately simplify the cross section and soil parameters into relatively homogeneous layers that can be accommodated by earth pressure theory.

Anchored bulkheads can be designed by determining the appropriate pressures acting on each side of the wall separately. Sometimes, it is more convenient to use *net pressure diagrams*, where the difference in the pressure on each side of the wall is calculated. Examples of a total pressure diagram and a net pressure diagram are shown in Figure 4-34.

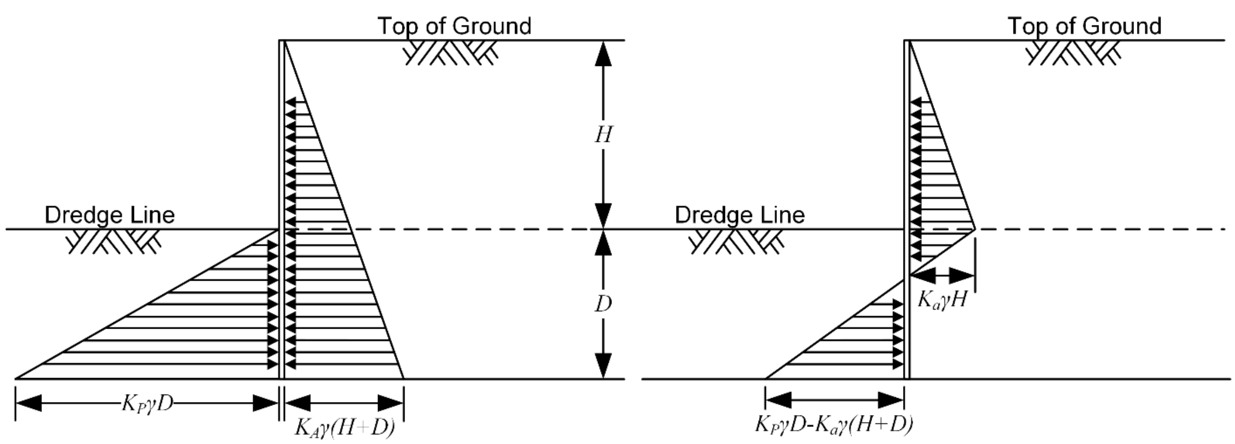


Figure 4-34 Total Regular Pressure Diagram and Net Pressure Diagram

Anchored bulkheads can be designed using limit equilibrium methods. An important element in using limit equilibrium methods is to define the possible modes of failure. Anchored bulkheads can fail in many different ways, as shown in Figure 4-35. A proper design will examine each potential mode of failure of the different anchored bulkhead elements. Interlock failure should also be considered.

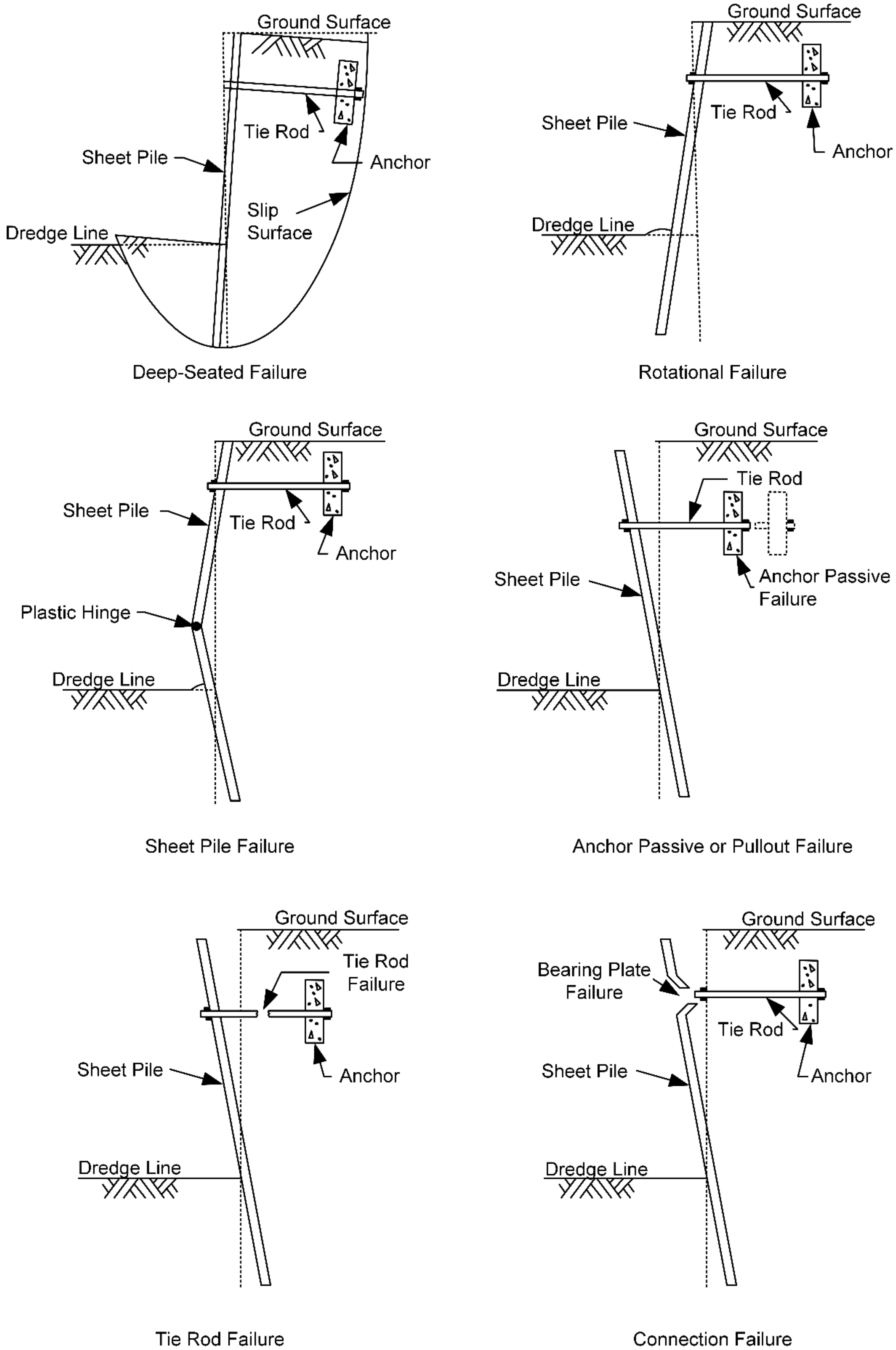


Figure 4-35 Failure Modes for Anchored Bulkheads (after USACE EM 1110-2-2504 1994)

Methods for the analysis of anchored bulkheads are often categorized into *free earth* or *fixed earth* support methods. The difference between these two methods involves the behavior of the wall below the dredge line. In free earth analysis, the passive resistance below the dredge line is not developed to the point that movement of the sheet pile tip is prevented. The tip of the sheet pile can deflect toward the water side. The free earth support system tends to overpredict the bending moments in the sheet pile, and techniques are available to correct the bending moment. In fixed earth analysis, which is less commonly used, the lower end of the wall is essentially fixed so that no movement is allowed.

Experience and scale model testing have shown that the free earth support method overpredicts the bending moment in flexible walls (Rowe 1952). The differences from theory are explained by flexural of the wall but above and below the dredge line. Corrections to the predicted moment, often referred to as *moment reduction*, depend on the relative flexibility (ρ) of the wall, which is defined as:

$$\rho = \frac{(H+D)^4}{EI} \tag{4-31}$$

where:
H = exposed height of the wall (inches),
D = depth of penetration below the dredge line (inches),
E = Young's modulus of the wall (psi), and
I = moment of inertia of the wall (inch^4/ft).

The relative flexibility is used with Figure 4-36 to determine the ratio of the design moment to the theoretical moment. The moment is reduced for walls that penetrate into medium dense or better sand. The moment is not reduced for penetration into fine-grained soils or loose sands.

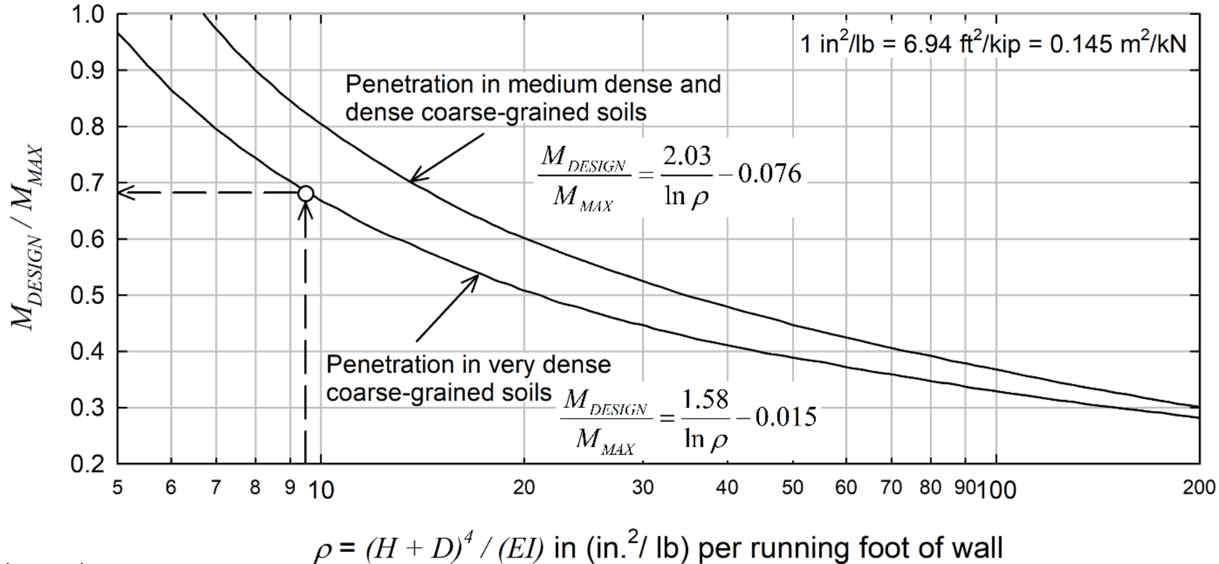
Three example scenarios showing the design steps for anchored bulkheads are shown in Figure 4-37. These examples are complex in that they have the following characteristics:

1) Two or more layers of soil,

2) Backfill loaded by point load (Q) and surcharge area (q), and

3) Different interior and exterior water levels. The difference in the water pressures is accommodated by a trapezoidal unbalanced water pressure distribution.

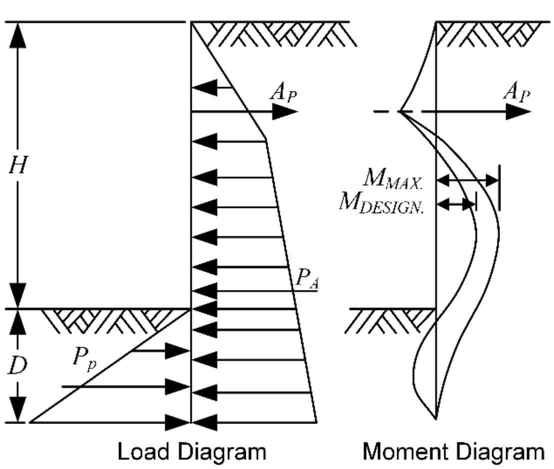
(a) Moment Reduction Factor Chart



Legend
M_{MAX} = Maximum positive moment in sheeting computed by methods of Figure 3-37
M_{DESIGN} = Maximum positive moment for design of sheeting
ρ = Flexibility Number = $(H+D)^4/EI$
Sheeting Properties: E = Modulus of Elasticity (psi) and I = Moment of Inertia (in^4) per running foot of wall

Notes
1. M_{DESIGN} is obtained by successive trials of sheeting size until max. bending stress in sheeting equals allowable bending stress.
2. No reduction in M_{MAX} is permitted for walls in fine-grained soils, or very loose to loose coarse-grained soils.
3. The flexibility number is computed on the basis of lubricated interlocks.

(b) Example: Penetration in Very Dense Sand



- Wall dimensions: H = 33 ft, D = 15 ft
- Sheet pile properties:
  Allowable stress f_s = 25,000 psi, E = 30,000,000 psi
- Calculated M_{MAX} = 950,000 in-lb/ft

Trial Sheet Pile Section: PZ32, I = 385.7 in^4, S = 38.3 in^3

$$\rho = \frac{(H+D)^4}{EI} = \frac{(33+15\,ft)^4(12\,in/1\,ft)^4}{(30{,}000{,}000\,psi)(385.7\,in^4)} = 9.5\,in^2/lb$$

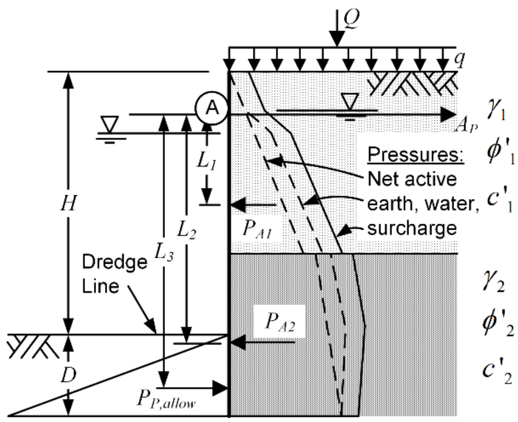
From the chart: M_{DESIGN}/M_{MAX} = 0.68
Thus: M_{DESIGN} = (0.68)(950,000 in-lb/ft) = 646,000 in-lb/ft

Checking tensile stress:
Required $f_s = M/S$ = 646,000/38.3 = 16,900 psi < 25,000 psi

Capacity greatly exceeds demand. Try a smaller section.

Figure 4-36 Rowe's Moment Reduction Factors for Flexible Walls

Scenario 1: Free Earth Support – General Case



1. Compute pressures by methods of Figures 4-4 to 4-13. Passive pressures for clean coarse grained soils include wall friction (see Table 4-1). For active or passive pressures in all other soil types, ignore wall friction.
2. Determine depth of penetration required by taking moments about Point A and solving for D:

$$P_{A1} \cdot L_1 + P_{A2} \cdot L_2 = P_{P,allow} \cdot L_3$$

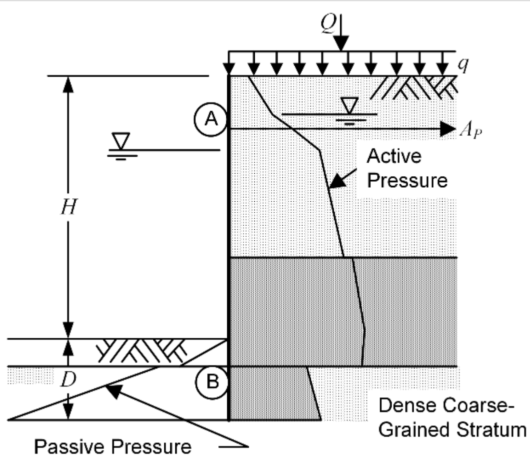
3. Calculate anchor pull (A_P) for anchor spacing (d)

$$A_P = \left[P_{A1} - P_{A2} + P_{P,allow} \right] \cdot d$$

4. Compute maximum bending moment (M_{MAX}) in sheeting by the free Earth support method, using P_{A1}, P_{A2}, $P_{P,allow}$, and A_P. for sheeting in sand. Apply moment reduction if appropriate (Figure 4-36).
5. Increase calculated penetration (D) by 20% to allow for dredging, scour, etc.

Note: L_1, L_2, and L_3 are the dimensions from Point A

Scenario 2: Penetration in Compact Coarse-Grained Stratum



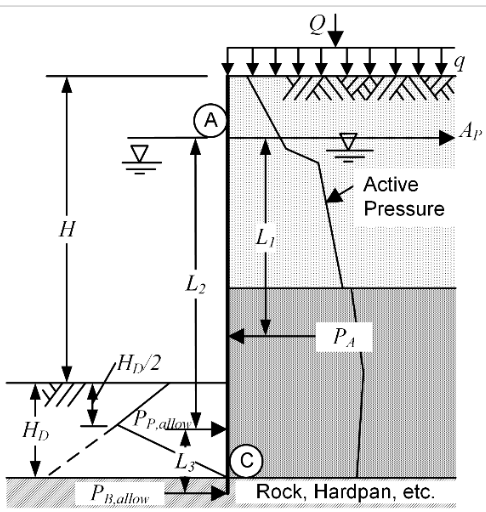
1-3. Use the same Design Steps 1, 2, and 3 as above for Free Earth Support method.

4. Compute maximum bending moment (M_{MAX}) in sheeting by Free Earth Support method, using P_A, $P_{P,allow}$, and A_P.
5. Compute ρ according to Figure 4-36.

   If $\rho \geq 20$, M_{DESIGN} is computed for the span Points A to B assuming simple support at Point B.

   If $\rho < 20$, use the moment reduction for flexibility from Figure 4-36.
6. Increase the calculated penetration (D) by 20% to allow for dredging, scour, etc.

Scenario 3: Penetration to Top of Hard Unyielding Stratum



1. Compute pressures as above, except that passive pressure decreases to zero at top of hard stratum.
2. Determine required penetration into hard stratum by taking moments about Point A and solving for $P_{B,allow}$:

$$P_A \cdot L_1 - P_{P,allow} \cdot L_2 = P_{B,allow} (L_2 + L_3)$$

   and estimate if reaction $P_{B,allow}$ can be provided by shallow penetration in hard stratum.
3. Calculate anchor pull:

$$A_P = \left[P_A - P_{P,allow} - P_{B,allow} \right] \cdot d$$

4. Compute maximum bending moment (M_{MAX}) in sheeting, using P_A, $P_{P,allow}$, and A_P to span Points A to C assuming simple support at Point C with no reduction for flexibility.

Note: L_1, L_2, and L_3 are the dimensions from Point A, respectively.

Figure 4-37 Anchored Bulkhead Design Scenarios

Important design details illustrated in the the example scenarios are as follows:

1) The effects of interface friction between the wall and soil are only considered for passive pressure in granular soils. Wall friction is ignored in all other cases.

2) A factor of safety is applied to the passive pressure determination below the dredge line, and for passive pressures calculated for the anchor.

3) The calculated depth of penetration below the dredge line (D) is increased by 20% to allow for scour, additional dredging, etc.

4) The calculated bending moment in the sheet pile is reduced using Figure 4-36.

Scenario 1 is the general case for the free-earth method. The step-by-step method, indicated on Figure 4-37 would be appropriate for coarse-grained soils, with the material below the dredge line being similar to the soil retained by the wall. The soil properties used for the layers would be drained or effective stress parameters (c' and ϕ'). For the calculation of the earth pressures, moist or total unit weights are used above the landside water table elevation, and effective or buoyant unit weights are used below the water table. The net water pressure applied to the landside of the wall decreases from the dredge line elevation to a value of zero at depth, D, to account for seepage effects.

Scenario 2 is similar, but a different method is needed to determine the design moment in the sheet pile. For this example, the sheet pile is driven into a dense granular soil. If the wall system is less flexible as reflected by the value of ρ (Figure 4-36), the moment is calculated assuming that the wall behaves like a simply-supported beam.

Scenario 3 in Figure 4-37 shows a case where the sheet pile is socketed or toed into a very hard material (rock or hardpan). Since no displacement occurs at the tip of the sheet pile, the passive pressure decreases to zero at the surface of the hard foundation. The moment is not reduced using Rowe's diagram (Figure 4-36).

4-7.3 Anchor Design.

Various types of anchors can be used with anchored bulkheads. Examples of different anchor systems are given in Figure 4-38. The *deadman* anchor has been historically popular and its design incorporates earth pressure theory. Deadman anchors can be discrete individual elements, or they can be a continuous reinforced concrete wall parallel to the bulkhead. Anchors are normally constructed to a depth equal to twice the anchor height. The distance between the anchor and the wall is important. In order to maximize the capacity, the anchor needs to be located outside of the potential failure wedge. Figure 4-39(a) provides guidance on the location of a deadman anchor relative to the active wedge.

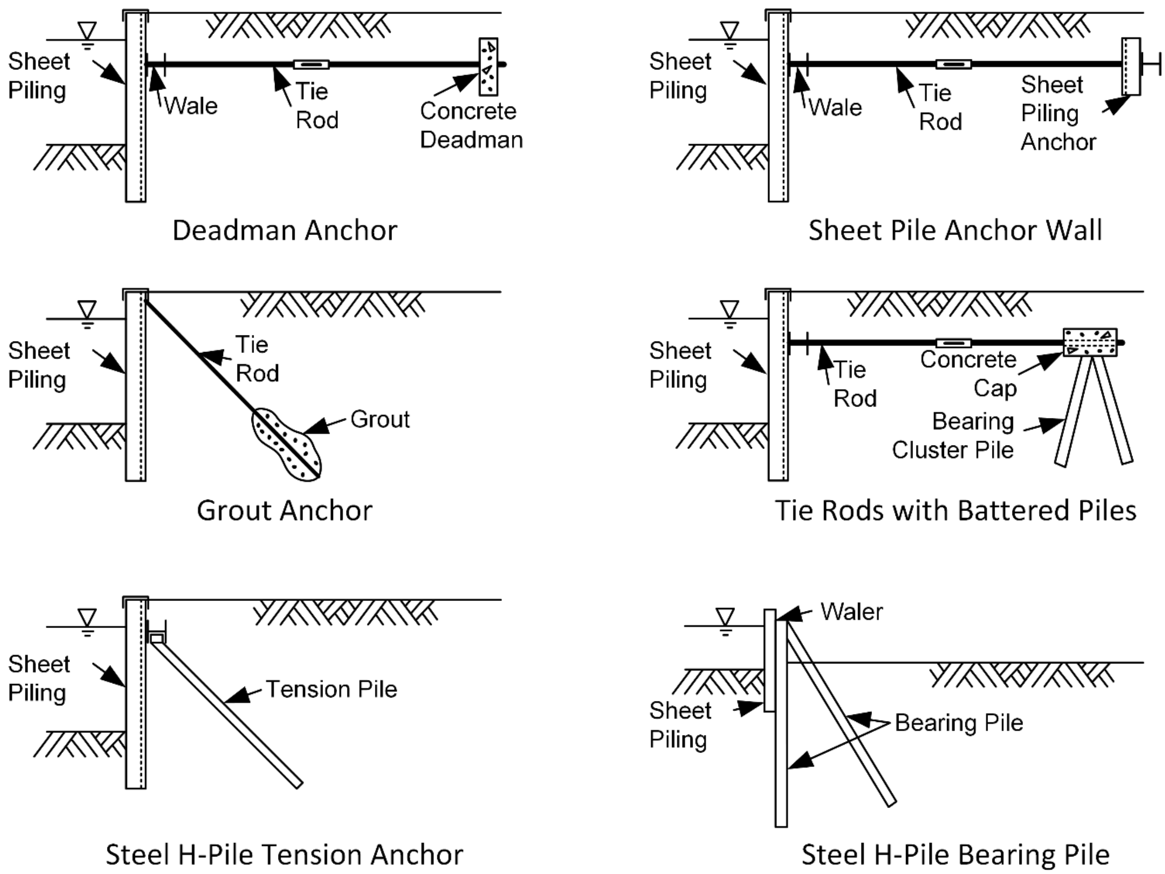


Figure 4-38 Types of Anchoring Systems for Bulkheads (after USACE EM 1110-2-2504)

The equations for calculating the capacity of a continuous wall anchor are shown in Figure 4-39(b). The interface friction angle between the anchor and soil is considered in the determination of the passive earth pressure coefficient. The calculated passive resistance of the anchor is dependent on where the anchor is located. A reduced anchor capacity results for anchors placed close to the active failure wedge. Figure 4-40 shows a section view of the wall anchor in Figure 4-39. The differences in the capacity of wall anchors versus individual anchor blocks are summarized.

The FHWA Geotechnical Engineering Circular No. 4 - *Ground Anchors and Anchored Systems* (FHWA 1999) provides design procedures for many different types of anchors.

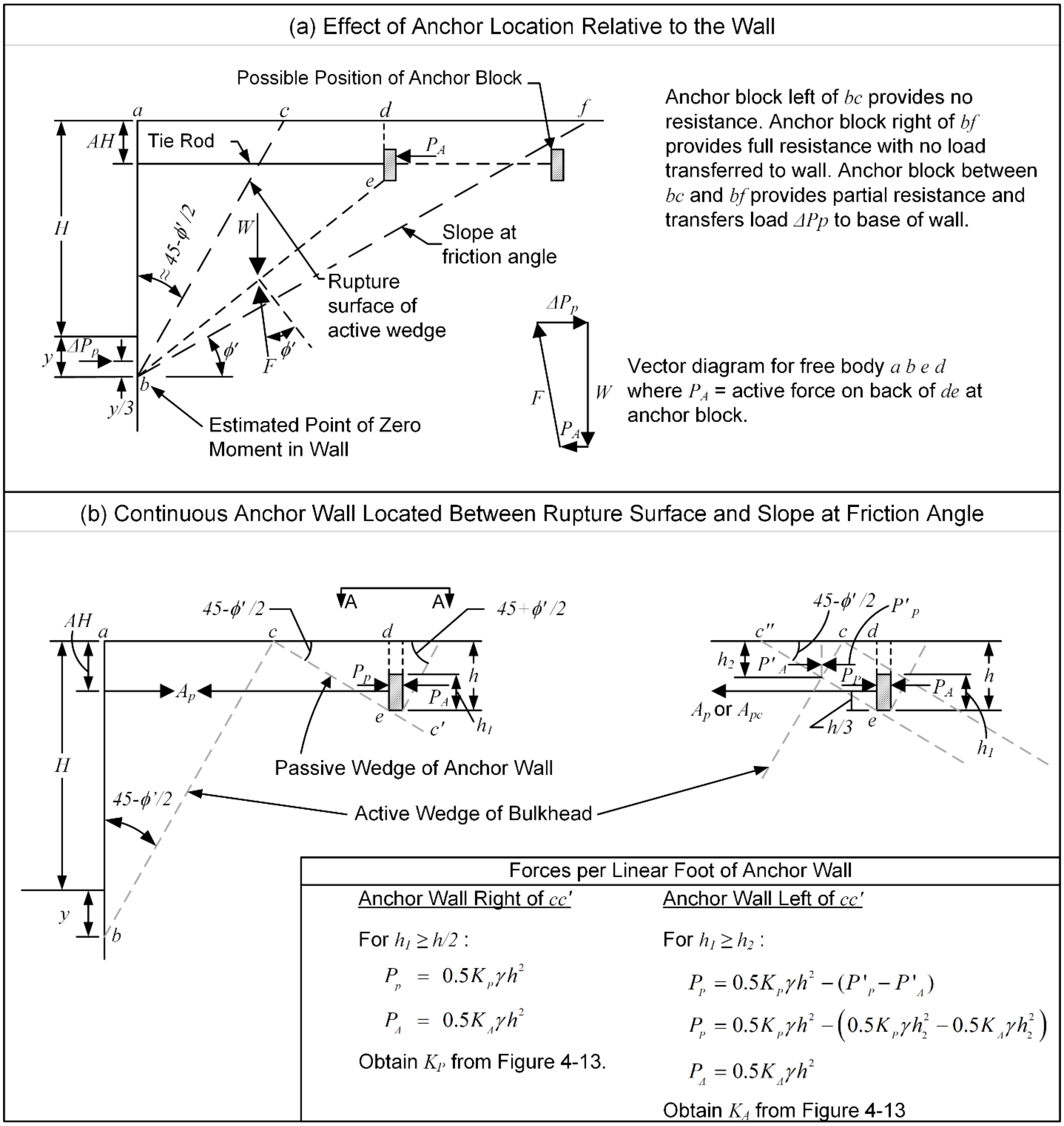
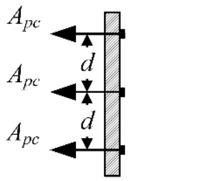
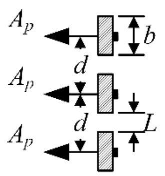


Figure 4-39 (a) Effect of Anchor Position Relative to Wall, and (b) Wall Anchor Capacity Equations

Effect of Depth and Spacing of Anchor Blocks



Section A-A
Continuous Wall



Section A-A
Individual Anchors

Anchor Resistance for $h_1 \geq h/2$

1. Continuous Wall: The ultimate resistance is $A_{pc} / d = P_p - P_A$, where A_{pc} / d is anchor resistance, and P_p and P_A are taken per linear foot of wall.
2. Individual Anchors:
   If $d > (b + h)$, the ultimate resistance is found using the resultant at-rest soil force (P_0) on vertical area cde or $c''de$ as $A_p = b(P_P - P_A) + 2P_0 \tan \phi'$.

   If $d = (h+b)$, the ultimate resistance (A_p/d) is 70% of A_{pc}/d for a continuous wall. L for this condition is L' and $L'=h$.

   If $d < (h+b)$, $L'=h$ and $A_p/d = A_{pc}/d - (L/L')(0.3\, A_{pc} / d)$.

Anchor Resistance for $h_1 < h/2$

The ultimate A_p / d OR A_{pc} / d equals the bearing capacity of a strip footing of width, h_1, and surcharge load $\gamma(h - h_1 / 2)$. See Chapter 5. Use friction angle (ϕ^*) such that $\tan \phi^* = 0.6 \tan \phi'$.

(see Figure 4-39 for definition of dimensions and section)

General Requirements:

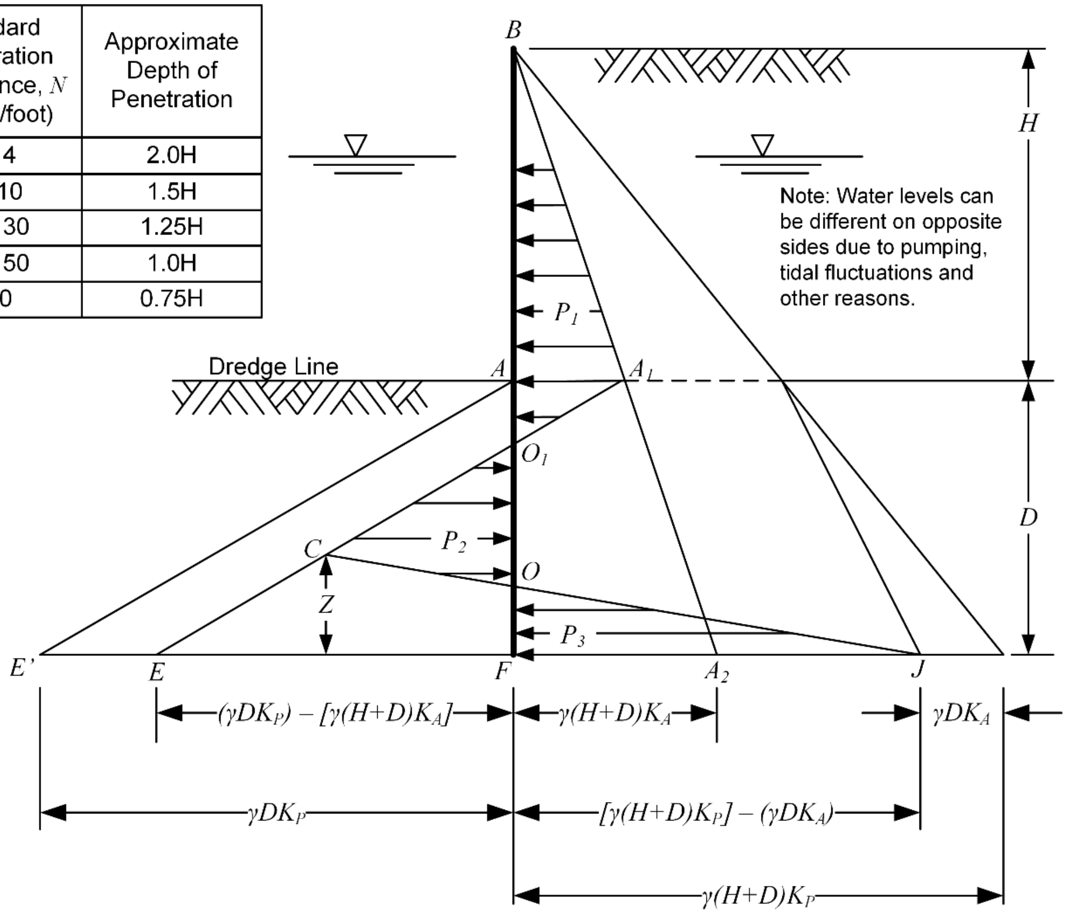
1. Divide the ultimate value of A_p or A_{pc} by 2 to determine the allowable value with a factor of safety of 2 against failure.
2. Values of K_A and K_P are for cohesionless materials. If backfill has both ϕ' and c' strength parameters, compute active and passive forces according to Figures 4-5 and 4-6 Fine-grained soils of medium to high plasticity should not be used to support the anchor.
3. Soils within passive wedge of anchorage shall be compacted to no less than 90% of maximum dry unit weight (ASTM D698).
4. Tie rod is designed for allowable A_p and A_{pc}. Tie rod connections to wall and anchorage are designed for 1.2 times the allowable A_p or A_{pc}.
5. Tie rod connection to anchorage is made at the location of the resultant earth pressures acting on the vertical face of the anchorage.

Figure 4-40 Effect of Depth and Spacing of Anchor Blocks

4-7.4 Cantilever Flexible Walls.

A *cantilever* flexible wall supports the soil without anchors or bracing. These walls are commonly constructed from sheet piling and can be used as earth retention structures for exposed wall heights less than about 15 feet. Stiffer types of flexible structure may be able to support higher walls. The pattern of deflection of the sheet pile results in complex earth pressures acting on the wall. Figure 4-41 shows the net pressure diagram for cantilever sheet piling. The designer should be aware of cases where there is a difference in the water level on each side of the wall. The figure shows a step-by-step approach to determine the depth of penetration (D) for design of a cantilever flexible wall for effective stress conditions.

Standard Penetration Resistance, N (blows/foot)	Approximate Depth of Penetration
0 - 4	2.0H
5 - 10	1.5H
11 - 30	1.25H
31 - 50	1.0H
+50	0.75H



Calculation steps:

1. Assume a trial depth of penetration, D. The SPT penetration resistance can be used with the table above.
2. Determine the active and passive lateral pressure using appropriate coefficients of lateral earth pressure. The passive earth pressure coefficient should be based on ϕ'_{allow} as discussed in Section 4-7.1. Alternatively apply a factor of safety to the value of K_p.
3. Satisfy the requirements of static equilibrium. The sum of the forces in the horizontal direction must be zero, and the sum of the moments about any point must be zero. The sum of the horizontal forces may be written in terms of pressure areas:

$$\Delta\left(EA_1A_2\right) - \Delta\left(FBA_2\right) - \Delta\left(ECJ\right) = 0 \quad \text{or} \quad P_1 - P_2 + P_3 = 0$$

   Solve the above equation to find distance, Z. For a uniform coarse-grained soil (either fully saturated or no water),

$$Z = \frac{K_P D^2 - K_A\left(H+D\right)^2}{\left(K_P - K_A\right)\left(H+2D\right)}$$

4. Take moments about Point F. If sum of moments is other than zero, adjust D and repeated calculations until sum of moments around Point F is zero.
5. Compute maximum moment at point of zero shear.
6. Increase D by 20% to allow for dredging, scour, etc.

Figure 4-41 Calculation Procedure for Cantilever Retaining Structures

Two charts are available to simplify the cantilever wall calculations for sites with simple stratigraphy. Figure 4-42 allows the penetration depth (D) to be determined for a site consisting of coarse-grained soil that can be characterized by a single value of effective stress friction angle. A phreatic surface can be accommodated assuming that the level is the same on both sides of the sheet pile. There are two families of curves on the chart, with one used for determining the maximum moment in the sheet pile and the other for determining the embedment depth. This chart was developed assuming that the total unit weight of the soil was 124.8 pcf, which is twice the buoyant unit weight. An example of the use of this chart for a cantilever sheet pile wall with a height of 15 ft in a coarse-grained soil is given in Figure 4-43.

The value of K_P used with Figure 4-42 should be factored as described in Section 4-7.1. In addition, the final value of D should be increased by about 20% to design against future dredging or scour.

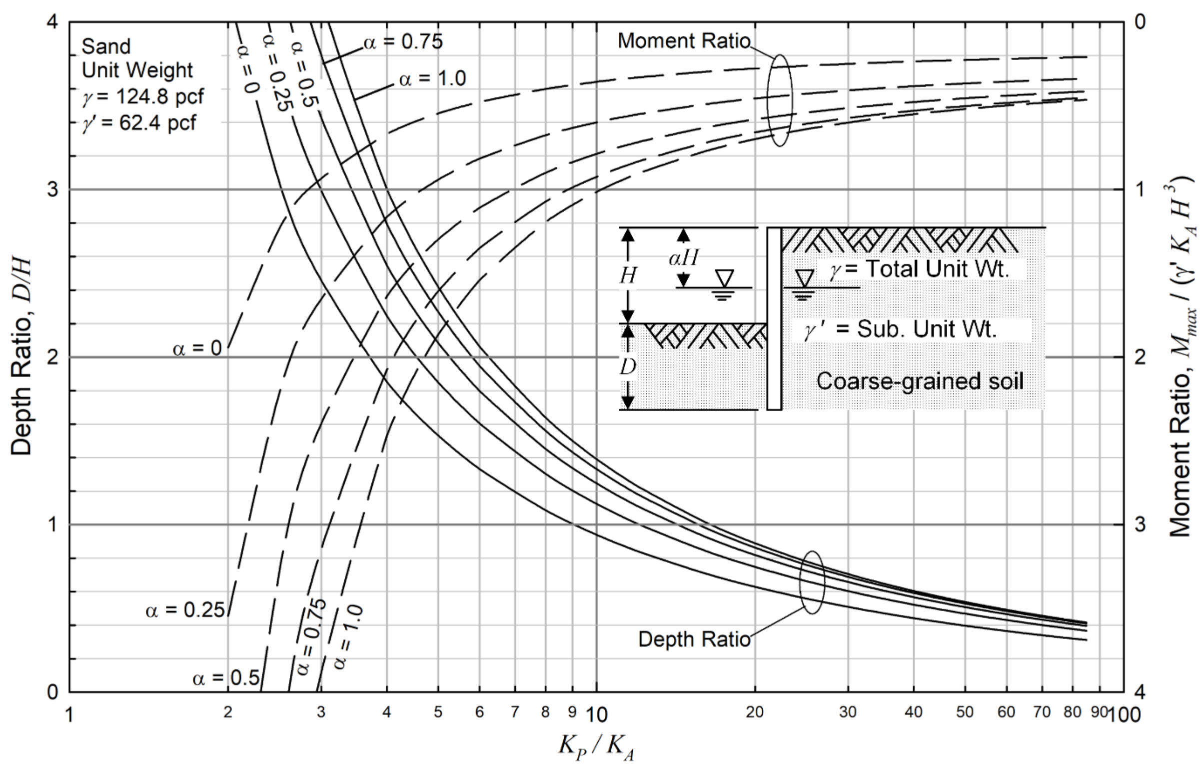
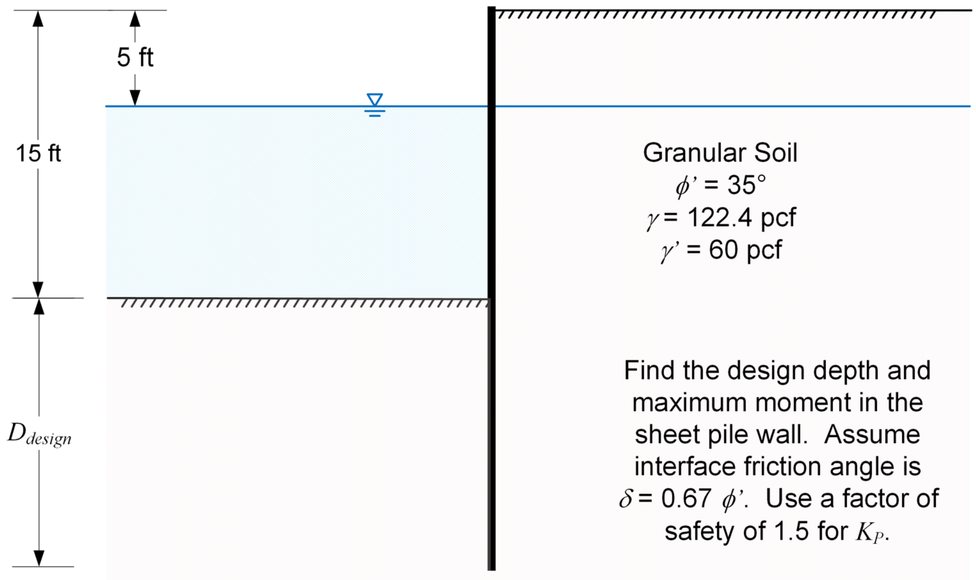


Figure 4-42 Chart for Determining Penetration Depth and Maximum Moment in a Cantilever Flexible Wall in Sand

The second chart (Figure 4-44) was developed for a sand layer overlying a saturated clay layer. The sand layer extends down to the dredge line. The sand layer is characterized by ϕ', and the clay layer is assigned a single undrained strength (s_u). The effective stress at dredge level in the sand layer should be calculated based on the position of the water table using the appropriate unit weights. An example using this chart is shown in Figure 4-45.

A wall designed using Figure 4-44 is supported by passive pressure associated with the undrained shear strength of the clay. The undrained shear strength can be factored as indicated in the figure. The strength is factored only on the passive side of the wall, which leads to the equation provided. This approach allows an explicit consideration of F. Alternatively, if the full undrained shear strength is used, the penetration depth must be increased by 30% to 40% to allow for a factor of safety. The magnitude of F is unknown with the latter approach.

The US Steel (USS) *Sheet Piling Design Manual* (USS 1984) contains more details about the design of cantilever sheet piles in coarse-grained and fine-grained soils and provides additional design examples.



Earth pressure coefficients:

K_A = 0.25 for ϕ' = 35 deg (from Figure 4-12)

ϕ'_{allow} = $\tan^{-1}$(tan(35 deg)/1.5) = 25 deg

K_P = 3.6 for ϕ'_{allow} = 25 deg (from Figure 4-12)

Inputs for Figure 4-42:

Relative water level: a = (5 ft) / (15 ft) = 0.33

K_P / K_A = 3.6 / 0.25 = 14.4

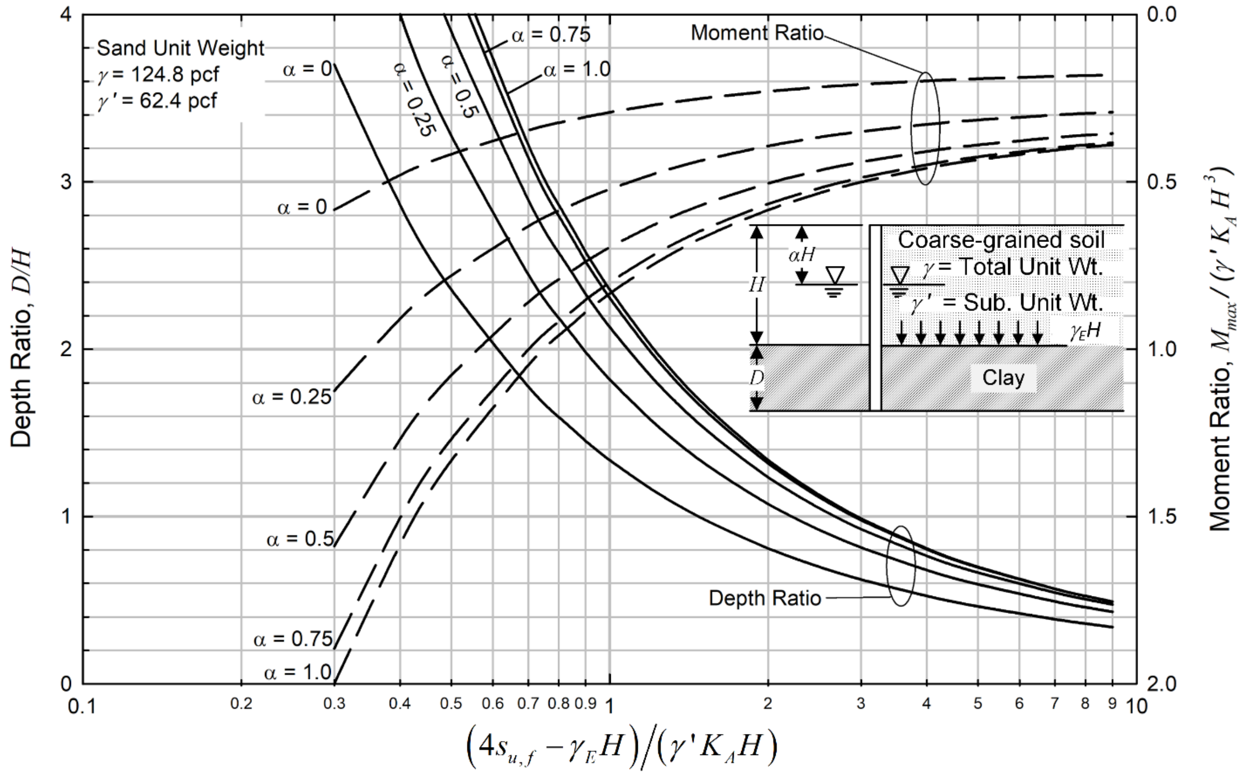
Depth ratio (from Figure 4-42): D / H = 0.95, D = 0.95 (15 ft) = 14.25 ft

Design depth: D_{design} = 1.2 (14.25 ft) = 17 ft

Moment ratio (from Figure 4-42): $M_{max} / (\gamma' K_A H^3)$ = 0.6

Maximum moment: M_{max} = 0.6 (62.4 pcf)(0.25)(15 ft)^3 = 31,590 ft-lb/ft of wall

Figure 4-43 Example for a Cantilever Wall in Sand



Factored undrained strength of clay ($s_{u,f}$):

$$s_{u,f} = s_u\left(\frac{F+1}{2F}\right)$$

where:

s_u = unfactored undrained strength

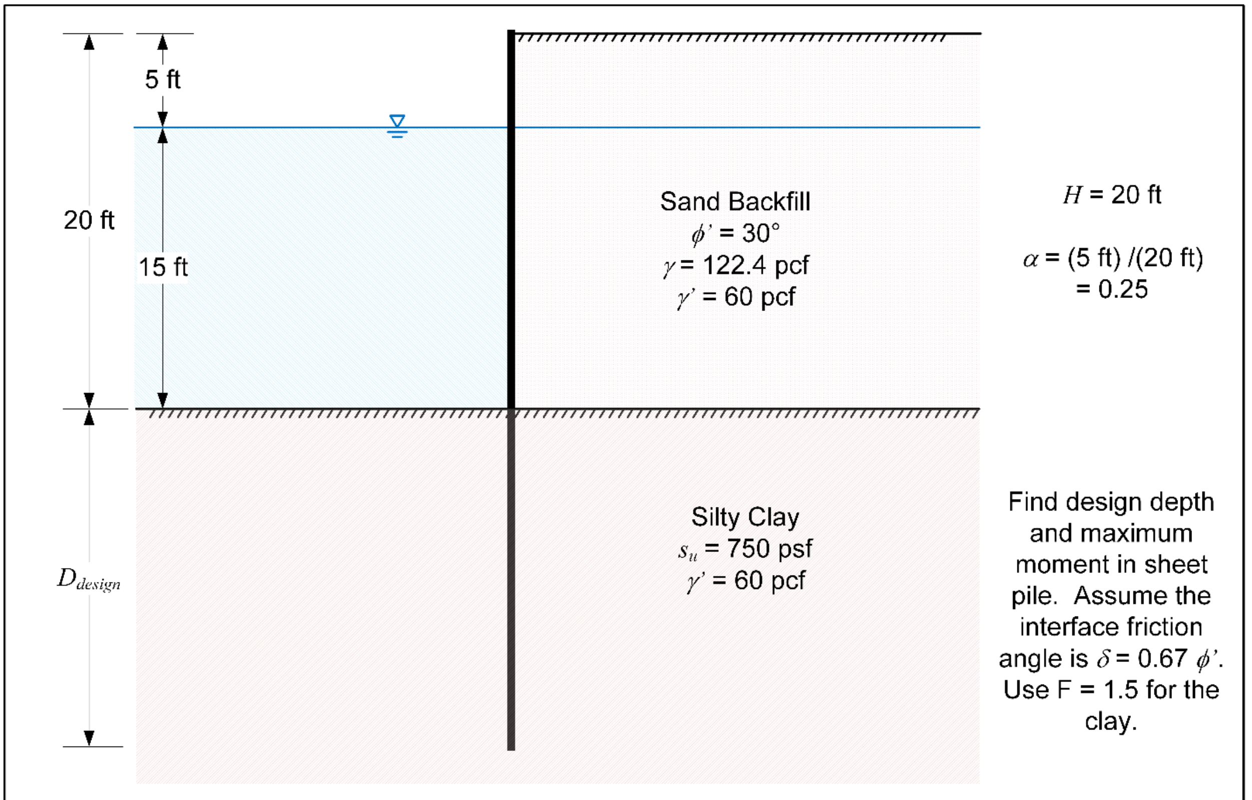
F = factor of safety

Vertical Effective Pressure at Top of Clay:

$$\gamma_E H = \alpha H\gamma + (1-\alpha)H\gamma'$$

$$\gamma_E H = \left[\alpha\gamma + (1-\alpha)\gamma'\right]H$$

Figure 4-44 Chart for Determining Penetration Depth and Maximum Moment in a Cantilever Flexible Wall in Sand Overlying Clay



Earth pressure coefficients:

Backfill - K_A = 0.30 for ϕ' = 30 deg (from Figure 4-12)

Vertical effective pressure at the dredge line:

$\gamma_E H$ = [(0.25)(122.4 pcf) + (1-0.25)(60 pcf)](20 ft) = 1512 psf

Factored undrained shear strength:

$s_{u,f}$ = (750 psf)[(1.5+1)/(2·1.5)] = 625 psf

Determine x-axis value for Figure 4-44:

$(4s_{u,f} - \gamma_E H) / (\gamma' K_A H)$ = [4(625 psf) - 1512 psf] / [(60 pcf)(0.30)(20 ft)] = 2.74

Depth ratio (Figure 4-44): D / H = 0.86; D = 0.86 (20 ft) = 17.2 ft

Design depth: D_{design} = 1.2 (17.2 ft) = 20.6 ft ≈ 21 ft

Moment ratio (Figure 4-44): $M_{max} / (\gamma' K_A H)$ = 0.36

Maximum moment: M_{max} = 0.36 (60 pcf)(0.30)(20 ft)^3 = 51,840 ft-lb/ft

Figure 4-45 Example for Cantilever Sheet Pile in Sand Underlain by Clay

4-7.5 Soldier Pile Walls.

Soldier pile and lagging walls consist of discrete vertical soldier piles (or beams) that support horizontal lagging as shown in Figure 4-46. The lagging transfers earth pressures from the soil to the soldier piles. In the typical construction sequence, the soldier piles are placed in shafts drilled prior to excavation for the wall. Concrete is used to secure the soldier pile in place below the dredge line. Above the dredge line, the shafts are often backfilled with low strength concrete or flowable fill. As excavation proceeds adjacent to the soldier piles, lagging is placed between the piles from the top down. Soldier pile and lagging walls may be supported internally or externally. A cantilever design can be used if strong soil or rock is present at the base of the wall and the soldier piles are sufficiently stiff.

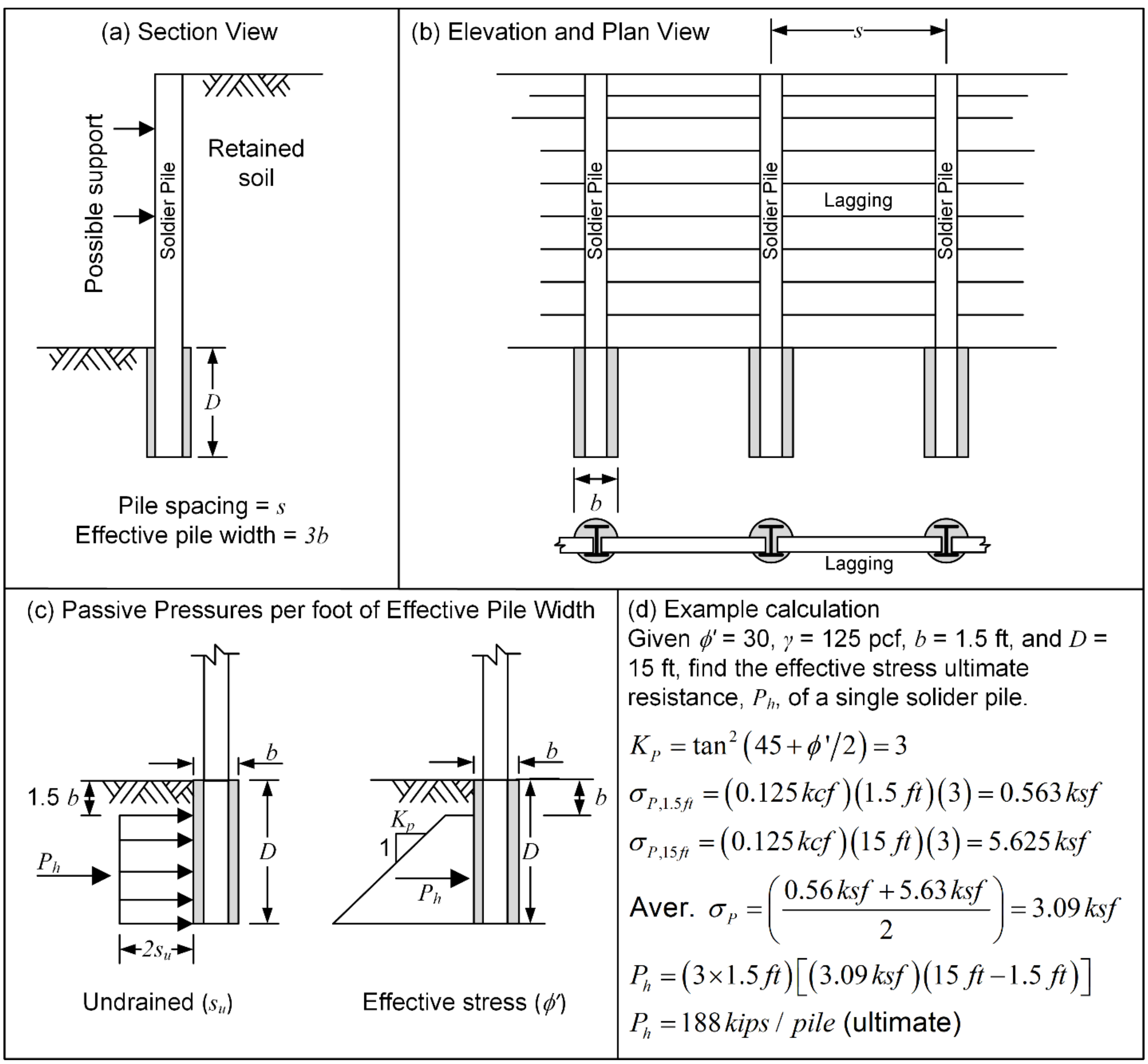


Figure 4-46 Soldier Pile and Lagging Walls – (a) Section View, (b) Elevation and Plan View, (c) Passive Pressure Assumptions, and (d) Example Calculation

The anchored and cantilever design methods can be used for soldier pile walls except that the passive resistance is developed by individual pile elements rather than a continuous wall. The passive earth resistance acting on individual soldier piles may be computed as shown in Figure 4-46. For fine-grained soils, a uniform resistance of $2 \cdot s_u$ can be used, neglecting the soil resistance to a depth of 1.5 times the shaft width, b, from the bottom of the excavation. For coarse-grained soils, the value of K_P should be determined without wall friction. The soil resistance should be ignored to a depth equal to b below the bottom of the excavation. Total resisting force accounts for arching between the piles and is computed by assuming the pile to have an effective width of $3b$ for all types of soils.

4-7.6 Secant Pile Walls and Tangent Pile Walls.

Secant and tangent pile walls are alternatives to sheet pile walls and soldier pile walls where greater lateral stiffness is required. As discussed in Section 2-4, the increased stiffness reduces vertical deformations at the ground surface adjacent to the wall. Neither secant nor tangent pile walls require the time-consuming lagging installation required for soldier pile walls.

Secant pile walls are constructed by installing primary and secondary concrete shafts that overlap (Figure 4-47). First, the primary shafts are drilled,[25] with the position of the shafts aligned by a template and the template controlling the distance between primary shafts. The concrete shafts are constructed without reinforcement. The secondary shafts are drilled between the primary piles such that they intersect the piles on both sides of the alignment. The secondary piles are reinforced with steel rebar cages or with steel beams (W sections). Secant pile walls have an additional benefit over sheet pile walls and soldier pile walls in that well-constructed secant pile walls provide a seepage barrier.

Tangent pile walls are constructed such that there is no overlap between piles (Figure 4-48). Ideally, the shafts are drilled such that they are tangent to the adjacent piles, but there is often a space between shafts. The shafts are reinforced with steel beams (I or W sections) or rebar cages. Tangent pile walls do not have the same seepage resistance as secant pile walls, since gaps are often present between piles. Also, clean sands may ravel or run between the piles in tangent pile walls.

Secant and tangent pile walls are often tied-back, especially when deformations outside of the excavation must be controlled or if the excavations are deep. Since controlling deformations is a key factor in the selection of secant and tangent pile walls, analysis procedures often are based on calculating deformations as opposed to determining

---

[25] In common geotechnical engineering nomenclature, piles are “driven” and shafts are “drilled.” However, the concrete shafts in tangent and secant pile walls are most often called “piles.”

stress limit states. Methods for estimating horizontal and vertical displacements behind these walls are provided in Section 2-4.4. Numerical methods that allow the use of constitutive models for soils, as well as interface elements to model soil-structure interaction, are frequently used in practice for the design of these types of walls.

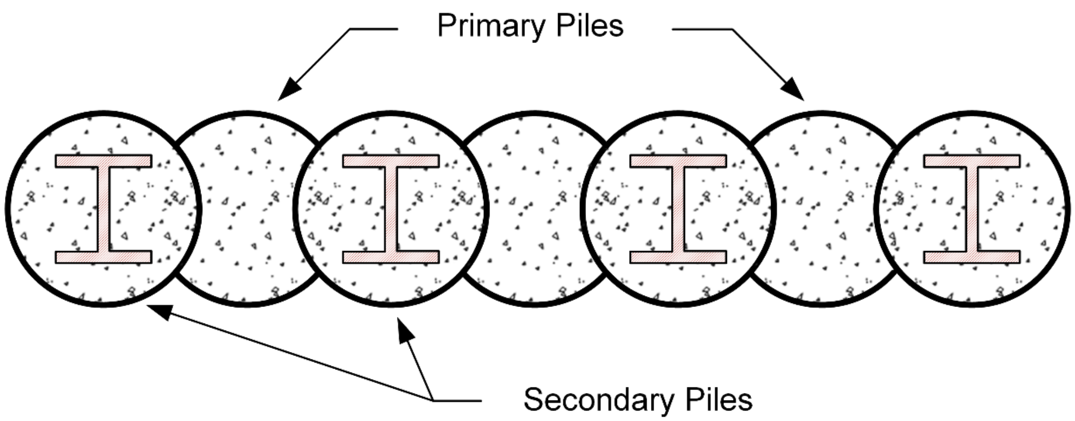


Figure 4-47 Plan View of Secant Pile Wall

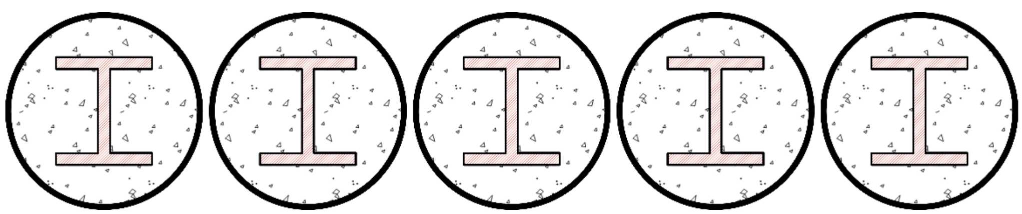


Figure 4-48 Plan View of Tangent Pile Wall

4-7.7 Soil Nail Walls.

Soil nailing is a method to create a reinforced soil mass for the purpose of long-term support of permanent excavations. Detailed design, construction, and inspection procedures for soil nail walls can be found in *Geotechnical Engineering Circular No. 7* (FHWA 2015).

Soil nail walls can be a cost-effective wall system for sites with limited right-of-way or overhead restrictions. The equipment used for constructing these types of walls is commonly available and limited in size, so these walls can be constructed at remote sites. This type of wall system also accommodates curves in the wall alignment better than other wall types.

A *soil nail* is commonly a steel reinforcing bar or steel tendon placed in a grout-filled hole. The reinforcing element acts passively, in that it is not post-tensioned. A soil-nail wall is constructed using a *top down* method where soil nails and shotcrete are installed as the excavation progresses. The nails are placed on a vertical spacing of 3 to 5 feet and a horizontal spacing of 4 to 6 feet. The soil nails are often oriented at 15 degrees below horizontal. Strip drains are typically installed at regular spacing between the nails to prevent water from collecting behind the facing. After the full depth of excavation is achieved, a final shotcrete or concrete facing is installed. A cross section of a soil nail wall is shown in Figure 4-49. The length of the soil nails is often around 70% of the height of the wall, but specific design cases may require longer or shorter nails.

Soil nail walls are best suited for soil deposits which can sustain vertical cuts of 4 to 6 feet for up to 48 hours to allow for the installation of the nails. In addition, it is desired that the drill holes remain open during the tendon installation and grouting. Soil deposits that have proven appropriate for soil nail wall construction include dense granular soils, weathered rock, stiff fine-grained soils, stiff residual soils, and some glacial tills. Adverse soil conditions include dry, uniform, granular soils, pervious soils with high phreatic surfaces, soils with cobbles and boulders, and soft organic and inorganic fine-grained soil.

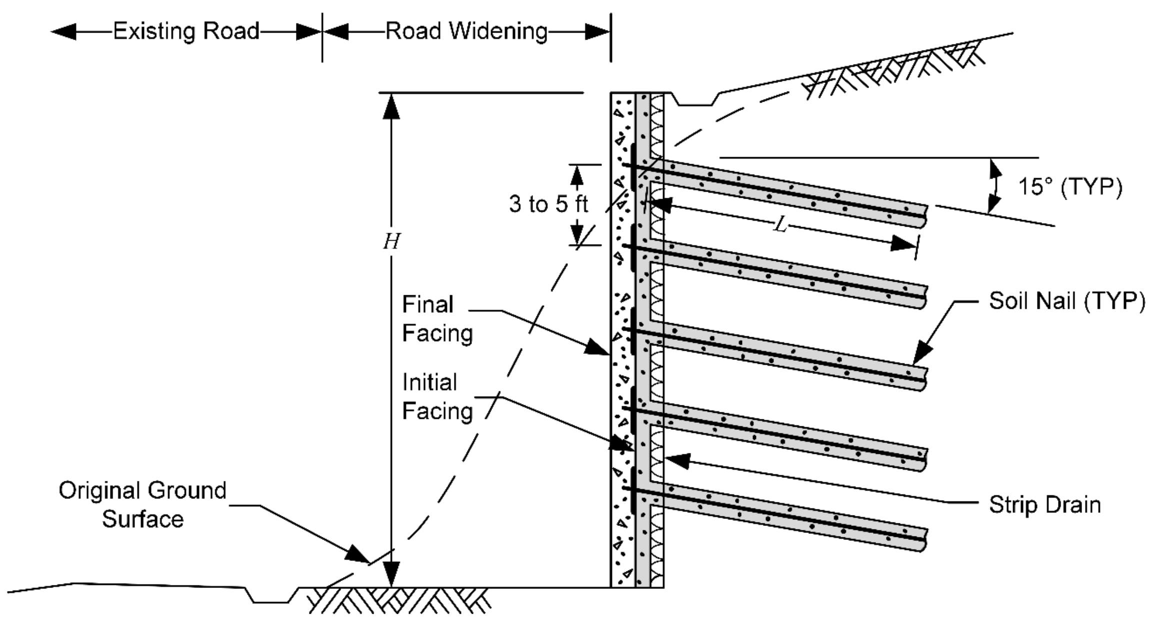


Figure 4-49 Cross Section of a Typical Soil Nail Wall (after FHWA 2015)

Soil nail walls are designed for long-term support; therefore, drained shear strength parameters are normally required for design.[26] For walls constructed to support stiff, overconsolidated soils, fully softened strengths obtained from triaxial or direct shear

[26] For walls constructed in weaker saturated fine-grained soils, it may be prudent to determine undrained strengths to assess if the unsupported slope is stable during excavation for the depth of the excavation stage. Undrained strengths might also be necessary for basal heave calculations (Section 2-4.3.3).

tests would be more appropriate than peak shear strengths. Since soil nail walls are often constructed to support granular soils, the results of *in situ* tests, such as the SPT or CPT, are often used to estimate the drained friction angle.

The design of soil nail walls is quite complex, and computer programs are normally used in practice. There are many potential failure modes, and a summary of these is shown in Figure 4-50. Earth pressures, in a classic sense, are not calculated per se, but stability is assessed based on limit equilibrium procedures, similar to that used in slope stability analyses.[27] Both internal and external stability are assessed. For internal stability assessment, a variety of slip surfaces are examined as the depth of the excavation proceeds. Failure surfaces are analyzed for slip surfaces intersecting the soil nails and for slip surfaces extending past the stabilized zone. Computer programs developed specifically for soil nail walls are available for these types of analyses. External stability is assessed assuming that the failure mass includes the entire area of reinforcement, and conventional slope stability computer software can be used.

Compared to conventional retaining wall analysis, there are many additional parameters necessary to assess the stability of a soil nail wall. These include nail pullout resistance and tendon tensile strength, along with many factors associated with the wall facing failure modes. Detailed examples for the design and analysis of soil nail walls, along with recommended factors of safety, are given in FHWA (2015).

4-8 EXCAVATION SUPPORT.

Flexible retaining structures are an important part of excavation design, which has been discussed in detail in Chapter 2. In many cases, the retaining walls for excavations must supported, either internally or externally. Determining the forces that act on the support system elements is an important part of the excavation design. The interaction between the wall, soil, and support system makes the forces quite complex. The forces depend on the rate of construction, the distance between supports, the installation quality, etc. The earth pressure distributions were based largely on case history measurements from instrumented excavations and are presented in the following section. These pressure distributions are then used to determine the forces that must be resisted by internal or external support.

[27] If basal sliding is deemed a possible failure mechanism, then active earth pressures determined using the Coulomb method can be used along with the conventional analysis of sliding stability of retaining walls (Section 4-5.1.3).

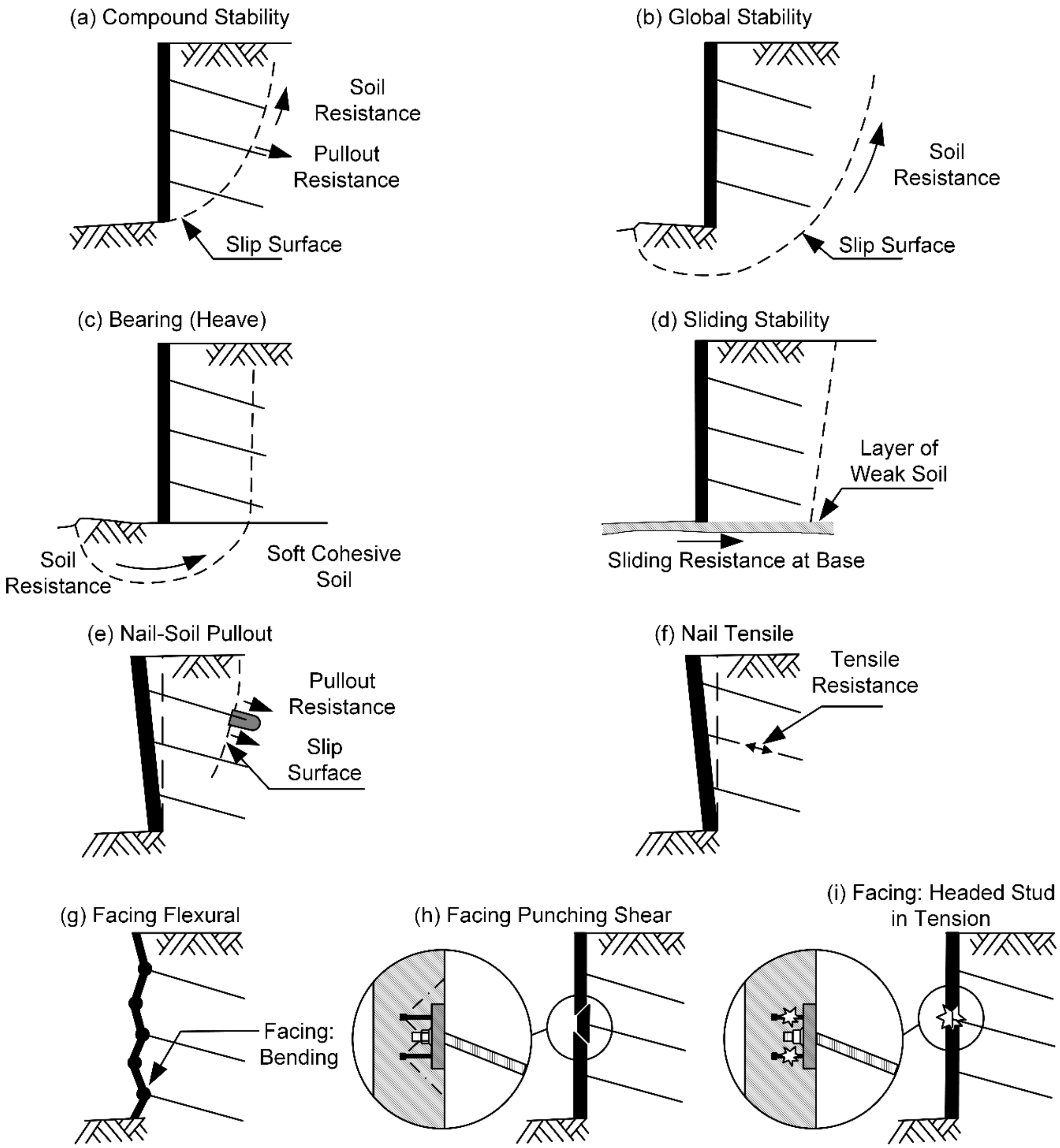


Figure 4-50 Potential Failure Modes of Soil Nail Walls (after FHWA 2015)

4-8.1 Apparent Earth Pressure Diagrams.

Earth pressures for supported flexible retaining structures have been semi-empirically determined based on measured support loads on engineering projects. The pressure diagrams were drawn to encompass the measured earth pressures, and actual pressures are likely lower than those shown. They are referred to as *apparent earth pressure* diagrams because of this semi-empirical basis. However, the diagrams have a basis in earth pressure theory in that the peak pressures are calculated with values of the active earth pressure coefficient, K_A. The shape of the diagrams depends on the vertical location of support force application (struts or anchors). Apparent pressure diagrams are used for the design of internally- and externally-supported excavations, which will be discussed later in this section.

The apparent earth pressure diagrams are provided in Figure 4-51 through Figure 4-53. The magnitude and shape of the diagrams depend on the soil type. One set of apparent earth pressure diagrams has been historically used for internally braced support systems (Terzaghi and Peck 1967). A different set of pressure diagrams was developed for externally supported systems (FHWA 1999). These diagrams were developed because of differences in when the supports are installed, the amount of displacement that can occur prior to support installation, and the magnitude of the preload applied to the support elements. It is up to the judgement of the design engineer to decide if the FHWA (1999) apparent earth pressure diagrams should be used for both internally- and externally-braced support structures, particularly when the struts are preloaded for excavation bracing.

The horizontal strut force, represented as T on the apparent earth pressure diagrams, is determined by using the earth pressure distribution in one of two different ways: (1) tributary area and (2) hinge method. For the tributary area method, the load on each strut is calculated using the assumption that a strut carries the pressures existing from one-half the vertical distance to the strut above to one-half the vertical distance to the strut below. The hinge method is based on summing moments about strut locations (e.g., “hinges” where moment = 0) to calculate specific strut loads.

In general, the apparent pressure diagrams were developed for fairly deep (> 20 ft) excavations that are relatively wide.

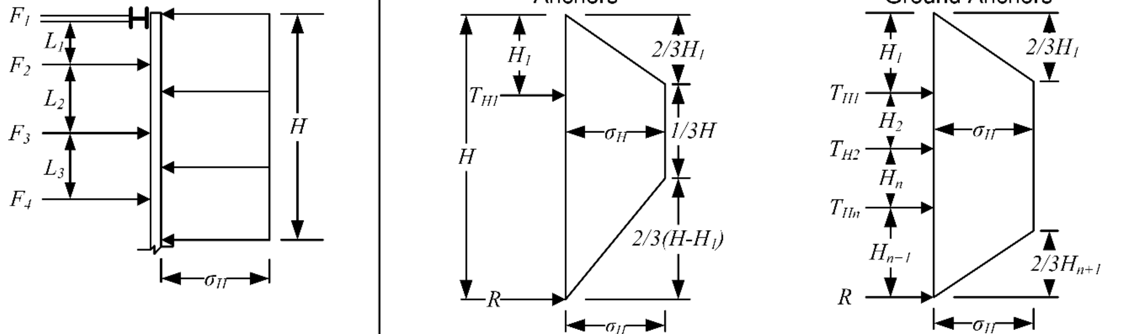
4-8.2 Stability of Base of Excavations.

The stability of the base of excavations is very important in that it is a potential failure mechanism for cuts. In addition, the base stability can also influence the earth pressure applied to the wall. Section 2-4.3 provides information regarding the basal stability of excavations.

4-8.3 Internal Support (Excavation Bracing).

Internal support or excavation bracing refers to support systems that are inside of the excavation, such as cross-lot braces or rakers (Figure 2-6). Once the support loads are predicted, the design of internal support is primarily a structural engineering task.

Internally Supported	Externally Supported	
	Walls with One Level of Ground Anchors	Walls with Multiple Levels of Ground Anchors



$$\sigma_H = 0.65 \cdot K_A \cdot \gamma \cdot H$$

$$K_A = \tan^2\left(45 - \phi'/2\right)$$

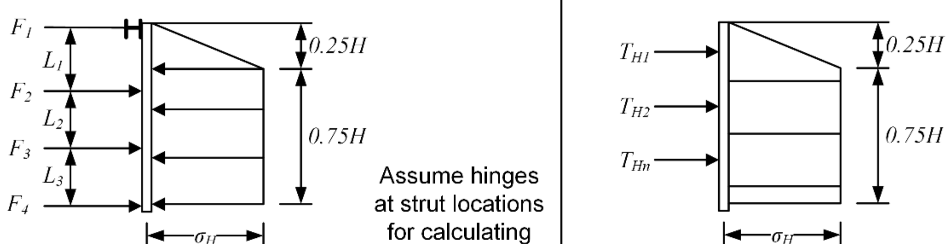
$$\sigma_H = \frac{0.65K_A \cdot \gamma \cdot H^2}{2/3 \cdot H} \approx K_A \cdot \gamma \cdot H$$

$$\sigma_H = \frac{0.65K_A \cdot \gamma \cdot H^2}{H - 1/3 \cdot H_1 - 1/3 \cdot H_{n-1}}$$

H_1 = Distance from Ground Surface to Uppermost Ground Anchor
H_{n+1} = Distance from Base of Excavation to Lowermost Ground Anchor
T_{Hi} = Horizontal Load in Ground Anchor i
R = Reaction Force to be Resisted by Subgrade (i.e., Below Base of Excavation)
σ_H = Maximum Ordinate of Diagram

Figure 4-51 Apparent Pressure Diagrams for Sands for Internally and Externally Supported Retaining Structures (Wolosick and Scott 2012; FHWA 1999).

Internally Supported	Externally Supported



Internally Supported

Assume hinges at strut locations for calculating strut forces.

Calculations:

$$N_0 = \frac{\gamma \cdot H}{s_u}$$

$$F_3 = \sigma_H \cdot \left(\frac{L_2}{2} + \frac{L_3}{2}\right)$$

$$\sigma_H = K_A \cdot \gamma \cdot H$$

$$K_A = 1 - m \cdot \frac{4s_u}{\gamma \cdot H}$$

Use m = 1 except where the cut is underlain by deep soft normally consolidated clay, then $m = 0.4F_{BH}$. F_{BH} is the factor of safety against bottom instability. See Section 2-4.3 for calculation methods.

Externally Supported

Requires competent layer for anchor bonding within reasonable depth.

Calculations:

$$N_0 = \frac{\gamma \cdot H}{s_u} > 4 \qquad \sigma_H = K_A \cdot \gamma \cdot H$$

For 4 < N_0 ≤ 5.14, use: $K_A = 0.22$

For N_0 ≥ 5.14, use:

$$K_A = 1 - \frac{4s_u}{\gamma \cdot H} + 2\sqrt{2}\frac{d}{H}\left(1 - \frac{5.14s_{u,b}}{\gamma \cdot H}\right)$$

where:
d = depth of the failure surface below the cut (depth to firm layer)
s_u = undrained strength of soil for depth of excavation
s_{ub} = undrained strength below excavation to firm layer

Figure 4-52 Apparent Pressure Diagrams for Soft to Medium Clay for Internally- and Externally-Supported Structures (Wolosick and Scott 2012; FHWA 1999)

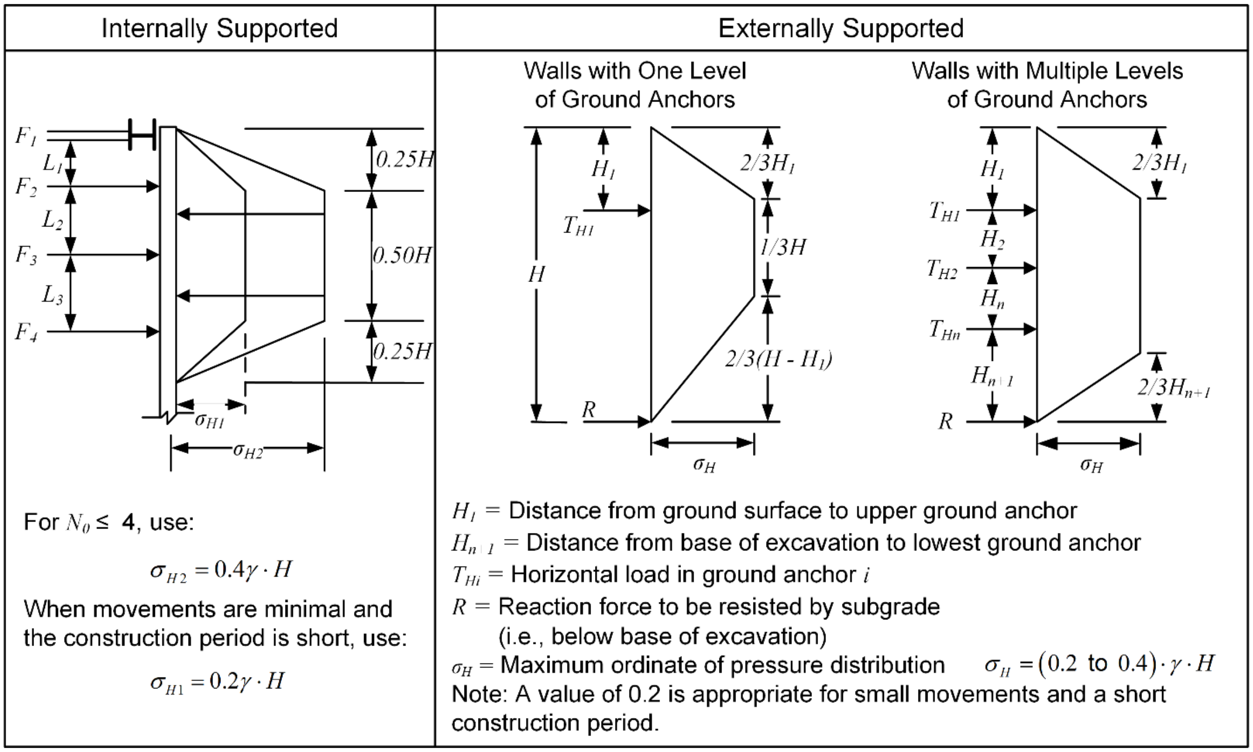


Figure 4-53 Apparent Pressure Diagrams for Stiff Clay for Internally and Externally Supported Structures (Wolosick and Scott 2012; FWHA 1999).

4-8.3.1 Internally-Braced Narrow Excavations.

Special design procedures are applied for narrow braced excavations. The design steps for a narrow cut supported by a flexible wall are shown in Figure 4-54. The appropriate apparent earth pressure diagrams are used to determine the pressure distribution above the excavation depth. The unbalanced water pressures need to be considered if the retained water table is above the base of the excavation. An example for this type of design is presented in Figure 4-55.

The basic procedure for the design of walls for narrow cuts is as follows:

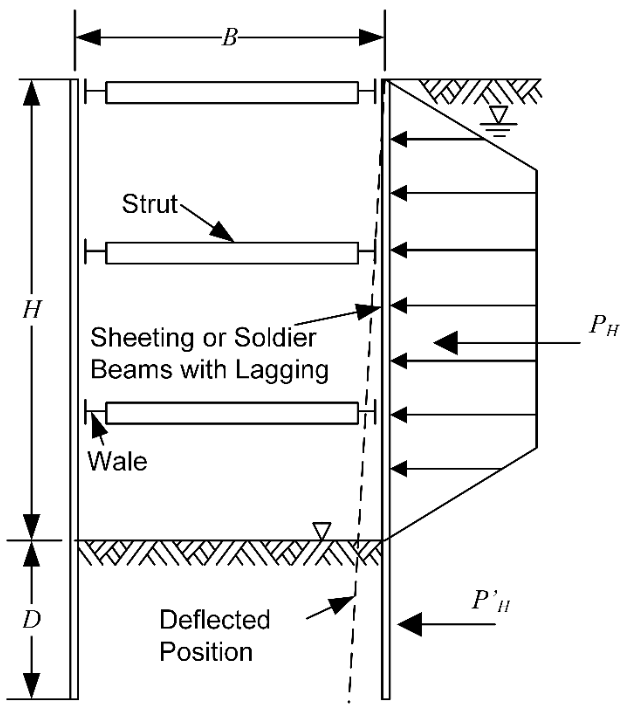
1) Calculate the factor of safety for base stability using the procedures shown in Section 2-4.3.

2) Compute the strut forces as outlined in Figure 4-54.

3) Compute the required section for the wall and wale. In computing the required wall section, arching could be accounted for by reducing the pressures in all but the upper span. A reduction of 80% of the values shown is appropriate.

4) Recompute the strut forces and the required sections of the wall and wales using active earth pressures at each stage instead of the active earth pressure diagrams (similar to Figure 4-56).

5) Compare the strut forces and required sections computed in Step 4 to Step 3, and select the larger force or section for design.



Soil Properties
γ, ϕ', or s_u

Use apparent earth pressure diagrams to determine P_H and strut forces.

Force on buried length, P'_H:

If $D > (\sqrt{2} \cdot B)/3$:

$$P'_H = 0.7\left(\gamma_T \cdot H \cdot B - 1.4 \cdot s_u \cdot H - \pi \cdot s_u \cdot B\right)$$

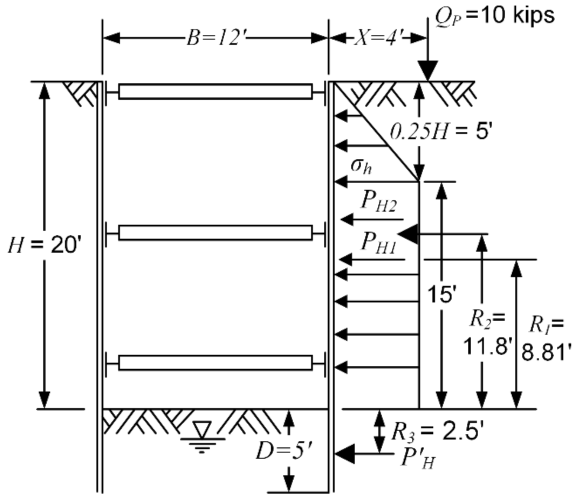
If $D < (\sqrt{2} \cdot B)/3$,

$$P'_H = 1.5D\left(\gamma_T \cdot H - 1.4 \cdot s_u \cdot (H/B) - \pi \cdot s_u\right)$$

Design Steps for a Narrow Cut

1. Compute pressures on wall above base of cut by methods of Figures 4-51 to 4-53. For saturated backfill, use $\gamma = \gamma'$ and add pressures for unbalanced water level. For water at base of cut, use total unit weight. Interpolate between these pressure diagrams for an intermediate water level.
2. Determine stability of base of cut by methods of Section 2-4.3.3. If the base is stable, the sheeting should penetrate several feet, and no force acts on the buried length. If the base is unstable (primarily a concern in clays), an unbalanced force, P'_H, acts on the buried length. In any case, penetration may be controlled by requirement for cut-off of underseepage.
3. Moments in sheeting braces are 80% of the simple span moments, except for the upper span where the moment equals the simple span moment. Moments in sheeting at the lowest strut are computed for the cantilever span below the lowest strut, including the unbalanced force P'_H.
4. Reactions at the braces are computed assuming simple span between braces.

Figure 4-54 Design Steps for Internally-Supported, Flexible Walls Used for a Narrow Excavation



<u>Given Conditions</u>
Excavation in silty clay with deep underlying normally consolidated clay:

$s_u = 400\,\text{psf},\ \phi = 0^\circ,\ \gamma = 120\,\text{pcf}$

Length of Excavation:

$L = 80'$

<u>Determine</u>:

- Stability of Base of Cut,
- Pressures on Wall, and
- Force on Buried Length of Sheeting.

<u>Stability of Base of Cut (See Section 2-4.3.3)</u>

- No uniform surcharge, q = 0
- $B_1 = 0.7\,B$ = 8.4 ft
- F_{SB} < 1.5 so drive sheeting below base of the excavation

$$F_{SB} = \frac{5.7(400\,psf)(8.4\,ft)+(400\,psf)(20\,ft)}{(120\,pcf)(20\,ft)(8.4\,ft)} = 1.35$$

<u>Pressure on Wall from Surrounding Soil</u>

- Use Soft to Medium Clay because N_0 = 6 (Figure 3-52)

$$N_0 = \frac{\gamma H}{s_u} = \frac{(120\,pcf)(20\,ft)}{400\,psf} = 6$$

- Determine m Coefficient

$$m = 0.4F_{SB} = 0.4(1.35) = 0.54$$

- Determine K_A

$$K_A = 1 - m\frac{4s_u}{\gamma H} = 1-(0.54)\left(\frac{4(400\,psf)}{(120\,pcf)(20\,ft)}\right) = 0.64$$

- Calculate Maximum Horizontal Stress

$$\sigma_h = K_A\gamma H = 0.64(0.12\,kcf)(20\,ft) = 1.54\,ksf$$

- Resultant Force, P_{H1}

$$P_{H1} = (15\,ft + 20\,ft)(1.54\,ksf)/2 = 27\,k/ft$$

- Resultant Location, R_1

$$R_1 = \left[(1.54)\left((5/2)(15+5/3)+(15)(15/2)\right)\right]/27 = 8.8\,ft$$

<u>Pressure on Wall from Surcharge Force (See Figure 4-18)</u>

- Relative Distance of Q_P from Wall

$$m = 4\,ft/20\,ft = 0.2$$

- Resultant Force, P_{H2}

$$P_{H2} = 0.80Q_P/H = 0.80(10\,kips/20\,ft) = 0.4\,kips$$

- Resultant Location, R_2

$$R_2 = 0.59H = 0.59(20\,ft) = 11.8\,ft$$

<u>Force on Buried Length of Sheeting (See Figure 4-54)</u>

- Buried Length: $D < \frac{\sqrt{2}}{3}B$

$$P'_H = 1.5D(\gamma_t H - (1.4s_u H)/B - \pi s_u)$$

$$P'_H = 1.5(5)((0.12)(20)-(1.4\cdot 0.4\cdot 20)/12 - \pi\cdot 0.4)$$

- Calculate Resultant Force, P'_H

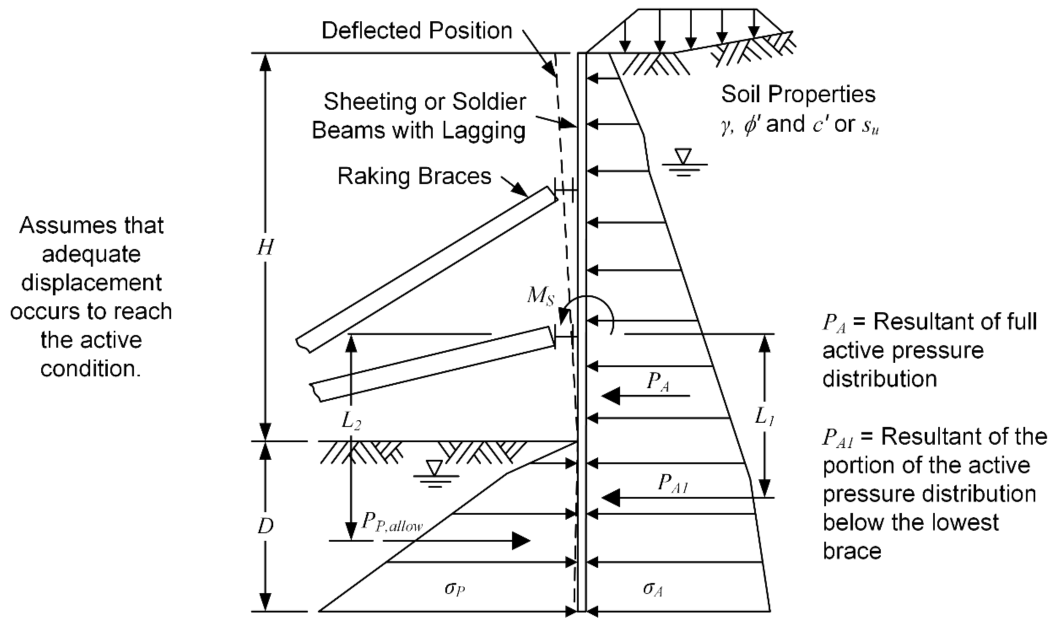
$$P'_H = 1.6\,kips$$

Note: All computations are per linear foot of wall.

Figure 4-55 Example of Excavation Bracing Analysis Procedure for a Narrow Cut in Fine-Grained Soil

4-8.3.2 Internally-Braced Excavations with Raking Braces.

When a wall is supported by raking braces, considerable displacement of the wall may occur prior to the installation of support elements. Figure 4-56 shows the earth pressure distribution on a flexible wall where wall displacements created an active earth pressure condition. This arrangement would be for temporary support. The unbalanced water load needs to be considered in this cross section.



Design Steps for Flexible Wall with Raking Braces

1. Compute active and passive pressures by methods in Sections 4-2 to 4-3. Passive pressures for clean, coarse-grained soils may include wall friction (for values of δ, see Table 4-1). Wall friction should be ignored for passive pressures in other soil types and for active pressures in all soils.
2. Maximum movements in sheeting and maximum loads in braces are usually obtained at the construction stage, when excavation for a brace and wale is complete and just prior to placing the brace. For each successive stage of excavation, compute sheeting moments and braces loads by assuming a simple span between the lowest brace in place and the point of zero net pressure below the excavation.
3. For temporary construction conditions, apply a factor of safety of 1.5 to compute passive pressures. To allow for possible construction surcharge and rigidity of the upper brace point, increase the load on the upper wale and brace by 15% of computed value.
4. Required penetration of sheeting below final subgrade elevation generally is controlled by conditions at completion of excavation. Penetration required is determined by equilibrium of the free ended span below the lowest brace. Assuming fixity at the lowest brace, the allowable moment in the sheeting (M_s) can be calculated as:

$$M_S = P_{A1} \cdot L_1 - P_{P,allow} \cdot L_2$$

5. Check positive moments in the span below the lowest brace for the final loading condition.

Figure 4-56 Design Steps for Flexible Wall Supported by Raking Braces (Rakers)

4-8.4 External Support (Tied Back Walls).

Tied back walls use external support, such as ground anchors, to provide stability and offer distinct advantages compared to internally-braced support systems. For excavation bracing, tied back walls keep the excavation open since the support elements are located outside of the excavation footprint. Tied back walls can be either temporary or permanent structures. The wall elements can be sheet piles, soldier beams and lagging, diaphragm walls, or other wall systems.

The FHWA Geotechnical Engineering Circular No. 4 (FHWA 1999) provides design details that can be applied to internally braced excavations. Many of the basic procedures shown for excavation bracing and anchored bulkheads are used for tied back walls. However, the anchors (tie-backs) can be installed earlier in wall construction. The anchors are preloaded and prevent significant displacement from occurring. For this reason, tied back wall design uses apparent earth pressure diagrams that are different than those used for internally supported excavation bracing. The apparent earth pressure diagrams for externally supported retaining structures are shown on the right side of Figure 4-51 through Figure 4-53.

For sands and stiff clays, the position of the top and bottom support must be known. The reaction force, R, is based on the passive resistance of the soil, and a factor of safety of 1.5 should be applied to this resistance. The depth of penetration, D, is selected to obtain the correct value of the passive resistance. A δ / ϕ' ratio equal to 0.5·to 1.0·can be used in the passive resistance calculation. Table 4-1 should be consulted for the value of δ. K_P should be obtained from Figure 4-12.

The design of tied back walls is complex, and a proper design consists of numerous steps. Compared to internally-braced excavations, externally-braced excavations have many additional elements that are geotechnical (as opposed to structural) in nature. FHWA (1999) outlines the individual steps, and these are given below:

1) Establish project requirements, including all geometry, external loading conditions (temporary and/or permanent, seismic, etc.), performance criteria, and construction constraints.

2) Evaluate site subsurface conditions and relevant properties of *in situ* soil and rock.

3) Evaluate design properties, establish design factors of safety or load and resistance factors, and select level of corrosion protection.

4) Select lateral earth pressure distribution acting on the back of the wall for final wall height. Add appropriate water, surcharge, and seismic pressures, and

evaluate total lateral pressure. A staged construction analysis may be required for walls constructed in marginal soils.

5) Calculate horizontal ground anchor loads and wall bending moments. Adjust vertical anchor locations until an optimum wall bending moment distribution is achieved.

6) Evaluate required anchor inclination based on right-of-way limitations, location of appropriate anchoring strata, and location of underground structures.

7) Resolve each horizontal anchor load into a vertical force component and a force along the anchor.

8) Evaluate horizontal spacing of anchors based on wall type. Calculate individual anchor loads.

9) Select type of ground anchor.

10) Evaluate vertical and lateral capacity of wall below excavation subgrade. Revise wall section if necessary.

11) Evaluate internal and external stability of anchored systems. Revise ground anchor geometry if necessary.

12) Estimate maximum lateral wall movements and ground surface settlements. Revise design if necessary.

13) Select lagging, if required. Design wales, facing drainage systems, and connection devices.

4-9 CELLULAR COFFERDAM DESIGN.

Cellular sheet pile cofferdams are structures constructed from sheet piles driven in a variety of geometries and filled with soil. Cofferdams perform many purposes, such as creating dewatered construction areas, lock walls, retaining structures, mooring structures, and spillway weirs.

Cofferdam geometries include circular cells, semicircular cells, and cloverleaf cells. These different configurations are shown in Figure 4-57(a). For hand calculations, these configurations are transformed into equivalent parallel wall cofferdams of width, B. The strict definition of B is that it is the width of a rectangular section that has a sectional modulus equivalent to that of the actual cofferdam cell. Since this can be a difficult calculation, approximate methods to calculate B for the different cofferdam cell configurations are shown on Figure 4-57(a).

Figure 4-57(b) shows a typical section used for cofferdam design. In some designs, there may be soil against the outboard face, and the berm may not be present on the inboard face.

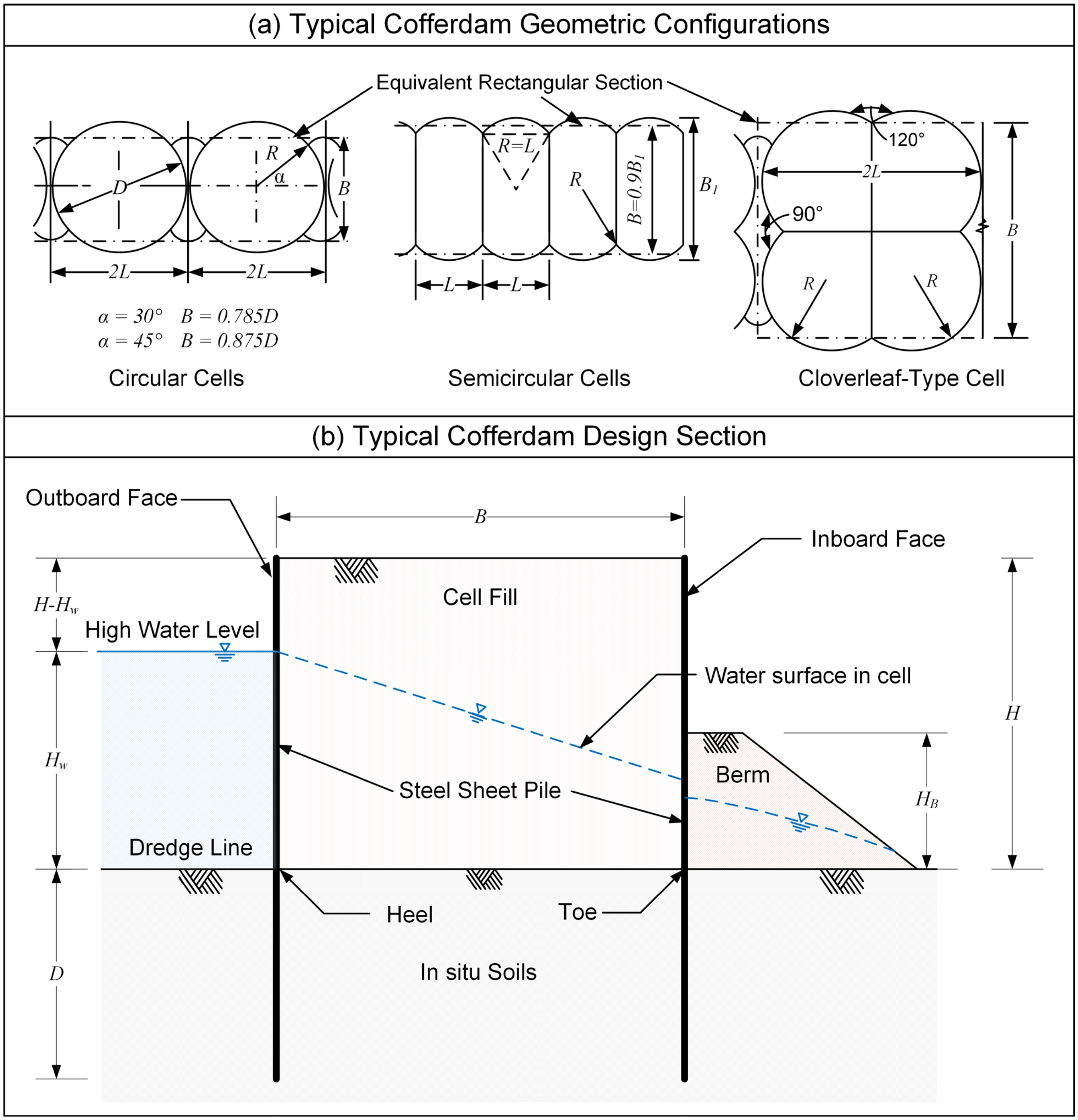


Figure 4-57 Geometry and Design Parameters for Cellular Cofferdams

Many factors must be considered in the design of cellular cofferdams. Because of the complexity involved in cofferdam design, numerical methods modeling soil-structure interaction are often used. The stability of cofferdams depends on ratio of the width to the height, the resistance of an inboard berm, if any, and the type and permeability of cell fill materials. Usually active and/or passive pressures act on exterior faces of the sheeting. The shear strength of the cofferdam fill material is a very important factor in the overall stability of cofferdams. Equally important is the line of saturation or phreatic surface in the cell fill. The position of the water surface or line of saturation in the cell fill is usually determined by the soil type used. For coarse-grained, free-draining fill, a slope of 1H:1V is assumed. For fine-grained, poorly-draining cell fill, a slope of 3H:1V is often used. In some cases, the line of saturation is assumed to extend from the outboard face of the cofferdam to the top elevation of the berm on the outside of the inboard face. The inboard ground surface or berm also may have an elevated phreatic surface, but the stabilizing effect of the inboard face water pressure is often ignored in design calculations (USS 1984; USACE 1989).

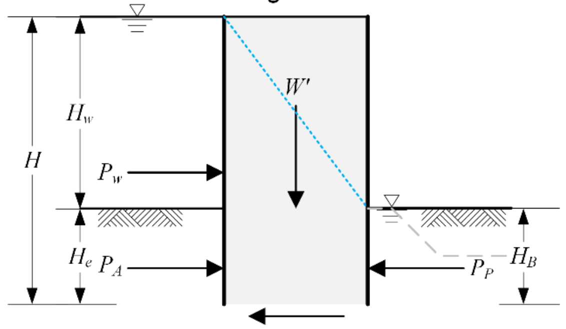
Many different loading cases and failure conditions are used to assess the stability and performance of cofferdams. The main loading conditions are: Case I – maximum pool conditions, Case II – initial filling conditions, and Case III – drawdown conditions (USACE 1989). For each of these loading conditions, the following modes of failure must be assessed:

- Sliding
- Overturning
- Rotation (Hansen method)
- Deep seated sliding
- Bearing capacity
- Settlement
- Seepage
- Interlock tension
- Vertical shear resistance (Terzaghi method)
- Horizontal shear resistance (Cummings method)
- Vertical shear resistance (Schroeder-Maitland method)
- Pullout of outboard sheets
- Penetration of inboard sheets

Some of the analysis methods, such as overturning, are very similar to those used for gravity retaining walls (Section 4-5.1). Other modes of failure are unique to cellular cofferdams and were developed specifically for the various modes of failure. Many of the failure modes employ earth pressure calculations outlined in this chapter, but the earth pressure coefficients, particularly for the cell fill material, lie between the active and passive pressure conditions used for other retaining structures. Table 4-7 outlines several failure modes and specifics of the analysis methods for cofferdams. Details regarding the stability of sheet pile cofferdams, along with solutions to example problems, can be found in the *USS Steel Sheet Piling Design Manual* (USS 1984) and the Corps of Engineers' EM 1100-2-2503 (USACE 1989).

Table 4-7 Modes of Failure and Design Details for Sheet Pile Cofferdams

<table>
<tr><th>Failure Mode</th><th>Design Guidance</th></tr>
<tr><td>
Sliding at Base

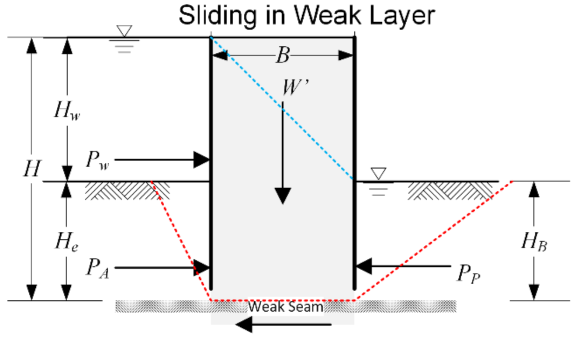


</td><td>

- Use $F \geq 1.25$ for temporary structures
- Use $F \geq 1.50$ for permanent structures

$$F = \frac{W' \tan \delta + P_P}{P_w + P_A}$$

where:
W' = effective weight of backfill
P_w = net water pressure force
δ = interface friction angle along bottom
= 0.5 for smooth rock = ϕ' for soil at base
</td></tr>
<tr><td>
Sliding in Weak Layer

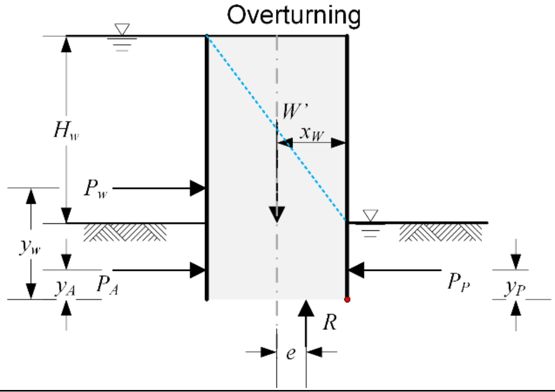


</td><td>

- Location of failure plane must be assumed
- Active and passive pressure calculated to top of weak seam
- W' includes soil beneath sheet piles to top of weak seam
- Use $F \geq 1.25$ for temporary structures
- Use $F \geq 1.50$ for permanent structures

$$F = \frac{W' \tan \phi' + c' B + P_P}{P_w + P_A}$$

where:
ϕ' = effective stress friction angle of weak seam
c' = effective stress cohesion of weak seam
</td></tr>
<tr><td>
Overturning

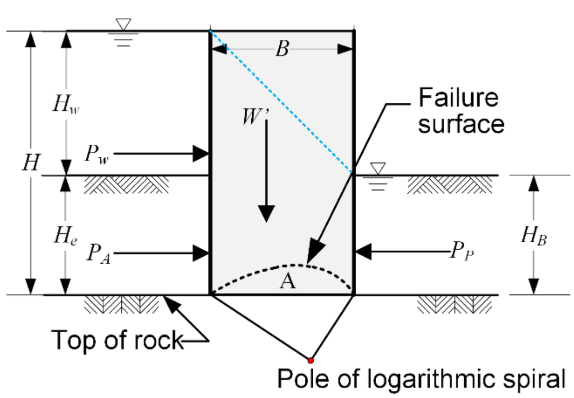


</td><td>

- Resultant force, R, must be located in the middle third of base
- Calculate eccentricity as:

$$e = \frac{P_w y_w + P_A y_A - P_P y_P}{W'} - x_W + \frac{B}{2}$$

- Maintain $|e| \leq B/6$
- Note: This is not a realistic failure mode owing to the flexibility of the cofferdam structure. Nonetheless, it is customary to still check the overturning mode in cofferdam design.
</td></tr>
<tr><td>
Rotation (Cofferdam on Rock)



</td><td>

- Failure is assumed to occur on a logarithmic spiral surface.
- W' calculated by removing the area (A) below the failure surface.
- Critical surface is found by trial and error or by locating the surface using the point of application of the W' and ΣP forces and the locus of poles of the logarithmic spiral function.
- Use $F \geq 1.25$ for temporary structures
- Use $F \geq 1.50$ for permanent structures

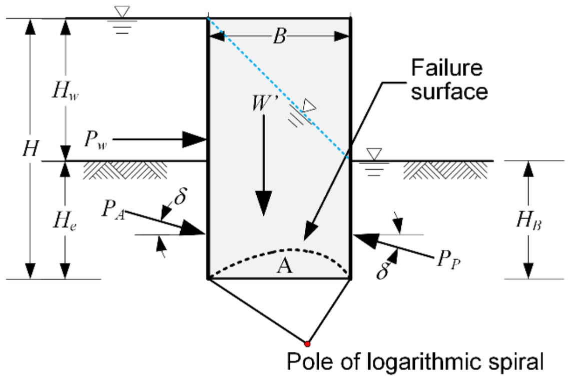
$$\sum P = P_W + P_A - P_P \quad \text{and} \quad F = \frac{M_B}{M_\omega}$$

where:
M_B = moment about pole for W'
M_ω = moment about pole for ΣP
</td></tr>
</table>

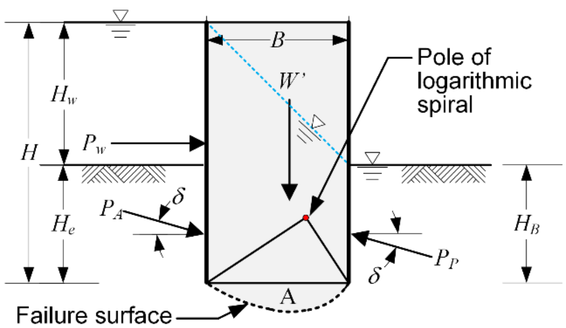
<table>
<tr><th>Failure Mode</th><th>Design Guidance</th></tr>
<tr><td>

Rotation (Cofferdam on Soil)

Failure Plane Outside of Cofferdam



Failure Plane Outside of Cofferdam



</td><td>

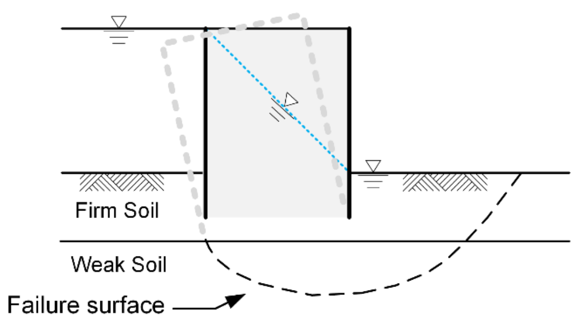
- Failure is assumed to occur on a logarithmic spiral surface. The surface may be located inside or outside of the cofferdam.
- The interface friction angle (δ) between the steel sheet pile and soil is often used in the analysis. Owing to the rotation of the cofferdam, the active and passive earth pressure forces are assumed to act in a reversed direction compared to conventional retaining wall analysis.
- Normally, only the horizontal component of the earth pressure force is used in the stability calculations.
- W' calculated by either adding or removing the area (A) depending if the pole is above or below the base of the cofferdam.
- The critical surface found by trial and error or by locating the surface using the point of application of the W' and ΣP forces and the locus of poles of the logarithmic spiral function.
- Use $F \geq 1.25$ for temporary structures.
- Use $F \geq 1.50$ for permanent structures.

$$\sum P = P_W + P_A - P_P \quad \text{and} \quad F = \frac{M_B}{M_\omega}$$

where:
M_B = moment about pole for W'
M_ω = moment about pole for ΣP

</td></tr>
<tr><td>

Bearing Capacity

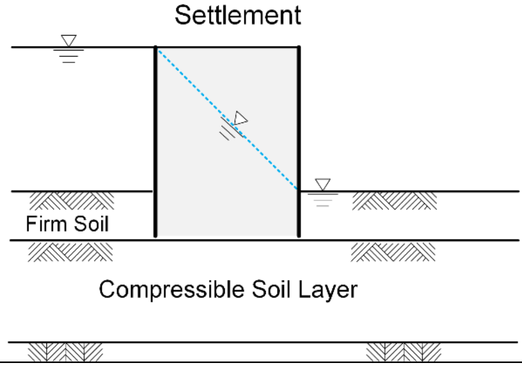


</td><td>

- Seepage into the cofferdam can affect bearing capacity.
- Bearing capacity analysis performed in addition to rotational failure analysis.
- Bearing capacity methods presented in Chapter 5 should be applied to cofferdam analysis.
- Use $F \geq 2.0$ for cofferdams founded on sand (permanent and temporary).
- Use $F \geq 3.0$ for cofferdams founded on clay (permanent and temporary).

</td></tr>
<tr><td>

Settlement

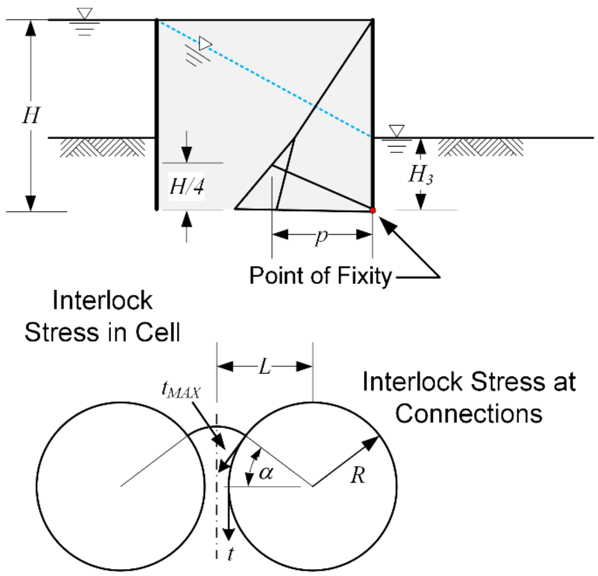
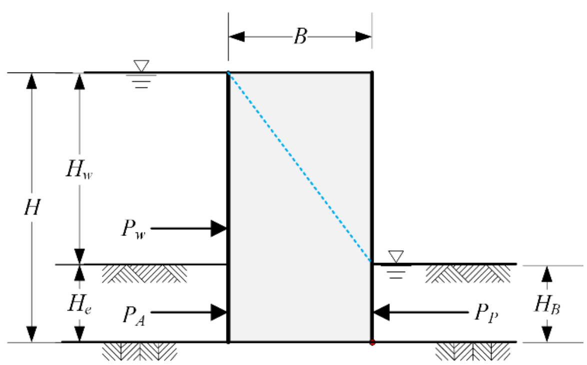
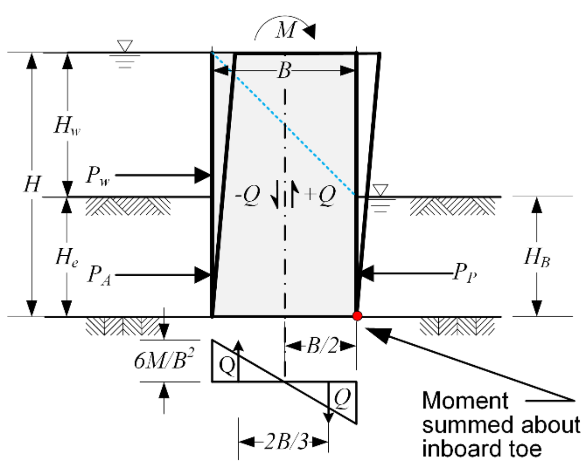


</td><td>

- Settlement of soil beneath cofferdam can increase tilt, which can increase the moment for overturning.
- Stress distribution varies both horizontally and vertically.
- Stress distributions can be estimated using elastic theory influence charts (See DM7.1, Chapter 4).
- Calculation of consolidation settlement should be performed using procedures presented in DM7.1 (Chapter 5).

</td></tr>
</table>

Table 4-7 Modes of failure and design details for sheet pile cofferdams (cont.)

Failure Mode	Design Guidance
Sheet Pile Interlock Tension  	• Pressure caused by cell fill should not cause the allowable sheet pile interlock tension to be exceeded. • Critical horizontal pressure assumed to occur at $H/4$ above the point of fixity. Alternatively, the earth pressure can be calculated at the top elevation of the inboard berm. • Use $F \geq$ 2 to 4. $F = \frac{\text{Manufacturer's reported interlock strength}}{\text{Computed interlock tension}}$ • For the main cell, the maximum inboard sheeting pressure (p) and maximum interlock tension (t_{max} in lbs per linear inch) can be found as: $p = K_A\left(\gamma(H - H_3) + \gamma'\left(H_3 - H/4\right)\right) + \gamma_w\left(H_3 - H/4\right)$ $t = p \cdot R$ where: K_A = 0.4 R = cell radius • For connections between the main cell and connecting arcs: $t_{max} = p \cdot L \cdot \sec\alpha$
Slippage between Sheeting and Cell Fill  	• Outboard sheet piles can lift out due to applied moment, and cell fill can be lost. • Shear occurs between fill and sheet piles. • F is the resisting moment due to friction on outboard piling divided by the overturning moment due to earth and water pressures. • Use $F \geq$ 1.5 for permanent structures. $F = \frac{3B(P_W + P_A)\tan\delta + P_P H_B}{P_W H + P_A H_e}$
Shear Failure on Centerline of Cell  	• Tilting can cause excessive shear on a vertical plane through the centerline of the cofferdam fill. • The shear resistance of the cofferdam cell fill and the frictional resistance of the sheet pile interlocks must exceed the applied shear stress due to the overturning forces. • Use $F \geq$ 1.5 for permanent structures. • The earth pressure coefficient used to calculate the shear resistance at the centerline is greater than the active earth pressure coefficient. • The total shear force (Q) is found as: $Q = \frac{3M}{2B}$ where: M = net overturning moment.

4-9.1 Cell Deformations.

The maximum bulging of cells occurs at about one-quarter of the height above the base of the cofferdam. Deflections under the lateral overturning loads are a function of the dimensions, the foundation support, and the properties of the cell fill (Brown 1963).

4-9.2 Cell Fill.

Clean, coarse-grained, free-draining soils are preferred for cell fill. They may be placed hydraulically or dumped through water without compaction or special drainage. Clean granular fill materials should be used in large and critical cells. A thorough study of alternatives should made before accepting fine-grained backfill. Fine-grained soils produce high bursting pressures and minimum cell rigidity. Their use may necessitate interior berms, increased cell width, or possibly consolidation by sand drains or pumping within the cell. All soft material trapped within the cells must be removed before filling.

4-9.3 Cofferdam Drainage.

Weep holes should be installed on inboard sheeting to the cell fill. For critical cells and cells with marginal fill material, supplementary drainage by well points, or wells within cells, have been used to increase cell stability.

4-9.3.1 Cofferdam Retardation of Corrosion.

When cofferdams are used as permanent structures, particularly in brackish water or seawater, severe corrosion occurs from top of the splash zone to a point just below mean low water level. Use protective coatings, corrosion resistant steel, and/or cathodic protection in these areas.

4-10 PROBLEM SOILS AND RETAINING WALLS.

Chapter 1 provides a summary of many types of problem soil conditions that can affect the design of foundations and earth structures. Table 4-8 summarizes important conditions for the design of retaining walls in problem soils.

Table 4-8 Problem Soil Considerations for Retaining Structures

Soil Type	Primary Considerations for Retaining Structures

Soft Clays	• Flexible walls built in soft clays will experience relatively high apparent earth pressures and must consider basal stability.
	• Walls founded in soft clays may experience problematic settlement
	  ○ Consolidation settlement of gravity and MSE structures built over soft clays should be determined using approaches in Chapter 5 of DM 7.1.
	  ○ Flexible walls can settle as a result of the downward components of the lateral pressure and any ground anchor forces. Soldier pile walls are especially susceptible, because the downward forces are concentrated at the soldier piles.

High Plasticity Expansive Clays	• Earth pressures for permanent walls retaining high plasticity soils should be determined using fully softened shear strength parameters.
Loess and Other Collapsible Soils	• In an undisturbed condition, earth pressures from these soils may be very low due to cementation of particles. However, collapse on wetting will increase earth pressures. • Any measured cohesion intercept should be ignored in the calculation of earth pressure.
Sensitive Clays	• Retaining structures in sensitive clays should minimize disturbance. Vibrations may be problematic. • Avoid local concentrations of shear stress from temporary steep slopes or open excavations.
Loose Sands	• Select methods that do not require an open excavation or exposed vertical face, particularly if the groundwater level is high. • Retaining wall construction methods that induce vibrations may cause settlement.
Glacial Till	• Construction of some times of wall can be difficult in glacial till as a result of the presence of cobbles and boulders.
Organic Soils, Peat, and Muskeg	• Low undrained shear strength may be present. • Passive resistance will be low because of low unit weight. • Wall settlement may be a concern.
Dredged Soils	• Similar considerations to soft clays and loose sands, depending on the soil composition.
Low Plasticity and Nonplastic Silts	• May be susceptible to “running” or fluid-like behavior, if below the groundwater level. • Construction methods that require open excavation may be difficult, if saturated.
Municipal Solid Waste	• Earth pressures may be difficult to characterize accurately. • Cut walls that require installation of vertical structural elements may encounter obstruction in the waste.

4-11 NOTATION.

Variable	Definition
c'	Effective stress cohesion intercept
C_a	Adhesion
E	Young’s modulus
F	Factor of safety
F_{OT}	Factor of safety against overturning
F_{SL}	Factor of safety against sliding
I	Moment of inertia
K_{AE}	Seismic active earth pressure coefficient

Variable	Definition
K_0	At-rest earth pressure coefficient
K_A	Active earth pressure coefficient
k_h	Horizontal ground acceleration
K_P	Passive earth pressure coefficient
k_v	Vertical ground acceleration
m	Parameter used to determine influence factors for stresss from applied loads
M_{Design}	Maximum moment used for design of cantilever cut walls
M_{max}	Maximum moment calculated for cantilever cut walls
n	Parameter used to determine influence factors for stresss from applied loads
OCR	Overconsolidation ratio
p	Earth pressure on the inboard side of a cofferdam
P_A	Resultant force from active earth pressure
P_{AE}	Seismic active earth pressure force
P_H	Resultant force from the horizontal component of earth pressure
P_N	Resultant normal force from earth pressure
P_P	Resultant force from passive earth pressure
$P_{P,allow}$	Allowable resultant force from passive earth pressure after applying a factor of safety
P_T	Resultant shear force from earth pressure
P_v	Resultant force from the vertical component of earth pressure
p_w	Hydrodynamic water pressure
P_w	Resultant force from water pressure
P_{wA}	Resultant force from water pressure on the active side of a wall
P_{wP}	Resultant force from water pressure on the passive side of a wall
q	Uniform surcharge pressure behind a retaining structure
q	Compaction pressure of a vibratory plate tamper
q	Compaction pressure of a rammer plate
$\bar{q}$	Compaction pressure from a roller
q_{max}	Maximum pressure below an eccentrically loaded retaining foundation

Variable	Definition
q_{min}	Minimum pressure below an eccentrically loaded retaining foundation
Q_p	Point load
r_u	Pore pressure coefficient
s_u	Undrained shear strength
$s_{u,F}$	Undrained shear strength with applied factor of safety
t_{max}	Maximum interlock tension for sheet piles in cofferdams
u	Water pressure
U	Resultant force from water pressure
Y	Horizontal displacement of wall
z	Depth below ground surface
$\alpha_A,\ \alpha_P$	Acute angle between critical Coulomb failure plane and vertical
β	Slope of inclined backfill
δ	Interface friction angle
ΔP_{AE}	Increase in resultant active earth pressure force caused by seismic loading
ΔP_A	Change in resultant active earth pressure force caused by seepage
ΔP_P	Change in resultant passive earth pressure force caused by seepage
ϕ	Total stress friction angle
ϕ'	Effective stress friction angle
ϕ'_{allow}	Allowable effective stress friction angle
γ	Total or moist unit weight
γ_b	Bouyant unit weight
γ_{eq}	Equivalent fluid unit weight
γ_{sat}	Saturated total unit weight
ρ	Flexibility number
σ'_h	Effective horizontal stress
$\sigma'_{H\theta}$	Increase in horizontal stress as a function of the location with respect to an applied load
σ'_z	Effective vertical stress
θ	Angle of the wall face on the retained side

Variable	Definition
θ_P	Obtuse angle between critical Coulomb failure plane and vertical
ψ	Horizontal acceleration angle for seismic loading

4-12 SUGGESTED READING

Topic	Reference
Anchored Bulkheads	United States Steel (USS). 1984. *Steel Sheet Piling Design Manual.*
Apparent Earth Pressures Ground Anchors Soil Nail Walls	FHWA. 1999. *Ground Anchors and Anchored Systems. Geotechnical Engineering Circular No. 4. Publication FHWA-IF-99-015*. Federal Highway Administration, Washington, D.C.
Mechanically Stabilized Earth Walls	FHWA. 2009. *Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volumes I and II, FHWA-NHI-10-024 and FHWA-NHI-10-025.* Federal Highway Administration, Washington, D.C.
Cofferdams	USACE. 1989. *Design of Sheet Pile Cellular Structures, Cofferdams, and Retaining Structures, EM 1110-2-2503.* Department of the Army, CECW-EP, 186 pp.

This Page Intentionally Left Blank

CHAPTER 5. SHALLOW FOUNDATIONS

5-1 INTRODUCTION.

5-1.1 Scope.

This chapter describes design for shallow foundations, including presumptive and empirical methods, as well as those based on bearing capacity theory for soil and rock. Special loading conditions for shallow foundations are discussed, including the design of foundations and slabs below the groundwater level and resistance of uplift. This chapter also considers special soil conditions, such as foundations on engineered fill, foundations on expansive and collapsing soil and expansive rock, and foundations in other problem soils.

Shallow foundations can be defined as foundations with a depth to width (D/B) ratio less than about 5. *Spread* foundations[28] transfer structural loads to the soil or rock over a relatively wide area and are usually synonymous with shallow foundations. Another type of shallow foundation is a *mat* foundation, in which the weight of the structure is distributed across the entire footprint of the structure. Most shallow foundations are constructed from reinforced, cast-in-place concrete. The interface between the shallow foundation and the soil or rock is referred to as the *bearing surface* and is located at the *foundation bearing elevation*. The *bearing pressure* is the stress imposed on the bearing surface by the foundation.

The primary geotechnical task for shallow foundation design is to select an allowable bearing pressure. This pressure is then used to size the foundations to support the anticipated structural loads. The allowable bearing pressure depends on two factors. First, an adequate factor of safety against ultimate bearing capacity failure must be provided. This is a strength limit state. Second, the settlements caused by changes in stress from the shallow foundations must not exceed the tolerances of the structure. This is a serviceability limit state. For the majority of structures, the design of shallow foundations is controlled by settlement, which is discussed in Chapter 5 of DM 7.1.

This chapter assumes that field investigations have been performed using sufficient *in situ* and laboratory testing to define the soil and/or rock stratigraphy as well as the groundwater conditions. For shallow foundations, the investigation should extend below the depth at which the change in stress imposed by the foundations is negligible (see Chapters 4 and 5 of DM 7.1). The investigation should provide the parameters required for bearing capacity and settlement analysis. Chapter 2 of DM 7.1 provides further information on field exploration while laboratory testing is discussed in Chapter 3 of that volume.

[28] The terms *footer* and *footing* are common synonyms for shallow spread foundations.

5-1.2 Applications.

Shallow foundations may be used at locations where suitable bearing soils are present within a few feet below the structure, provided that the stresses imposed by the foundation do not create unacceptable settlements.

Where suitable bearing soils are underlain by more compressible soils with depth and settlements are unacceptable, either deep foundations (see Chapter 6), ground improvement methods (see Chapter 1), or temporary surcharging (Chapter 5 of DM 7.1) may be required to bypass or modify the compressible soils. In some cases, shallow foundations can still be used if the bearing capacity of the near surface soils can be improved to allow smaller footings with higher bearing pressures. Construction of high quality compacted structural fill may also allow higher bearing pressures. In both cases, smaller footings will reduce stress penetration, which may reduce settlements.

Where a relatively thin layer of unsuitable loose or soft soil is present near the ground surface, it may be possible to deepen spread footings to suitable soils. Alternatively, the unsuitable soils can be excavated and replaced with higher quality compacted structural fill.

Shallow foundations may also be supported on rock. Where both rock and soil are found at bearing grade in different areas of a building, differential settlements may be of concern as discussed in Section 5-2.4.1. Over excavation of rock and replacement with a soil cushion between rock and the foundation may be required to reduce differential settlement.

5-1.3 Design Philosophy.

Two design philosophies are used to prevent bearing capacity failure of shallow foundations. Allowable stress design determines the ultimate bearing capacity of the soil and applies a factor of safety to determine an allowable bearing pressure. Load and resistance factor design (LRFD) uses load factors to account for uncertainties in loading conditions and resistance factors to accommodate uncertainty in resistance. The basis of the LRFD approach is discussed in Section 7-4.5. Settlement analysis is typically performed using unfactored loads, removing any difference between the two approaches.

Allowable stress design, which will be used in this chapter, requires the selection of a factor of safety against bearing capacity failure. The appropriate factor of safety, F_{BC}, depends on the uncertainty of both the loading and the soil conditions, as well as the consequences of failure. Lower values of F_{BC} are appropriate for well-defined conditions and low consequences, while higher F_{BC} should be used for greater uncertainty and consequences. Typical values of F_{BC} are in the range of 2 to 3 when the bearing pressure is calculated using dead load and permanent live load. Mat and tank foundations may use a factor of safety of 1.7 to 2.5 for cases with sufficient field exploration. The lower factor of safety may be reduced by about one-third for cases with temporary or transient live load, such as earthquake, wind, and snow. UFC 3-220-01 (2021) contains additional information about factors of safety.

5-2 SHALLOW FOUNDATION DESIGN CONSIDERATIONS.

5-2.1 Foundation Depth.

In general, individual footings should be placed below: 1) the depth of frost penetration (see Chapter 1 of DM 7.1 for guidance or the National Oceanic and Atmospheric Adminstration website for site specific data), 2) zones of high volume change due to moisture fluctuations, and 3) scour depths for foundations in or adjacent to rivers and streams. Section 6-2.2.1 provides additional guidance for scour. Footings should extend to bear below organic materials, disturbed upper soils, uncontrolled fills, and zones of collapse-susceptible soils that are present. Alternatively, the unsuitable material should be removed and replaced with compacted structural fill.

Where other constraints do not control, shallow foundations on soil are typically embedded at least 12 to 18 inches. Some building codes specify minimum depth as a function of load.

5-2.2 Gross and Net Bearing Pressure.

The total load applied to the foundation bearing surface is the sum of the structural load (Q_{DL+LL}), the weight of the foundation (W_F), and the weight of any overlying soil (W_S). The *gross bearing pressure* applied to the soil by a shallow foundation is the total load divided by the area (A) of the bearing surface. The gross allowable bearing pressure is found as:

$$q_{gross} = \frac{Q_{DL+LL} + W_F + W_S}{A} \quad (5\text{-}1).$$

The net bearing pressure is sometimes used as a more convenient measure because it does not depend upon the weight of the foundation and overlying soil. The *net bearing pressure* is the gross bearing pressure minus the existing vertical overburden pressure at the foundation bearing elevation or:

$$q_{net} = q_{ult} - \sigma_{zD} \quad (5\text{-}2).$$

The unit weights of the foundation and soil backfill are typically assumed to be the same as the existing soil, which means that:

$$q_{net} = q_{gross} - \sigma_{zD} \approx \frac{Q_{DL+LL} + W_F + W_S}{A} - \frac{W_F + W_S}{A} = \frac{Q_{DL+LL}}{A} \quad (5\text{-}3).$$

Equation 5-3 defines the net bearing pressure only in terms of the structural load and foundation dimensions.

5-2.3 Eccentricity.

Shallow foundations may be eccentrically loaded by moments applied about one or both axes. The applied moments may be the result of either non-concentric vertical loading or directly applied to the foundation by the structure. The resulting eccentricity (e) is defined as the horiztonal distance between the resultant force on the bearing surface and the centerlines of the foundation.

Eccentricity is calculated as:

$$e = \frac{M}{Q} \quad (5\text{-}4)$$

where:
M = applied moment and
Q = gross vertical load on the footing.

For cases where non-concentric vertical loading causes eccentricity, the applied moment can be determined by summing moments about the centerline of the footing. Where the eccentric loading is not aligned with the axes of the foundation, it is convenient to split the eccentricity into two parts and calculate e_B and e_L from the respective moments, M_B and M_L. By convention, the width (B) is the shorter dimension of the foundation, and the length (L) is the longer dimension.

Eccentricity causes an uneven bearing pressure. If the eccentricity is too high, the bearing pressure will no longer be compressive under all of the foundation. In order to prevent this, the eccentricity must be limited for normal loading. For eccentricity in one direction, the resultant must be in the middle one-third of the foundation or:

$$|e_B| \le \frac{B}{6} \text{ or } |e_L| \le \frac{L}{6} \quad (5\text{-}5)$$

For cases with eccentricity in two directions, the resultant must fall within a diamond-shaped area in middle of the rectangular foundation called the *kern* and the following should be satisfied:

$$\frac{6|e_B|}{B} + \frac{6|e_L|}{L} \le 1 \quad (5\text{-}6).$$

If the eccentricity falls within these limits, the bearing pressure at the four corners of the rectangular foundation can be found as:

$$q_{corner} = q_{gross}\left(1 \pm \frac{6\left|e_B\right|}{B} \pm \frac{6\left|e_L\right|}{L}\right) \quad (5\text{-}7).$$

The maximum value, q_{max}, should be used for comparisons with ultimate bearing capacity for brittle materials such as sensitive soil and rock. For more ductile materials, it is appropriate to approximate the applied bearing pressure using the equivalent footing method (Meyerhof 1953). The *equivalent footing* is the bearing area on which the resultant bearing force is centered. The equivalent width (B') and length (L') are calculated as:

$$B' = B - 2e_B \quad (5\text{-}8)$$

and

$$L' = L - 2e_L \quad (5\text{-}9).$$

The equivalent uniform bearing pressure for a rectangular foundation can be found as:

$$q_{unif} = \frac{Q_{LL+DL} + W_F + W_S}{B' \cdot L'} \quad (5\text{-}10).$$

The conditions for two-way eccentricity for a rectangular foundation are summarized in Figure 5-1(a). The theoretical pressure distributions with solid lines are indicated along the four sides of the foundation. The equivalent dimensions and area are shown by the shaded rectangle. The dashed pressure distribution shows the equivalent uniform bearing pressure.

Circular footings can only have eccentricity in one direction as shown in Figure 5-1(b). The resultant is centered on the lens-shaped area circumscribed by the two arcs labeled $abcd$. The equivalent rectangular area is shaded. If the aspect ratio of the equivalent rectangle is the same as the circumscribed area, then the equivalent dimensions can be calculated as:

$$L' = \overline{a'b'} = \sqrt{\left[2r^2\cos^{-1}\left(\frac{e_x}{r}\right) - 2e_x\sqrt{r^2 - e_x^{\,2}}\right]\left(\frac{\sqrt{r^2 - e_x^{\,2}}}{r - e_x}\right)} \quad (5\text{-}11)$$

and

$$B' = \overline{b'c'} = L'\left(\frac{r - e_x}{\sqrt{r^2 - e_x^{\ 2}}}\right) \qquad (5\text{-}12)$$

where:
e_x = eccentricity and
r = radius of the foundation.
Note that the inverse cosine term in Eqn. 5-11 must be expressed in radians.

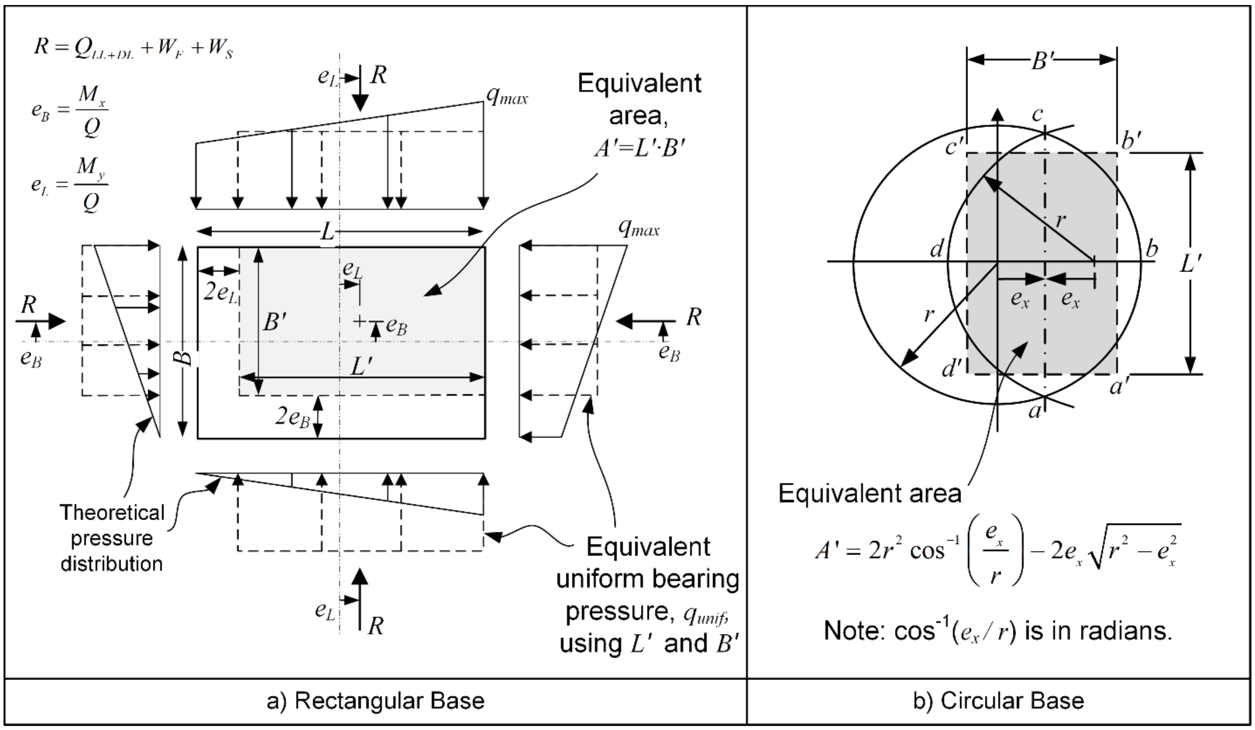


Figure 5-1 Eccentricity for (a) Rectangular Footing and (b) Circular Footing (after Bowles 1996)

5-2.4 Allowable Bearing Pressure.

The *allowable bearing pressure* (q_{all}) is the highest bearing pressure that meets the design requirements for both factored bearing capacity and settlement. In a general sense, the allowable bearing pressure can be determined using the following steps:

1) Calculate the ultimate bearing capacity (q_{ult}) using the methods in Section 5-3.

2) Apply an appropriate factor of safety (F_{BC}) to the ultimate bearing capacity. In some cases, it may be appropriate to start with a presumptive allowable bearing pressure from Section 5-2.5 rather than factoring a calculated bearing capacity.

   a. The gross allowable bearing pressure is found as:

$$q_{all,gross} = \frac{q_{ult}}{F_{BC}} \qquad (5\text{-}13).$$

b. The net allowable bearing pressure is found as (Peck et al. 1974):

$$q_{all,net} \le \frac{q_{ult}}{F_{BC}} - \sigma_{zD} \qquad (5\text{-}14).$$

3) Calculate settlement using foundations sized according to $q_{all,net}$.

a. If the total, differential, and distortion settlement criteria are met, then the net allowable bearing pressure from Equation 5-14 can be used and the design is controlled by the bearing capacity.

b. If not, reduce the bearing pressure until the settlement criteria are met. The reduced value is the net allowable bearing pressure that should be used for design. The design is controlled by settlement.

Once an allowable bearing pressure has been determined, it is compared to the calculated bearing pressure. Either net or gross pressures can be used, as appropriate. The foundation dimensions are adjusted to obtain an applied bearing pressure less than, but not greatly exceeding, the allowable value. This process is often iterative.

5-2.4.1 Settlement Considerations.

Settlement constraints govern the design of many shallow foundations and should be carefully considered prior to a comprehensive consideration of bearing capacity. Chapter 5 of DM 7.1 provides detailed instructions for settlement calculations. Some additional considerations specific to shallow foundations are considered in this section.

Some structures have widely varying column or wall loads that have the potential to cause problematic differential settlement. In this case, $q_{all,net}$ can be varied in attempt to equalize settlements. Often this requires using a lower bearing pressure and larger footings to support the heavier column loads. If the settlement prone soils are shallow, it may also be possible to increase the $q_{all,net}$ for the heavily loaded footings by excavating poor soils and replacing with high-quality compacted structural fill along an interior line of columns.

At some sites, the depth to rock varies widely and both rock and soil may be found at the bearing elevation. In this case, differential settlements will be a concern, because of the dissimilar settlement characteristics of soil and rock. The choice of an appropriate solution will be informed by both the extent of the dissimiliar bearing condition and the relative flexibility of the supported structure. One procedure that may be used to reduce differential settlement is to over excavate the rock where footings are located and backfill with compacted structural fill. The compacted structural fill should be designed to compress such that differential settlements are no longer a concern. Typically, the fill is clay placed with a lower relative compaction criterion, such as to 90 percent of maximum dry density. A thickness of one to two feet of this type of material will usually improve the differential settlement characteristics. The length of the transition zone required to mitigate differential settlement will depend on the flexibility of the structure. Section 5-6.1 further describes procedures for shallow foundations on fill.

Alternatively, a deepened footing can be reinforced as a grade beam that can allow the differential settlement to be distributed over a longer span. In other cases, it may be most economical to use shallow foundations bearing on rock for most of the structure along with deep foundations and grade beams at the locations where the rock is deeper.

5-2.4.2 Alternative Methods of Supporting Shallow Spread Foundations.

For sites with highly compressible soils, very low bearing pressures may be required to meet the settlement criteria. As the size of isolated foundations becomes large, the use of a mat foundation should be considered (see Section 5-4).

Other alternatives to individual shallow foundations are available. If stronger or less compressible soils are present, the foundation depth may be increased to reach suitable bearing soils. Another alternative is to excavate and replace unsuitable soils with compacted structural fill for individual column footings, or in strips along column lines. Turned down edge foundations integral with the floor slab may be used for lightly loaded structures. Many of the site improvement techniques discussed in Chapter 1 are suitable to improve bearing capacity and reduce settlement for shallow foundations. Some of these techniques work by transferring load to a suitable bearing stratum while others densify the soil, reducing settlement potential. Useful techniques for shallow foundations include rigid inclusion piers, aggregate piers, vibro-compaction, dynamic compaction, soil mixing methods, and preloading with or without wick drains to facilitate improved drainage.

5-2.5 Presumptive Allowable Bearing Pressure.

Presumptive bearing pressures are selected without formal calculation of bearing capacity and/or settlement. They are sometimes used to estimate allowable bearing pressures (q_{all}) for: 1) preliminary estimates for any project, 2) design values for lightly loaded structures, or 3) design values for foundations on rock materials where detailed analysis is unnecessary due to the relatively high bearing capacity of the rock. Presumptive bearing pressures should not be used for foundations on normally consolidated clays, organic soils, or uncontrolled fills.

Table 5-1 lists presumptive allowable bearing pressures for a variety of rock and soil types. These presumptive q_{all} values are intended to provide a reasonable safety factor against ultimate failure and to avoid detrimental total and differential settlements of individual footings for footings subjected to vertical loads. The effects of eccentricity on bearing pressure should be considered when using presumptive q_{all}. Presumptive q_{all} values for soils should be used with caution and verified by performance of nearby structures founded on similar density or consistency material. Bearing strata underlain by a weaker material can be considered using presumptive bearing pressures and the method illustrated in Figure 5-2.

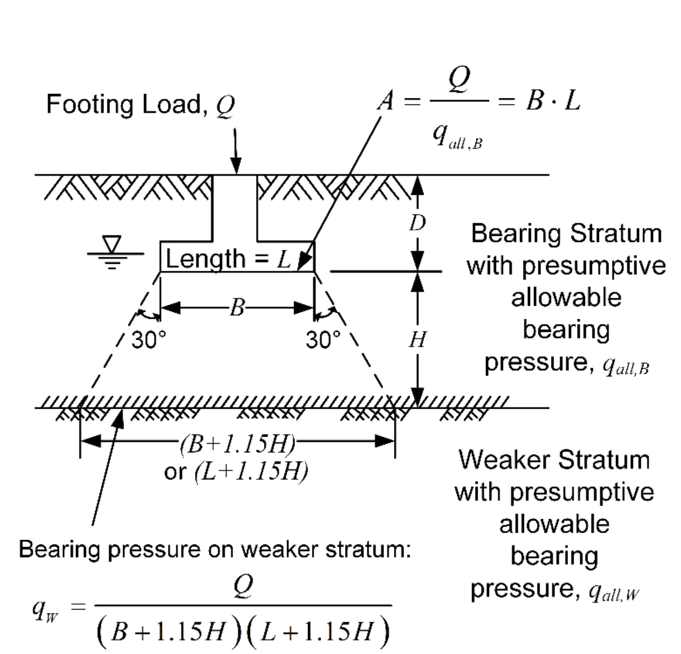
When presumptive q_{all} are used in lieu of bearing capacity analysis, it may still be appropriate to check settlement. The zones of induced stresses from adjacent foundations should not overlap within a depth of $2B$ below square footings or $4B$ below continuous footings because of settlement concerns. In order to accomplish this, lines projected downward from adjacent footings at angle of 30^{o} from the vertical should not intersect within these depths.

Table 5-1 Presumptive Allowable Bearing Pressures (B > 3 ft) (after NRCS 2022, Das 2022)

Type of Bearing Material	Rock or Soil Quality, Consistency, or Relative Density (RQD, UCS, or SPT N)	q_{all} (ksf)
Massive crystalline igneous/metamorphic rock: granite, diorite, basalt, gneiss, marble	Very hard, sound rock (RQD ≥ 75%) UCS = 1400 to 5200 ksf	160
Foliated metamorphic rock: slate, schist	Hard, sound rock (RQD ≥ 50%) UCS = 650 to 3600 ksf	70
Sedimentary rock; siltstone, sandstone, limestone without cavities	Moderately hard, sound rock (RQD ≥ 25%) UCS = 240 to 2800 ksf	40
Weathered rock of any kind, except highly argillaceous rock (shale)	Moderately soft, sound rock (RQD ≤ 25%) UCS = 110 to 800 ksf	20
Indurated clay; shale	Soft, unsound rock (RQD = 0% by definition) UCS = 20 to 800 ksf	10
Well graded gravel and sand mixtures with clay: glacial till, hardpan (GW-GC, GC)	Very dense (N > 50) Medium to dense (N = 10 to 50) Compacted ($R.C.$ ≥ 95% of D698)	8 5 5
Sand with gravel (SW-SC, SC)	Very dense (N > 50) Medium to dense (N = 10 to 50) Compacted ($R.C.$ ≥ 95% of D698) Very loose/Loose (N ≤ 10)	7 5 5 3
Sand, silty, or clayey (SW, SM, SC)	Very dense (N > 50) Medium to dense (N = 10 to 50) Compacted ($R.C.$ ≥ 95% of D698) Very loose/Loose (N ≤ 10)	5 4 4 2
Homogeneous inorganic lean or fat clay, sandy or gravelly (CL, CH)	Hard (N > 30) Stiff to very stiff (N = 8 to 30) Compacted ($R.C.$ ≥ 95% of D698) Soft to medium (N = 2 to 8)	6 3 3 1.5
Inorganic silt and elastic silt, sandy (ML, MH)	Very dense (N > 50) Medium to dense (N = 10 to 50) Very loose/Loose (N ≤ 10)	6 3 1.5

Notes:

- Definitions: RQD = Rock quality designation, UCS = Unconfined compressive strength
- Minimum bearing depth is 18 inches for foundations bearing on soil or soft rock.
- For foundations with width (B) < 3 ft, multiply q_{all} by (B / 3) with B in feet.
- Presumptive q_{all} for rock should not exceed 10% of the UCS, if measured.
- For foundations on soft rock or coarse-grained soil, increase presumptive q_{all} by 5% for each foot of depth below 18 inches.
- For foundations on moderately hard or better rock, increase presumptive q_{all} by 10% for each foot of depth below the ground surface.
- Presumptive q_{all} for compacted soil assumes relative compaction ($R.C.$) ≥ 95% based on ASTM D698, moisture content within 2% of optimum, and lift thickness ≤ 8 inches. Higher q_{all} may be appropriate for higher levels of relative compaction.
- Presumptive q_{all} for transient loads from wind or earthquakes.



Design process

- Estimate $q_{all,B}$ and $q_{all,W}$ from Table 5-1.
- Using the footing load, Q, and $q_{all,B}$, estimate the required footing dimensions, B and L.
- Estimate bearing pressure at top of weaker stratum, q_W.
- If $q_W \leq q_{all,W}$, the design is acceptable.
- If $q_W > q_{all,W}$, the footing dimensions must be increased to reduce the bearing pressure on the weaker stratum, q_W.
- Stresses for adjacent foundations should not overlap.

Figure 5-2 Presumptive Bearing Pressure for Weaker Layer Underlying Bearing Stratum

5-3 BEARING CAPACITY OF SOIL AND ROCK.

5-3.1 Bearing Capacity Theory.

The *ultimate bearing capacity* can be defined as the highest applied stress that the soil or rock withstands at the point of plastic failure. As developed by Terzaghi (1943), ultimate bearing capacity considers two types of failure.

General shear failure occurs along a well-defined failure surface below and beyond the edges of a footing as shown in Figure 5-3(a). The triangular Zone I under the footing in Figure 5-3 acts as though it is part of the footing, and the soil remains in an elastic state. For a vertical load, the major principal stress is aligned vertically in Zone I. In Zone III, the soil reaches a state of Rankine passive earth pressure with the major principal stress aligned horizontally. Zone II is known as the zone of radial shear, which allows the stress system to rotate between Zones I and III.

General shear failure normally occurs in a dense coarse-grained or very stiff cohesive soil. At failure, the soil on both sides of the footing bulges and the footing may rotate. A state of plastic equilibrium is reached in Zones II and III in this type of failure. General shear failure can be catastrophic for large mat supported structures although individual footings rarely experience this type of failure. Dense and very stiff soils generally experience relatively low settlements at typical allowable bearing pressures.

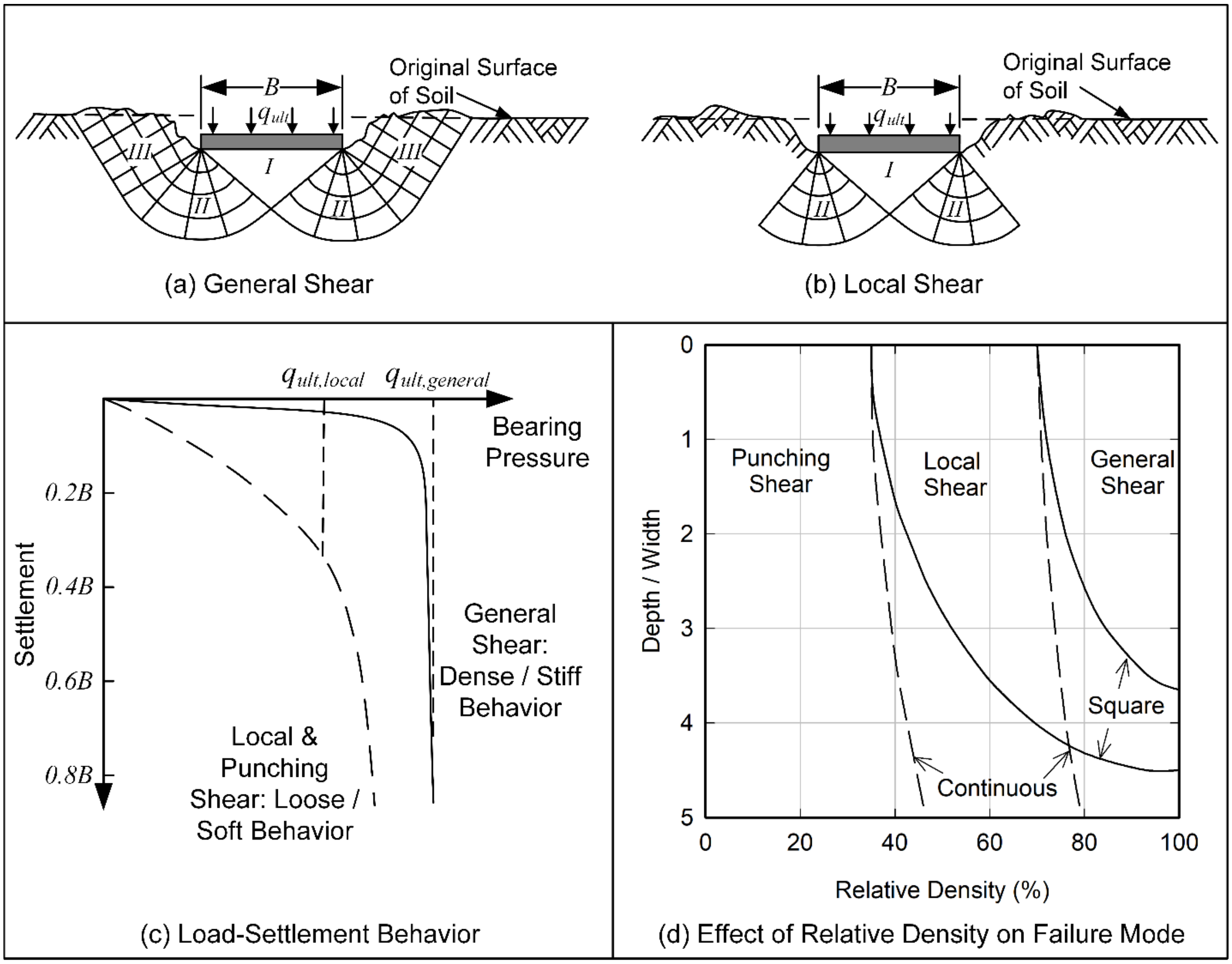


Figure 5-3 Bearing Capacity Failure Modes – (a) General Shear, (b) Local Shear, (c) Load-Settlement Behavior, and (d) Effect of Relative Density on Failure Mode (after Das 2022, Terzaghi 1943, Vesic 1973)

Local shear failure occurs when the soil in Zone II compresses rather than developing a plastic shear state as shown in Figure 5-3(b). For this reason, the soil in Zone III is not engaged in the failure mechanism. Individual shear failure surfaces typically do not reach the ground surface. Failure is not sudden, and tilting does not occur. Settlements are usually substantial, and plastic equilibrium is only partially developed.

As shown in Figure 5-3(c), the dense or stiff soils associated with general shear failure develop q_{ult} at low strain or settlement. The ultimate bearing capacity is well-defined. In constrast, the local shear mechanism in loose or soft soils results in large strains and settlements. Because much of the movement is associated with the compressibility of the soil, the magnitude of q_{ult} is much less distinct.

Punching shear is dominated by compression of the soil below and vertical shear along the sides of the footing (Vesic 1973). Little to no movement occurs in the soil adjacent to the footing. Considerations of settlement will control when punching shear is the dominant bearing capacity failure mode. The term punching shear is also used by some to refer to the case of a footing punching through a thin layer of stiff consistency or dense soil into a soft consistency or loose soil below. This mechanism is discussed in Section 5-3.6.

As indicated by Figure 5-3(d), the general shear mechanism applies mostly to dense soils at relatively shallow depths. At lower relative densities and greater footing depths, the failure mode transitions through local failure to punching shear. The bearing capacity theories discussed in Section 5-3.1.2 assume a general shear failure mechanism. Methods to account for local shear are discussed in Section 5-3.1.3.

5-3.1.1 Shear Strength for Bearing Capacity Analysis.

Bearing capacity is controlled by the shear strength of the soil. The type of shear strength parameters used in bearing capacity analyses depends on the field loading condition, soil type, and groundwater level. Loads are typically applied to foundations over a period of time, such as when a building or a bridge is under construction. This loading condition may represent drained or undrained loading depending on the type of soil being loaded and the length of time required to apply the load.

In clean sands and gravels, drainage is almost instantaneous and does not practically depend on how long it takes to build the structure. These soils only require effective stress analysis unless dynamic loading is anticipated. If substantial fines are present, the possibility of developing an undrained condition should be considered.

In contrast, substantial time is required for excess pore pressures to dissipate in fine-grained soils after loading. These soils usually require undrained analysis for conditions at the end of loading as well as for any rapid or dynamic loading. In some cases, long-term effective stress conditions should also be checked. For example, the drained bearing capacity of heavily overconsolidated clays often controls the design.

Laboratory and field testing methods to determine shear strength parameters for most soil types are summarized in the Prologue. For bearing capacity analysis, effective strength parameters (ϕ', c') should be used for long-term conditions in all soil types. For saturated fine-grained soils, the use of undrained shear strength (s_u) with $\phi = 0$ is appropriate. Undrained shear strength parameters (ϕ, c) should be used for unsaturated soils with low permeability, including coarse-grained soils with substantial fines.

5-3.1.2 Calculation of Ultimate Bearing Capacity.

Bearing capacity is a complex phenomenon that cannot be modeled exactly. Multiple equations have been developed to estimate the ultimate bearing capacity of soil. These equations are based on the upper and lower bound theorems of plasticity and include the work of Prandtl (1920), Terzaghi (1943), Meyerhof (1951), Brinch Hansen (1970), and Vesic (1973, 1975). In their basic form, the equations apply to general shear failure below a continuous strip footing of width, B, with soil shear strength governed by the Mohr-Coulomb failure criterion. The basic bearing capacity solutions also assume vertical loading, a horizontal bearing surface, foundation depth less than the width, and a horizontal ground surface. Methods to address other variations of these factors are discussed in Section 5-3.3.

In most methods, the bearing capacity problem is simplified by replacing the soil above the bearing elevation with an equivalent surcharge as shown in Figure 5-4(a). This conservatively neglects the shear strength of the soil above the foundation depth. Alternatively, Meyerhof (1951) assumed that the failure surface continued to the ground surface and replaced the triangular wedge with equivalent stresses, p_0 and s_0. Meyerhof's geometry is shown in Figure 5-4(b). Basic formulations also assume that the groundwater table is deeper than the failure zone.

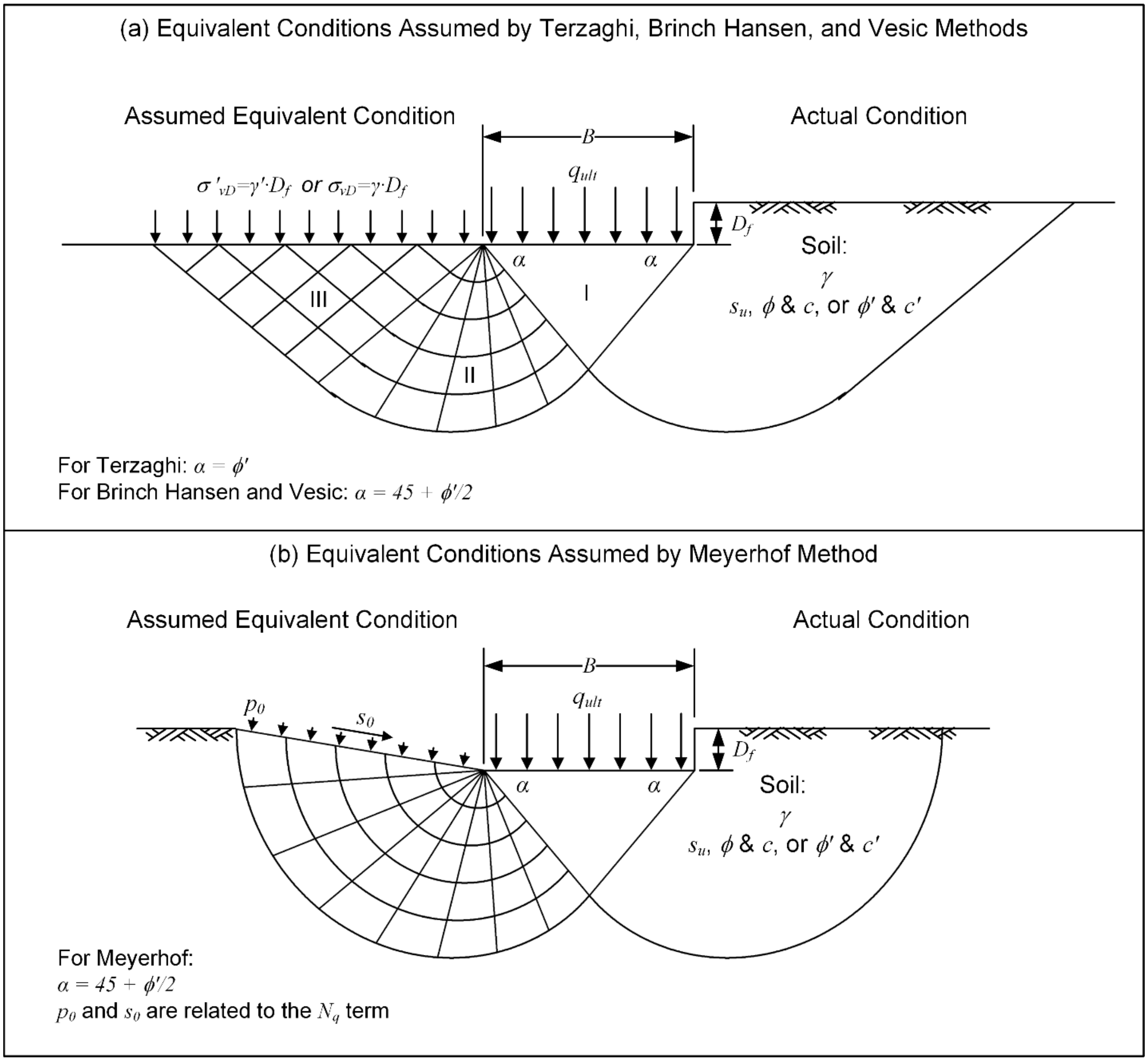


Figure 5-4 Assumptions for Bearing Capacity of a Continuous Footing - a) Terzaghi, Brinch Hansen, and Vesic Methods and b) Meyerhof Method

With these assumptions, the bearing capacity problem can be separated into three distinct terms or superimposed sources of bearing resistance. The first term is connected to the cohesion (or undrained shear strength) along the failure surface and has a bearing capacity factor, N_c. The second term is related to the surcharge and has a bearing capacity factor, N_q. The third term is related to the weight of the soil above the failure surface and has a bearing capacity factor, N_γ.

For effective stress or drained analysis, the ultimate bearing capacity of the soil is:

$$q_{ult} = c' N_c \Psi_c + \sigma'_{zD} N_q \Psi_q + 0.5\gamma B N_\gamma \Psi_\gamma \tag{5-15}$$

where:
c' = effective stress cohesion,
ϕ' = effective stress friction angle,
γ = average effective unit weight of soil between D_f and $D_f + B$,
σ'_{zD} = effective vertical stresss at the bearing elevation,
N_c, N_q, N_γ = bearing capacity factors that depend on the effective friction angle, ϕ', and
Ψ_c, Ψ_q, Ψ_γ, = factors used to correct for complicating effects (see Section 5-3.3).

For undrained conditions in unsaturated soils, the ultimate bearing capacity is:

$$q_{ult} = c \cdot N_c \Psi_c + \sigma_{zD} N_q \Psi_q + 0.5\gamma B N_\gamma \Psi_\gamma \tag{5-16}$$

where:
c = undrained cohesion,
ϕ = undrained friction angle,
γ = average total unit weight of soil between D_f and $D_f + B$,
σ_{zD} = total vertical stresss at the bearing elevation, and
N_c, N_q, N_γ = bearing capacity factors that depend on the total stress friction angle, ϕ.

For undrained conditions in saturated soils, the ultimate bearing capacity is:

$$q_{ult} = s_u N_c \Psi_c + \sigma_{zD} \Psi_q \tag{5-17}$$

where:
s_u = undrained cohesion,
σ_{zD} = total vertical stresss at the bearing elevation, and
N_c = bearing capacity factor for $\phi = 0$.

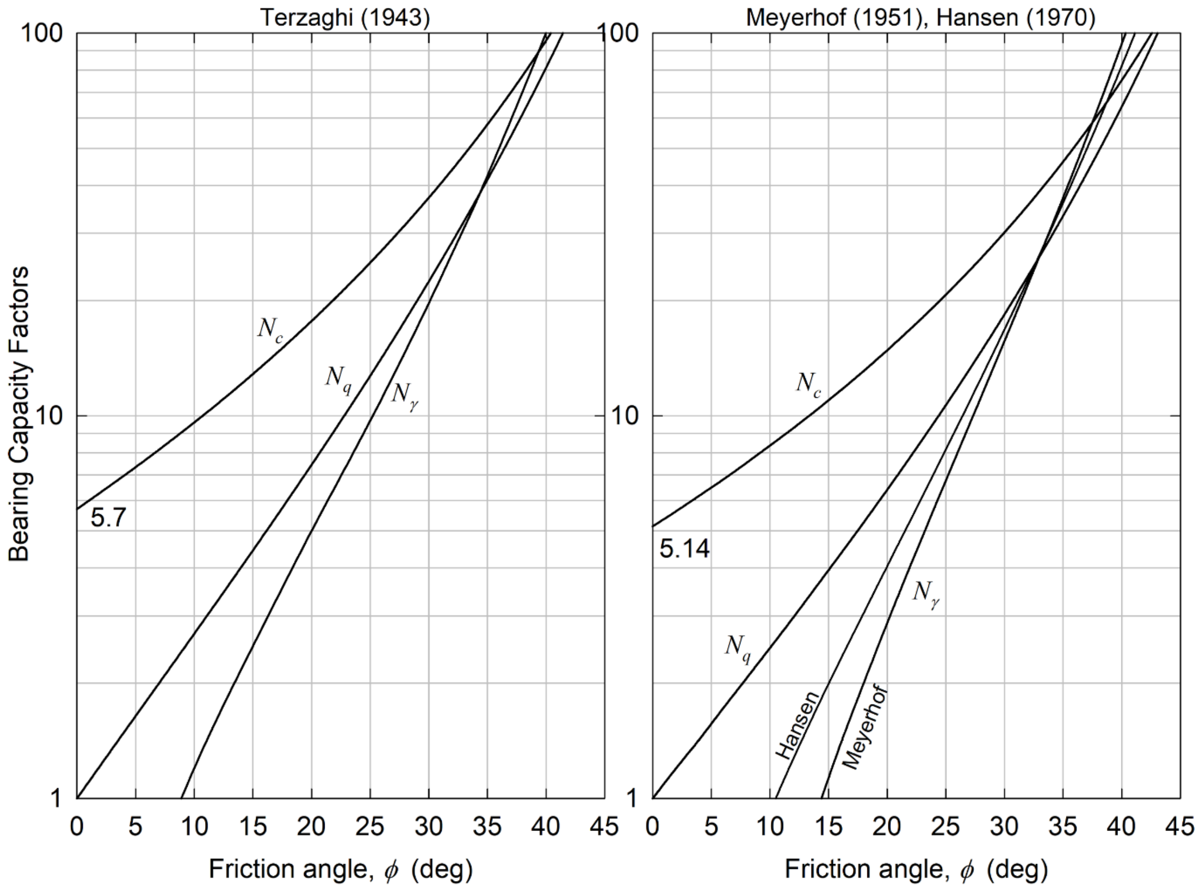
The bearing capacity factors depend on the friction angle of the soil because it controls the shape of the failure surface. Three methods are provided herein to determine the bearing capacity factors. The values are provided in Table 5-2 for the Terzaghi (1943), Meyerhof (1951), and Brinch Hansen (1970) methods. The factors provided by Vesic (1973) are nearly identical to those proposed by Meyerhof and Hansen. The factors can also be determined from the plots or equations provided in Figure 5-5.

Table 5-2 Bearing Capacity Factors, N_c, N_q, and N_γ

ϕ (deg)	N_c		N_q		N_γ		
	Terzaghi	*Meyerhof & Brinch Hansen*	*Terzaghi*	*Meyerhof & Brinch Hansen*	*Terzaghi*	Meyerhof	*Brinch Hansen*
0	5.7	5.14	1.0	1.0	0	0	0.00
2	6.3	5.6	1.2	1.2	0.15	0.01	0.01
4	7.0	6.2	1.5	1.4	0.31	0.04	0.05
6	7.7	6.8	1.8	1.7	0.51	0.11	0.11
8	8.6	7.5	2.2	2.1	0.74	0.21	0.22
10	9.6	8.4	2.7	2.5	1.0	0.37	0.39
12	11	9.3	3.3	3.0	1.4	0.60	0.6
14	12	10.	4.0	3.6	1.9	0.92	1.0
16	14	12	4.9	4.3	2.5	1.4	1.4
18	15	13	6.0	5.3	3.3	2.0	2.1
20	18	15	7.4	6.4	4.4	2.9	2.9
21	19	16	8.3	7.1	5.1	3.4	3.5
22	20	17	9.2	7.8	5.9	4.1	4.1
23	22	18	10.	8.7	6.8	4.8	4.9
24	23	19	11	9.6	7.9	5.7	5.7
25	25	21	13	11	9.2	6.8	6.8
26	27	22	14	12	11	8.0	7.9
27	29	24	17	13	12	9.5	9.3
28	32	26	18	15	15	11	11
29	34	28	20	16	17	13	13
30	37	30.	22	18	20	16	15
31	40	33	25	21	24	19	18
32	44	35	29	23	28	22	21
33	48	39	32	26	33	26	24
34	53	42	37	29	40	31	29
35	58	46	41	33	47	37	34
36	64	51	47	38	57	44	40
37	70	56	54	43	68	53	47
38	78	61	62	49	82	64	56
39	86	68	71	56	100	77	67
40	96	75	81	64	120	94	80
41	110	84	94	74	150	110	95
42	120	94	110	85	180	140	110
43	130	110	130	99	230	170	140
44	160	120	150	120	280	210	170
45	170	130	170	130	350	260	200
46	200	150	200	160	440	330	250
47	220	170	240	190	550	410	300
48	260	200	290	220	700	530	370
49	300	230	350	270	890	670	460
50	350	270	420	320	1150	870	570

Notes:
Terzaghi (1943) only provided N_γ values for 0, 34, and 48 degrees. In addition, the method for determining $K_{P\gamma}$ involves complex graphical procedures. The values provided in this table have been calculated using an approximation by Coduto et al. (2016).
Values for large friction angles have been rounded to limit implied accuracy.

Various studies have compared the bearing capacity methods to full-scale loading test data (e.g. Milovic 1965, Bowles 1996). The comparisons focused on foundations with D_f / B less than one and L / B less than four. Recommendations for the suitability of the various methods are provided in Table 5-3.



	Terzaghi	Meyerhof (1951)	Brinch Hansen (1970)
N_γ	$N_\gamma = \left(\frac{\tan\phi'}{2}\right)\left(\frac{K_{P\gamma}}{\cos^2\phi'} - 1\right)$	$N_\gamma = \left(N_q - 1\right)\tan\left(1.4\phi'\right)$	$N_\gamma = 1.5\left(N_q - 1\right)\tan\left(\phi'\right)$
N_q	$N_q = \frac{e^{2\pi(0.75-\phi'/360)\tan\phi'}}{2\cos^2\left(45+\phi'/2\right)}$	$N_q = \tan^2\left(45+\phi'/2\right)e^{\pi\tan\phi'}$	
N_c $\phi = 0$	$N_c = 5.7$	$N_c = 5.14$	
N_c $\phi > 0$	$N_c = \left(N_q - 1\right)\cot\phi'$		

Note: Either ϕ or ϕ' can be used in these equations. Angles should be entered in degrees.
Terzaghi's N_γ value can be approximated as: $N_\gamma \approx [2(N_q+1)\tan\phi'] / [1+0.4\sin(4\phi')]$

Figure 5-5 Bearing Capacity Factors
(after Terzaghi 1943, Meyerhof 1951, Brinch Hansen 1970, Coduto et al. 2016)

Table 5-3 Suitability of Terzaghi, Meyerhof, and Brinch Hansen Methods to Calculate q_{ult} (after Bowles 1996)

Method	Applicability	Comments
Terzaghi	Undrained conditions soils where $D_f / B \leq 1$. Do not use for footings with inclined load, on slopes, or with tilted bases.	Most accurate for soils with shear strength dominated by cohesive parameters (i.e., high s_u or c')
Meyerhof	Any bearing capacity conditions, except footings with a tilted base, including footings with $D_f / B > 1$.	Use with soils with shear strength dominated by frictional parameters (high ϕ'). Also reasonably accurate for soils with higher cohesive shear strength.
Hansen	Any bearing capacity conditions including footings with $D_f / B > 1$.	

5-3.1.3 Bearing Capacity Corrections for Local and Punching Shear.

As noted in the introduction to this section, the bearing capacity theories assume a general shear failure mode, which is only appropriate for dense and/or stiff soils. For most soils, a local or punching shear mechanism is more appropriate. In these cases, settlement considerations will almost always control the allowable bearing pressure and an accurate determination of the ultimate bearing capacity is less important. A variety of methods to approximate local shear have been proposed. A few of the more common approaches are summarized in Table 5-4.

Table 5-4 Bearing Capacity Methods for Local Shear

Local Shear Method	Application	Comments
Constant reduction of shear strength parameters (Terzaghi 1943)	Use c^* and ϕ^* to calculate q_{ult}: $c^* = 0.67\ c'$ $\phi^* = \tan^{-1}(0.67 \tan \phi')$	Probably too conservative for sands. Doesn't account for transitional behavior with D_r. May be unsafe in some cases (Vesic 1973).
Variable reduction of shear strength parameters based on relative density (D_r) (Vesic 1973)	Use c^* and ϕ^* to calculate q_{ult}: $c^* = R \cdot c'$ $\phi^* = \tan^{-1}(R \cdot \tan \phi')$ For $D_r < 0.67$, $R = 0.67 + D_r - 0.75 D_r^2$ For $D_r > 0.67$, $R = 1$	Allows for transitional behavior between local and general shear. Based on limited test results by Vesic (1973).
Compressibility factors based on rigidity index (Vesic 1973)	Calcualte rigidity index based on footing dimensions, soil properties, and stress conditions.	See Vesic (1973) for detailed description.

5-3.2 Groundwater Correction.

Groundwater correction is required when the groundwater table is higher than one footing width below the bearing elevation. Groundwater correction is only required for drained (effective stress) analysis. Groundwater is considered by changing the unit weight used in the bearing capacity calculations. The three possible cases are shown in Figure 5-6. These cases assume hydrostatic conditions (i.e., no seepage forces exist).

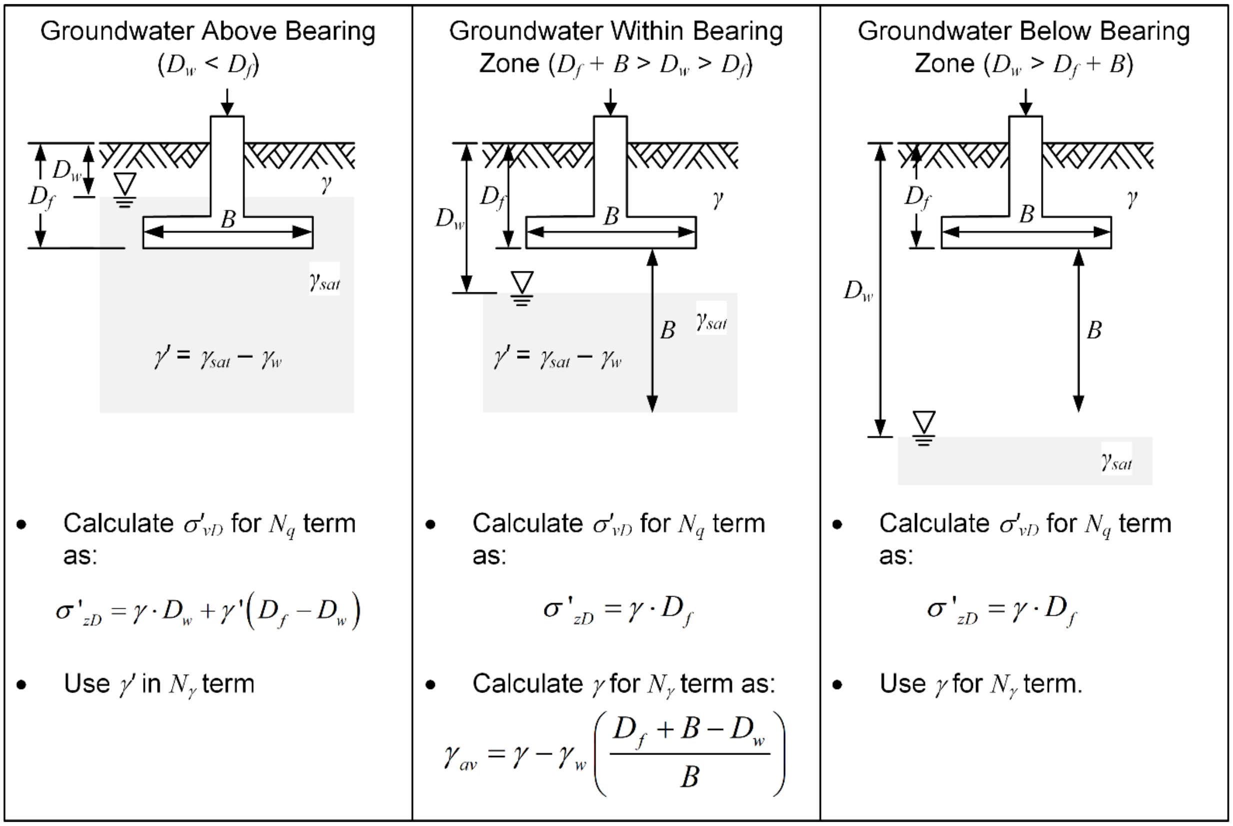


Figure 5-6 Effects of Groundwater Table on Bearing Capacity Calculations

For undrained analysis, total unit weights are used without regard to the position of the groundwater table.

Uplift is present on the base of the foundation when the groundwater table is above the bearing elevation. Its effect on the bearing pressure can be conservatively ignored unless sliding or uplift is a concern.

5-3.3 Methods to Account for Complicating Effects.

Multiple aspects of a foundation design can affect the bearing capacity that are not included in the basic solutions presented in Section 5-3.1.2. These include foundation shape and depth, load inclination, base inclination, and ground inclination. A shallow foundation with all three inclinations is illustrated in Figure 5-7.

The correction methods in the following sections are based on both theoretical considerations and empirical evidence. For this reason, the correction factors cannot usually be applied across methods, i.e., Meyerhof corrections should be used only with the Meyerhof bearing capacity factors. In addition, care should be taken combining many corrections within a given method. If bearing capacity controls a design with multiple complicating factors, numerical analysis is likely warranted. Limit equilibrium slope stability analysis can be used to analyze strip foundations on slopes.

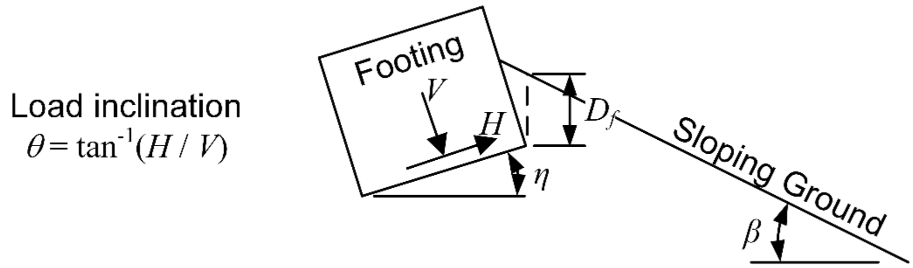


Figure 5-7 Shallow Foundation with Inclined Load, Base, and Ground (after Brinch Hansen 1970)

Lumped correction factors for complicating effects (Ψ_c, Ψ_q, and Ψ_γ) were included in Eqn. 5-15 to 5-17. In most cases, these factors are found by multiplying factors for individual effects, such that:

$$\Psi_c = s_c \cdot d_c \cdot i_c \cdot b_c \cdot g_c \quad (5\text{-}18),$$

$$\Psi_q = s_q \cdot d_q \cdot i_q \cdot b_q \cdot g_q \quad (5\text{-}19),$$

and

$$\Psi_\gamma = s_\gamma \cdot d_\gamma \cdot i_\gamma \cdot b_\gamma \cdot g_\gamma \quad (5\text{-}20),$$

where:
s_c, s_q, s_γ = shape factors,
d_c, d_q, d_γ = depth factors,
i_c, i_q, i_γ = load inclination factors,
b_c, b_q, b_γ = sloping base factors, and
g_c, g_q, g_γ = sloping ground factors.

As discussed in Section 5-2.3, foundations are sometime eccentrically loaded. Eccentricity affects the bearing capacity as well as the bearing pressure. The most common approach is to use the equivalent dimensions, B' and L' (Eqn. 5-8 and 5-9), to determine the shape factors. The B' dimension should also be used in the N_γ term to calculate bearing capacity. Conservatively, the actual dimensions should be used to calculate the depth factors.

5-3.3.1 Terzaghi (1943) Method.

Shape is the only complicating factor considered by the Terzaghi upper bound method. The factors are listed in Table 5-5. In some cases, interpolation can be used between the shape factors for square and continuous foundations. The other factors should be set equal to 1 in Eqn. 5-18 to 5-20.

Table 5-5 Shape Factors for the Terzaghi Upper Bound Method

Method	Shape	Analysis Condition	Shape Factors		
			s_c	s_q	s_γ
Terzaghi	Continuous	Any	1	1	1
	Square	Any	1.3	1	0.8
	Circular	Any	1.3	1	0.6

5-3.3.2 Meyerhof (1963) Method.

Meyerhof (1963) presents shape, depth, and load inclination factors, which are summarized in Table 5-6. The laboratory experiments used to develop the inclination factors indicated that the shape factors tend toward one under inclined load. In other words, it is safe to assume that $s_c = s_q = s_\gamma = 1$ if load inclination is present.

Meyerhof (1963) did not provide base or inclination factors in this form. Meyerhof developed a separate solution for sloping ground that is discussed briefly in Section 5-3.4.

Table 5-6 Bearing and Correction Factors for the Meyerhof (1963) Method

Factor	Analysis Condition	*c* Factor	*q* Factor	*γ* Factor
Bearing	$\phi = 0°$	$N_c = 5.14$	$N_q = K_P \cdot e^{\pi \tan(\phi')}$	$N_\gamma = (N_q - 1) \cdot \tan(1.4\phi')$
	$\phi' > 10°$	$N_c = (N_q - 1)\cot(\phi')$		
Shape[A]	$\phi = 0°$	$s_c = 1 + 0.2(B/L) \cdot$	$s_q = 1$	$s_\gamma = 1$
	$\phi' > 10°$	$s_c = 1 + 0.2(B/L) \cdot K_P$	$s_q = 1 + 0.1(B/L) \cdot K_P$	$s_\gamma = 1 + 0.1(B/L) \cdot K_P$
Depth	$\phi = 0°$	$d_c = 1+0.2\ k\ (K_P)^{0.5}$	$d_q = 1$	$d_\gamma = 1$
	$\phi' > 10°$		$d_q = 1 + 0.1\ k\ (K_P)^{0.5}$	$d_\gamma = 1+0.1\ k\ (K_P)^{0.5}$
Inclined Load[B]	All	$i_c = (1 - 2\theta / \pi)^2$	$i_q = (1 - 2\theta / \pi)^2$	$i_\gamma = (1 - \theta / \phi')^2$

Angles are expressed in radians for consistency.
B = width; L = Length; ϕ' = drained friction angle; ϕ = undrained friction angle; $K_P = \tan^2(\pi/4+\phi'/2)$, $k = D_f / B$
H = horizontal component of load, V = vertical component of load; $\theta = \tan^{-1}(H / V) < \phi'$ (in radians)

[A] Use B/L = 1 for circle. Do not combine factors for shape and inclined load.

5-3.3.3 Brinch Hansen (1970) Method.

The Brinch Hansen (1970) method allows the most complicating factors to be considered. For this reason, it is more complex than the other methods. Similar to Meyerhof, the shape factors are adjusted for inclined loading.

Brinch Hansen considered conditions for undrained shear strength ($\phi = 0$) separately. The $\phi = 0$ factors are summarized in Table 5-7. An important difference is that the lumped correction factor is additive, yielding:

$$\Psi_{c,BH,\phi=0} = \left(1 + s_c + d_c - i_c - b_c - g_c\right) \quad (5\text{-}21)$$

where:
$\Psi_{c,BH,\phi=0}$ = Brinch Hansen correction factor for N_c term for $\phi = 0$ analysis.

Table 5-7 Bearing and Correction Factors for the Brinch Hansen (1970) Method – $\phi = 0$

Brinch Hansen	*c* Factor	*q* Factor
Bearing	$N_c = 5.14$	$N_q = 1$
Shape - (vertical load)	$s_c = 0.2(B/L)$	No correction $\Psi_q = 1$
Shape - (inclined load)	$s_{cB} = 0.2 i_{cB} \cdot (B/L)$, $s_{cL} = 0.2 i_{cL} \cdot (L/B)$	
Depth	$d_c = 0.4\,k$	
Inclined Load	$i_c = 0.5 - 0.5[1 - H / (A' \cdot C_a)]^{0.5}$	
Inclined Base	$b_c = \eta / (\pi / 2 + 1)$	
Inclined Ground	$g_c = \beta / (\pi / 2 + 1)$	
Angles are expressed in radians for consistency. For $D_f / B < 1$: $k = D_f / B$. For $D_f / B \geq 1$: $k = \tan^{-1}(D_f / B)$ in radians H = horizontal component of load; C_a = base adhesion; A' = equivalent bearing area		

The Brinch Hansen factors for unsaturated undrained ($\phi > 0$) and drained conditions are summarized in Table 5-8. Brinch Hansen did not provide factors for the N_c term. Three options are available to address this shortcoming:

- Use Brinch Hansen's alternative bearing capacity equation, which is provided in the notes to Table 5-8,
- Ignore the contribution of the N_c term, which is often an appropriately conservative assumption, or
- Use the c factors provided in Table 5-8, which are based on the relationship between N_c and N_q (Hansen 1961, de Beer 1970).

For vertical loading, the bearing capacity of a rectangular foundation is controlled by the narrower dimension (B). However, load inclination may cause the longer dimension to control. The direction of the horizontal loading should be considered when calculating the inclination factors in Table 5-7 and Table 5-8. The direction of the inclination factor affects the shape factors. Bearing capacity should be checked in both directions for a rectangular foundation with inclined loading.

The development of Brinch Hansen's method does not clearly consider the interaction between inclined ground and the other factors. Caution should be used with the Brinch Hansen g factors for cases with inclined ground steeper than 2H:1V or $D_f / B > 1$.

Table 5-8 Bearing and Correction Factors for the Brinch Hansen (1970) Method – $\phi' > 0$

Factor	c Factor[C]	q Factor	γ Factor
Bearing	$N_c = (N_q - 1)\cot(\phi')$	$N_q = \tan^2(\pi + \phi'/2)e^{\pi\tan(\phi')}$	$N_\gamma = 1.5\cdot(N_q - 1)\cdot\tan(\phi')$
Shape[A] (vertical load)	$s_c = 1+(B/L)(N_q / N_c)\cos(\phi')$	$s_q = 1 + \sin(\phi')(B/L)\cdot$	$s_\gamma = 1 - 0.4(B/L)$
Shape[A] (inclined load)	$s_c = 1+(B/L)(N_q/N_c)\cos(\phi')i_c$	$s_{qB} = 1 + \sin(\phi')(B/L)\cdot i_{qB}$ $s_{qL} = 1 + \sin(\phi')(L/B)\cdot i_{qL}$	$s_{\gamma B} = 1 - 0.4(B/L)(i_{\gamma B} / i_{\gamma L}) \geq 0.6$ $s_{\gamma L} = 1 - 0.4(L/B)(i_{\gamma L} / i_{\gamma B}) \geq 0.6$
Depth[B]	$d_c = 1+ k\cdot(1-\sin\phi')^2(N_q/N_c)$	$d_q = 1+2k\cdot\tan\phi'\cdot(1-\sin\phi')^2$	$d_\gamma = 1$
Inclined Load	$i_c = \dfrac{i_q N_q - 1}{N_q - 1}$	$i_q = \left[1 - \dfrac{0.5H}{V + A'C_a\cot\phi'}\right]^5$	$i_\gamma = \left[1 - \dfrac{\left(0.7 - \eta/2.5\pi\right)H}{V + A'C_a\cot\phi'}\right]^5$
Inclined Base	Not provided.	$b_q = \exp(-2\cdot\eta\cdot\tan\phi')$	$b_\gamma = \exp(-2.7\cdot\eta\cdot\tan\phi')$
Inclined Ground	Not provided.	$g_q = (1 - 0.5\tan\beta)^5$	$g_\gamma = (1 - 0.5\tan\beta)^5$

Angles are expressed in radians for consistency.

B = equivalent width; L = equivalent length; ϕ' = drained friction angle; ϕ = undrained friction angle; H = horizontal component of load; V = vertical component of load; C_a = base adhesion; A' = equivalent bearing area

[A] Use B/L = 1 for circle.

[B] For $D_f / B < 1$: $k = D_f / B$. For $D_f / B \geq 1$: $k = \tan^{-1}(D_f / B)$ in radians

[C] Shape, depth, and factors have been determined based on the q factors using correspondence formula found in Brinch Hansen (1961) and de Beer (1970). This approach is not appropriate for the inclined base and ground factors. Brinch Hansen did not provide c factors for $\phi' > 0$ but presented the following equivalent form of the bearing capacity equation:

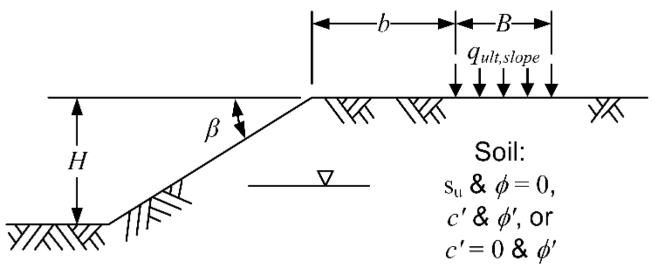
$$q_{ult} = \left(\sigma'_{vD} + c'\cot\phi'\right)N_q\Psi_q - c'\cot\phi' + 0.5\gamma BN_\gamma\Psi_\gamma$$

This equation does not require c factors but only applies to conditions with no ground inclination.

5-3.4 Foundations Near the Top of Slopes.

In some cases, foundations must be placed near slopes, which may reduce the bearing capacity of the soil. Many procedures have been proposed with varying levels of complexity. The solutions by Leshchinsky and Xie (2017) and Meyerhof (1957) have been selected for their relative simplicity and general applicability using the geometry summarized in Figure 5-8. These solutions are for strip foundations and can be used as a conservative estimate for rectangular foundations. The shape factors from Section 5-3.3 may be appropriate but have not be fully explored by numerical or laboratory testing.

Saturated undrained conditions and drained conditions are considered separately in this section. The Leshchinsky and Xie (2017) approach ignores the effects of embedment, which is an appropriately conservative assumption if the foundation is relatively close to the slope. The depth factors in Table 5-6 to Table 5-8 do not include slope effects and should not be included. A comprehensive method that incorporates embedment depth can be found in Yang et al. (2019). The Yang et al. method can accommodate any combination of shear strength parameters. Slope stability software can also model foundation loading and can be used to explore this condition in more detail.



Saturated, undrained soil:

$$q_{ult,slope} = 5.14 \cdot s_u RC_{slope}$$

See Table 5-9 for values of RC_{slope}.

Drained c'-ϕ' or undrained c-ϕ soil:

$$q_{ult,slope} = \left[c' N_c + 0.5 \cdot \gamma \cdot B \cdot N_\gamma \right] RC_{slope}$$

See Table 5-10 for values of RC_{slope}.

Use Meyerhof / Brinch Hansen value of N_q (Figure 5-5) to calculate $N_\gamma = 2(N_q + 1) \tan \phi'$.

Use average effective unit weight to account for groundwater. See Section 5-3.2.

Drained $c' = 0$ soil (Meyerhof 1957):

$$q_{ult,slope} = 0.5 \cdot \gamma \cdot B \cdot N_{\gamma,slope}$$

See Figure 5-9 for values of $N_{\gamma,slope}$.

Use average effective unit weight to account for groundwater. See Section 5-3.2.

Figure 5-8 Foundations Near the Top of Slopes (After Meyerhof 1957, Leshchinsky and Xie 2017)

5-3.4.1 Saturated Undrained Conditions.

For saturated undrained conditions (s_u, $\phi = 0$), the effect of the slope tends to be small unless the foundation is close to the slope ($b/B < 2.5$) or the slope is steep ($\beta > 30°$). The influence of the stability of the slope on bearing capacity can be incorporated using a stability number defined as:

$$N_S = \frac{\gamma \cdot H}{s_u} \tag{5-22}$$

where:
γ = total unit weight of the soil,

H = slope height, and
s_u = undrained shear strength of the soil.

The ultimate bearing capacity for foundations near slopes is calculated using a reduction coefficient (RC_{slope}) as indicated in Figure 5-8. Table 5-9 provides values of RC_{slope} based on foundation dimensions (B/H), distance from the slope (b/B), slope angle (β), and slope stability number (N_S) (Leschinsky and Xie 2017). Interpolation should be used to determine RC_{slope} for intermediate conditions. For steeper slopes or larger b/B, Leshchinsky and Xie (2017) should be consulted.

Table 5-9 Bearing Capacity Reduction Coefficients for Foundations Near Slopes in Undrained Conditions (after Leshchinsky and Xie 2017)

B/H	b/B	RC_{slope} for $N_s = \gamma H / s_u = 0$			RC_{slope} for $N_s = \gamma H / s_u = 2$			RC_{slope} for $N_s = \gamma H / s_u = 4$		
		$\beta = 0°$	$\beta = 30°$	$\beta = 60°$	$\beta = 0°$	$\beta = 30°$	$\beta = 60°$	$\beta = 0°$	$\beta = 30°$	$\beta = 60°$
0.2	0	1	0.8	0.59	1	0.78	0.56	1	0.76	0.52
	1.25	1	1	0.85	1	0.97	0.79	1	0.95	0.54
	2.5	1	1	1	1	1	0.92	1	1	0.53
0.4	0	1	0.77	0.57	1	0.73	0.49	1	0.63	0.30
	0.63	1	0.83	0.73	1	0.83	0.59	1	0.66	0.30
	1.25	1	0.94	0.83	1	0.92	0.66	1	0.71	0.33
	1.88	1	1	0.92	1	1	0.72	1	0.75	0.39
	2.5	1	1	1	1	1	0.79	1	0.79	0.46
1	0	1	0.76	0.56	1	0.62	0.37	1	0.40	0.16
	0.25	1	0.80	0.63	1	0.66	0.43	1	0.43	0.20
	0.5	1	0.83	0.69	1	0.70	0.49	1	0.44	0.24
	0.75	1	0.87	0.74	1	0.74	0.55	1	0.46	0.29
	1.0	1	0.90	0.79	1	0.77	0.60	1	0.48	0.32
	1.25	1	0.92	0.83	1	0.81	0.65	1	0.50	0.36
	1.5	1	0.95	0.86	1	0.84	0.70	1	0.53	0.39
	1.75	1	0.97	0.90	1	0.87	0.74	1	0.56	0.42
	2.0	1	0.98	0.93	1	0.90	0.78	1	0.61	0.47
	2.5	1	1	0.96	1	0.95	0.85	1	0.65	0.60

5-3.4.2 Drained Conditions.

For drained conditions, the effect of the slope on bearing capacity can be more significant. The reduction in bearing capacity depends on the effective stress friction angle in addition to similar factors as the undrained case. Table 5-10 summarizes reduction coefficients for common conditions encountered in engineering practice where $c' > 0$. Coefficients for $B/H = 2$ and other slope angles are available in Leshchinsky and Xie (2017). For conditions with $c' = 0$, the Meyerhof (1957) method presented at the end of this section can be used.

For soils modeled using an effective stress cohesion intercept, a stability number is required to incorporate its influence as:

$$N_S = \frac{\gamma \cdot H}{c'} \quad (5\text{-}23)$$

where:
γ = unit weight of the soil considering groundwater effects (Section 5-3.2),
H = slope height, and
c' = undrained shear strength of the soil.

Table 5-10 Bearing Capacity Reduction Coefficients for Foundations Near Slopes in Saturated Drained Conditions (after Leshchinsky and Xie 2017)

B/H	*b/B*	RC_{slope} for $N_s = \gamma H / c' = 0$						RC_{slope} for $N_s = \gamma H / c' = 2$					
		$\phi' = 20°$		$\phi' = 30°$		$\phi' = 40°$		$\phi' = 20°$		$\phi' = 30°$		$\phi' = 40°$	
		β=10°	β=30°	β=10°	β=30°	β=10°	β=30°	β=10°	β=30°	β=10°	β=30°	β=10°	β=30°
0.2	0	0.91	0.62	0.84	0.52	0.77	0.4	0.89	0.58	0.81	0.46	0.71	0.34
	0.5	0.88	0.68	0.83	0.57	0.76	0.43	0.87	0.65	0.81	0.52	0.73	0.38
	1.25	0.92	0.77	0.86	0.63	0.78	0.48	0.92	0.75	0.85	0.6	0.77	0.44
	2.5	0.97	0.88	0.9	0.72	0.81	0.54	0.98	0.89	0.92	0.73	0.83	0.53
	5	1	1	0.99	0.88	0.88	0.65	1	1	1	0.95	0.93	0.72
	10	1	1	1	1	0.99	0.84	1	1	1	1	1	1
	15	1	1	1	1	1	1	1	1	1	1	1	1
0.4	0	0.88	0.64	0.83	0.53	0.76	0.43	0.61	0.61	0.77	0.38	0.77	0.38
	0.5	0.91	0.7	0.85	0.58	0.78	0.47	0.91	0.68	0.81	0.44	0.81	0.44
	1.25	0.93	0.76	0.87	0.63	0.8	0.51	1	0.75	0.82	0.49	0.82	0.49
	2.5	1	0.9	0.93	0.74	0.84	0.59	1	0.94	0.92	0.62	0.92	0.62
	5	1	1	1	0.9	0.91	0.71	1	1	1	0.82	1	0.82
	10	1	1	1	1	1	0.89	1	1	1	1	1	1
	15	1	1	1	1	1	0.96	1	1	1	1	1	1
1.0	0	0.88	0.48	0.83	0.46	0.78	0.58	0.71	0.34	0.77	0.38	0.78	0.48
	0.5	0.91	0.7	0.86	0.64	0.79	0.71	0.73	0.38	0.81	0.44	0.81	0.66
	1.25	0.93	0.76	0.87	0.68	0.8	0.73	0.77	0.44	0.82	0.49	0.84	0.69
	2.5	1	0.9	0.93	0.78	0.86	0.76	0.83	0.53	0.92	0.62	0.92	0.78
	5	1	1	1	0.92	0.93	0.8	0.93	0.72	1	0.82	1	0.9
	10	1	1	1	1	1	0.94	1	1	1	1	1	1
	15	1	1	1	1	1	0.98	1	1	1	1	1	1

Note: $RC_{slope} = 1$ for for conditions without a slope (β = 0°).

As indicated in Figure 5-8, the reduced bearing capacity is found by multiplying RC_{slope} with q_{ult} for non-sloping conditions with no embedment. The largest reductions in bearing capacity occur for foundations with low b/B ratios and steep slopes.

The reduction coefficients provided in Table 5-10 are for N_S less than 2, which indicates relatively high values of c'. Leshchinsky and Xie also provide coefficients for $N_s = 4$. For these higher stability numbers, the stability of the slope itself is likely controlling, or the situation is dominated by frictional strength and it may be appropriate to ignore the effects of c'.

When c' is absent or ignored, the chart solution provided by Meyerhof (1957) can be used and is provided in Figure 5-9. Meyerhof provided factors ($N_{\gamma,slope}$) for embedment effects for $D_f/B = 1$ and recommended interpolation for intermediate embedment ratios. As indicated in Figure 5-8, the N_q term is not used to calculate bearing capacity because its contribution is included in the values of $N_{\gamma,slope}$.

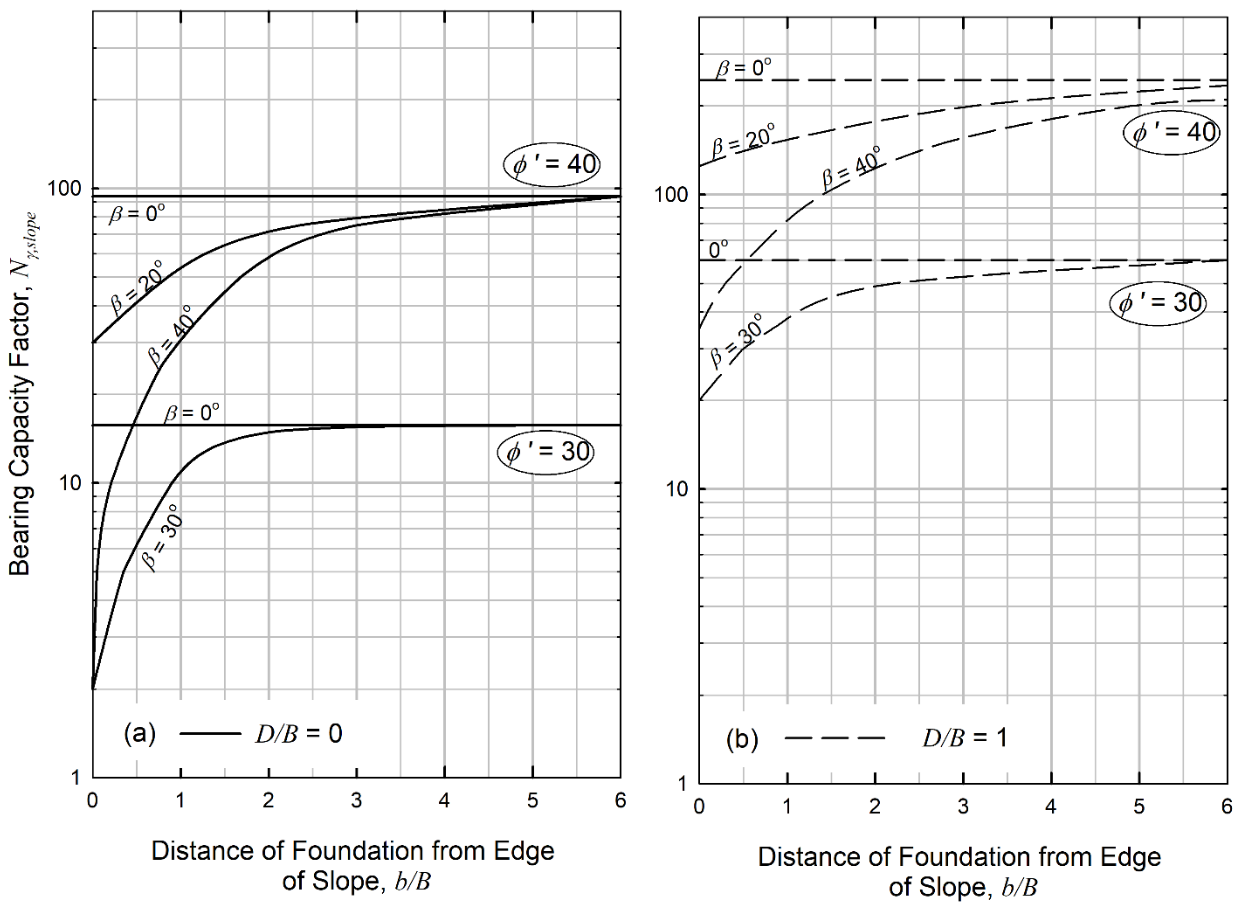
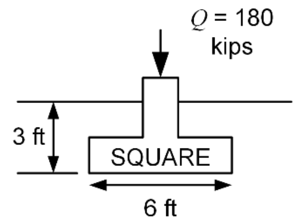


Figure 5-9 Bearing Capacity Factors for Strip Footing for c' = 0 Conditions – a) No Embedment and b) $D_f / B = 1$ (after Meyerhof 1957)

5-3.5 Bearing Capacity Examples.

Figure 5-10 to Figure 5-12 provide detailed examples of the application of the Terzaghi, Meyerhof, and Brinch Hansen methods for bearing capacity analysis. They illustrate the use of shape, depth, and inclination factors. Eccentricity calculations using both the Meyerhof and Brinch Hansen approaches are provided in Figure 5-13.

Problem Statement: Estimate the ultimate and allowable bearing pressure using the Terzaghi Method and check with the Meyerhof method

Project and Site Details	Trial Foundation Size	Trial Design
Three-story Building 100 ft by 200 ft Column Q = 180 kips Estimated q_{all}=5000 psf Very stiff clay (CH) s_u = 2000 psf based on five SPT borings (Average N = 20) γ_t = 130 pcf (assumed) Groundwater at depth of 3 ft	$AREA = \frac{Q}{q_{all}} = \frac{180{,}000\,lb}{5000\ psf} = 36\ ft^2$ $B = \sqrt{AREA} = \sqrt{36\ ft^2} = 6\ ft$	

Terzaghi Method

Bearing capacity factors for ϕ = 0 deg: $N_c = 5.7,\ N_q = 1,\ N_\gamma = 0$

Vertical stress at foundation level: $\sigma_{zD} = D_f\gamma_t = (3\ ft)(130\ pcf) = 390\ psf$

Ultimate bearing capacity:

$$q_{ult} = s_c s_u N_c + qN_q + \tfrac{1}{2}s_\gamma \gamma_t B N_\gamma$$
$$= (1.3)(2000\ psf)(5.7) + (390\ psf)(1) + 0$$
$$= 14{,}820 + 390 = 15{,}210\ psf$$

Allowable bearing pressure:
(Use F = 3 because s_u estimated from SPT)

$$q_{all,net} = \frac{15{,}210\ PSF}{3} - 390\,psf = 4680\ psf$$

Meyerhof Method (Check)

Bearing capacity factors for ϕ = 0 deg: $N_c = 5.14,\ N_q = 1,\ N_\gamma = 0$

Shape, depth, and lumped factors:

$$s_c = 1 + 0.2\left(\tan^2(45 + 0/2)\right) = 1.2,\ d_c = 1 + 0.2\left(\frac{3\ ft}{6\ ft}\right) = 1.1$$
$$\Psi_c = (1.2)(1.1) = 1.32$$
$$s_q = 1,\ d_q = 1$$
$$\Psi_q = (1)(1) = 1$$

Ultimate bearing capacity:

$$q_{ult} = s_u N_c \Psi_c + \sigma_{zD} N_q \Psi_q + \tfrac{1}{2}s_\gamma d_\gamma \gamma_t B N_\gamma$$
$$= (2000\ psf)(5.14)(1.32) + (390\ psf)(1) + 0$$
$$= 13{,}570 + 390 = 13{,}960\ psf$$
$$q_{ult,net} = 13{,}960 - 390 = 13{,}570\,psf$$

Check Factor of Safety with q_{all} = 5000 psf:

$$F = \frac{13{,}570\ psf}{5000\ psf} = 2.71$$

The net allowable bearing pressure calculated with the Terzaghi method is lower than 5000 psf. Similarly, the factor of safety found by Meyerhof's method is less than 3. Thus, the proposed foundation dimensions may be slightly small based on the design requirements. Consideration should be given to increasing B or refining the value of s_u based on shear strength testing.

Figure 5-10 Example Calculations Illustrating the Terzaghi Method with the Meyerhof Method Used as a Check

Problem Statement: Estimate the ultimate and allowable bearing pressure using the Meyerhof method for both the vertical and inclined loads

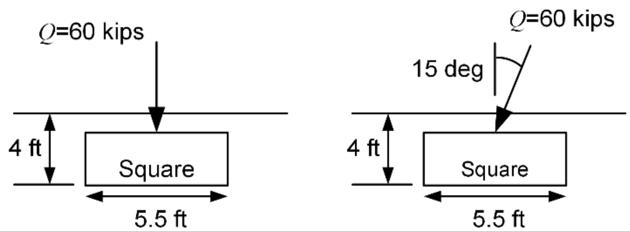
Project and Site Details

One-Story Building - 200 × 600 ft,
Column Loads of 60 kips,
One Inclined with θ = 15 deg

Medium Dense Silty Sand
N_{ave} = 10 based on 21 borings (20 ft deep)
Groundwater at depth of 6 ft
Assumed Parameters: ϕ' = 30 deg, c' = 0 psf
Measured: γ_t = 120 pcf

Trial Designs

Estimated q_{all} = 2000 psf



Meyerhof Method – Vertical Load

Bearing Capacity Factors for ϕ' = 30 deg: $N_q = 18.4, N_\gamma = 15.7$

Vertical Stress at Foundation Level: $\sigma_{zD} = D_f \gamma_t = (4\,ft)(120\,pcf) = 480\,psf$

Groundwater within B below bearing
Interpolate to Determine Average Unit Weight: $\gamma_{ave} = 120\,pcf - (62.4)\dfrac{(4 + 5.5 - 6\,ft)}{5.5\,ft} = 80.3\,pcf$

Shape and Depth Factors:

$$s_q = s_\gamma = 1 + 0.1\left(\tan^2\left(45 + 30/2\right)\right) = 1.30$$

$$d_q = d_\gamma = 1 + 0.1\left(4\,ft/5.5\,ft\right)\left(\tan\left(45 + 30/2\right)\right) = 1.12$$

$$\Psi_q = \Psi_\gamma = (1.3)(1.12) = 1.456$$

Ultimate Bearing Capacity:
(No Cohesion Term)

$$q_{ult} = \sigma_{zD} N_q \Psi_q + 0.5\gamma_{ave} B N_\gamma \Psi_\gamma$$
$$= (480\,psf)(18.4)(1.456) + (0.5)(80.3\,pcf)(5.5\,ft)(15.7)(1.456)$$
$$= 12{,}859 + 5{,}048 = 17{,}907\,psf$$

Net Allowable Bearing Pressure:
(Use F = 3 because ϕ' estimated from SPT)

$$q_{all,net} = \frac{17907\,psf}{3} - 480\,psf = 5{,}489\,psf > 2{,}000\,psf$$

Meyerhof Method – Inclined Load

Bearing capacity factors and depth factors are unchanged. Shape factors are not used.

Inclination Factors: $i_q = \left(1 - 15^\circ/90^\circ\right)^2 = 0.69$ $\quad i_\gamma = \left(1 - 15^\circ/30^\circ\right)^2 = 0.25$

Lumped Factors: $\Psi_q = (0.69)(1.12) = 0.773$ $\quad \Psi_\gamma = (0.25)(1.12) = 0.28$

Ultimate Bearing Capacity:
(No Cohesion Term)

$$q_{ult} = \sigma_{zD} N_q \Psi_q + 0.5\gamma_{ave} B N_\gamma \Psi_\gamma$$
$$= (480\,psf)(18.4)(0.773) + 0.5(80.3\,pcf)(5.5\,ft)(15.7)(0.28)$$
$$= 6{,}827 + 970 = 7{,}797\,psf$$

Allowable Bearing Pressure:
(Use F = 3 because ϕ' estimated from SPT)

$$q_{all,net} = \frac{7{,}797\,psf}{3} - 480 = 2{,}119\,psf > 2{,}000\,psf$$

The column foundation design is appropriate because q_{all} exceeds the design bearing pressure.

Figure 5-11 Example Calculations Illustrating the Meyerhof Method

Problem Statement: Estimate the Ultimate and Allowable Bearing Pressure Using the Brinch-Hansen Method for Both the Vertical and Inclined Loads

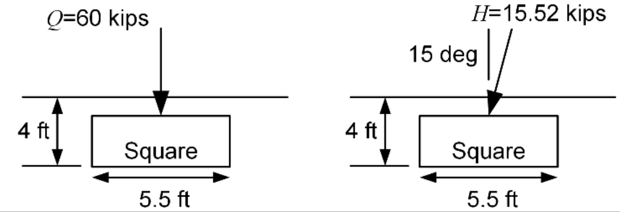
Project and Site Details

One-Story Building - 200 × 600 ft,
Column Loads of 60 kips,
One Inclined with θ = 15 deg

Medium Dense Silty Sand
N_{ave} = 10 based on 21 borings (20 ft deep)
Groundwater at Depth of 6 ft
Assumed Parameters: ϕ' = 30 deg, c' = 0 psf
Measured: γ_t = 120 pcf

Trial Designs

Estimated q_{all} = 2000 psf



Brinch-Hansen Method – Vertical Load

Bearing Capacity Factors for ϕ' = 30 deg: $N_q = 18.4, N_\gamma = 15$

Vertical Stress at Foundation Level: $\sigma_{zD} = D_f \gamma_t = (4\,ft)(120\,pcf) = 480\,psf$

Groundwater within B below Bearing Surface Interpolate to Determine Average Unit Weight:

$$\gamma_{ave} = 120\,pcf - 62.4\,pcf\left(\frac{(5.5+4-6\,ft)}{5.5\,ft}\right) = 80.3\,pcf$$

Shape and Depth Factors:

$$s_q = 1+\sin(30) = 1.50, \quad s_\gamma = 0.6$$

$$d_q = 1+2(4\,ft/5.5\,ft)\tan(30)(1-\sin(30))^2 = 1.21, \quad d_\gamma = 1$$

$$\Psi_q = (1.5)(1.21) = 1.82, \quad \Psi_\gamma = (0.6)(1) = 0.6$$

Ultimate Bearing Capacity:
(No Cohesion Term)

$$\begin{aligned} q_{ult} &= \sigma_{zD} N_q \Psi_q + 0.5\gamma_{ave} B N_\gamma \Psi_\gamma \\ &= (480\,psf)(18.4)(1.82) + (0.5)(80.3\,pcf)(5.5\,ft)(15)(0.6) \\ &= 16,074 + 1,987 = 18,061\,psf \end{aligned}$$

Allowable Bearing Pressure:
(Use F = 3 because ϕ' estimated from SPT)

$$q_{all,net} = \frac{18061\,psf}{3} - 480\,psf = 5540\,psf > 2,000\,psf$$

Brinch-Hansen Method – Inclined Load

Bearing capacity factors and depth factors are unchanged.

Inclination and Shape Factors:
(η = 0 deg, c_a = 0)

$$i_q = \left[1-0.5\left(\frac{15.52k}{57.96k}\right)\right]^5 = 0.487 \qquad i_\gamma = \left[1-\left(\left(0.7-\frac{\eta}{450^\circ}\right)\left(\frac{15.52k}{57.96k}\right)\right)\right]^5 = 0.354$$

$$s_q = 1+\sin(30)(5.5/5.5)\cdot 0.487 = 1.24 \qquad s_\gamma = 1-0.4(5.5/5.5) = 0.6$$

$$\Psi_q = (0.487)(1.24)(1.1) = 0.73 \qquad \Psi_\gamma = (0.354)(0.6) = 0.212$$

Ultimate Bearing Capacity:
(No Cohesion Term)

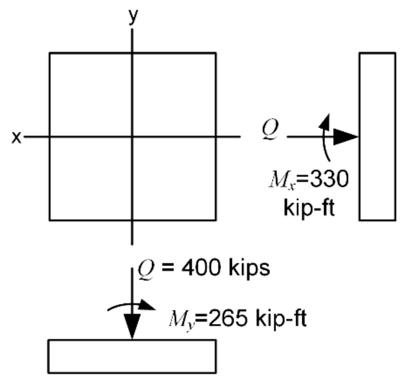
$$\begin{aligned} q_{ult} &= \sigma_{zD} N_q \Psi_q + 0.5\gamma_{ave} B N_\gamma \Psi_\gamma \\ &= (480\,psf)(18.4)(0.73) \\ &\quad + 0.5(80.3\,pcf)(5.5\,ft)(15)(0.212) \\ &= 6447 + 702 = 7149\,psf \end{aligned}$$

Allowable Bearing Pressure:
(Use F = 3 because ϕ' estimated from SPT)

$$q_{all,net} = \frac{7419\,psf}{3} - 480\,psf = 1903\,psf < 1,916\,psf = \frac{57960\,lb}{(5.5\,ft)^2}$$

The column foundation design is appropriate for the vertical load. For the inclined load, the bearing pressure is greater than the net allowable bearing pressure. The size of the footing should be increased for the inclined load.

Figure 5-12 Example Calculations Illustrating the Brinch Hansen Method



Find eccentricity and allowable bearing pressure using Meyerhof and Brinch Hansen methods

- Square Footing, B = 10 ft
- Silty Sand, γ_t = 120 pcf
- Estimated ϕ' = 30 deg
- Estimated c'=0
- D_f = 6 ft
- Groundwater at 20 ft Depth

Eccentricity

$$e_L = \frac{M_y}{Q} = \frac{265k - ft}{400k} = 0.662\,ft$$

$$e_B = \frac{M_x}{Q} = \frac{330k - ft}{400k} = 0.825\,ft$$

$$\frac{6(0.662\,ft)}{10\,ft} + \frac{6(0.825\,ft)}{10\,ft} = 0.892 < 1$$

$$B' = 10 - 2(.825) = 8.35\,ft$$

$$L' = 10 - 2(0.662) = 8.68\,ft$$

Meyerhof Method

Equivalent Area: $A' = B'L' = (8.35\,ft)(8.68\,ft) = 72.48\,ft^2$

Bearing Capacity Factors for ϕ' = 30 deg: $N_q = 18.4, N_\gamma = 15.7$

Vertical Stress at Foundation Level: $\sigma_{zD} = D_f \gamma_t = (6\,ft)(120\,pcf) = 720\,psf$

Shape and Depth Factors:
(Using B' and L')

$$s_q = s_\gamma = 1 + 0.1(8.35/8.68)\left(\tan^2(45 + 30/2)\right) = 1.29$$

$$d_q = d_\gamma = 1 + 0.1(6\,ft/8.35\,ft)\left(\tan(45 + 30/2)\right) = 1.12$$

$$\Psi_q = \Psi_\gamma = (1.29)(1.12) = 1.44$$

Ultimate Bearing Capacity:
(No Cohesion Term)
(Using B' for B)

$$q_{ult} = \sigma_{zD} N_q \Psi_q + 0.5\gamma_{ave} B N_\gamma \Psi_\gamma$$
$$= (720\,psf)(18.4)(1.44)$$
$$+ (0.5)(120\,pcf)(8.35\,ft)(15.7)(1.29)$$
$$= 19{,}077 + 11{,}326 = 30{,}403\,psf$$

Allowable Bearing Pressure:
(Use F = 3 because ϕ' estimated from SPT)

$$q_{all,net} = \frac{30{,}403\,psf}{3} - 720 = 9{,}414\,psf$$

Applied Bearing Pressure:
(Using Equivalent Area)

$$q_{applied} = \frac{400{,}000\,lb}{72.48\,ft^2} = 5{,}519\,psf < 9{,}414\,psf$$

Brinch-Hansen Method

Bearing Capacity Factors for ϕ' = 30 deg: $N_q = 18.4, N_\gamma = 15$

Shape and Depth Factors:
(Using B' and L')

$$s_q = 1 + \sin(30)(8.35/8.68) = 1.381, \quad s_\gamma = 1 - 0.4(0.962) = 0.615$$

$$d_q = 1 + 2(6\,ft/8.35\,ft)(\tan(30))(1 - \sin 30)^2 = 1.21, \quad d_\gamma = 1$$

$$\Psi_q = (1.381)(1.21) = 1.67, \quad \Psi_\gamma = (0.615)(1) = 0.615$$

Ultimate Bearing Capacity:
(No Cohesion Term)
(Using B' for B)

$$q_{ult} = (720\,psf)(18.4)(1.67) + (0.5)(120\,pcf)(8.35\,ft)(15)(0.615)$$
$$= 22{,}124 + 4{,}621 = 26{,}745\,psf$$

Allowable Bearing Pressure:
(Use F = 3 because ϕ' estimated from SPT)

$$q_{all,net} = \frac{26{,}745\,psf}{3} - 720 = 8{,}195\,psf > 5{,}519\,psf$$

The column foundation design is appropriate because $q_{all,net}$ exceeds the applied bearing pressure (either method).

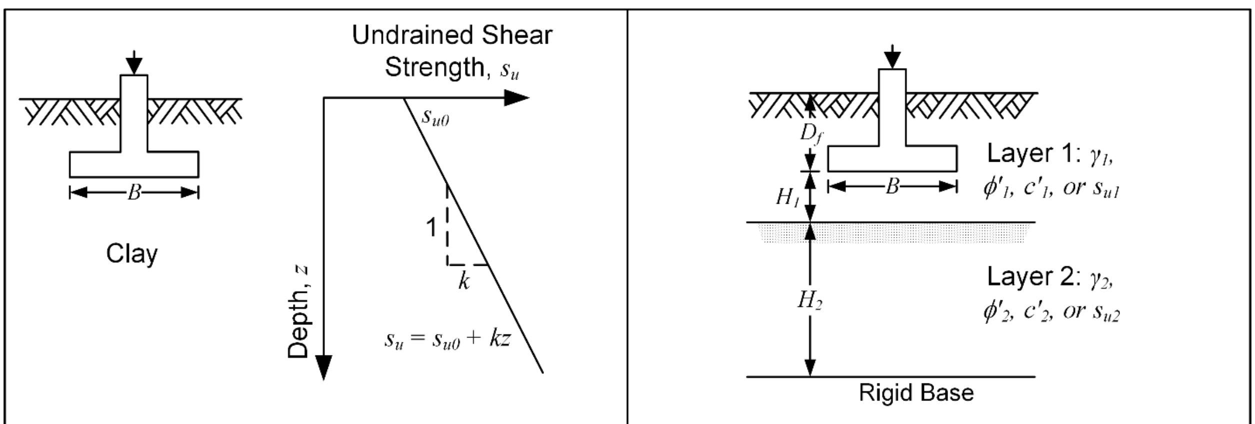
Figure 5-13 Eccentricity Calculations – Meyerhof and Brinch Hansen Methods

5-3.6 Nonuniform Soil and Layered Stratigraphy.

Soil conditions are rarely uniform as assumed by the bearing capacity theories. For example, clays are often modeled using an undrained shear strength that increases with depth. Layered soils may present a problem for bearing capacity analysis when the strength of the two layers differs significantly. Layering must be considered when the top of the lower layer is above the maximum depth of general shear failure. In this case, both layers contribute to the bearing capacity of the footing. Zone II (Figure 5-4) typically extends to a depth of about $0.85B$ to B below the bearing elevation. Conservatively, this depth has been assumed to equal B for these methods. Four cases can be considered for layered soils as follows:

- Case 1: Undrained – increasing s_u with depth,
- Case 2: Undrained – layered clay,
- Case 3: Undrained – mixed unsaturated soils (c-ϕ), and
- Case 4: Sand (drained, $c' = 0$) over clay (undrained, s_u).

Figure 5-14 illustrates the conditions used for these four cases. Each of these cases is discussed in the following paragraphs.



(a) Clay with Increasing Undrained Shear Strength — (b) Two Layered Stratigraphy

Figure 5-14 Non-uniform and Stratified Soils Conditions – (a) Case 1 and (b) Cases 2 to 4

5-3.6.1 Case 1: Undrained Clay - Increasing s_u with Depth.

Case 1 represents typical strength gain with depth for normally and some overconsolidated clays, as illustrated in Figure 5-14(a). The bearing capacity will increase as a result of increased strength with depth. Davis and Booker (1973) considered this in terms of the undrained strength ratio.

Based on an upper bound plasticity solution, Chi and Lin (2020) suggested that the bearing capacity factor, N_c, for a perfectly smooth strip footing on clay soil with increasing strength with depth can be found as:

$$N_c = 5.14 + \frac{k \cdot B}{s_{u0}} \quad (5\text{-}24)$$

where:
s_{u0} = cohesion at surface of clay layer,
B = footing width, and
k = rate of increase in s_u with depth.

Solutions for N_c from Davis and Booker (1973) and Chi and Lin (2020) are plotted in Figure 5-15. Equation 5-22 lies between the solutions for perfectly smooth and perfectly rough footings. Since footings are neither perfectly smooth or perfectly rough, this approach is a good fit for actual footings. Bearing capacity is determined using the calculated value of N_c and s_{u0}. An example is provided in Figure 5-16.

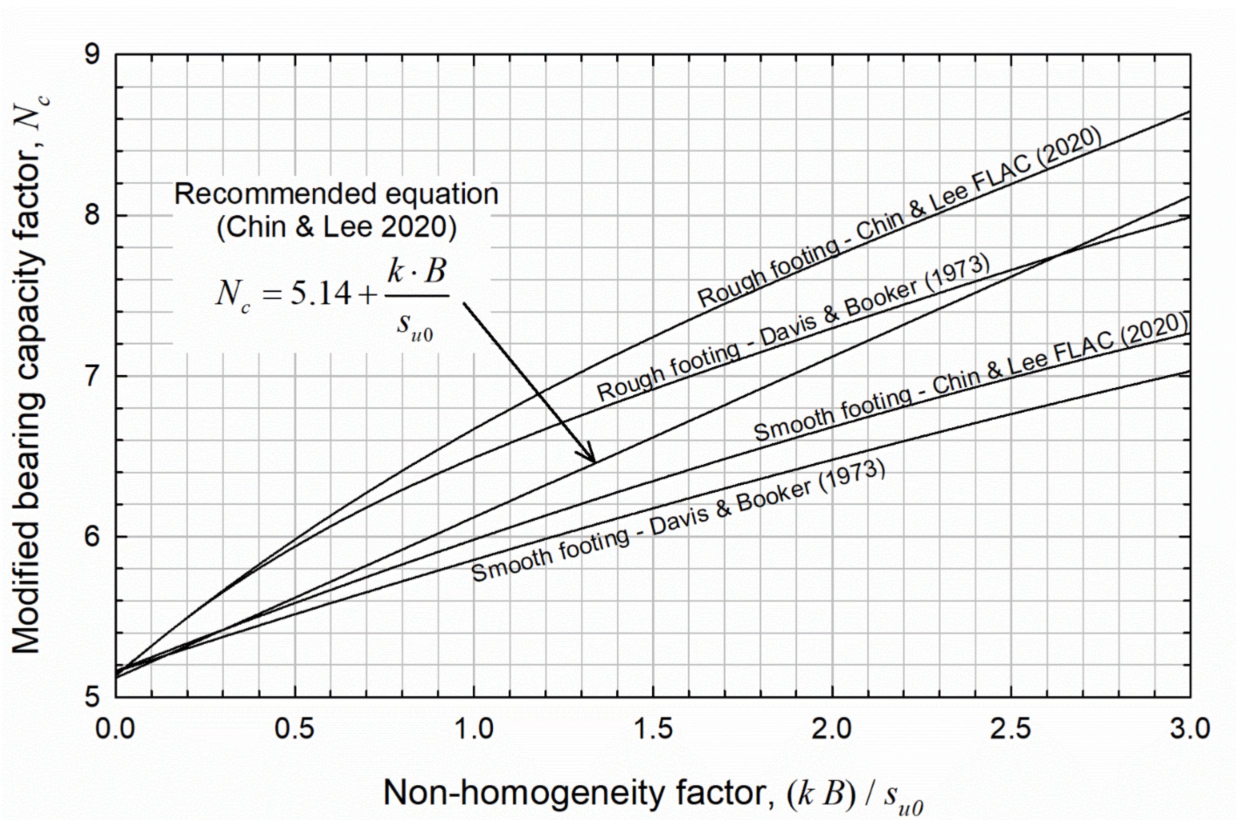
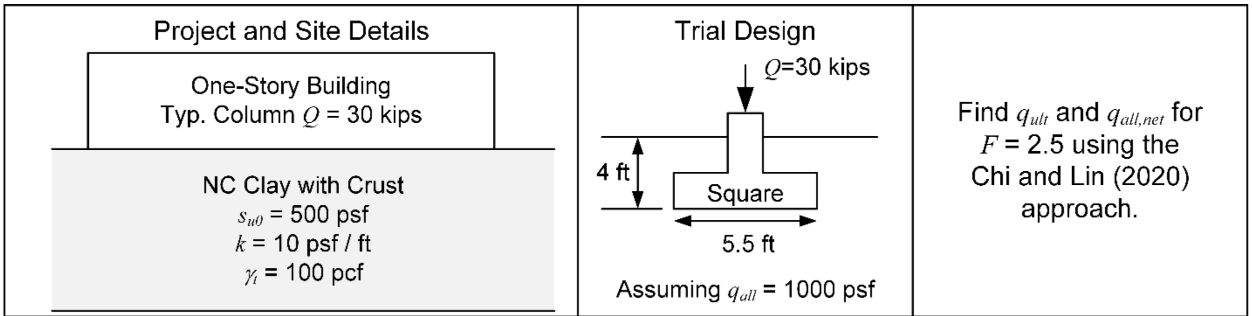


Figure 5-15 Variation of N_c for Clay with Increasing s_u with Depth (after Chi and Lin 2020)



Increasing Strength with Depth (Case 1) – Chi and Lin (2020)

Bearing Capacity Factor:

$$N_c = 5.14 + \frac{(10\,psf\,/\,ft)(5.5\,ft)}{500\,psf} = 5.25$$

Ultimate Bearing Capacity:

$$q_{ult,net} = s_{u0}N_c = (500\,psf)(5.25) = 2625\,psf$$

Net Allowable Bearing Pressure:

$$q_{all,net} = \frac{2625\ psf}{2.5} = 1,050\ psf > 1000\ psf$$

The column foundation design is adequate for bearing because $q_{all,net}$ exceeds the applied pressure. Note that settlement considerations are likely to govern this design.

Figure 5-16 Bearing Capacity Example – Increasing Strength with Depth (Case 1)

5-3.6.2 Case 2: Undrained, Layered Clay.

Layered clay stratigraphy occurs often in practice. For example, a younger post-glacial low strength clay may overlay an older stiffer clay. In other cases, a stiffer clay, created by desiccation, may overlay a softer clay. Many researchers have considered this type of layering (e.g., Button 1953, Brown and Meyerhof 1969, Griffiths 1982, Merifield et al. 1999, Zhu 2004, Szypcio and Dołżyk 2006, and Chi and Lin 2020).

When the top layer is softer or weaker than the underlying clay, the failure occurs in the upper soft layer or along the interface of the two layers. This can be illustrated with computer simulations as shown in Figure 5-17(a) (Griffiths 1999). In this case, a classic general shear bearing capacity failure does not occur; rather, a squeezing type failure occurs above or along the boundary. Brown and Meyerhof (1969) presented the relationships shown in Figure 5-18 to estimate modified bearing capacity factors ($N_{c,m,s}$ and $N_{c,m,c}$) for strip and circular footings on two layer clay systems. The right side of the figure is used for conditions where the upper layer is soft. When the top of the strong layer is more than 70% of the foundation width below the bearing elevation ($H / B \geq 0.7$), the bearing capacity is not affected by the presence of the stronger layer. Brown and Meyerhof did not define equations for the right side of Figure 5-18. However, Table 5-11 presents ranges of modified bearing capacity factors for these conditions.

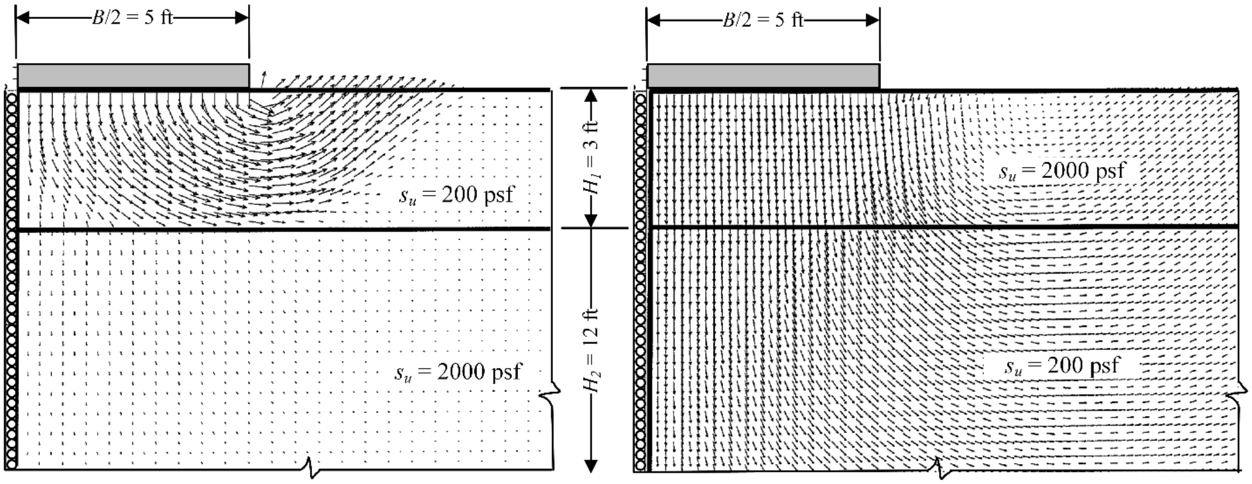


Figure 5-17 Displacement Vectors for a) Soft Over Stiff Clay and b) Stiff Over Soft Clay (after Griffiths 1999)

When the stiffer or stronger layer is on top, the footing tends to punch through the stiff layer into the soft layer developing a general shear failure in the soft clay as shown in Figure 5-17(b). The equations provided in Figure 5-18 can be used when the top layer is stiffer or stronger. The undrained strength of the top layer is used to calculate bearing capacity with these modified bearing capacity factors. When 0.7 < s_{u2}/s_{u1} < 1, it is prudent to reduce the values of $N_{c,m,s}$ and $N_{c,m,c}$ by 10 percent. When the weak layer is more than three foundation widths below the bearing elevation (H/B > 3), the bearing capacity is not affected by the presence of the deeper layer.

For a layered clay soil profile, the modified bearing capacity for a rectangular foundation ($N_{c,m,r}$) can be estimated from the circular and strip factors as:

$$N_{c,m,r} = N_{c,m,c}\left(\frac{B}{L}\right) + N_{c,m,s}\left(1 - \frac{B}{L}\right) \quad (5\text{-}25)$$

where:
$N_{c,m,s}$ = modified bearing capacity factor for strip footing - Figure 5-18(a),
$N_{c,m,c}$ = modified bearing capacity factor for circular footing - Figure 5-18(b),
B = rectangular foundation width, and
L = rectangular foundation length.

The effect of overburden (N_q = 1) may be included along with the $N_{c,m}$ factors discussed in this section. Inclined loads were not included in the experiments on which these factors are based. Thus, inclination factors should not be combined with these modified bearing capacity factors. An example is provided in Figure 5-19.

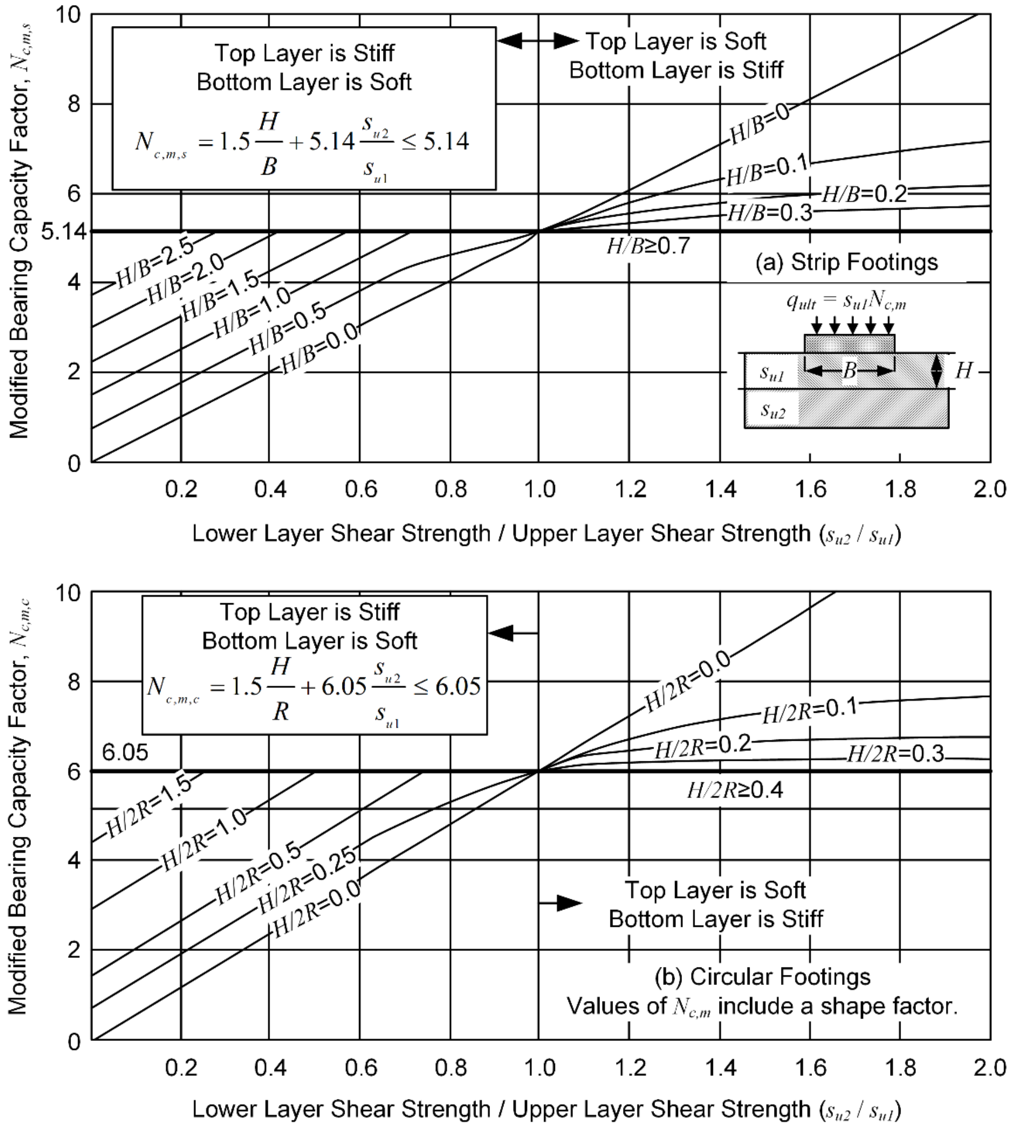
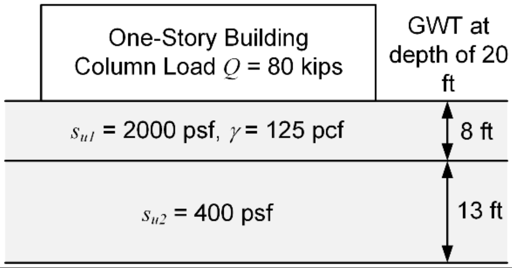


Figure 5-18 Modified Bearing Capacity Factors for Two-Layer Clay Stratigraphy for a) Strip and b) Circular Footings (after Brown and Meyerhof 1969)

Table 5-11 Values of Bearing Capacity Factor, N_{ms}, for Strip Footings (after Brown and Meyerhof 1969, Meyerhof and Hanna 1978, Merifield et al. 1999, and Zhu 2004)

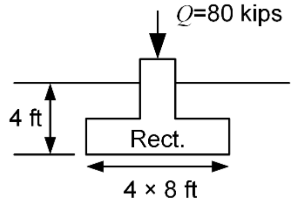
H/B	Values of $N_{c,m,s}$ for Ratios of s_{u2} / s_{u1}						
	0.2	**0.5**	**0.67**	**1.00**	**1.5**	**2.0**	**5.0**
	Stiff over soft			**Uniform**	**Soft over stiff**		
0.125	1.2 to 1.4	2.8 to 2.9	3.7 to 3.8	5.14	6.4 to 7.0	6.9 to 8.6	8.2 to 9.4
0.50	1.8 to 2.3	3.5 to 3.7	4.3 to 4.4	5.14	5.2 to 5.3	5.2 to 5.4	5.2 to 5.4
0.75	2.2 to 2.8	4.0 to 4.2	4.6 to 4.9	Little effect of layering			
1.5	3.4 to 4.2	Little effect of layering					

Project and Site Details



Trial Design

Trial q_{net} = 2500 psf



Find q_{ult} and $q_{all,net}$ for F = 2.5 using the Brown and Meyerhof (1969) two layer approach.

Undrained, Layered Clay (Case 2) – Brown and Meyerhof (1969)

Bearing Capacity Factors:
(Use $2R = B$ in $N_{c,m,c}$ equation)

$$N_{c,m,s} = 1.5\frac{H_1}{B} + 5.14\frac{s_{u2}}{s_{u1}} < 5.14$$

$$= 1.5\frac{(4\,ft)}{(4\,ft)} + 5.14\frac{(400\,psf)}{(2000\,psf)} = 1.5 + 1.03 = 2.53 \le 5.14$$

$N_{c,m,s}$ and $N_{c,m,c}$ are required to calculate $N_{c,m,r}$ because the footing is rectangular.

$$N_{c,m,c} = 1.5\frac{H_1}{R} + 6.05\frac{s_{u2}}{s_{u1}} < 6.05$$

$$= 1.5\frac{(4\,ft)}{(4\,ft)} + 6.05\frac{(400\,psf)}{(2000\,psf)} = 3 + 1.21 = 4.21 > 6.05 \rightarrow \text{use } 4.21$$

$$N_{c,m,r} = N_{c,m,c}\frac{B}{L} + N_{c,m,s}\left(1 - \frac{B}{L}\right) = 4.21\left(\frac{4\,ft}{8\,ft}\right) + 2.53\left(1 - \frac{4\,ft}{8\,ft}\right) = 3.37$$

Ultimate Bearing Capacity:

$$q_{ult} = s_{u1}N_{c,m,r} + \sigma_{zD}N_q = (2000\,psf)(3.37) + (500\,psf)(1) = 7240\,psf$$

Net Allowable Bearing Pressure:

$$q_{all,net} = \frac{7240\,psf}{2.5} - 500 = 2396\,psf > 2500\,psf$$

The column foundation design is inadequate for bearing because $q_{all,net}$ is less than the applied pressure. The base dimensions should be increased.

Figure 5-19 Bearing Capacity Example – Layered, Undrained Clay (Case 2)

5-3.6.3 Case 3: Mixed Soil Layers - Unsaturated Undrained.

The bearing capacity of mixed soil profiles of sand and clay can be evaluated using the method by Satyanarayana and Garg (1980). The method was validated using unsaturated, compacted samples and should be considered applicable to unsaturated, undrained conditions characterized by c-ϕ parameters. Unless a rigid boundary is encountered as shown in Figure 5-14(b), the thickness of the second layer is defined as:

$$H_2 = (2B - H_1)\left(\frac{c_1 + \tan\phi_1}{c_2 + \tan\phi_2}\right) \quad (5\text{-}26)$$

where:
B = width of strip footing,
H_1 = thickness of top layer below bearing elevation,

c_1, c_2 = undrained cohesion of top and bottom layers, respectively, and
ϕ_1, ϕ_2 = undrained friction angle of top and bottom layers, respectively.

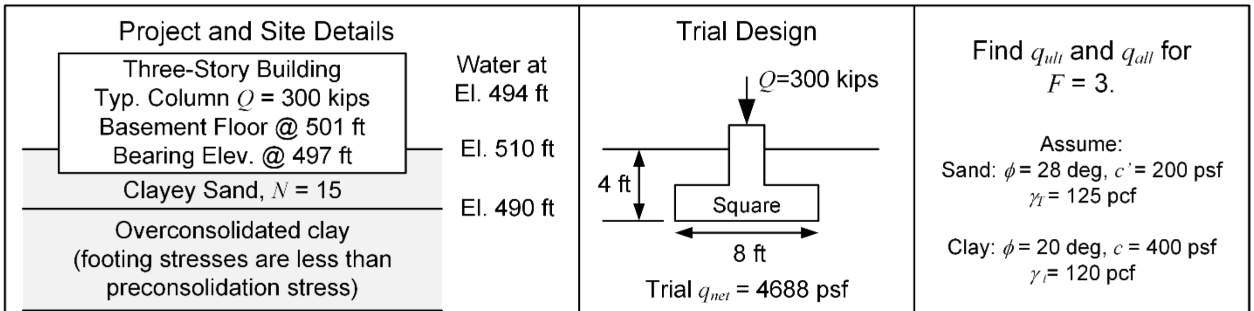
The average shear strength parameters calculated as:

$$c_{ave} = \frac{H_1 c_1 + H_2 c_2}{H_1 + H_2} \tag{5-27}$$

and

$$\phi_{ave} = \tan^{-1}\left[\frac{H_1 \tan\phi_1 + H_2 \tan\phi_2}{H_1 + H_2}\right] \tag{5-28}$$

These parameters should be used with Terzaghi's bearing capacity theory.



Mixed Soil Layers (Case 3) – Satyanarayana and Garg (1980)

Dimensions:

$$H_1 = 497 - 490 = 7\,ft$$

$$H_2 = (2B - H_1)\left(\frac{c_1 + \tan\phi_1}{c_2 + \tan\phi_2}\right) = \left(2(8\,ft) - 7\,ft\right)\left(\frac{200\,psf + \tan(28)}{400\,psf + \tan(20)}\right) = 4.5\,ft$$

Average Strength Parameters:

$$c_{ave} = \frac{(7\,ft)(200\,psf) + (4.5\,ft)(400\,psf)}{7 + 4.5\,ft} = 278\,psf$$

$$\phi_{ave} = \frac{\tan^{-1}\left((7\,ft)\tan(28) + (4.5\,ft)\tan(20)\right)}{7 + 4.5\,ft} = 25\,\deg$$

Bearing Capacity Factors:
(Use Terzaghi for 25 deg)

$$N_c = 25, N_q = 13, N_\gamma = 9.2$$

Average Unit Weight:

$$\gamma_{ave} = \frac{(125\,pcf)(7\,ft) + (120\,pcf)(4.5\,ft)}{11.5\,ft} = 123\,pcf$$

Ultimate Bearing Capacity:

$$q_{ult} = 1.3(278\,psf)(25) + (4\,ft)(125\,pcf)(13) + 0.4(123\,pcf)(8\,ft)(9.2)$$

$$q_{ult} = 19{,}156\,psf$$

Allowable Bearing Pressure:

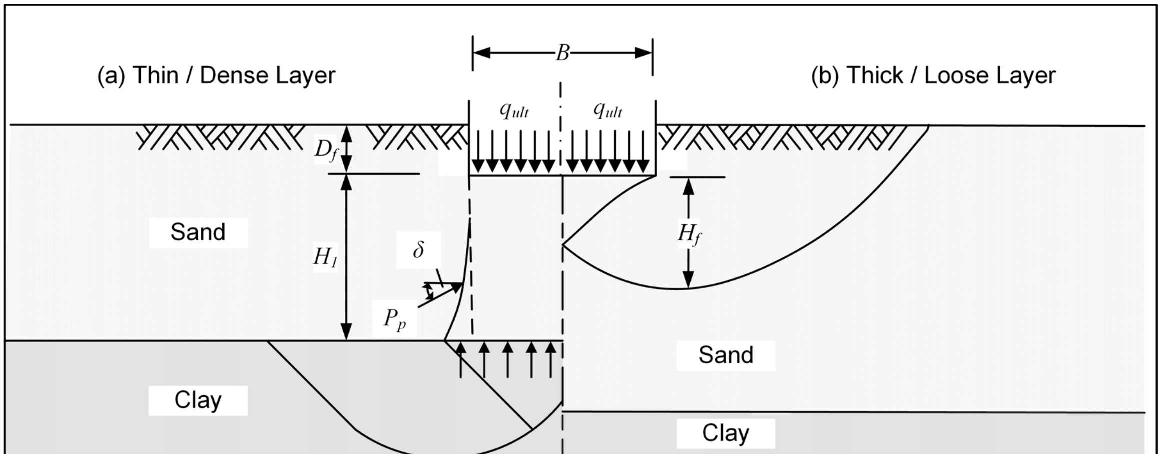
$$q_{all,net} = \frac{19{,}156\ psf}{3} - 500\ psf = 5{,}885\ psf > 5000\ psf$$

The column foundation design is adequate for bearing capacity because $q_{all,net}$ exceeds the applied pressure.

Figure 5-20 Bearing Capacity Example – Mixed Soil Layers (Case 3)

5-3.6.4 Case 4: Sand Layer Over Clay.

Meyerhof (1974) investigated shallow foundations on layers of sand and clay. In some cases, surficial layers of sand or coarse-grained soil are underlain by clay. The sand layer may be natural or a layer of engineered fill. Figure 5-21 shows two possibilities. A thin and/or dense layer of sand is depicted on the left, and the bearing capacity failure surface may break through the sand into the clay. A passive force (P_P) develops along the failure surface through the sand, which helps to resist the foundation loading.



Use the minimum value of the following as q_{ult}:

Strip	$s_u N_c + \gamma H_1^2 \left(1+\frac{2D_f}{H_1}\right)\left(\frac{K_s \tan\phi'}{B}\right) + \gamma D_f$	$\gamma D_f N_q + 0.5\gamma B N_\gamma$
Circle	$1.2 s_u N_c + 2\gamma H_1^2 \left(1+\frac{2D_f}{H_1}\right)\left(\frac{s \cdot K_s \tan\phi'}{B}\right) + \gamma D_f$	$\gamma D_f N_q + 0.3\gamma B N_\gamma$

Variables: s_u = undrained strength of the clay, γ = unit weight of sand, ϕ' = sand friction angle, K_s or $s \cdot K_s$ = punching shear coefficient, N_c = BC factor for clay, N_q and N_γ = BC factors for sand

Figure 5-21 Bearing Capacity of Sand Over Relatively Weak Clay (after Meyerhof 1974)

When the sand is loose or thick, the bearing capacity failure surface may remain within the sand layer as shown in Figure 5-21(b). The location of the failure depends on the relative density of the sand, the ratio of the footing width to the depth of the sand below the bearing elevation, H_1, and the relative strength of the underlying clay. If both strata have similar individual bearing capacities, the bearing capacity failure surface may extend into the clay.

The coefficients, K_s and $s \cdot K_s$, can be estimated using the trends in Figure 5-22. The value of δ/ϕ' is for the inclination of the passive force on the failure surface through the sand as shown in Figure 5-21. Model tests by Meyerhof (1974) and field observations of full-sized footings indicate that the theoretical trends can be safely used. Meyerhof and Hanna (1978) show that δ/ϕ' increases to 1 as the bearing capacity of the clay approaches the bearing capacity of the sand. An example is provided in Figure 5-23.

If stiff clay or rock lies below the sand, the thin sand layer may squeeze out from under the footing as it fails. The bearing capacity and shape factors applicable to this situation depend on the ratio of H_1 / B, where H_1 is the thickness of the sand layer below the bearing elevation. The modified bearing capacity and shape factors can be found in Figure 5-24 and should be used with Equation 5-15. The bearing capacity calculated using the modified factors should be compared to the bearing capacity of the underlying stiff clay. If the bearing capacity of the clay is lower, it should be used instead.

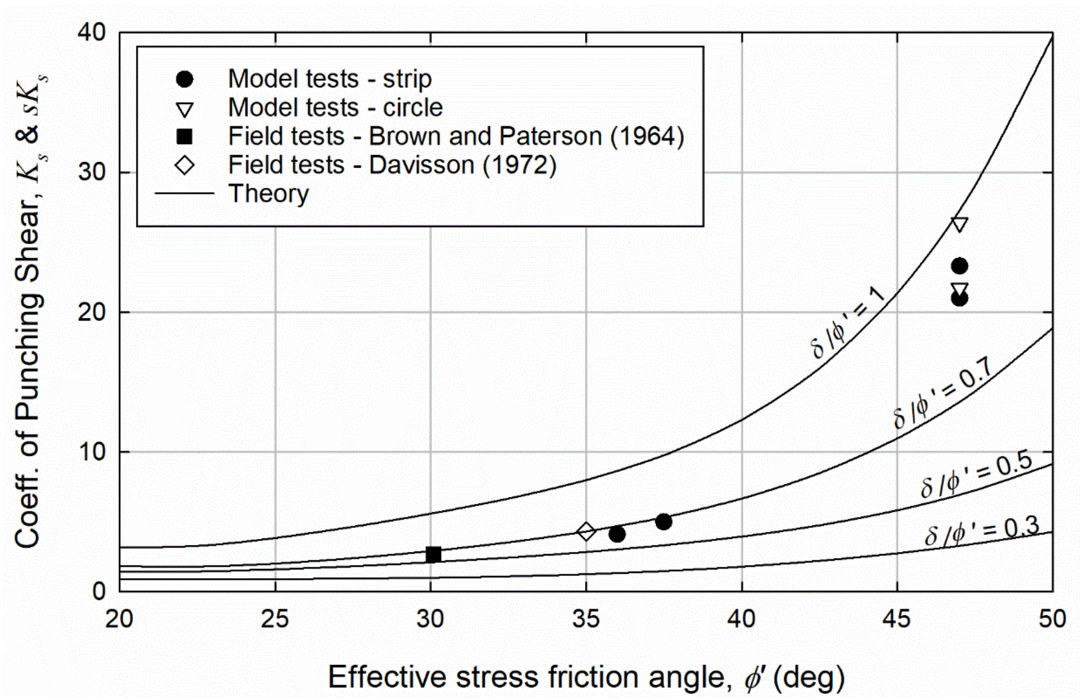
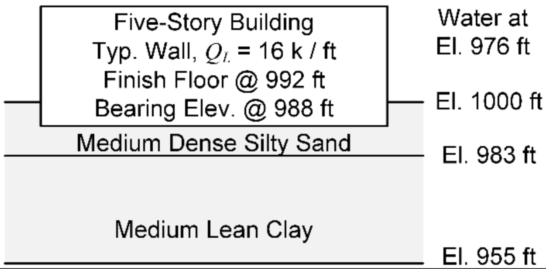
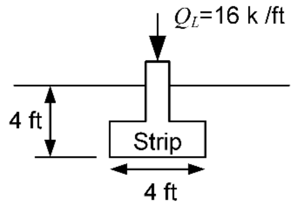


Figure 5-22 Coefficients K_s and $s{\cdot}K_s$ for Punching Shearing Resistance (after Meyerhof 1974, Meyerhof and Hanna 1978)

Project and Site Details



Trial Design



Trial q_{net} = 4000 psf

Find q_{ult} and q_{all} for F = 2.5.

Soil Parameters:
Sand: ϕ' = 34 deg, γ_t = 125 pcf

Clay: s_u = 1600 psf, γ_t = 120 pcf

<u>Sand Layer Over Clay (Case 4) – Meyerhof (1974)</u>

Thickness of Sand Layer: $H_1 = 988 - 983 = 5\,ft$

Bearing Capacity Factors: For clay: $N_c = 5.14$ For sand: $N_q = 29,\ N_\gamma = 31$

Coefficient of Punching Shear: Assume δ/ϕ' = 0.7, $K_s \approx 4$ from Figure 5-22

Ultimate Bearing Capacity:

$$q_{ult} = \min\begin{cases}(5.14)(1600\,psf) + (125\,pcf)(5\,ft)^2\left(1+\dfrac{2(4\,ft)}{5\,ft}\right)\left(\dfrac{(4.0)\tan(34)}{4\,ft}\right) + (125\,pcf)(4\,ft) = 14,204\,psf \\ (125\,pcf)(4\,ft)(29) + 0.5(125\,psf)(4\,ft)(31) = 22,250\,psf\end{cases}$$

$$q_{ult} = 14,204\,psf$$

Allowable Bearing Pressure:

$$q_{all,net} = \frac{14,204\ psf}{2.5} - 500\ psf = 5,186\ psf > 5000\ psf$$

The column foundation design is adequate for bearing because $q_{all,net}$ exceeds the applied pressure. The ratio of bearing capacity of the clay to the sand is about 0.6 for K_s = 4. According to Meyerhof and Hanna (1978), a slightly higher value of δ/ϕ' and K_s might be warranted. This would increase the bearing capacity further.

Figure 5-23 Bearing Capacity Example – Sand Layer Over Clay (Case 4)

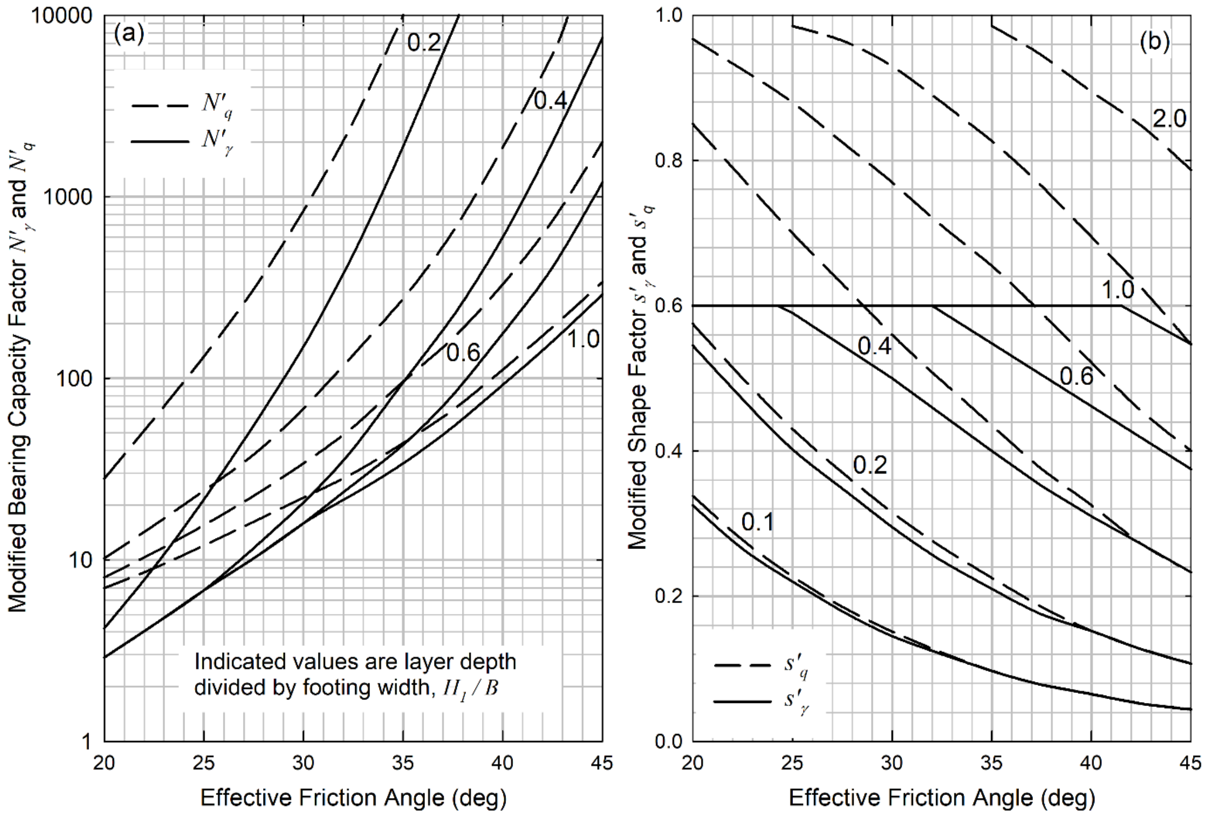


Figure 5-24 Modified Factors for – (a) Bearing Capacity and (b) Shape for Circular Footings (after Meyerhof 1974)

5-3.7 Bearing Capacity of Rock.

Three types of shear strength parameters are used in rock mechanics depending on the rock structure being evaluated: 1) shearing of an intact specimen, 2) shearing along a joint or fracture, or 3) shearing through a fractured rock mass. For bearing capacity, shearing along a rock fracture is the most applicable.

Table 5-12 provides typical ϕ' values for rock fractures and joints. Rock fractures have undulations or irregularities called *asperities*, which add to the frictional resistance of smooth rock fractures (Stagg and Zienkiewicz 1968). The asperity angle (i) usually ranges from 10 to 15°. The design friction angle (ϕ'_{rf}) is found by adding the rock friction angle, such as those in Table 5-12, and the asperity angle.

Table 5-12 Range of Properties for Rock Types (after Wyllie and Norrish 1996 and Bowles 1996)

Rock Type	Unit Weight, γ (pcf)	Average Effective Rock Fracture Shear Strength	
		ϕ' (deg)	c' (psf)
Granite, Basalt, Conglomerate, Limestone	170	37	0
Sandstone, Siltstone, Gneiss, Slate	160	31	0
Schist (high mica content)	165	27	0
Shale	120	24	0

The bearing capacity of rock may be calculated using the Terzaghi method along with the Terzaghi shape factors (Table 5-5). However, the bearing capacity factors are different for rock and are given by Stagg and Zienkiewicz (1968) based on ϕ'_{rf} as:

$$N_c = 5\tan^4\left(45 + \phi'_{rf}/2\right) \quad (5\text{-}29),$$

$$N_q = \tan^6\left(45 + \phi'_{rf}/2\right) \quad (5\text{-}30),$$

and

$$N_\gamma = N_q + 1 \quad (5\text{-}31),$$

where:
ϕ'_{rf} = rock fracture friction angle including the effect of asperities.

The evaluation of rock bearing capacity should also include some measure of the rock quality, such as Rock Quality Designation (RQD) or Geological Strength Index (GSI). RQD can be incorporated as a reduction to the ultimate bearing capacity as suggested by Bowles (1996):

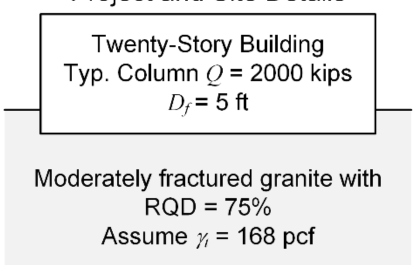
$$q'_{ult} = q_{ult} \cdot RQD^2 \quad (5\text{-}32)$$

where:
q'_{ult} = reduced ultimate bearing capacity.

For Equation 5-32, the RQD should be evaluated to a depth of B below the footing and should be expressed as a decimal, not a percentage. A factor of safety of 3 to 4 is recommended to calculate $q_{all,net}$ from q'_{ult} for rock foundations. When using RQD, the rock material must meet the hardness and soundness criteria defined by Deere and Deere (1989). In massive rock with few fractures, the RQD will likely be 100 percent (1.0), and the q'_{ult} value will equal q_{ult}.

Some rock is soft and highly weathered to completely weathered, which means that most or all of the minerals have decomposed to soil. Texture becomes indistinct but fabric and structure are preserved (ISRM 1978). Soft rock can be scraped with a knife and indented 1 to 3 mm with a pick (NRCS 2022). In this case, the RQD will be close to zero, and the soft rock material should be evaluated as soil using the bearing capacity factors from Section 5-3.1.2. The undrained shear strength for this calculation may be obtained from a soil pressuremeter or rock pressuremeter (rock dilatometer) depending upon the strength of the material as discussed in Chapter 2 of DM 7.1. Example calculations illustrating rock bearing capacity are provided in Figure 5-25.

Project and Site Details



Trial Foundation Size

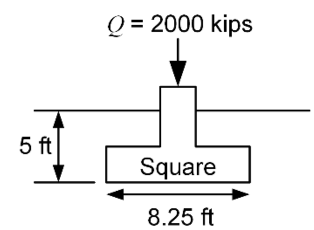
Initial assumption: $q_{all,net}$ = 30 ksf

$$A = \frac{Q}{q_{all,net}} = \frac{2000\,kips}{30\,ksf} = 66.7\,ft^2$$

$$B = \sqrt{A} = \sqrt{66.7\,ft^2} = 8.17\,ft$$

Use $B = 8.25\,ft$

Trial Design



<u>Rock Properties</u>

Rock Fracture Shear Strength (From Table 5-10): ϕ' = 37 deg, Asperity Angle, i = 10 deg, ϕ_{rf} = 47 deg

<u>Ultimate Bearing Capacity</u>

Bearing Capacity Factors:
(Stagg and Zienkiewicz 1968)

$$N_q = \tan^6\left(45 + 42/2\right) = 268$$

$$N_\gamma = 268 + 1 = 269$$

Vertical Stress at Foundation Level:

$$\sigma_{zD} = \left(5\,ft\right)\left(168\,pcf\right) = 840\,psf$$

Ultimate Bearing Capacity:

$$\begin{aligned} q_{ult} &= \sigma_{zD} N_q + 0.4\gamma_t B N_\gamma \\ &= \left(840\,psf\right)\left(268\right) + 0.4\left(168\,pcf\right)\left(8.25\,ft\right)\left(269\right) \\ &= 225{,}120 + 149{,}134 = 374{,}254\,psf \end{aligned}$$

RQD Reduction:

$$q'_{ult} = q_{ult} \cdot RQD^2 = \left(374\,ksf\right)\left(0.75\right)^2 = 211\,ksf$$

Allowable Bearing Pressure:
(F = 3)

$$q_{all,net} = \frac{210\,ksf}{3} - 0.84\,ksf = 69.2\,ksf > 30\,ksf$$

The design is suitable for bearing because the allowable bearing pressure exceeds the assumed design value.

Figure 5-25 Example Calculations for Bearing Capacity of Rock

5-4 GEOTECHNICAL DESIGN OF COMBINED AND MAT FOUNDATIONS.

Combined footings and mat foundations are designed as described by the American Concrete Institute (ACI) (2002). The following paragraphs describe the required input that geotechnical engineers need to provide to structural engineers before and during their design of these foundations. An extended example of the necessary field investigation, laboratory testing, and calculations is provided in Appendix B.

5-4.1 Definitions and Applications.

This section considers the design of shallow foundations carrying more than a single column or wall load as defined above. The following definitions are helpful and have been summarized from ACI (2002):

- *Combined footing* – footing supporting more than one column load. Combined footings are used when column loads are closely spaced so that individual footings would overlap and thus the footings are combined to support the loads.
- *Continuous footing* – footing supporting two or more columns in a row. Continuous foundations are used under wall loads and when the distance between columns is sufficiently close that individual footings can be combined.
- *Grid foundation* – a foundation formed by intersecting continuous footings. Grid foundations are a variation on continuous footings.
- *Mat foundation* – a continuous footing supporting columns in several rows in each direction, covering an area of at least 75 percent of the total structure area. Mat foundations are generally appropriate if: 1) the sum of individual footing base areas exceeds about 75% of the total foundation area; 2) the subsurface strata contain cavities or compressible lenses and differential settlements are a concern; 3) the subsurface strata are highly compressible and a reduction in bearing pressures is helpful; or 4) resistance to hydrostatic uplift is required.
- *Rigid foundation* – loads cause differential to total settlement ratios ≤ 0.1.
- *Flexible foundation* – does not meet requirements for rigid foundations.

Design of these foundations, especially mats, is an iterative process between the geotechnical engineer and the structural engineer. The soil response is based on mat contact pressures, which in turn are based on mat loads, flexibility, and modulus. Thus, the computed mat deflections and soil responses must converge. Economic considerations will also have an impact on selection of a combined footing and mat foundation over other alternatives. Slabs-on-grade are excluded from this discussion.

5-4.2 Rigid Foundations.

Rigid foundations are those which, because of their stiffness, will not allow individual columns or walls to settle differentially. Rigid foundations produce uniform settlements if loaded uniformly. The contact pressures, however, are not uniform for ideal coarse-grained soil (c' = 0 psf) or saturated fine-grained soil (ϕ = 0), as shown in Figure 5-26. In design, structural engineers generally assume the contact pressure to be an average of the total load on the foundation divided by the area of the foundation for these rigid foundations. This is an acceptable approach according to ACI (2002) because of conservative load estimates used for calculation of settlement and an ample safety factor against the ultimate bearing capacity. Many foundations, however, support loads that are not uniform. It is common practice, in these cases, to assume a linear, nonuniform contact pressure, such as under a retaining wall where the toe pressure is maximum and the heel pressure is minimum.

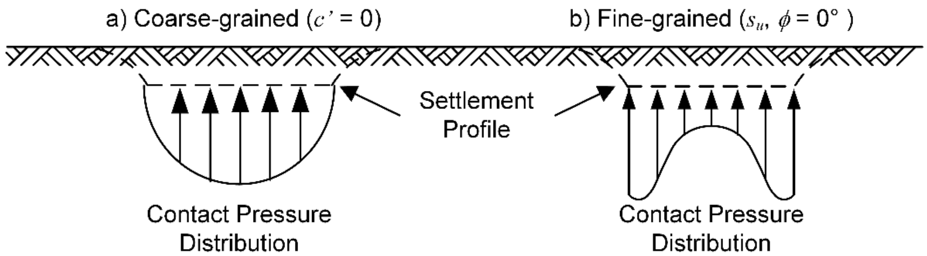


Figure 5-26 Idealized Distribution of Contact Pressure and Settlement Under a Uniformly Distributed Load for a Rigid Foundation - a) Coarse-grained (c' = 0 psf) and b) Fine-grained (ϕ = 0°) (after Das 2022)

5-4.2.1 Rigid Foundation Criteria.

Combined footings and mat foundations may be designed as rigid structures if they meet the relative stiffness factor criteria, K_r, developed by Meyerhof (1953):

$$K_r = \frac{E' \cdot I_b}{E_s \cdot B^3} \tag{5-33}$$

where:
$E' \cdot I_b$ = flexural stiffness of the structure (beyond scope of this document),
E_s = soil modulus, and
B = width of foundation.

Calculation of the relative stiffness is a joint effort of the structural and geotechnical engineers. A preliminary E_s value must be provided by the geotechnical engineer to the structural engineer. An approximate value of stiffness per unit width of building and foundation width is estimated by the structural engineer. Using this information, the structural engineer calculates the relative stiffness, K_r, of a foundation. The structural engineer should indicate to the geotechnical engineer whether the foundation is rigid or flexible, or whether both types of foundations should be considered by the geotechnical engineer. When $K_r \geq 0.5$, the ratio of differential to total settlement is about 0.1 or less and the foundation may be considered rigid.

The spacing of columns can be used to determine if continuous foundations may be considered rigid using a factor (λ) based on soil and foundation stiffness:

$$\lambda = \sqrt[4]{\frac{k_s \cdot B}{4E_c \cdot I}} \quad (5\text{-}34)$$

where:
k_s = modulus of subgrade reaction (see Section 5-4.5),
E_c = modulus of concrete, and
I = moment of inertia of footing.

A foundation can be considered rigid if the average spacing of two adjacent column spans is less than $1.75 / \lambda$, provided adjacent column loads and column spacing do not vary by more than 20 percent. This assessment is typically completed by the structural engineer.

If the foundation meets either of these criteria, it may be designed as a rigid foundation with a linear distribution of soil pressure based on statics. Thus, the assumption for design is that a straight-line relationship exists between maximum and minimum contact pressures below the footing. In this case, the geotechnical engineer is responsible for providing a net allowable soil bearing pressure, $q_{all,net}$, as described in Section 5-2.4. The settlement should be estimated using the methods of Chapter 5 of DM 7.1.

5-4.3 Flexible Foundation Criteria.

If $K_r < 0.5$, the foundation should be designed as a flexible foundation. For example, when $K_r = 0$, the ratio of differential settlement to total settlement is about 0.5 and 0.35 for continuous and square footings, respectively, according to ACI (2002).

If a foundation is considered flexible, it is usually designed by the structural engineer as a beam on elastic foundation. Figure 5-27 illustrates the contact pressure for these foundations when uniformly loaded and supported on ideal coarse-grained soil ($c' = 0$) and fine-grained soil ($\phi = 0$). The contact pressure will be uniform for a uniform load, and the settlement will be greatest at the edges of the foundation for coarse-grained soil and dish shaped (concave up) for a saturated clay with the greatest settlement at the center of the foundation.

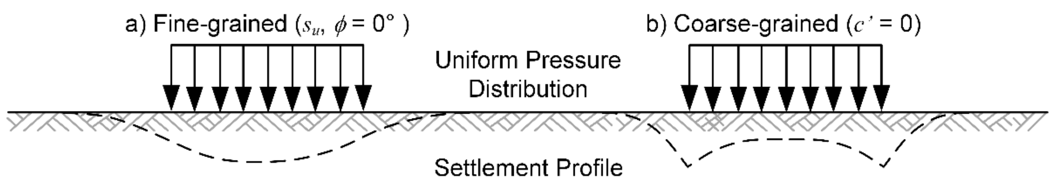


Figure 5-27 Idealized Distribution of Contact Pressure and Settlement Under a Uniformly Distributed Loading for a Flexible Foundation – a) Fine-grained Soil, (ϕ = 0 deg) and b) Coarse-grained Soil (c' = 0) (after Das 2022)

5-4.4 Required Input for Analysis of Continuous and Mat Foundations.

Most structural engineers use software to design continuous and mat foundations. Closed form analytical solutions are available for specific problems (Hetenyi 1948) but not more complex situations. The two procedures often used to evaluate the soil response for continuous footings or mat foundations are the finite element method (FEM) using elastic constants and the finite grid method (FGM) using a Winkler foundation model with elastic springs. The springs can be either coupled or uncoupled. The properties of these springs are estimated using a subgrade modulus (k_s), which is adjusted for footing size or tributary area of a node for a mat. Consideration is also given to the change of subgrade modulus with depth. Uncoupled springs are a simplifying assumption that structural engineers may use in their design.

Flexible foundations present significant soil structure interaction issues that require the geotechnical engineer and structural engineer to work together to find an appropriate solution. When the relative stiffness factor indicates the foundation may be borderline rigid/flexible, the structural engineer may choose to analyze the foundation as both a rigid and flexible structure. The analyses of a foundation as a flexible plate on an elastic foundation may appear to be a more exact approach. However, a number of factors reduce the accuracy of this approach, including:

- Difficulty in estimating and assigning elastic soil parameters: k_s, E_s, and ν,
- Horizontal and vertical variation of soil strata thickness and properties,
- Mat shape,
- Variety of superstructure loads and assumptions in their development, and
- Interaction effects between the superstructure stiffness and stiffness of the continuous footing or mat foundation.

Depending on whether an FEM or FGM approach is being used, the structural engineer may require the following input from geotechnical engineers for flexible foundation design:

- Net allowable soil bearing pressure, $q_{all,net}$,
- Estimated settlement, s,
- Estimated soil modulus, E_s,
- Poison’s ratio, ν, and
- Estimated modulus of subgrade reaction, k_s.

Generally, the soil is not homogeneous under a combined footing or mat foundation and the geotechnical engineer must develop soil behavior and properties that represent the stratigraphy, loading condition, and depth of stress penetration. Estimation of the allowable bearing pressure was discussed in Sections 5-2 and 5-3. Methods of calculating the estimated settlement are included in Chapter 5 of DM 7.1. Methods to estimate k_s, E_s, and ν are discussed in the following section.

These input recommendations must also consider time-dependent effects that can result in changes to moments and shear forces within the mat foundation and superstructure. Time-dependent effects occur both during and after construction and include the following:

- Heave and recompression of the subgrade after excavation and
- Long-term consolidation settlement of clays.

The following loadings must be considered: 1) staged loading, 2) dead loading followed by live loading, 3) short-term elastic settlement of sands, and 4) foundation soil shear displacements. Staged loading and dead and live loading will be included in the settlement estimate since the structural loading is used for settlement estimates. Time-dependent elastic settlement of sands can also be included in the settlement estimate by using the Schmertmann et al. (1978) approach. Soil shear displacements should not occur if an adequate bearing capacity factor of safety is used.

5-4.5 Modulus of Subgrade Reaction.

The modulus of subgrade reaction (k_s) is the ratio of the contact pressure divided by the corresponding deformation, or settlement, and has the units of force per cubic length. Other names include the coefficient of subgrade reaction or subgrade reaction. The modulus of subgrade reaction is depicted in Figure 5-28 and can be calculated as:

$$k_s = q/s \qquad (5\text{-}35)$$

where:
q = contact pressure acting perpendicular to the contact area and
s = soil settlement.

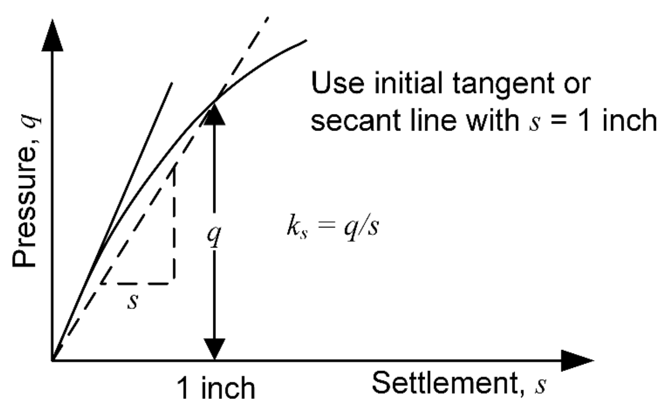


Figure 5-28 Subgrade Pressure versus Settlement Curve Defining k_s (after Bowles 1996)

Typical k_s values are provided in Table 5-13 that can be used as a guide for comparison to measured or calculated values. The table should not be used to calculate an average value of k_s because of the breadth of the range of values. Two procedures for estimating k_s are discussed below.

Table 5-13 Typical Modulus of Subgrade Reaction Values (after Bowles 1996)

Soil Type		k_s (pci)
Loose sand		20 to 60
Medium dense sand		30 to 300
Dense sand		250 to 500
Clayey medium dense sand		120 to 300
Silty medium dense sand		100 to 200
Clay	q_{all} ≤ 4,000 psf	50 to 100
	q_{all} = 4,000 to 16,000 psf	100 to 200
	q_{all} > 16,000 psf	> 200

5-4.5.1 Estimating k_s from Plate Load Tests.

A plate load test may be used to estimate k_s, which pushes a 1-foot wide square or circular plate into the ground. The pressure and deflection are measured as shown in Figure 5-28. The pressure-deflection relationship is typically nonlinear. The secant modulus through a specific settlement point, for example 1-inch of settlement and the origin, is usually used to define k_s for a plate load test.

The plate load test is of limited value for foundations due to the size of the plate and scale effects. If the combined footing has a width less than or equal to 5 ft with uniform soil conditions within the depth of influence ($2B$ for square footings or $4B$ for continuous footings), the k_s value for design of the footing may be approximated from a plate load test as suggested by Sowers (1977):

$$k_s = k_p \left(B_p / B\right)^n \tag{5-36}$$

where:
k_p = the modulus of subgrade reaction from the plate load test,
B_p = width of plate,
B = width of foundation, and
n = 0.5 to 0.7.

Plate load test results cannot be scaled for larger footings and mats because of the variation of soil properties within the depth of stress penetration.

5-4.5.2 Estimating k_s from Elastic Parameters.

Assuming the soil acts as an elastic medium, settlement can be estimated based on the foundation size and bearing pressure as well as the soil properties, E_s and ν. Influence factors (μ_0 and μ_I) are used to account for depth of embedment, foundation shape and depth to a firm layer. These factors are provided in Figure 5-29.

Using the definition of k_s in Equation 5-32, the elastic settlement equation can be rewritten as:

$$k_s = \frac{q}{s} = \frac{1}{\left(B/E_s\right)\mu_0\mu_1} \tag{5-37}$$

where:
B = width of foundation,
E_s = elastic modulus of the soil within the zone of influence for the foundation,
μ_0 = influence factor related to embedment of the load and ν, and
μ_1 = influence factor related to problem geometry and ν.

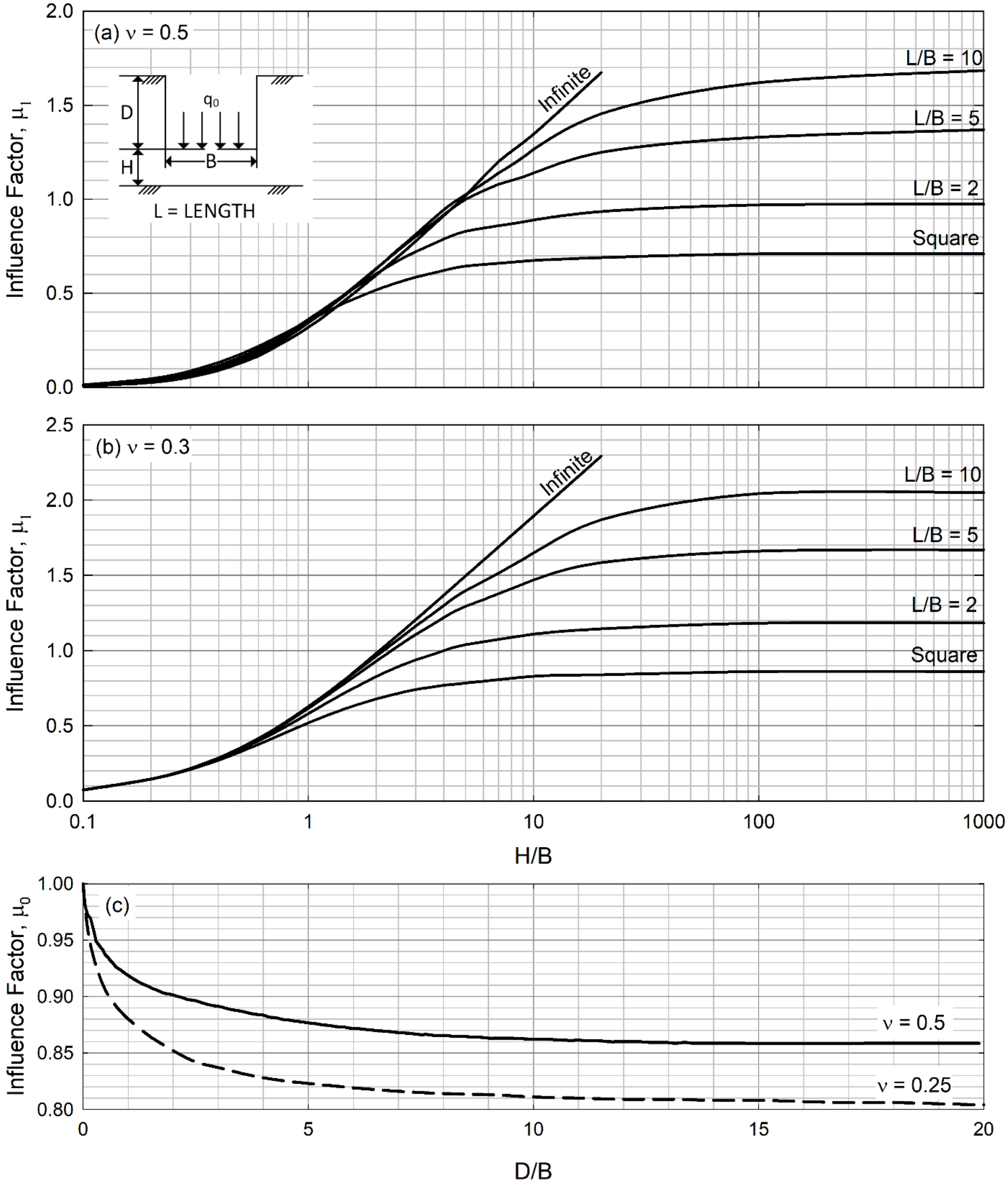


Figure 5-29 Elastic Influence Factors - (a) μ_1 with $\nu = 0.5$, (b) μ_1 with $\nu = 0.3$, and (c) μ_0 with $\nu = 0.25$ and 0.5 (after Giroud 1972 and Burland 1970)

5-4.5.3 Estimating Elastic Parameters, E_s and ν.

Accurately estimating the value of the soil modulus, E_s, with depth below a combined footing or mat foundation can be challenging. The modulus tends to:

- Increase with increasing overconsolidation ratio (OCR),
- Increase with increasing unit weight,
- Decrease with increasing water content,
- Decrease in the laboratory compared to the field, and
- Decrease due to disturbance.

The soil modulus also depends on the drainage condition with E_s used as general soil modulus, E'_s for drained soil modulus, and E_{us} for undrained soil modulus. These modulus values are much different than a true elastic material. In addition, the method of laboratory testing (confined, unconfined, drained, undrained) has an impact on the value of modulus. The values are typically defined using a secant method based on the stress and strain a particular percentage of the ultimate strength. Typically, drained secant moduli are used for coarse-grained soils, and undrained secant moduli are used for fine-grained soils. Soil modulus values may be obtained from triaxial tests on undisturbed samples or *in situ* tests. The typical soil modulus values for all types of soil that are summarized in Table 5-14 should be used as a guide to check the validity of values from *in situ* or laboratory testing.

Table 5-14 Typical Soil Moduli (after Bowles 1996)

Soil Type	Consistency or Density	E_s (tsf)
Clay	Very soft	20 to 140
	Soft	45 to 235
	Medium	140 to 465
	Hard	465 to 930
Sandy clay	Any	235 to 2,330
Glacial till	Loose	95 to 1,400
	Dense	1,400 to 6,715
	Very dense	4,660 to 13,425
Loess	Any	140 to 560
Sand	Loose	94 to 235
	Dense	465 to 750
Silty sand	Any	45 to 185
Sand and gravel	Loose	465 to 1,400
	Dense	930 to 1,865

In coarse-grained soil, the value of E'_s varies with confinement. Thus, under a flexible mat foundation, the edges of the mat will deflect more than the center because the confinement is less at the edges. Also, the modulus increases with depth due to increased confining stress and increases during the application of load on the mat. *In situ* tests are preferred for estimating E'_s for granular soils due to disturbance issues with laboratory testing. Table 5-15 provides correlations of drained E'_s with SPT N and CPT q_c values for coarse-grained soils.

Table 5-15 Correlations for the Drained Modulus of Coarse-Grained Soils with SPT and CPT (after FHWA 2002a, Duncan and Bursey 2007, Coduto 2015, McGregor and Duncan 1998)

Soil Type		E'_s (tsf)	E'_s (tsf)
Silts, sandy silts, slightly cohesive mixtures		$4\ (N_1)_{60}$	(1 to 2) q_c
Clean fine to medium sands and slightly silty sands		$7\ (N_1)_{60}$	
Coarse sands and sands with little gravel		$10\ (N_1)_{60}$	
Sandy gravels		$12\ (N_1)_{60}$	
Gravelly sand and gravels	For $N_{60} \leq 15$	$6\ (N_{60}+6)$	
	For $N_{60} > 15$	$6\ (N_{60}+6)+20$	
Clayey sands		$3.2\ (N_{60}+15)$	
Silty sands		$3\ (N_{60}+6)$	
OC clean sands (age < 100 years) (SW-SP)		$5\ (N_{60}+15)$ all ages	(2.5 to 3.5) q_c
NC clean sands (age > 100 years) (SW-SP)			(3.5 to 6) q_c
OC clean sands (SW-SP)		$180+7.5\ N_{60}$	(6 to 10) q_c
NC silty or clayey sands (SM-SC)			$1.5\ q_c$
OC silty or clayey sands (SM-SC)			$3\ q_c$
Notes: NC = Normally consolidated, OC = over consolidated, q_c = CPT tip resistance N_{60} = SPT blow count corrected to 60% of the theoretical free-fall hammer energy $(N_1)_{60}$ = SPT blow count corrected to 1 tsf of overburden pressure and 60% of the theoretical free-fall hammer energy			

For fine-grained soils, the undrained modulus usually increases with increasing vertical effective stress and undrained shear strength. The modulus also increases with OCR and lower moisture contents. Figure 5-30 provides a simple correlation between E_{us}, plasticity index (PI), and overconsolidation ratio (OCR). Once an appropriate ratio is selected, the undrained modulus can be estimated based on the undrained shear strength. Either *in situ* or laboratory tests are suitable for estimating E_{us} for fine-grained soils.

When layers with different soil properties underlie the mat, an appropriate weighted average E_s must be determined. Within the depth of influence, the modulus of each layer can be multiplied by the layer thickness and summed. The weighted average is this sum divided by the total thickness. The depth of influence is usually assumed to be $2B$ and $4B$ for square and continuous foundations, respectively.

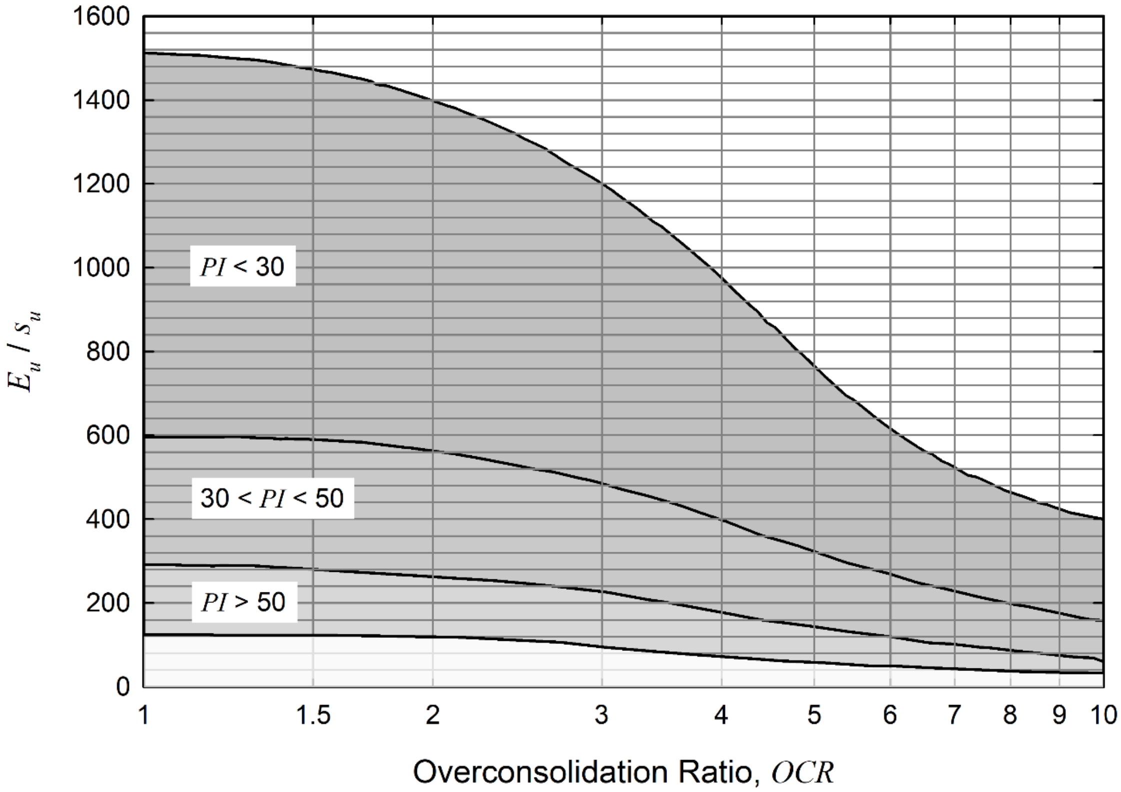


Figure 5-30 Undrained Modulus Correlation for Clay Soils with OCR and PI (after Duncan and Buchignani 1976)

Typical values of Poisson's ratio, which is also required for an elastic analysis, are provided in Table 5-16. Note, ν is 0.5 for undrained conditions (i.e., no volume change ΔV = 0). For drained conditions, ν can be related to the friction angle:

$$\nu = \frac{1 - \sin\phi'}{2 - \sin\phi'} \qquad (5\text{-}38).$$

When ϕ' = 20° to 55°, the ν values range from 0.4 to 0.15.

Table 5-16 Typical Values of Poisson's Ratio (after Bowles 1996)

Soil Type	Poisson's Ratio, ν
Clay, saturated	0.45 to 0.5
Clay, unsaturated	0.1 to 0.3
Sandy clay	0.2 to 0.3
Silt	0.3 to 0.35
Medium to dense sand, gravelly sand	0.3 to 0.4
Loose to medium sand	0.2 to 0.35
Loess	0.1 to 0.3
Concrete	0.15

5-4.5.4 Evaluation of k_s for Time-Dependent Settlement.

Time-dependent settlements must be included in the estimate for k_s for a continuous footing or mat foundation when the structure imposes stresses beyond the preconsolidation stress, or when recompression or heave occurs due to excavation for the foundation. Neither of these settlements are included in the k_s values estimated from Equation 5-35. In this case, consolidation settlement (s_c) must be added to the elastic settlement, and the reduced subgrade modulus (k_{sc}) is:

$$k_{sc} = \frac{s \cdot k_s}{s + s_c} = \frac{q}{q\left(B/E_s\right)\mu_0\mu_1 + s_c} \quad (5\text{-}39).$$

5-4.6 Iterative Process in Design.

Although the contact pressures below a flexible mat are uniform for a uniform load, the settlements may vary across the mat because of variable stratigraphy. Also, the mat may not be uniformly loaded, and this will also cause settlements to be varied. Both of these nonuniformities can cause the design of a mat foundation to be an iterative process.

Contact pressures and settlements may be estimated by the structural engineer in the mat analysis, using the initial data provided by the geotechnical engineer including k_{sc}. These should be compared to the contact pressures and settlements estimated by the geotechnical engineer. If they are substantially different, the geotechnical engineer should reevaluate the E_s, ν, and k_s or k_{sc} values and settlements. Revised values should be provided to the structural engineer for the next iteration of modeling. The purpose is to make the settlements and contact pressures developed by the geotechnical engineer match closely with those of the structural engineer. An example mat design has been included in Appendix B.

5-4.7 Node Coupling of Soil Effects.

Mats are commonly designed using software that employs the FEM or FGM (ACI 2002). At the interface between the mat and the soil, the soil response is concentrated at nodes using a concept called a Winkler foundation. The soil is replaced by an equivalent spring with stiffness, K. The value of K for each node is determined by multiplying k_s or k_{sc} by the area (A_{cont}) that contributes to the node:

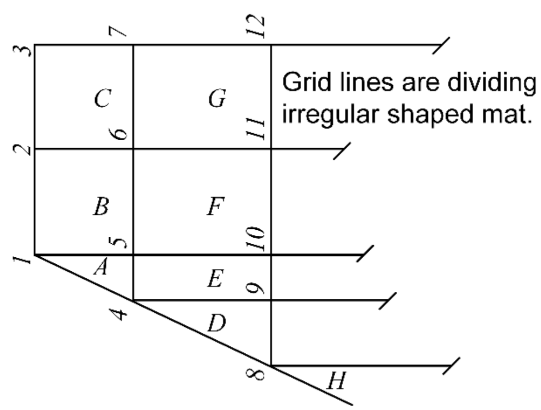
$$K = k_s \cdot A_{cont} \quad (5\text{-}40).$$

The units of K are force per length. Figure 5-31 illustrates the procedure that is used to estimate K for various mat foundation contributary areas. The k_s value assigned to each area shown in Figure 5-31 is based on the closest boring. A number of areas defined by the mat nodes may use the same k_s value. This method produces uncoupled spring K values. An indirect method to allow coupling of nodes of Winkler foundations is discussed in the next section.

Uncoupled and coupled springs are illustrated in Figure 5-32. Uncoupling means that the settlement at any spring is unrelated to the settlement at any adjacent spring. The impact of coupling can be significant and can be seen for a uniformly loaded flexible foundation, such as a tank supported on clay. When the nodes are coupled, the deflection is correct and is dish shaped (concave). When uncoupled, the settlement is uniform and incorrect.

Coupling allows the responses at adjacent springs to affect each other. Coupling can also be accomplished when using a finite element computer program with the subgrade defined as an elastic medium, E_s and ν, but this is seldom done because of the difficulty in programing and cost.

Plan View of Irregularly Shaped Mat



Calculation Process

Compute spring constants K_i as follows:

- Represent the area of each element with a letter, such as Area(1-4-5) = A.
- Let the modulus of subgrade reaction within an element be k_A, k_B, etc.
- Representative spring calculations:

$K_1 = A \cdot k_A / 3 + B \cdot k_B / 4$

$K_2 = B \cdot k_B / 4 + C \cdot k_C / 4$ (Typical Side Spring)

$K_3 = C \cdot k_C / 4$ (Typical Corner Spring)

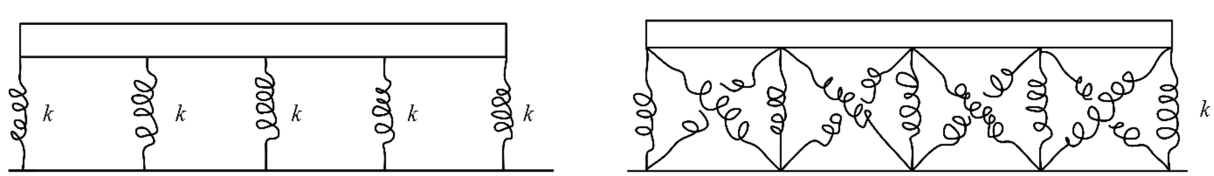
$K_4 = A \cdot k_A / 3 + E \cdot k_E / 4 + D \cdot k_D / 3$

$K_5 = A \cdot k_A / 3 + (B \cdot k_B + E k_E + F \cdot k_F) / 4$

$K_6 = (B \cdot k_B + C \cdot k_C + F \cdot k_F + G \cdot k_G) / 4$

(Typical Interior Spring)

Figure 5-31 Computation of Uncoupled Winkler-type Soil Node Springs (after ACI 2002)



(a) Uncoupled Springs

(b) Coupled Springs

Figure 5-32 Coupled and Uncoupled Springs (after ACI 2002)

5-4.8 Indirect Method to Allowing Coupling.

Bowles (1996) suggested an indirect method for considering coupling in a mat foundation. This a structural consideration but is included herein to illustrate why this concept of coupling is important. The procedure is accomplished by selecting points on the mat plan so that the mat can be zoned with different values of k_s. One point must be on the edge of the mat, and this must be assigned the k_s value calculated for that location. The k_s values on other interior points on the mat foundation are then reduced based on the edge k_s using the procedure described in the following steps (see Figure 5-33):

1) Select sufficient points on the mat plan so that the mat can be zoned with different values of k_s. See Points 1, 2, and 3 for a square mat in Figure 5-33. Point 1 is on the edge of the mat.

2) Select a depth of influence of $4B'$ (B' = the <u>longest</u> side of the mat and is unrelated to the usual depth of influence of $2B$ for square footings).

3) Plot vertical stress profiles for the square mat at points 1, 2, and 3 using the Boussinesq method (Figure 5-33b). For a square mat, $4B' = 4B$ and q_0 is the contact pressure.

4) Numerically integrate stress profiles to obtain the average vertical stress, $\sigma_{z,ave} = (\sigma_z / q_{net}) \cdot q_{net}$. See Table 5-17.

5) These $\sigma_{z,ave}$ are then designated $\sigma_{z,ave(1)}$, $\sigma_{z,ave(2)}$, and $\sigma_{z,ave(3)}$ to correspond to Points 1, 2, and 3.

6) Compute k_s for any point i as follows:

$$k_{s,i} = k_s \left(\frac{\sigma_{z,ave(1)}}{\sigma_{z,ave(i)}} \right) \tag{5-41}$$

where:
$\sigma_{z,ave(i)}$ = average vertical stress at other points (Points 2 and 3 in Figure 5-33).

This procedure assumes an initial uniform k_s value throughout the mat foundation. The example illustrates the difference between contributary areas and zones for the indirect method of allowing coupling. When k_s values vary, as in the example in Figure 5-33 where Areas A, B, and C had different k_s values, k_s in Equation 5-39 varies with location. The procedure will reduce the k_s values, but they will not be based on a uniform k_s value as shown in the example of Figure 5-33. Table 5-17 contains estimated k_{si} values for different B' / L ratios.

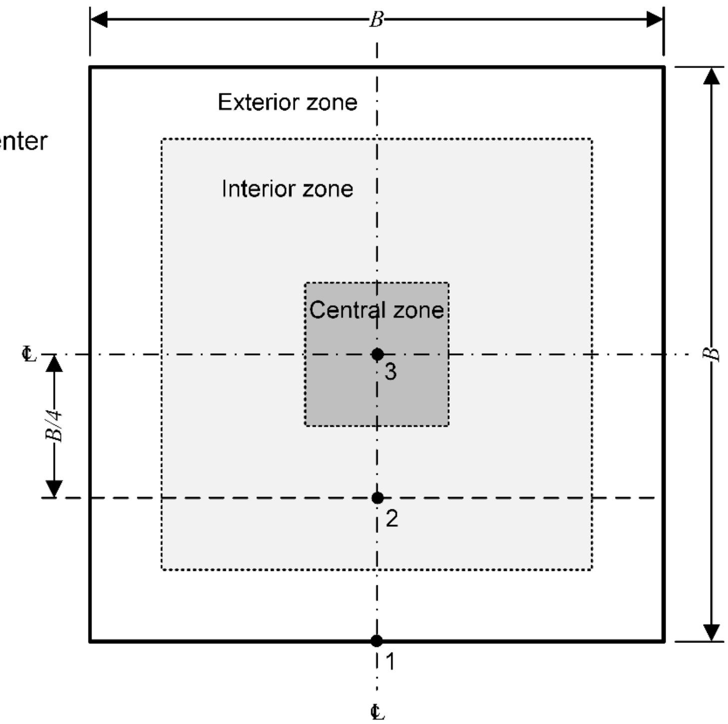
(a) Mat dimensions and zones

Point 1 on edge
Point 2 half way from edge to center
Point 3 at center

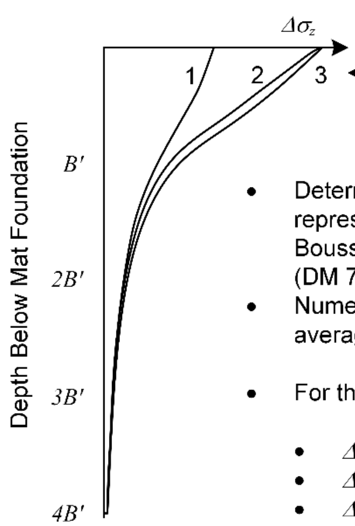
Mat is divided into three zones:

- Exterior zone represented by Point 1
- Interior zone represented by Point 2
- Central zone represented by Point 3

The value of k_s is provided or determined for the soil at the location of the mat (see Section 5-4.5).



(b) Change in Stress Distribution at Representative Points



- Determine $\Delta\sigma_z$ below representative points using Boussinesq theory (DM 7.1, Ch. 4) or Table 4-14.
- Numerically integrate to obtain average $\Delta\sigma_z$ over depth of $4B'$
- For this example:
  - $\Delta\sigma_{z,ave(1)}$ = 0.162 q_0
  - $\Delta\sigma_{z,ave(2)}$ = 0.235 q_0
  - $\Delta\sigma_{z,ave(3)}$ = 0.250 q_0

(c) Modulus of Subgrade Reaction using Indirect Coupling

Subgrade modulus for zone and representative point i is found as:

$$k_{s,i} = k_s\left(\frac{\Delta\sigma_{z,ave(1)}}{\Delta\sigma_{z,ave(i)}}\right)$$

For the three zones in this example:

$$k_{s,1} = k_s\left(\frac{0.162 \cdot q_0}{0.162 \cdot q_0}\right) = k_s$$

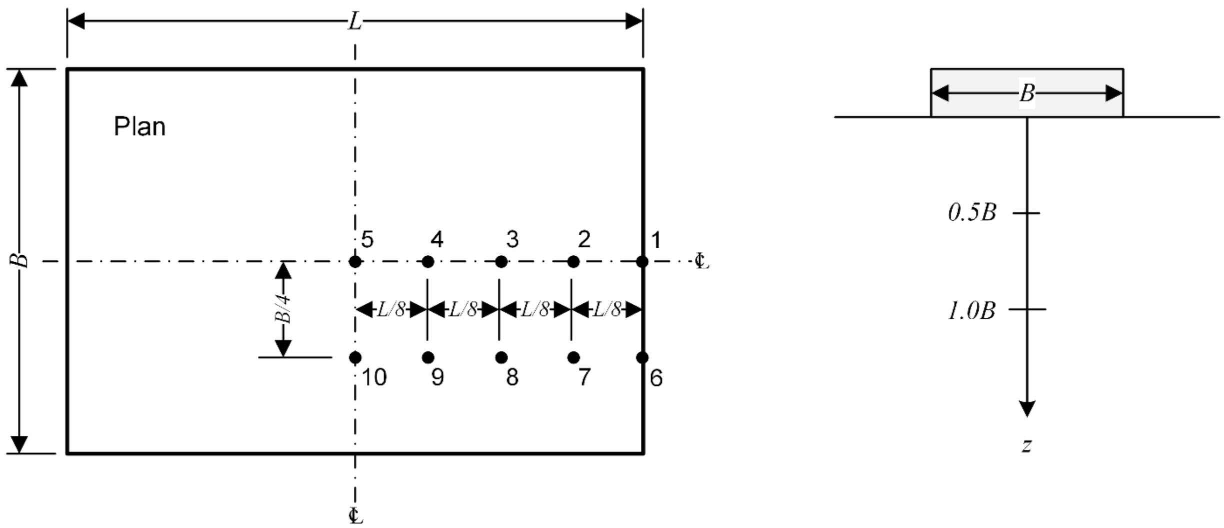
$$k_{s,2} = k_s\left(\frac{0.162 \cdot q_0}{0.235 \cdot q_0}\right) = 0.69 \cdot k_s$$

$$k_{s,1} = k_s\left(\frac{0.162 \cdot q_0}{0.250 \cdot q_0}\right) = 0.65 \cdot k_s$$

Figure 5-33 Example Mat Foundation Indirect Coupling Problem

Table 5-17 Vertical Pressure Profiles for Selected Points Beneath a Foundation Mat (after ACI 2002)

Mat Aspect Ratio, B/L	Average $\Delta\sigma_z$ / q_0 from 0 to 4B below Points 1 to 10 (see inset)									
	1	2	3	4	5	6	7	8	9	10
1	0.162	0.217	0.235	0.246	0.250	0.153	0.206	0.222	0.232	0.235
2	0.189	0.273	0.304	0.319	0.324	0.180	0.259	0.288	0.302	0.306
3	0.198	0.305	0.340	0.355	0.359	0.189	0.289	0.321	0.336	0.340



Note: Values of $\Delta\sigma_{z,ave}$ / q_0 found by numerically integrating $\Delta\sigma_z$ over z from 0 to 4B and dividing by 4B.

5-4.9 Floating Mat Foundation.

Depending on the structural geometry, weight, and load distribution on the mat, a mat foundation may *float* the structure in the soil, so that settlement only relates to recompression or heave. Where uniform, the pressure that results in settlement in a mat analysis can be computed as follows:

$$q_{net} = \frac{W_{structure} - W_{excavated}}{A_{mat}} \quad (5\text{-}42)$$

where:
$W_{structure}$ = total weight of structure,
$W_{excavated}$ = total weight of excavated soil, and
A_{mat} = area of mat.

5-4.10 Two- or Three-Dimensional Problems.

A two-dimensional analysis is normally defined as a mat designed as a beam on elastic foundation using soil concentrations at the nodes. A three-dimensional analysis involves modeling the soil as a three-dimensional elastic solid. Three-dimensional analyses are very expensive and are not recommended except for very elaborate projects.

5-5 DESIGN FOR SPECIAL LOADING CONDITIONS.

This section discusses the design of shallow foundations for special loading conditions. Design considerations for foundations and slabs to resist high groundwater are presented. Uplift resistance of shallow foundations is also considered.

5-5.1 Pressure Resistant and Relieved Foundation Slabs and Walls.

Hydrostatic pressure resistant and relieved foundation slabs and walls are considered in this section. Guidelines for the selection of appropriate drainage material are presented. Methods of dampproofing and waterproofing are also discussed.

Where the water table is deep, infiltration of surface water may still occur, and basement walls should be dampproofed. A drainage layer should be installed along walls with a foundation drain. A layer of drainage material should be placed under the slab with a vapor barrier.

Where the permanent water table is above the top of the basement slab, two general schemes are employed for basements. A pressure resistant slab and exterior foundation walls, *pressure slab and walls,* can be used. In this case, walls must be waterproofed to the maximum potential level of groundwater. Alternatively, the uplift pressures on the slab and the water pressure on walls can be relieved by a drainage system. This is referred to as a *relieved slab and walls* and requires dampproofing. In some cases, groundwater can be cut off by exterior foundation walls that extend into a low permeability thick clay layer or low permeability rock. In this case, a relieved slab is used and the exterior walls are waterproofed.

In general, the choice between pressure resistant or relieved slabs and walls depends on overall economy, maintenance, layout, and operation. This must be evaluated for each project individually.

5-5.1.1 Hydrostatic Pressure Slabs and Walls.

For basements extending only a small depth below groundwater, a pressure slab to resist maximum probable hydrostatic uplift pressures may be economical. Water-stops should be provided at the construction joints, and a drainage layer should be installed between the pressure slab and floor slab to collect any leakage through the pressure slab. Drainage material should be as described in Section 5-5.1.3, and a slotted PVC corrugated drainage pipe should be added beneath the slab depending on the anticipated flow. A sump will be required to remove any water from the drainage layer. The exterior walls must be designed to withstand water pressure to the maximum anticipated level of ground water and must be waterproofed below this level. A vapor barrier should be placed over the drainage layer and under the slab to reduce the potential for moisture to migrate to the floor. An illustration of the pressure slab concept is shown in Figure 5-34.

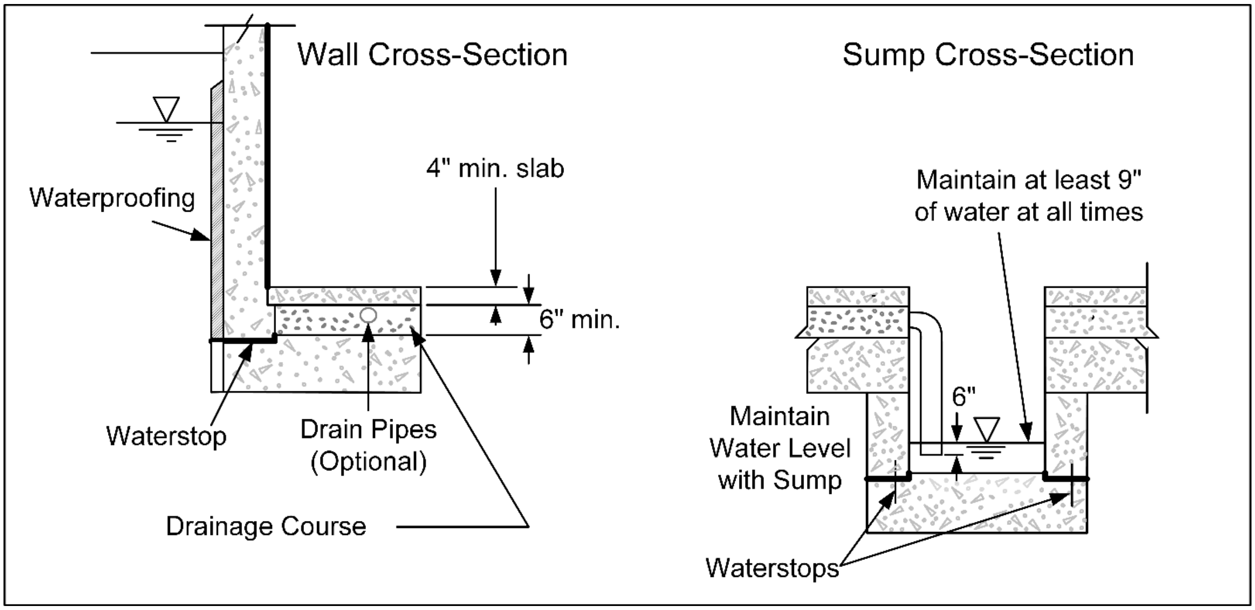


Figure 5-34 Schematic of a Pressure Slab and Wall System

5-5.1.2 Relieved Slabs.

For basements at considerable depth below the groundwater level, it is usually economical to provide pressure relief along the foundation walls and beneath the floor slab. Drainage layers and drains are required at exterior walls and under floors to maintain no hydrostatic pressure on the walls or floor slab. Exterior walls below grade must be dampproofed. Additional dampproofing may be required on the interior of the basement walls depending upon the use. Figure 5-35 provides an example for this type of design.

If a thick, underlying stratum of low permeability clay or rock is relatively shallow, a cutoff foundation wall system may be economical as shown in Figure 5-36. In this case, the foundation walls extend into the low permeability stratum and reduce water flow and pressures under the slab. Exterior walls below grade must be waterproofed, but wall drains may be omitted. Since some seepage may occur under the cutoff foundation walls, a drainage layer is required below the floor slab to maintain no hydrostatic pressure. Drain pipes are likely not needed due to low anticipated flow requirements.

Additional dampproofing may be required on the interior of the basement walls depending upon the use.

Drainage material for relieved slabs should be as described in Section 5-5.1.3, and slotted PVC corrugated drain pipes may be needed beneath slab, depending on the anticipated flow. A sump is required to remove any water from the drainage layers as shown in Figure 5-34. A vapor barrier should be placed over the drainage layer and under the slab to reduce the potential for moisture to migrate to the floor.

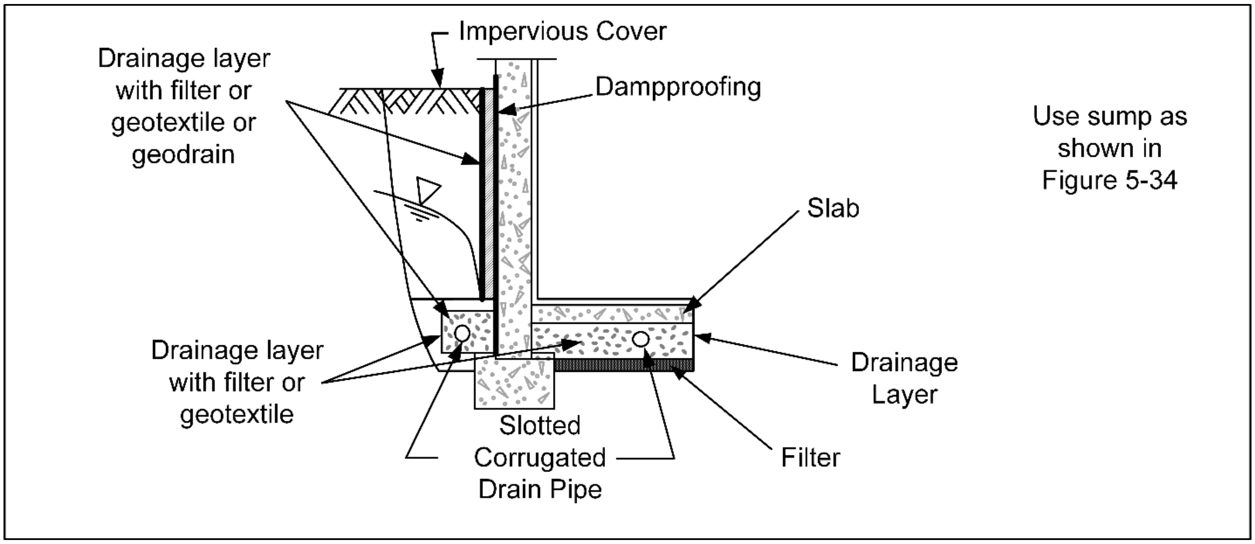


Figure 5-35 Schematic of a Relieved Slab and Wall System

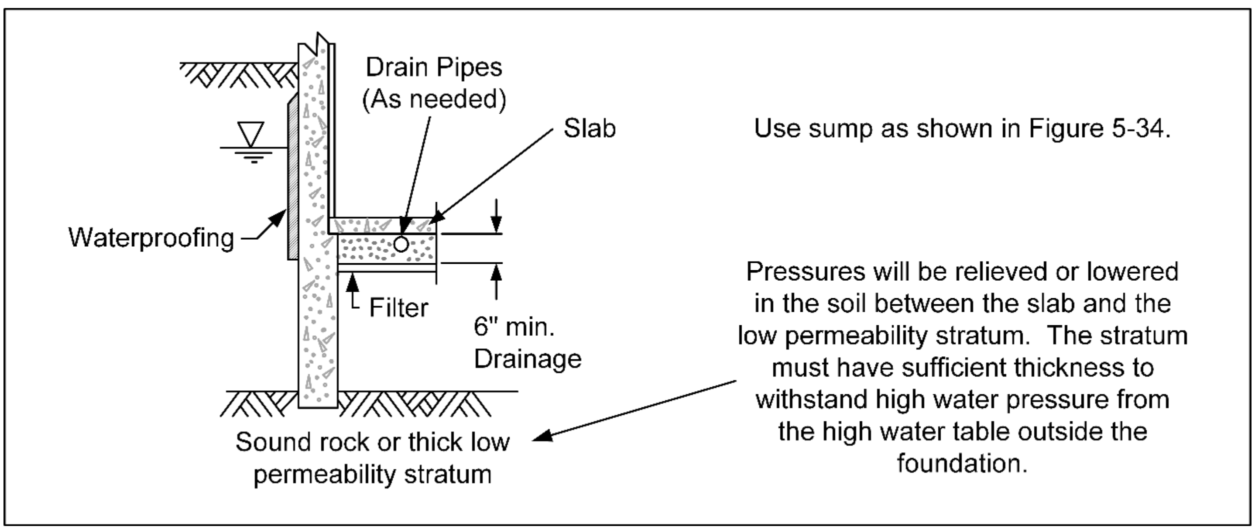


Figure 5-36 Schematic of a Cutoff Foundation Wall to a Low Permeability Stratum

5-5.1.3 Underdrain System.

Drainage material should be sound, clean gravel or crushed stone graded between 3/4 and 2 inches. This material should be densified and leveled with a plate compactor. If needed, slotted PVC corrugated drainage pipes may be added beneath the slab and around the exterior walls. The pipes should be sized to carry the anticipated flow. The drainage material and pipes should flow to the sump for discharge. Drainage layer filter requirements and drain spacing are discussed in Chapter 6 of DM 7.1.

5-5.1.4 Dampproofing and Waterproofing Requirements.

Dampproofing is defined as material that resists the passage of water with no hydrostatic pressure. Dampproofing is intended to keep soil moisture from entering a below grade space. A coating, usually asphalt-based, is either sprayed or hand applied to the outside of the wall. Dampproofing is not used when the groundwater level will be above a below grade space. *Waterproofing* is defined as material that resists the passage of water under hydrostatic pressure. A listing of damp proofing and waterproofing systems is provided in Table 5-18. Before application of damp proofing or waterproofing, all wall surfaces must be clean and dry and any defects corrected.

Table 5-18 Methods of Foundation Dampproofing and Waterproofing

	Type	Material	Application and Workmanship	Remarks
Dampproofing	Surface Treatment	Silicates of sodium or potassium and sulphates of aluminum, zinc, and magnesium	Applied with a brush.	
	Surface Course	Bitumen	Applied with brush, thickness ~ 3 mm	
		Mastic asphalt	Heating asphalt with sand or mineral fillers.	
		Cement mortar	Add small quantity of lime (1:6) and water proofing agents.	
	Integral	Chalk, talc, flutter earth: chemical compounds such as calcium chloride, aluminum sulphate, calcium chloride and waxes, oils, fatty acids, soaps, petroleum compounds	It is advisable to avoid waxes and fats in the tropics because they melt at elevated temperatures.	
Waterproofing	Cementitious	Portland hydraulic cement with acrylic additives and may be fiber reinforced	Can be brushed or sprayed.	Easy to apply but less flexibility.
	Hot-applied bitumen systems	Applied in alternating layers of bitumen (coal, tar, or asphalt) and felt (fiberglass or organic).	Three to five plies of reinforcement provide durability. Fumes and high temperatures (400° F) can create safety and environmental hazards.	Less use than the previous.
	Hot-applied rubberized asphalt	Blend of asphalt and modified rubber polymers containing mineral stabilizers.	High temperatures (400°F) can create safety hazards.	Seamless
	Film or sheet membrane	Bentonite clay imbedded in mesh with protective cover.	Applied in sheets which are mechanically attached or can be spray applied.	Joints critical for success
		High density polyethylene (HDPE) sheet	Usually, self-adhered but also mechanically applied.	
		Ethylene propylene diene monomer (EPDM)	Usually, self-adhered but also mechanically applied.	
		Polyvinyl chloride (PVC)	Usually, self-adhered but also mechanically applied.	

5-5.2 Uplift Resistance.

Ground anchors to resist uplift must be designed for two possible failure mechanisms: 1) failure of an individual anchor to resist the uplift load and 2) failure of a group of anchors in a ground mass where the total uplift load exceeds the capacity of the ground mass. In a group of anchors, the capacity of the group may be less than that of individual anchor times the number of anchors.

5-5.2.1 Applications.

Anchors can be either passive or active. A *passive anchor* is one which is not prestressed and usually has no unbonded or free length. As load is applied, the anchor must move to engage resistance in the soil or rock. An *active anchor* is prestressed to a specific load and locked off. Active uplift anchor systems are considered herein and include: 1) resistance to transient uplift loads on tower legs, guys, and antennas, 2) sustained uplift loads on structures, and 3) structures impacted by hydrostatic uplift forces. Anchored systems, such as flexible anchored walls and soil nails have been discussed in Chapter 4. Landslide stabilization anchors are not considered. A brief discussion of corrosion protection is included at the end of this section. More detailed guidance for these subjects is found in FHWA (1999).

A ground anchor has multiple components as shown in Figure 5-37. A stressing anchorage and bearing plate connect the anchor to the structure. Anchors usually have an unbonded length that will transfer the load to soil or rock further from the structure. The final section of the anchor is the bond length where the resistance is developed. The load is transferred from the beginning of the anchor bond length and then progresses to the end of the anchor. Only a portion of the bond length is stressed under the allowable load. Ground anchors usually consist of deformed bars grouted in soil or rock. Tendons consisting of steel strand are also acceptable, and FHWA (1999) should be consulted for design. Bond stress may be increased by using washers or splayed bar ends. Spacers are used in angled holes to maintain the centrality of the bar in the anchor hole. The bond length and unbonded length should be grouted in one stage. This will help assure hole stability and provide continuous grout cover.

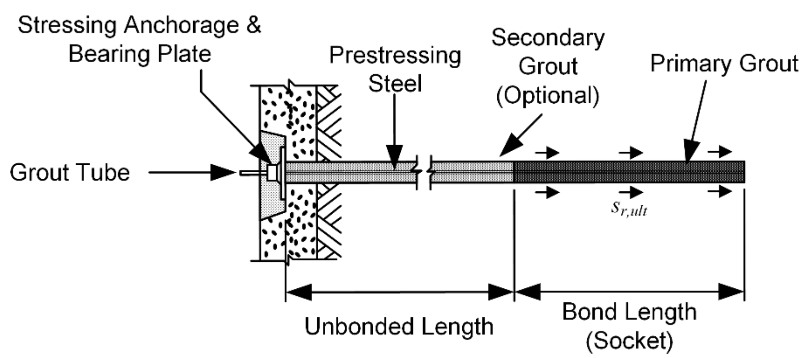


Figure 5-37 Schematic of Ground Anchor Components

5-5.2.2 Rock Anchors.

Anchors are often bonded into rock. In most cases, local experience and knowledge should be relied upon to obtain the best anchor performance. As an alternative, the rock mass breakout theory presented in this section can be applied. It should be recognized that this theory is very conservative and is primarily applicable to weathered, severely fractured rock.

Rock mass breakout is resisted by the weight of the material above the bonded length. Four potential failure modes are considered in rock anchors that are often used to tiedown foundations:

- Failure from to cone breakout of the rock mass
- Failure in shear along the grout/rock interface,
- Failure in shear along the grout/tendon interface, and
- Failure of the tendon in tension.

Design for these four failure modes is summarized in Figure 5-38. The required embedment or unbonded length is calculated based on the volume of the inverted cones above each anchor. The unbonded length (h) must be greater than 10 ft for bar anchors. When the anchor extends through soil before encountering rock, the cone diameter at the surface of rock is projected to the ground surface as a cylinder. The weight of the soil is included in the evaluation of h without considering the shear strength of the soil. Typically, the apex of the cone is placed at the top of the bond length of the anchor. The cone angle is typically assumed to fall between 60 to 90°, as shown in Figure 5-38(a) and is selected based on the quality of rock. As stated above, this approach assumes that the rock is severely fractured and acts as a strong soil, rather than an intact rock mass.

The spacing of rock anchors must consider the interference of cones shown in Figure 5-38(a). In essence, the depth will be greater if the spacing causes the cones to overlap since the volume of the individual cone will be less. This lowers the allowable capacity unless the unbonded length is increase. Spacing can also be constrained by the necessity for closely spaced anchors due to structural stiffness issues and the presence of existing underground structures. If the anchor spacing is flexible, the spacing can be set as $2R$, which causes the cones to touch but not overlap.

The anchor capacity will also be limited by the shear strength of the interface between the grout and the rock. For transient loads, a factor of safety of 2 to 3 is applied to the ultimate bond stress. For sustained loads, F of 3 is appropriate. The required anchor bond length (L) may be determined as shown in Figure 5-38(b). Presumptive ultimate bond stresses for various rock types are shown in Table 5-19. A lower factor of safety may be used for competent rock that is not highly fractured, and a higher factor of safety is required when highly weathered, fractured, or loose rock is engaged.

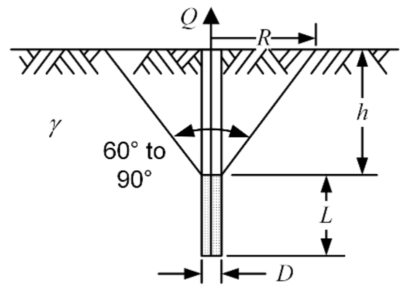
(a) Rock or Soil Mass Breakout

<u>Use 60°:</u>
For highly weathered, soft rock; highly-fractured rock mass; or fine-grained soils

$$R = h \rightarrow V = 1.036h^3$$

<u>Use 90°:</u>
For slightly weathered fresh rock mass or coarse-grained soils

$$R = 0.5h \rightarrow V = 0.262h^3$$



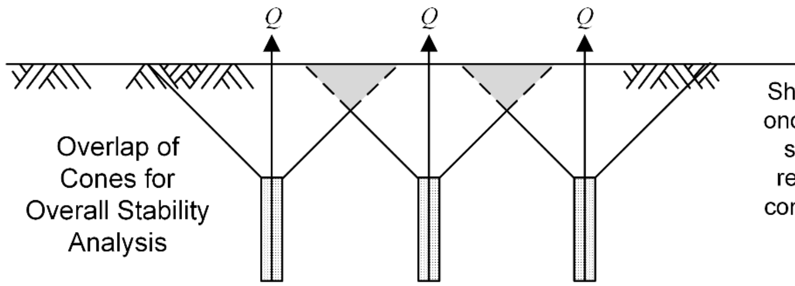
Volume of rock or soil in the cone:

$$V = \frac{\pi}{3} R^2 \cdot h$$

Required unbonded length (consider overlap separately):

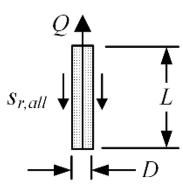
$$Q = V \cdot \gamma$$

$$h \geq \frac{3Q}{\pi \cdot R^2 \cdot \gamma}$$



Shaded zones can only be counted once in the calculation of volume for soil or rock mass breakout. The reduced volume from overlapping cones will require larger values of h.

(b) Shear Along Grout-Rock or Grout-Soil Interface (Bonded Length)



The allowable bond stress ($s_{r,all}$) along the bonded length (L) multiplied by the grouted side area must equal or exceed Q. Allowable bond stress between grout and rock (or soil) is found by dividing the ultimate bond stress ($s_{r,ult}$) by a factor of safety. The values of $s_{r,all}$ and L can be found as:

$$s_{r,all} = \frac{s_{r,ult}}{F} \qquad L \geq \frac{Q}{\pi \cdot D \cdot s_{r,all}}$$

(c) Shear Along Grout-Tendon Interface (Bonded Length)

The allowable bond stress between the grout and tendon can be assumed as: $s_{g,all} = 0.1\ UCS$, where UCS is the unconfined compressive strength of the grout. The stress applied to grout-tendon interface (s_g) is the load divided by the side area of the tendon with bar diameter, D_b.

$$s_g = \frac{Q}{\pi \cdot D_b \cdot L}$$

$$s_{g,all} \geq s_g$$

(d) Tendon Tensile Capacity

The allowable tensile capacity of the tendon ($s_{s,all}$) must exceed the tensile stress applied to the tendon. An allowable stress of 20 ksi can be assumed. The applied stress is the load divided by the tendon area, A_b.

$$s_{s,all} \geq \frac{Q}{A_b}$$

Figure 5-38 Ground Anchor Design Requirements – (a) Mass Breakout, (b) Grout-Rock or Grout-Soil Shear, (c) Grout-Tendon Shear, and (d) Tendon Capacity (after FHWA 1999)

In weak rocks, such as mudstones and shales, rock anchor capacity is typically limited by the grout-rock interface. In strong, massive rock, the limiting failure mode may be at the grout-tendon interface as described in Figure 5-38(c), depending on the assumptions and construction methods. The allowable bond stress between the grout and tendon is typically assumed to be 10% of the unconfined compressive strength of the grout.

Finally, the tensile capacity of the tendon must be checked as described in Figure 5-38(d). The applied tensile stress should be calculated based on the applied load and the cross-sectional area of the tendon. Example calculations for a rock anchor are included in Figure 5-39.

Table 5-19 Presumptive Average Ultimate Bond Stress for Anchor Grout/Rock Interfaces with Gravity Grouting (After PTI 1996, in FHWA 1999)

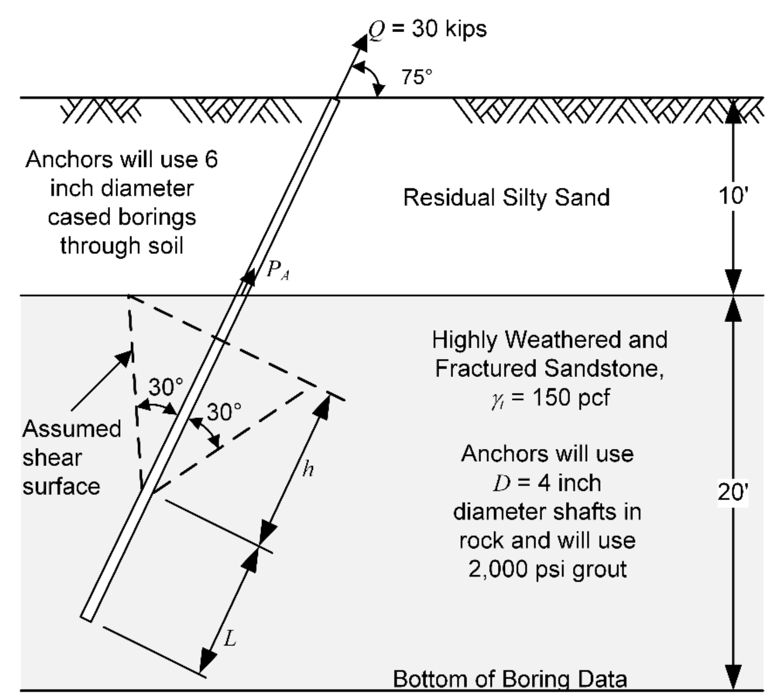
Material	Ultimate Grout/Rock Interface Bond Stress, $s_{r,ult}$ (psi)	Comments
Granite and Basalt	250 to 450	The ultimate bond stress at grout/rock interface may be estimated as 10% of the unconfined compressive strength (UCS) of the rock, not exceeding 450 psi.
Dolomitic Limestone	200 to 300	
Soft Limestone	150 to 200	
Slates and Hard Shale	120 to 200	
Soft Shale	30 to 120	
Sandstone	120 to 250	
Concrete	200 to 400	

FHWA (1999) provides guidance on corrosion protection for ground anchors. Three levels of minimum corrosion protection are usually specified in U.S. practice.

- Class I protection – used for permanent anchors:
  - Unbonded length – bar surrounded with grease filled sheath within smooth bond breaker surrounded by grout and casing.
  - Bonded length – bar within grout-filled encapsulation surrounded by grout within soil or rock.
- Class II protection:
  - Unbonded length – bar surrounded with grease filled sheath surrounded with grout and casing.
  - Bonded length – grout surrounding bar within soil or rock.
- No protection for unbonded length and grout in bonded length.

Each ground anchor is load tested past the design load before putting it into service. About 2 percent of anchors are performance tested to 133 percent of the design load in a cycled test where 25, 50, 75, 100, 125, and 133 percent of the load is applied in steps and released. The load is then locked off at 75 to 100 percent of the design load. A hold is included in the performance test at 133 percent of design load to monitor creep movements. Every anchor that is not performance tested is proof tested to 125 percent of design load. This test is conducted in the same steps noted above, and the load is then locked off at 75 to 100 percent of the design load. FHWA (1999) provides additional guidance.

Rock Anchor Example: Tower Guy Wire Support



Find Anchor Length (L), Bar Size, and Free Length (h)

Anchor Length

Select an Interface Bond Strength: $s_{r,ult} = 120\,psi$

Allowable Bond Strength (F=3): $s_{r,all} = 40\,psi$

Required Length:

$$L = \frac{Q}{\pi D s_{u,all}} = \frac{30,000\,lb}{\pi(4\,inch)(40\,psi)}$$

$L = 59.7\,inches$, use $L = 5\,ft$

Bar Size

Determine Required Bar Area:
(Use $s_{s,all}$ = 90 ksi)

$$A \geq \frac{Q}{s_{s,all}} = \frac{30\,k}{90\,ksi} = 0.33\,in^2$$

A 1-inch deformed bar with area of 0.85 in^2 will be acceptable.

Free Length

For simplicity, ignore the anchor inclination and soil above the rock.

The cone volume for a 60° angle is: $V = 0.262 \cdot h^3$

The weight of the cone must equal Q; thus: $V = \frac{Q}{\gamma_t} = \frac{30,000\,lb}{150\,pcf} = 200\,ft^3$

Solving for h: $V = 200\,ft^3 = 0.259h^3 \rightarrow h = 9.17\,ft$, use $h = 10\,ft$ (Minimum of 10 ft)

The minimum value for h is 10 ft for a deformed bar. In this case, the additional rock due to the angle of the anchor and 10 ft of soil will more than meet this requirement.

Check Bar Pullout from Grout

Applied Grout-Bar Interface Stress, s_g: $s_g = \frac{Q}{\pi D_b L} = \frac{30,000\,lb}{\pi(1\,in)(60\,in)} = 159\,psi$

Allowable Grout-Bar Interface Stress: $s_{g,all} = 0.1 \cdot UCS = 0.1(2000\,psi) = 200\,psi$ OK

Summary: Anchor Length: L = 5 ft, Bar Size: D_b = 1 inch, Free Length: h = 10 ft

Figure 5-39 Example Problem for Single Rock Anchors

5-5.2.3 Soil Anchors.

Shallow anchors in soil have similar failure mechanisms as in rock: cone breakout and shear along the grout/soil interface. The cone breakout mechanism is typical for shallow anchors. However, if the minimum unbonded length of 10 feet for bars is used, it is generally not necessary to consider cone breakout. Soil anchors tend to be much deeper because the grout/soil interface bond stress is lower. Soil anchors with an uplift load are essentially to micropiles with an uplift load. The minimum spacing between soil anchors should be 5 feet (Caltrans 2020). The appropriate inverted cone angle is in the range of 60 to 90°.

The design requirements shown in Figure 5-38 can also be used for soil anchors. The design should include selection of h, L, and tendon size. Presumptive ultimate bond stresses at the grout/soil interface for various soil types are shown in Table 5-20. Factors of safety of 2 and 3 can be used for transient and sustained loads, respectively, to calculate allowable bond stress. If the soil type changes along the anchor length, the side resistance can be divided into layers to allow the calculation of L.

Table 5-20 Presumptive Average Ultimate Bond Stress for Anchor Grout/Soil Interfaces with Gravity Grouting (After PTI 1996 in FHWA 1999)

Category	Soil Type	Plasticity or Relative Density	$s_{s,ult}$ (psf)
Fine-Grained	Soft lean clay	--	600
	Stiff fat clay	Medium to high	600
	Very stiff fat clay	Medium to high	1,400
	Stiff fat clay	Medium	2,100
	Very stiff fat clay	Medium	2,900
	Very stiff sandy silt	Medium	5,800
Coarse-Grained	Silty sand	--	3,500
	Fine to medium sand	Medium dense to dense	1,700
	Medium to coarse sand with gravel	Medium dense	2,300
	Medium to coarse sand with gravel	Dense to very dense	5,200
	Sandy gravel	Medium dense to dense	4,400
	Sandy gravel	Dense to very dense	5,800
	Glacial till	Dense	6,300

5-5.2.4 Design of Anchors to Resist Hydrostatic Uplift.

Ground anchors may also be used to provide resistance against uplift forces caused by hydrostatic pressures. Two cases can be considered: 1) the structure is founded on rock or relatively stiff soil or 2) the structure is founded on relatively compressible soil with the anchors are secured in deeper soil or rock. When the structure is founded on rock or suitable soil for anchor development, the calculations presented in Section 5-5.2.2 and 5-5.2.3 can be used. When a more compressible soil layer exists between the structure and the anchors, as shown in Figure 5-40, changes in anchor loads resulting from movement of enclosed compressible ground mass (i.e., groundwater fluctuations, consolidation settlement or heave, or creep deformations) must be considered.

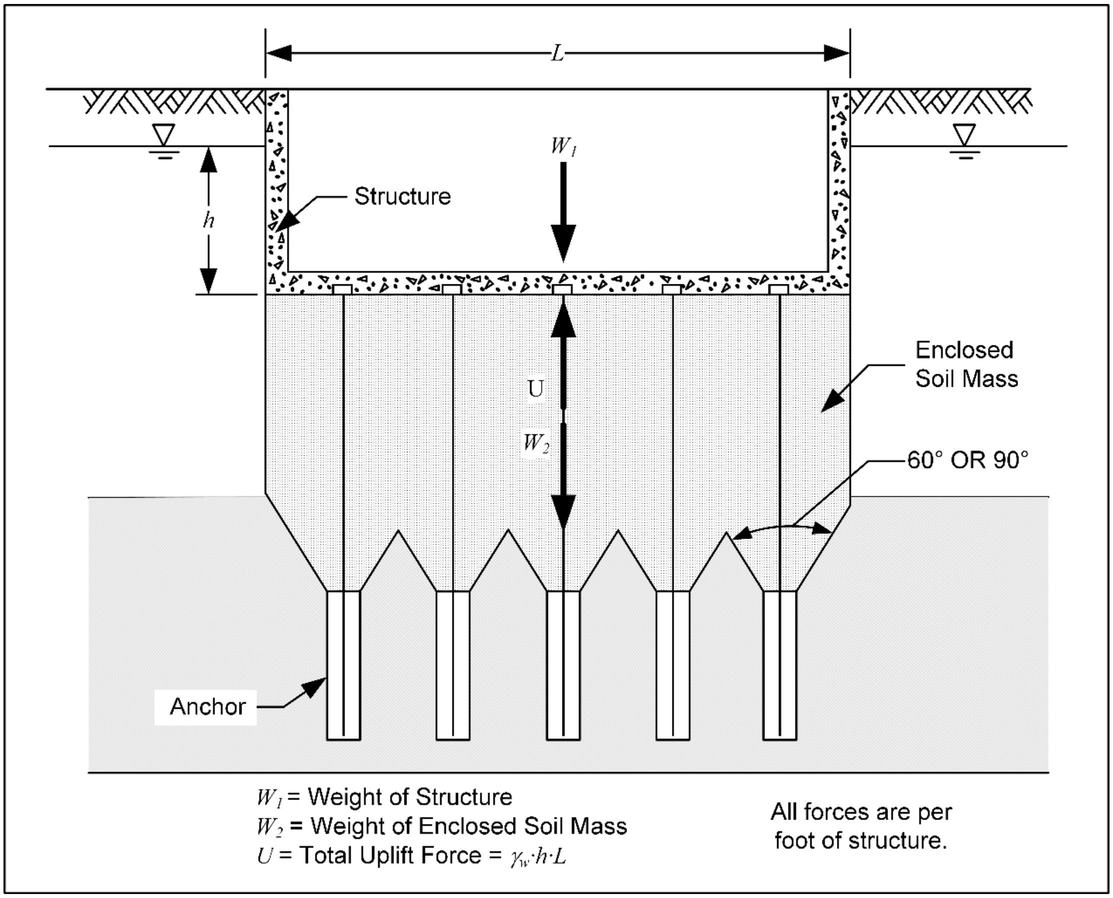


Figure 5-40 Resisting Hydrostatic Uplift with Ground Anchors (after FHWA 1999)

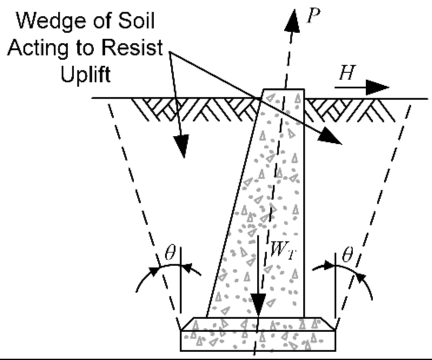
The design should verify that the hydrostatic uplift force (U) can be resisted by the weight of the structure (W_1) plus the weight of the enclosed soil mass (W_2). The uplift force should be calculated based on the maximum elevation of the water table. The buoyant unit weight of soils should be used for soils below the water table. Frictional resistance is neglected between the soil and walls of the structure. Friction is also neglected along the hypothetical vertical plane within the soil between the structure and the top of the bonded zone for the anchor (FHWA 1999).

The anchor loads can change with time. Groundwater fluctuations may cause cyclic changes in the anchor load. Consolidation and creep may result in detensioning. If any of these movements could cause additional tension in the tendons after lock-off, the tendons should be sized accordingly (FHWA 1999).

5-5.2.5 Transient Uplift Loads and Moments on Footings, Piers, and Posts.

Transient uplift and moment loads can be resisted by shallow foundations. Some simple methods to consider these loadings are presented in Figure 5-41. Design for moment loading can use methods for rigid retaining walls in Chapter 4. Uplift and lateral loading of piers, posts, and piles is addressed in more detail in Chapter 6.

Footing Resisting Large Uplift and Small Horizontal Load



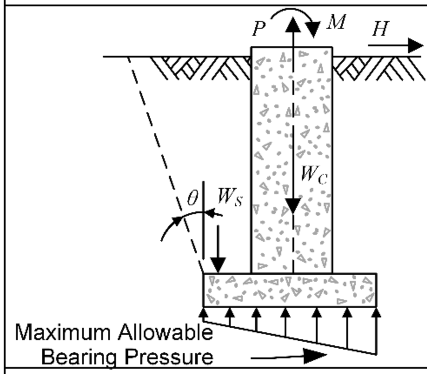
Angle:
- Fine-grained: $\theta = 30°$
- Coarse-grained: $\theta = \phi' / 2 \leq 20°$

W_T = weight of footing plus wedge of soil acting to resist uplift

Safety Factor = W_T / P,

Safety factors should be no less than 1.5 where transient loads apply.

Footing Resisting Large Moment and Small Uplift and Horizontal Load

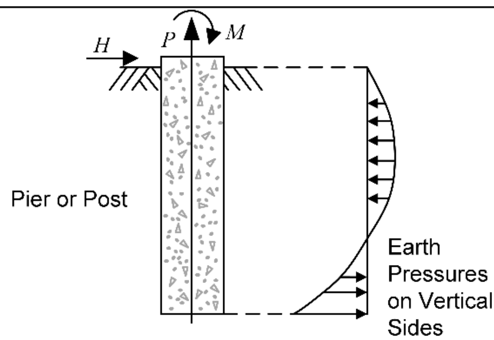


W_S = Weight of wedge of soil on side of footing tending to move upward.

W_T = Weight of Footing.

Analysis of stability and soil pressures same as in Figure 4-27. Maximum soil pressure on base of footing is obtained by combining W_S, W_C, applied load, and moment. Required safety factor against overturning ≥1.5, where transient loads apply.

Pier or Post Resisting Large Moment and Small Uplift and Horizontal Load



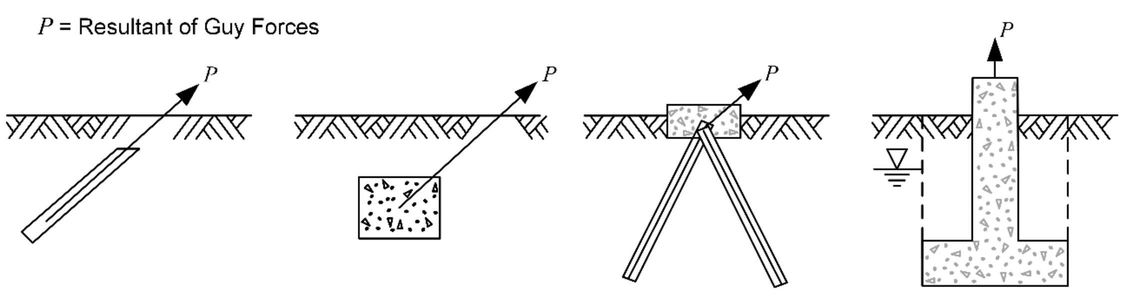
Moment and horizontal force are resisted by earth pressure on sides of pier or post. Arching in front of the post generates additional passive resistance.

For analysis of stress or deflections, see Chapter 6.

Allowable moment ordinarily is limited by the tolerable movement of the foundation.

Tower Guy Anchorage

P = Resultant of Guy Forces



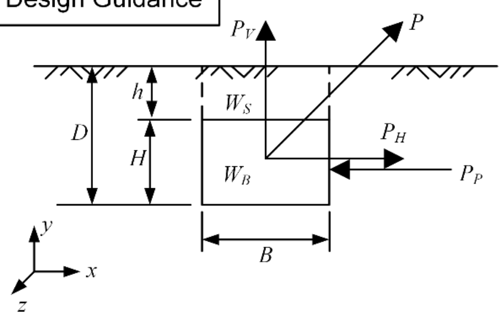
In Rock (See Figure 5-39) | In Soil (See Figure 4-54) | By Piles (See Chapter 6) | By Footing

Figure 5-41 Resistance to Transient Uplift Loads on Footings, Piers, and Posts

5-5.2.6 Uplift Resistance Using a Deadman.

Guidance for the use of a concrete deadman for uplift resistance is provided in Figure 5-42. For a deadman in weak soil, it may be feasible to replace a considerable volume of soil with granular backfill and construct the block within the new backfill. If this is done, the passive wedge should be contained entirely within the granular fill, and the stresses on the remaining weak material should be investigated.

Design Guidance



P = Resultant of maximum guy forces
P_H, P_V = Components of P
P_P = Passive earth pressure force (see Section 4-3)
B, H = Block dimensions
L = Block dimension in the z direction
γ = Unit weight of soil
ϕ' = Effective friction angle
W_B = Weight of block
W_S = Weight of soil on block = $B \cdot L \cdot H \cdot \gamma$
W_S = Total weight = $W_B + W_S$

<u>Design Criteria</u>

1. Resistance to Vertical Force

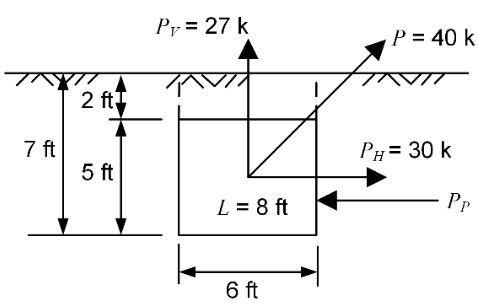
Provide design such that: $\frac{W_T}{P_V} \geq 1.5$ and $\frac{W_B}{P_V} \geq 1.0$

2. Resistance to Horizontal Force

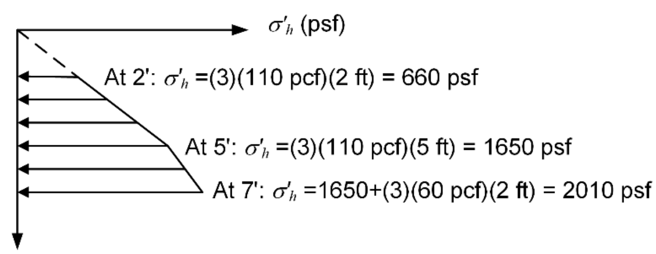
Provide design such that: $\frac{P_P}{P_H} \geq 1.5$

Notes: Passive resistance is calculated only on face of block (Area = $H \cdot L$). Block backfill shall be compacted as described in Chapter 3. Use total unit weights above the water table, and buoyant unit weights below the water table. Keep P_H at 1/2 to 2/3 of block depth.

Example



Weights:
W_S = (6 ft)(8 ft)(2 ft)(110 pcf) = 10,500 lb
W_B = (6 ft)(8 ft)[(3 ft)(150 pcf) + (2 ft)(87.5 pcf)]= 30,000 lb
W_T = 10,500 + 30,000 = 40,500 lb



Soil: γ = 110 pcf, γ' = 60 pcf, ϕ' = 30 deg
Groundwater at a depth of 5 ft
Using Rankine: K_P = 3

$$P_P = (8\,ft)\left[(3\,ft)\left(\frac{660+1650}{2}\right)+(2\,ft)\left(\frac{1650+2010}{2}\right)\right] = 57{,}000\,lb$$

<u>1. Resistance to Vertical Force</u>

$\frac{W_T}{P_V} = \frac{40.5k}{27k} = 1.5,\quad \frac{W_B}{P_V} = \frac{30k}{27k} = 1.1 > 1.0$ OK

<u>2. Resistance to Horizontal Force</u>

$\frac{P_P}{P_H} = \frac{57k}{30k} = 1.9 \geq 1.5$ OK

<u>Conclusion:</u> The block design will adequately resist the applied loads. A more efficient design may be found by varying the block dimensions and embedment.

Figure 5-42 Design Guidance for Uplift Resistance by Concrete Deadman

5-6 DESIGN FOR SPECIAL SOIL CONDITIONS.

5-6.1 Shallow Foundations on Engineered Fill.

Engineered fill or compacted structural fill can be used to support structures and/or floor slabs. This fill is designed to have specific strength and compressibility properties and, as such, must be controlled in the field by personnel under the direction of a geotechnical engineer. Chapter 3 provides additional detail on fill compaction.

Compacted structural fill is commonly used to raise the general grade for support of a structure. Structural fill may also be used beneath structures to allow for higher bearing pressures and reduce settlements by replacing unsuitable foundation soils and/or providing a relatively stiff mat of soil above less suitable soils.

5-6.1.1 Compacted Structural Fill Requirements.

As noted in Chapter 3, compacted structural fill must be designed and monitored in order to provide adequate foundation support. Design of compacted fill includes selection of appropriate fill type by engineering classification and moisture content limitations. The suitability of subgrade for support of compacted structural fill should be evaluated by the subsurface exploration and field observations. Specifications for fill placement must be selected, including loose lift thickness, minimum relative compaction, and relative moisture content ranges. Section 5-2.5 provided presumptive bearing pressures for compacted fill.

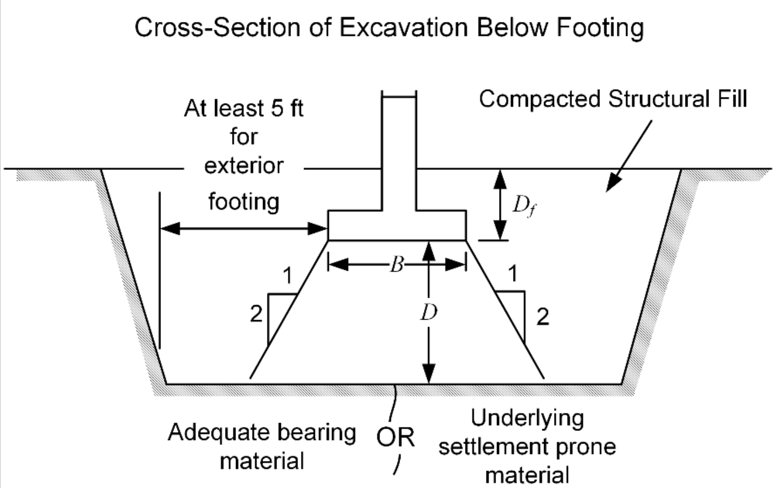
During construction, structural fill should be monitored to determine if the material meets the classification and compaction requirements. Compaction control testing should verify that specifications have been met. Control tests should be checked for errors in testing or interpretation, such as degree of saturation greater than 100%. The fill should be protected against wetting by proper grading and surface drainage. In cold weather, a protective layer should be used to protect the surface from frost penetration.

5-6.1.2 Geometric Limits of Compacted Structural Fill.

Where the general grade is raised for a structure, the entire building pad should be treated as compacted structural fill. The structural fill should extend laterally at least 5 ft outside the edge of the exterior footings or should encompass a zone extending downward at at 1H:2V angle from the footings, whichever is greater. More guidance on deep fills is provided in Section 3-6.5. In some cases, the upper few feet of a structural fill only support floor slabs and will have reduced compaction requirements.

Fill may also be used to replace unsuitable bearing soil. The vertical and lateral limits of the zone of compacted structural fill beneath footings should consider the vertical stresses imposed by the footings as shown in Figure 5-43. Unless adequate bearing soil is reached sooner, the excavation must extend to a depth that adequately reduces the change in stress from the foundation at the base of the fill. Continuous footings impose stresses to a greater depth than square footings with the same width. With high-quality fill, higher bearing pressures may allow narrower foundations that limit the depth of influence from individual foundations on the underlying soil.

Adequate bearing material may not be present within the depths indicated in Figure 5-43. In that case, the structural fill must be placed over underlying settlement prone material. The bottom of the excavation may require stabilization with geogrid or geotextile to allow fill to be placed and compacted. Alternatively, a bridging layer of gravel or cobble-sized material may be required. Settlement will likely control the net allowable bearing pressure for this situation. Settlement calcuations should consider the increased stress on the underyling soil because of higher unit weight of the fill. Settlement may be caused by individual foundation loading as well as the combined change in stress from all of the building foundations. These should both be evaluated. If settlement cannot be mitigated, either ground improvement or deep foundation will likely be required.



- D_f = depth required by frost penetration considerations, typically not less than 18 inches
- Excavation depth below the footing, D, is controlled by:
  - Depth to adequate bearing material or
  - Depth where stresses from footing do not negatively impact underlying weak or settlement prone soils
- Minimum values of D are:
  - About $2B$ for square footings, or
  - About $4B$ depth for continuous footings.

Figure 5-43 Geometric Limits for Structural Fill Beneath Footings

5-6.2 Foundations on Expansive Soil and Rock.

Soils that undergo substantial or problematic volume changes upon wetting and drying are termed expansive or swelling soils. Surficial clays above the water table with a PI greater than about 20 and relatively low natural water content should be considered potentially expansive. These soils are most commonly found where the groundwater table is low in arid climates with a deficiency of rainfall and conditions of over-evaporation. Expansive soils are also found in more temperate climates where clay deposits are present that contain montmorillonite. Mottled, fractured, or slickensided clays, showing evidence of past desiccation, are particularly troublesome. For other causes of swelling in soils and for the computations of resulting heave see Chapter 5 of DM 7.1. Regional experience is critical for the identification of expansive soils and selection of foundation solutions. Additional information on these soils can be found in Section 1-2.12.

Climate has an important effect on the interaction between expansive soils and foundations. In arid regions, the soils tend to have a relatively low natural water content. Seasonal wetting tends to cause heave around the perimeter of structures and lifting of the edges of exterior foundations and slabs. In contrast, the soils in temperate climates tend to have a relatively high natural water content. Seasonal drying tends to cause shrinkage around the perimeter of structures. In this case, the exterior foundations and slab edges tend to drop or settle within time. These tendencies can affect the selection of appropriate mitigation alternatives for expansive soils.

Foundation design should also consider the potential for sulfide induced heave from soils and rock.

5-6.2.1 Reducing Soil Expansion Potential.

Where economically feasible, remove potentially expansive soils from beneath footings and replace with compacted structural fill of non-expansive materials as shown in Figure 5-44(a). The fill should not allow water to collect or to be introduced to deeper expansive soils. Thus, low plasticity fine-grained soils are preferred. Alternatives to removal and replacement are discussed in the following paragraphs.

In some cases, column loads and floor loads with straight or underreamed drilled shafts founded below the zone of active swelling as illustrated in Figure 5-44(b). The soil along the upper part of the shaft will impart an upward force that must be resisted by the weight of the pier, the dead load, and the underreamed section. At any depth, the tensile force exerted on the shaft equals the shaft adhesion (see Chapter 6) times the difference in side area above and below the point under consideration. The reinforcement must resist these tensile forces and, if used, should extend into the underreamed section of the drilled shaft to allow engagement of the bell to resist uplift. An alternative is to place the shaft in an oversized hole and fill the annular space with a plastic material that can deform without developing adhesion to the shaft. Viscoelastic polymers, such as liquid rubber, are materials that fit this category. Placing the base of the foundation near the water table reduces heave damage because little change in moisture content occurs.

If the structure is sufficiently heavy and the soil is strong, the swell pressures can be resisted by the dead load of the structure. The floor slabs must be structurally supported overlying degradable carboard forms as shown in Figure 5-44(c).

5-6.2.2 Minimizing Expansion Effects.

Where it is not economically feasible to remove expansive materials or to support foundations below depths of possible expansion, the effects can be minimized by the following.

- Place fill with expansion prone plastic fines at moisture contents multiple percentage points above optimum moisture content at dry unit weight no higher than required for strength and compressibility.
- Construct grade beams over degradable carboard.
- Provide impervious blankets or grade surface around structure to drain away from foundations.
- Locate water and drainage lines away from soils supporting foundations.
- Consider stabilization of the foundation soils with lime or cement to reduce the plasticity.

Where heave of the floor slab is not a critical concern, place concrete floor slabs directly on problem soil but provide expansion joints so the floor can move freely from structure.

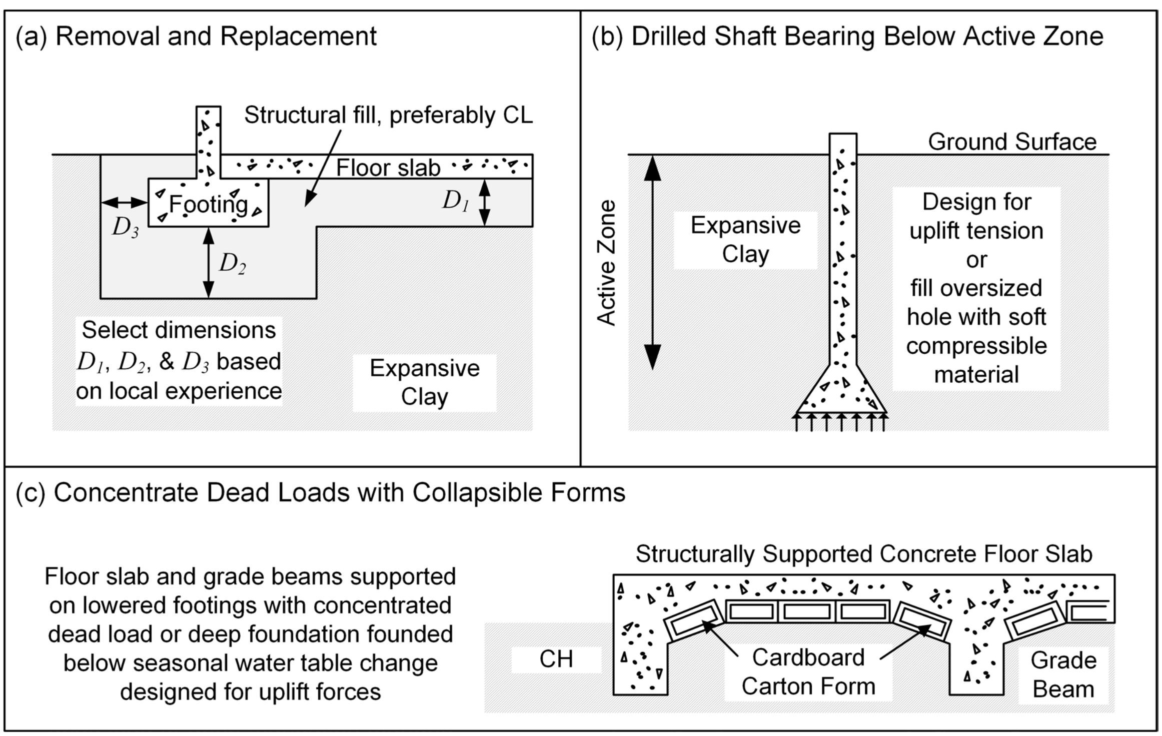


Figure 5-44 Construction Details for Swelling Soils

5-6.2.3 Heave of Sulfide Soils and Rock.

Foundation design should consider the potential for sulfide induced heave and corrosion. Sulfur may be present in sulfidic rock or soils below foundations or within compacted structural fill constructed of sulfidic rock or soils. The different forms of sulfur consist of (Dubbe 1984):

- Sulfate sulfur - represents a measure of the degree of oxidation and is an indication of the amount of expansion that has taken place before sampling;
- Sulfide (pyritic) sulfur - represents the amount of unoxidized sulfidic material and the potential expansion that can take place in the future; and
- Organic sulfur – represents material that is not believed to be involved in the expansive reaction.

Sulfide soil and rock is typically identified by testing. Samples of rock or soil for chemical testing of total sulfur forms should be wrapped in plastic to prevent any change in moisture content and to reduce oxidation before testing. Bryant et al. (2003) found that sulfide-induced heave can occur in materials containing as little as 0.1% sulfide [pyritic] sulfur. Figure 5-45 illustrates the potential for heave for various concentrations of sulfide [pyritic] sulfur.

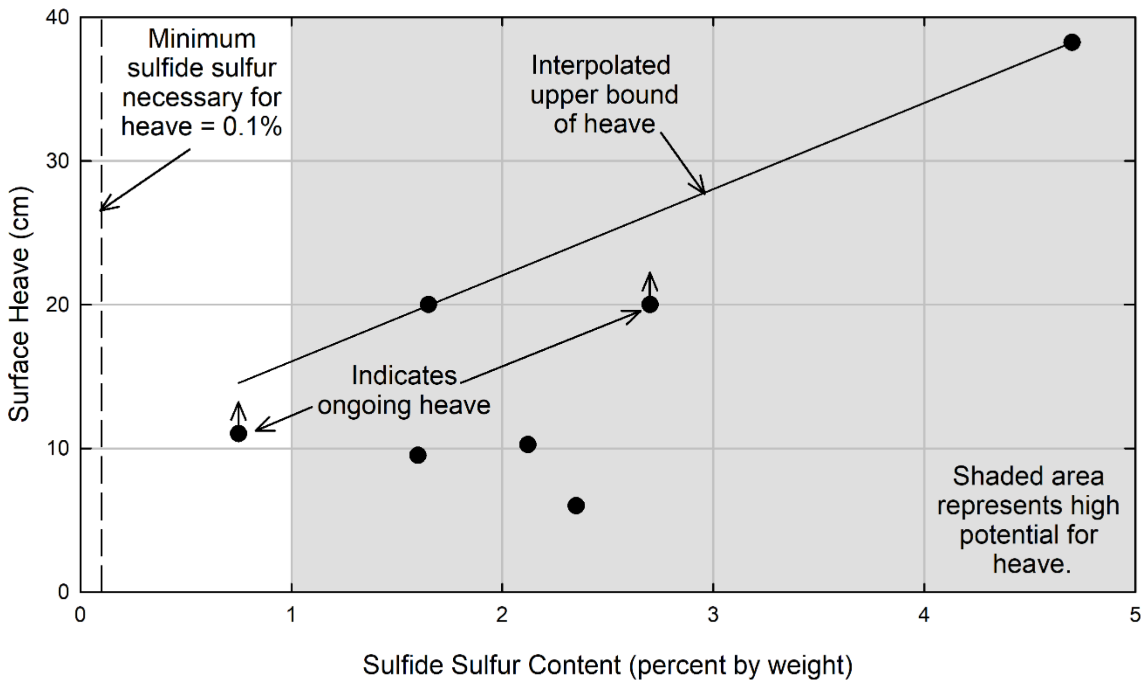


Figure 5-45 Potential Sulfidic Rock Heave (after Bryant et al. 2003)

Ground water should also be tested if it can rise to be in contact with foundations. Sulfide-induced corrosion of concrete can occur if sulfide (pyritic) sulfur exceeds 1200 ppm.

When testing indicates mitigation measures are warranted, the following should be considered:

- For new structures: remove sulfidic soil or rock below floor slab and/or footings unless dead loads are sufficient to prevent heave and use void filler below grade beams and slabs as discussed for expansive soils;
- For protection of concrete subject to sulfidic groundwater use: 1) sulphate resistant cement such as Type V Portland cement, 2) lower water-cement ratio concrete, or 3) coat concrete with bitumen; and
- For existing structures consider partial or complete removal of sulfidic soil or rock below floor slab and/or footings depending upon how heave has impacted the structure.

If testing indicates oxidation is complete and damage has already occurred, the sulfidic soil or rock does not need to be removed. Partial excavation and replacement can be used if necessary but any sulfidic material left in place below the structure should be completely covered with spray mastic to seal the area from air. The excavated areas should be backfilled with structural fill that is below problematic levels for sulfur. Flowable fill has also been used as backfill.

Electrical corrosive properties of soil are important where metal structures such as pipelines, etc. are buried underground. A resistivity survey of the site may be necessary to evaluate the need for cathodic protection.

5-6.3 Foundations on Collapsible Soils.

Collapsible soils are characterized by a metastable structure and undergo an abrupt collapse when they are inundated. Thus, existing deposits are located above the water table in their natural state. Most collapsible soils are either debris flow deposits of low unit weight or wind deposits (loess). Loose fills and decomposed igneous rocks can also be collapsible. They usually consist of silts and sands with a substantial fines content. Additional information on loess is found in Section 1-2.3.

Collapsible soils are located in the Midwest and Southwest United States, parts of Asia, South America, and Southern Africa according to Mitchell and Soga (2005). The geographic location of loess deposits in the United States, South America, Europe, and Asia are shown in Figure 5-46. The depth of collapsible soil deposits can be very great, often up to 100 ft and sometimes over 500 ft (USBR 1992). Because of the substantial thickness, large settlements can result from collapse. USBR (1992) also stated that the amount of collapse is affected by layer thickness, soil mineralogy, initial void ratio, stress history, grain shape, moisture content, pore sizes, any cementing agents, and the amount of added load (hydrostatic or structural).

5-6.3.1 Identification of Collapsible Soils.

The following tasks need to be accomplished when working with collapsing soils (Houston et al. 2001):

- Identification and characterization of collapsible soil sites,
- Estimation of the extent and degree of wetting when collapse occurs,
- Estimation of collapse settlements, and
- Selection of design and mitigation alternatives.

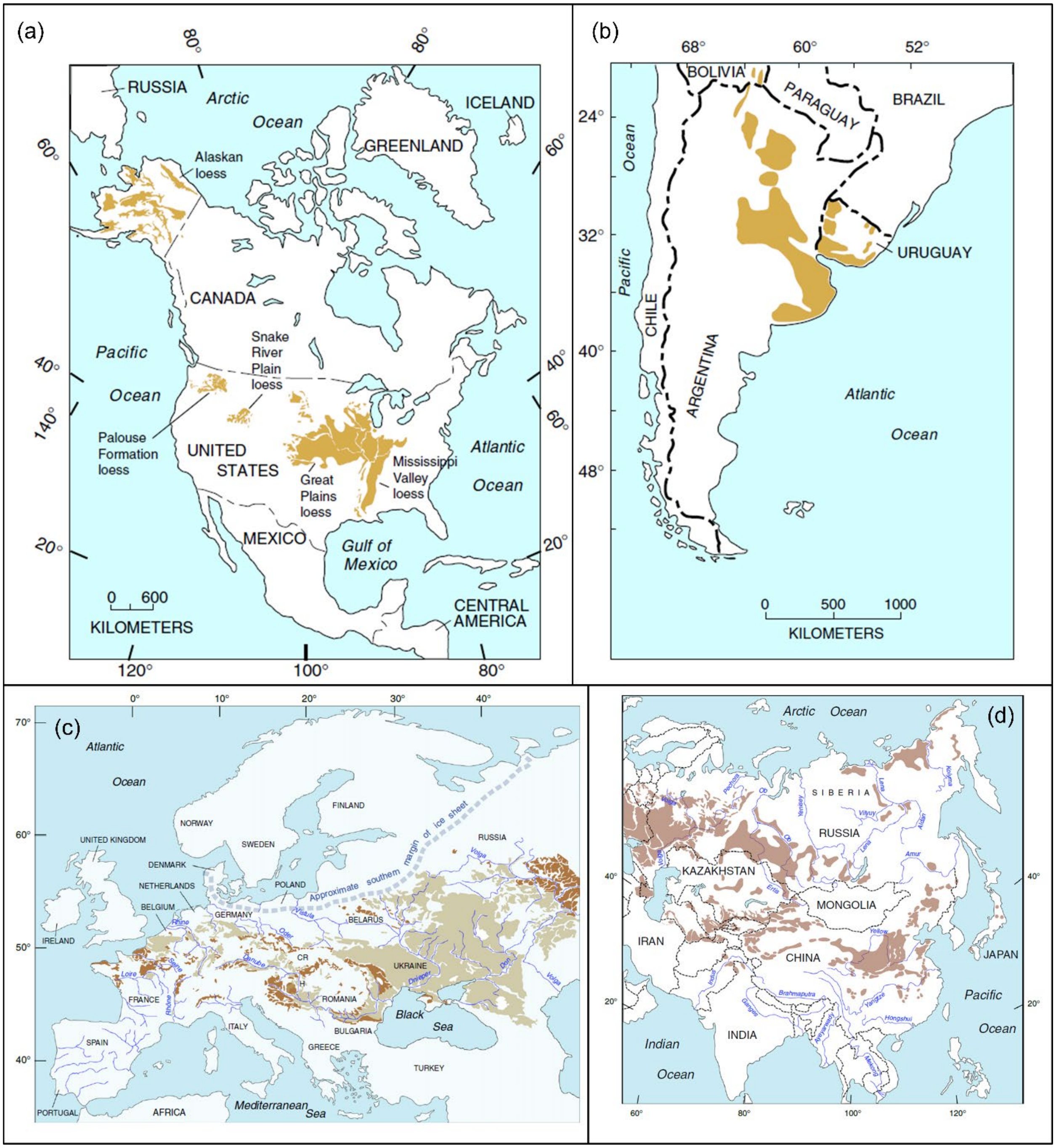


Figure 5-46 Loess Distribution – (a) United States, (b) South America, (c) Europe, and (d) Asia (after Muhs 2013)

Estimation of the extent and degree of wetting required for collapse is the most difficult of these tasks. Rising groundwater is the only method that will ensure 100 percent saturation. Irrigation from the surface will not usually result in 100 percent saturation.

The most danger occurs when these soils are not identified, and a structure is damaged due to soil collapse. As a simple test to identify collapsible soils, the natural dry unit weight of a soil sample can be plotted against the liquid limit on Figure 5-47 (USBR 1992). The curves represent the dry unit weight corresponding to a saturated soil with a water content equal to the liquid limit. If the natural dry unit weight is lower than the saturation line, the soil is potentially collapsible. The most difficult problem with this identification test is obtaining undisturbed samples for testing. Undisturbed sampling of silts and fine sands is difficult, and disturbance will impact the results. Many collapsing soils will slake upon immersion, but this is not a definitive indicator.

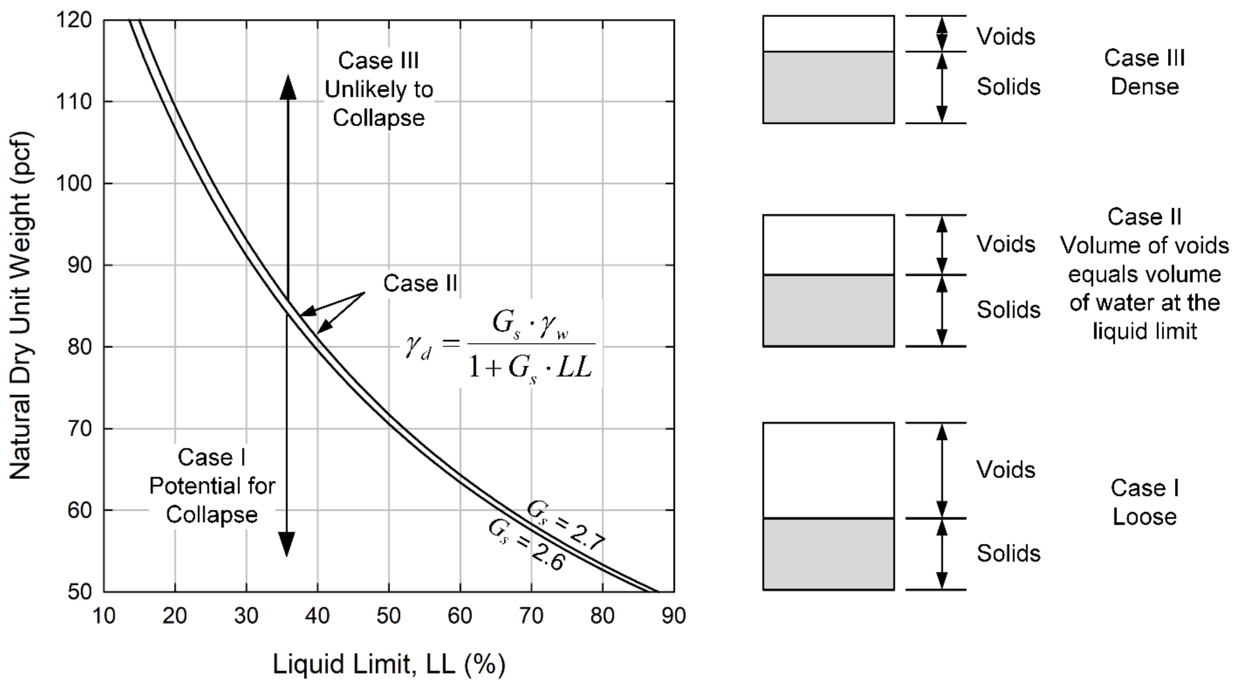


Figure 5-47 Criteria for Evaluation of Collapsing Soils (after USBR 1992)

5-6.3.2 Estimated Degree of Wetting When Collapse Occurs.

Houston et al. (2001) indicate that full collapse only occurs in the field with a rising water table, but partial collapse can occur at moisture contents less required for 100 percent saturation, such as from irrigation. Typical saturation levels achieved during irrigation are 35 to 60 percent. Full wetting collapse is usually identified in the laboratory using one-dimensional consolidation tests in accordance with ASTM D4546[29].

5-6.3.3 Estimation of Collapse Settlements.

One-dimensional consolidation tests can be used to determine two different qualitative measures of collapse. The *collapse potential* is the strain caused by wetting at any stress level while the *collapse index* is the relative collapse for inundation at a stress of 4000 psf (ASTM D5333, Jennings and Knight 1975). Relative classification of collapse associated with these two measures are summarized in Table 5-21.

Table 5-21 Classification of Collapse (after ASTM D 5333, Jennings and Knight 1975)

<table>
<tr><th>Classification of Collapse</th><th>Collapse Index (%) (inundation at any stress level)</th><th>Collapse Potential (%) (inundation at any 4000 psf)</th></tr>
<tr><td>None</td><td>0 to 0.1</td><td>0 to 1</td></tr>
<tr><td>Slight</td><td>0.1 to 2</td><td>1 to 5</td></tr>
<tr><td>Moderate</td><td>2.1 to 6</td><td rowspan="2">5 to 10</td></tr>
<tr><td>Moderately Severe</td><td>6.1 to 10</td></tr>
<tr><td>Severe</td><td>>10</td><td>>10</td></tr>
</table>

The magnitude of collapse can be estimated using the results of one-dimensional tests on one or more specimens inundated at vertical stress conditions applicable to the project conditions (ASTM D4546). The strain caused by wetting is directly measured for each specimen and used to estimate strain under field conditions. Because close to full saturation is achieved, the strains measured in the laboratory tests tend to be conservative compared to typical field wetting. Boundary conditions and nonuniformity in field conditions can make the laboratory measured rates of collapse unreliable (ASTM D4546).

Settlement caused by collapse can be estimated by multiple the decimal strain by the thickness of the soil layer. If multiple collapse tests are performed at different vertical stresses, the settlement can be predicted for each layer and summed.

In earthquake prone areas, densification and collapse may occur even after mitigation and should be evaluated (Houston et al. 2001). For example, prewetting may only cause partial wetting collapse, and the soil may still be subject to densification by earthquake shaking.

[29] ASTM D5333 and the collapse index have sometimes been used to estimate collapse settlements. However, this standard has been withdrawn from use.

5-6.3.4 Mitigation Alternatives.

Available mitigation alternatives for collapsible soils include:

- Removal and replacement with compacted structural fill,
- Avoidance of wetting,
- Deep dynamic compaction,
- Chemical stabilization or grouting,
- Deep foundations, and
- Prewetting.

The most widely used mitigation method is removal and replacement with compacted structural fill. Often the excavated material is reused as fill. For shallow depths of collapsible material, this is the least costly and best alternative. Avoidance of wetting has also been used where slopes are used to divert water away from the structure. Prewetting is less successful where little additional load is applied during wetting.

5-6.4 Other Problem Soils.

Chapter 1 provides a summary of many types of problem soil conditions that can affect the design of foundations and earth structures. Table 5-22 summarizes important conditions for the design of shallow foundations in problem soils.

Table 5-22 Problem Soil Considerations for Shallow Foundations

Soil Type	Primary Considerations for Shallow Foundations
Soft Clays, Organic Soils, Peat, and Muskeg	• Low shear strength and high compressibility result in very low allowable bearing pressures, which can be uneconomical. • Secondary compression should be included in settlement calculations. • Ground improvement will often improve economic viability. • Deep foundations may also be a more economical solution for foundation support.
Stiff Fissured Expansive Clays and Shales	• Bearing capacity and settlement are typically not a concern, except for very high loads. • Shrink/swell potential of the clay or rock will control foundation design (see DM 7.1, Ch. 5). • Design options include: ○ Removal and replacement of expansive material within zone of active moisture change, ○ Deepening of foundations through the active zone, ○ Chemical modification of the soil to reduce expansive properties, and ○ Concentration of load to resist swell pressures.
Loess and Other Collapsible Soils	• Metastable structure of the soil can collapse under loading, especially wetting. • Collapse potential increases when the natural dry unit weight is lower than that corresponding to saturation at the liquid limit. • Solutions can vary from controlled wetting to ground improvement to deep foundations.
Sensitive Clays	• The shear stress should not exceed the peak shear strength of the clay at any point below the foundation. • For eccentrically loaded foundations, the factor of safety should be calculated using the maximum bearing pressure caused by the eccentricity.
Residual Soils	• Correlations to engineering properties are less reliable for residual soils and may not be valid. • Settlement calculations may be more accurate using the coefficient of compressibility.
Laterites	• If weakly cemented, laterites may provide poor foundation support, especially for cyclic loads or if exposed to flowing groundwater.
Talus	• Global stability of the talus should be assessed prior to use for the support of shallow foundations.

Loose Sands	• Settlements that exceed the tolerable limits for most shallow foundations can result, even for relatively low bearing pressures. • Settlement should be calculated using an appropriate empirical procedure (see DM 7.1, Chapter 5), preferably selected based on local experience. • In many cases, the CPT provides better characterization of saturated loose sands than SPT.
Dredged Soils	• Dredged soils should be treated as soft or loose for design of shallow foundations (see comments above)
Low Plasticity and Nonplastic Silts	• Difficult construction conditions may occur for shallow foundations resulting from: o Wetting of the bearing surfaces or o Instability of saturated silts caused by dilatancy. • Protection of the bearing surface by a mud mat (thin layer of concrete) may be required to maintain a stable bearing surface during construction.
Municipal Solid Waste	• Shallow foundations will rarely be supported within or above MSW. • Settlement will likely control with special consideration given to differential movement due to the high variability of the MSW. • Ongoing consolidation of MSW under its own weight must also be considered.

5-7 NOTATION.

Variable	**Definition**
b_c, b_q, b_γ	Bearing capacity factors to account for sloping base conditions
c	Total stress cohesion intercept
c'	Effective stress cohesion intercept
c^*	Reduced cohesion intercept to account for the effects of local and punching shear
d_c, d_q, d_γ	Bearing capacity factors to account for foundation embedment depth
D_r	Relative density
e	Eccentricity
$E' \cdot I_b$	Flexural stiffness of a structure
E_c	Young’s modulus of concrete
E_s	Elastic modulus of soil
E'_s	Effective or drained modulus of soil
E_{us}	Undrained modulus of soil
F_{BC}	Factor of safety against bearing capacity failure
g_c, g_q, g_γ	Bearing capacity factors to account for sloping ground conditions
G_s	Specific gravity of solids
GSI	Geological Strength Index
h	Depth of structure below groundwater level for design against hydrostatic uplift
H	Horizontal load

Variable	Definition
I	Moment of inertia
i_c, i_q, i_γ	Bearing capacity factors to account for load inclination
K	Equivalent spring stiffness
k_p	Modulus of subgrade reaction from plate load test
Kr	Relative stiffness factor
k_s	Modulus of subgrade reaction
k_{sc}	Modulus of subgrade reaction reduced for time-dependent settlement
K_s	Punching shear coefficient
K_P	Passive earth pressure coefficient
L	Width of structure for design against hydrostatic uplift
LL	Liquid limit
M	Applied moment
N	Standard Penetration Test blow count
$N_{1(60)}$	Standard Penetration Test blow count corrected for overburden and energy
N_{60}	Standard Penetration Test blow count corrected for energy
N_c, N_q, N_γ	Bearing capacity factors
$N_{c,m,s}$, $N_{c,m,c}$	Modified bearing capacity factors for strip and continuous footings
OCR	Overconsolidation ratio
PI	Plasticity index
P_P	Resultant force from passive earth pressure
Q	Gross vertical load
q	Contact pressure
$q_{all,gross}$	Gross allowable bearing pressure
$q_{all,net}$	Net allowable bearing pressure
qc	Cone penetration test tip resistance
Q_{DL+LL}	Structural dead load plus live load
q_{net}	Net bearing pressure
q_{ult}	Ultimate bearing capacity

Variable	Definition
q'_{ult}	Reduced ultimate bearing capacity
q_{unif}	Equivalent uniform bearing pressure
$R.C.$	Relative compaction
RC_{slope}	Reduction coefficient for bearing capacity of foundations near slopes
RQD	Rock quality designation
s	Settlement
s_c	Consolidation settlement
s_g	Stress applied at grout-tendon interface
$s_{g,all}$	Allowable stress for grout-tendon interface
$s_{r,all}$	Allowable bond strength for ground anchors
$s_{r,ult}$	Strength of grout-rock interface
$s_{s,all}$	Allow stress for grout-rock interface
s_c, s_q, s_γ	Bearing capacity factors to account for foundation shape
s_u	Undrained shear strength
U	Hydrostatic uplift force
UCS	Unconfined compressive strength
V	Shear load
W_1	Weight of structure
W_2	Weight of enclosed soil mass
W_f	Weight of foundation
W_s	Weight of soil overlying foundation
α	Bearing capacity failure plane angle
β	Angle of sloping ground
$\Delta\sigma_{z,ave}$	Average change in vertical stress below a mat foundation
γ	Total unit weight
γ'	Bouyant or effective unit weight
γ_d	Dry unit weight
γ_w	Unit weight of water

Variable	Definition
ϕ	Total stress friction angle
ϕ'	Drained or effective stress friction angle
ϕ^*	Reduced friction angle to account for the effects of local and punching shear
ϕ_{rf}	Rock fracture friction angle including the effects of asperities
ν	Poisson's ratio
σ_{vD}	Effective vertical stress at the foundation bearing elevation
Ψ_c, Ψ_q, Ψ_γ	Lumped bearing capacity factors used to correct for complicating factors

5-8 SUGGESTED READING.

Topic	Reference
Bearing capacity of soil	Meyerhof, G. G. 1951. "The ultimate bearing capacity of foudations." *Geotechnique*, 2(4), 301-332.
	Vesić, A. S. 1973. "Analysis of ultimate loads of shallow foundations." *Journal of the Soil Mechanics and Foundations Division*, 99(1), 45-73.
	Brinch Hansen, J. 1970. *A Revised and Extended Formula for Bearing Capacity, Bulletin No. 28*. Danish Geotechnical Institute, Copenhagen.
Bearing capacity of rock	Stagg, K. G. and Zienkiewicz, O. C. 1968. *Rock Mechanics in Engineering Practice*. John Wiley & Sons, New York, 442 pp.
Mat foundations	American Concrete Institute (ACI). 2002. *Suggested Analysis and Design Procedures for Combined Footings and Mats, ACI 336.2R-88*, ACI.
Anchors for foundations	FHWA. 1999. *Ground Anchors and Anchored Systems. Geotechnical Engineering Circular No. 4. Publication FHWA-IF-99-015*. Federal Highway Administration, Washington, D.C.
Foundations in expansive soils	Chen, F.H. 1988. *Foundations on Expansive Soils*. 2nd Edition, Elsevier Science Publications, New York, NY.
Foundations in collapsible soils	Houston, S. L., Houston, W. N., Zapata, C. E., and Lawrence, C. 2001. "Geotechnical engineering practice for collapsible soils." *Unsaturated soil concepts and their application in geotechnical practice*, 333-355.

CHAPTER 6. DEEP FOUNDATIONS

6-1 INTRODUCTION.

6-1.1 Scope.

This chapter presents information on the common types of deep foundations, analysis and design procedures, and procedures for installation and quality control. The term *deep foundations*, as used in this chapter, refers to foundations that obtain capacity along their length and/or at their base, generally with a foundation length to width ratio (Z/b) exceeding five. Deep foundations include driven piles and formed-in-place columns, such as drilled shafts, continuous flight auger columns (CFAs), drilled displacement piles (DDPs), aggregate columns, micropiles, and helical piles. This is not an exhaustive list of deep foundation technologies nor is there a consensus on the naming of the technologies.

Since common deep foundation technologies are discussed together in this chapter, generic terminology is used as much as possible to unify the discussion of technical concepts. The terms *column*, *element*, and *pile* are used interchangeably, with the term *driven pile* used to distinguish the specific foundation type. The term *top* is used to refer to the end of the element closest to the ground surface in lieu of alternatives such as *head* and *butt*; the terms *side* and *shaft* are used interchangeably; and the terms *base, tip,* and *toe* are used interchangeably to refer to the end of element that is furthest from the ground surface. This variety of terms is more consistent with source material and disrupts excessive repetition of particular words.

Given the extensive body of knowledge in the area of deep foundations, the scope of this chapter is to provide technical background and present selected design approaches for several popular deep foundation options concisely in one organized location. This chapter is intended to be useful as a standalone resource as well as a primer to the information provided in technology-specific design manuals. Potentially helpful resources that were used in the development of this chapter are provided in Section 6-13.

6-1.2 Organization

Chapter 6 is organized into ten sections. Table 6-1 outlines some key information found in each section as a supplement to the information provided in the Table of Contents for this manual.

6-1.3 Applications.

Deep foundations are used in a variety of applications including:

1) To transmit loads through an upper weak and/or compressible stratum to an underlying competent zone;

2) To provide support in areas where shallow foundations are impractical, such as underwater, in close proximity to existing structures, situations where the magnitude and/or rate of consolidation is intolerable, and on contaminated sites.

3) To provide uplift resistance and/or lateral load capacity.

Deep foundation technologies are also used in ground improvement applications and slope stabilization. These applications are not covered in this chapter.

Table 6-1 Organization of Chapter 6

Section	Key information provided
6-1 Introduction	Scope, applications, and general considerations
6-2 Design aspects and considerations	Overview of design process and considerations related to the project, site, subsurface, and construction
6-3 Foundation types	Overview of deep foundation types and some useful material properties
6-4 Construction	Summary of construction equipment, materials, and processes for common types of deep foundations
6-5 Geotechnical static axial capacity and settlement	Details of practical methods for evaluating geotechnical axial compressive and uplift capacity and settlement for single or a group of deep foundation elements founded in coarse-grained soil, fine-grained soil, or rock.
6-6 Geotechnical lateral capacity	Overview of software and analytical methods for evaluating lateral behavior for single or a group of deep foundation elements founded in coarse-grained or fine-grained soil; details for Broms ultimate load analysis and Characteristic Load Method.
6-7 Structural capacity	Considerations for allowable stresses, buckling, and design of the pile cap
6-8 Static load testing	Overview of axial load tests and details for common methods used to interpret axial compressive load tests
6-9 Dynamic methods of analysis and testing	Summary of basic wave mechanics, use of wave equation, high-strain dynamic measurements, the Case Method, signal matching, and rapid load tests.
6-10 Integrity testing	Overview of common high-strain, low-strain, acoustic, thermal, and nuclear methods to assess foundation integrity

6-1.4 General Considerations.

The decision to use a particular deep foundation type is driven by a variety of technical and non-technical factors. Performance requirements include axial load capacity, durability, response to dynamic and/or lateral loads, and loss of ground support. The latter can occur due to liquefaction, scour, and/or dissolution of carbonate rock, i.e.

karst. Practical considerations for construction include transport, site access, high groundwater, obstructions, noise/vibration, ground deformations, and speed/ease of installation. Some nontechnical factors that influence the selection of a deep foundation include the costs and availability of materials, contractor familiarity, mobilization, available labor, as well as local codes. Navigating the collective technical and nontechnical factors on a particular project requires a careful and diligent evaluation of available options informed by local experience and engineering judgment.

6-2 DESIGN ASPECTS AND CONSIDERATIONS.

6-2.1 Design Aspects.

While the design of deep foundations is specific to the particular technology and application, there are many common elements of the design process. These elements are provided in 15 steps in Figure 6-1 and relevant steps can be applied generally to the design of foundations. The sequential organization of the design steps in Figure 6-1 belies the fact that all designs, especially for complex projects, are iterative and involve communication and coordination among many parties.

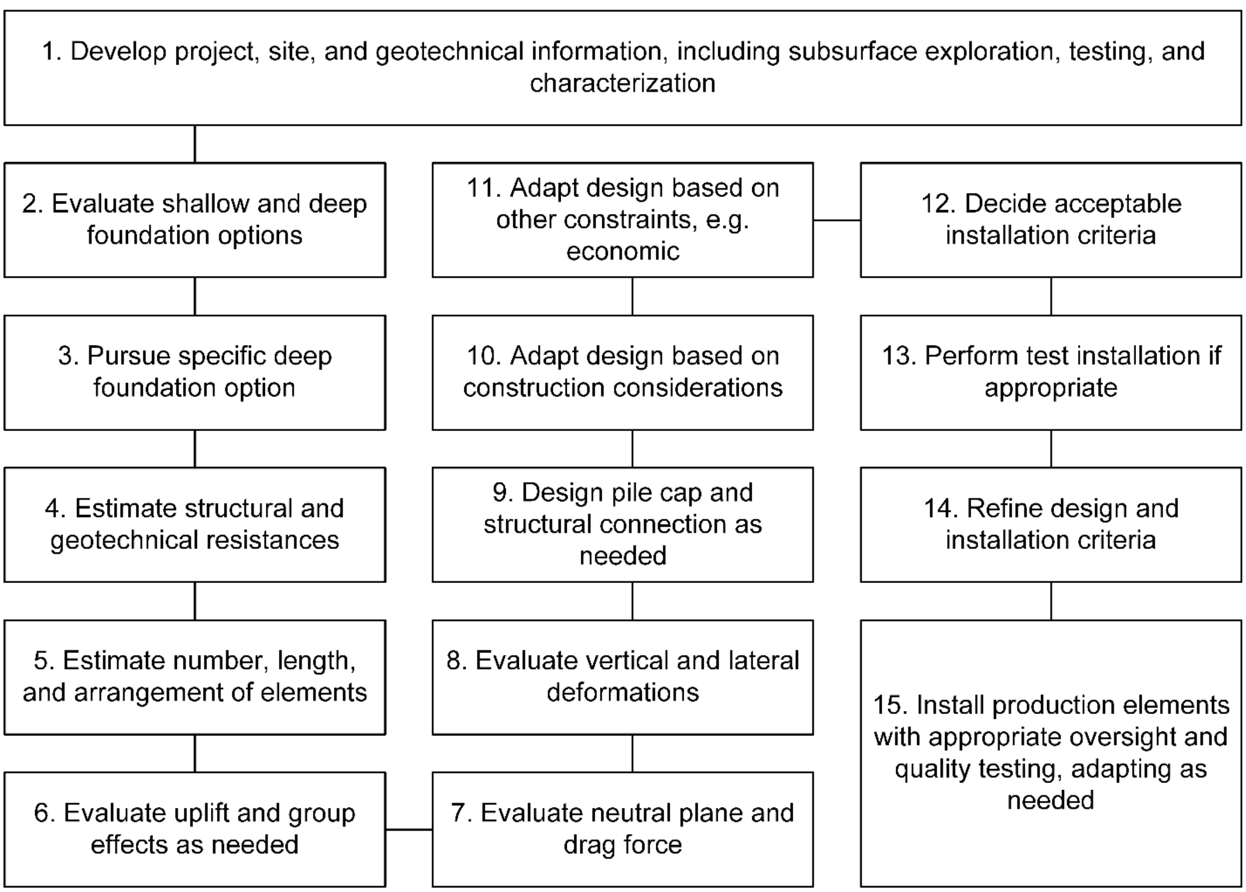


Figure 6-1 Major Elements of the Process to Design Deep Foundations

The following locations in DM 7.1 and 7.2 provide useful information for each step of the deep foundation design process:

1) Develop project, site, and geotechnical information: Project and site considerations are discussed in Section 6-2.2, and subsurface characterization considerations are discussed in Section 6-2.3. Chapters 1, 2, 3, and 8 of DM 7.1 provided detailed information related to the geotechnical characterization of sites and materials.

2) Evaluate shallow and deep foundation options: Refer to Chapter 4 of DM 7.2 for information on shallow foundations and this chapter for information on deep foundations. Ground improvement, discussed in Chapter 1 of DM 7.2, can be employed to increase the suitability of shallow foundations. When suitable, shallow foundations are usually a more economical solution than deep foundations.

3) Pursue specific deep foundation option: After the decision to pursue deep foundations has been made (see Section 6-1.3), refer to guidance in Section 6-3 for selecting a particular technology.

4) Estimate geotechnical and structural resistances: Refer to Section 6-5.4 for guidance related to estimating geotechnical axial resistance in soil and rock and Section 6-7 for guidance related to structural capacity.

5) Estimate the number, length, and arrangement of elements: Figure 6-2 shows typical arrangements of deep foundations. While drilled shafts are often used as single elements without a pile cap, a majority of deep foundation elements are installed in groups that are usually tied together in a pile cap. Driven piles, micropiles, and helical piles can be installed at a batter angle to provide lateral resistance. Batter piles also can be used to avoid obstructions or undesirable subsurface features.

6) Evaluate uplift and group effects as needed: Refer to Section 6-5.5 for group effects on geotechnical axial capacity and Section 6-5.6 for guidance related to uplift (tension loading).

7) Evaluate neutral plane and drag force: In many cases, deep foundation elements are subjected to the effects of settling ground. Ground that settles more than the element imposes a drag force on the sides of the element, while ground that settles less than the element contributes to the settlement of the element in the form of downdrag. These concepts are covered in Sections 6-5.7 and 6-5.8.

8) Evaluate vertical and lateral deformations: Settlement analysis is covered in Section 6-5.8, and evaluation of the lateral deformation of vertical elements is

covered in Section 6-6. Most analysis of lateral loading on vertical elements is performed using commercial software.

9) Design pile cap and structural connection as needed: Comprehensive structural design of deep foundations, pile caps, and other structural connections is not covered in this chapter. Section 6-7 provides some high-level guidance for sizing pile caps. Designers should consult appropriate building code requirements and authorities on reinforced concrete design, e.g., American Concrete Institute (ACI).

10) Adapt design based on construction considerations: Good deep foundation designs consider the constructability of the foundation and the impacts of construction, especially vibration. Section 6-2.4 covers construction considerations, and Section 6-4 provides more detailed information about the construction equipment and processes for popular deep foundation types.

11) Adapt design based on other constraints: Consideration of economic, environmental, and social factors in foundation design and construction is beyond the scope of this chapter. Section 6-2.4 mentions some logistical considerations related to construction, e.g., transport of materials and equipment.

12) Decide acceptable installation criteria: Section 6-4 discusses common installation criteria for popular deep foundation types, such as minimum blow count and/or penetration depth. Installation criteria must be decided to reliably satisfy the performance requirements for the project while considering subsurface conditions and special site considerations, such as obstructions. Static load testing (Section 6-8) and dynamic methods of analysis and testing (Section 6-9) are common approaches to establish installation criteria. Test installations (Step 13) can be an effective way to refine installation procedures and criteria.

13) Perform test installation if appropriate: Test installations or test pile programs allow the observational method to be implemented early enough in the project for the engineers and contractor to make adjustments. Test installations allow the length of driven piles to be tailored for material efficiency (piles not too long) and construction efficiency (number of splices minimized). Test installations allow experimentation with equipment and procedures in advance of the installation of production elements and provide opportunities to perform static and dynamic load testing.

14) Refine design and installation criteria: At this stage, design engineers, construction engineers, and other members of the project team refine the design based on what was learned during the test installation.

15) Install production elements with appropriate oversight and quality testing, adapting as needed: Section 6-2.4 discusses the role of visual inspection, periodic testing, and being prepared for unexpected conditions during construction.

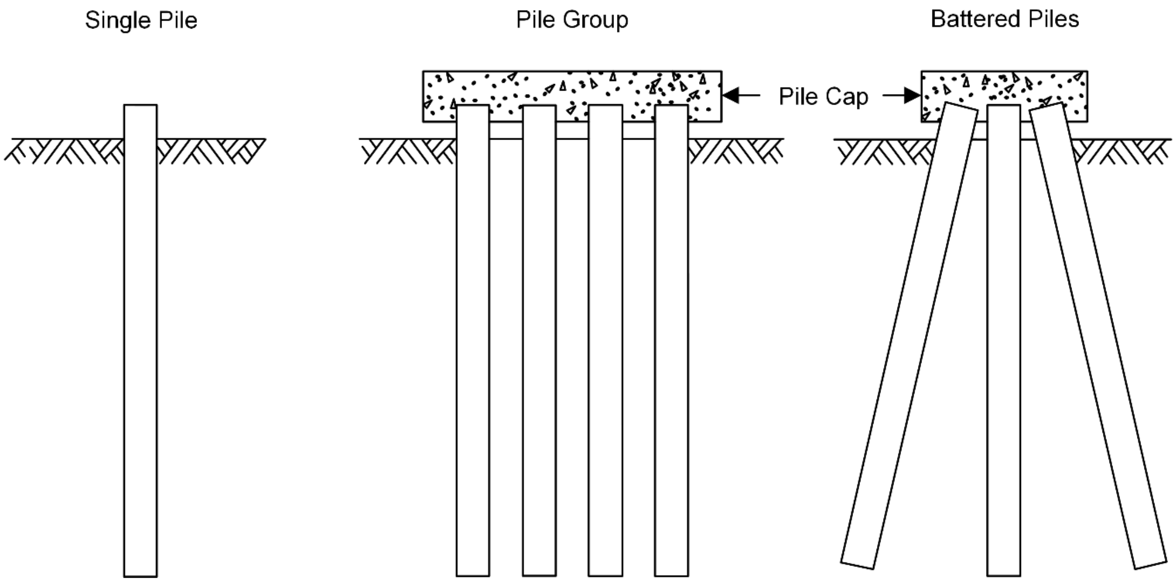


Figure 6-2 Configurations of Deep Foundation Elements

6-2.2 Site and Project Considerations.

The selection of a foundation type, design of the foundation, construction, and long-term maintenance planning require numerous site and project considerations. A non-exhaustive list of these considerations is provided in Table 6-2.

Table 6-2 Site and Project Considerations for Deep Foundations

Category	Site and Project Considerations
Structural and project management	• Structural loading • Deformation tolerances • Service life • Project delivery schedule
Geotechnical	• Qualty and variability of soil and rock • Obstructions • Voids or karst • Groundwater level and fluctuation
Environmental	• Existing contamination • Limits of project disturbance • Protection of aquatic life
Hydraulic and hydrological	• Scour • Debris and ice loading
Seismic	• Seismic loading • Liquefaction potential
Foundation deterioration	• Chemical – corrosion • Mechanical – freeze/thaw, thermal cycling, excessive loading • Biological – insects, marine borers
Site Constraints	• Noise and vibrations • Waterborne sediment and airborne dust • Physical space, including low headroom • Material transportation and staging
Other	• Supply chain disruptions • Natural disruptive events – extreme weather • Human-caused disruptive events

Addressing these considerations requires technical expertise, local experience, and coordination within a multidisciplinary design team and requires project or site specific details. Scour and foundation deterioration can be treated more generally and are discussed in the following sections.

6-2.2.1 Scour.

Scour is the loss of soil by erosion due to the drag force of moving water (Briaud 2008). There are three categories of scour commonly associated with river and stream flows: 1) long-term changes to the stream bed by aggradation and degradation of sediments, 2) contraction of the overall stream channel by the constricting effect of obstacles to flow, and 3) localized scour due to the effect of obstacles on flow path and velocity. Scour is also categorized as either clear water or live bed (FHWA 2012a). *Clear water scour* occurs when the upstream bed material is not being actively transported and deposited. In contrast, *live bed scour* refers to a condition where the upstream bed material is transported and deposited to partially replenish eroded materials. Other sources of scour include wave action and ship propulsion. In the context of bridges and waterfront structures, obstacles to flow include bridge piers, abutments, bulkheads, and pilings for wharves.

Scour occurs whenever hydrodynamic shear stresses acting on the erodible material exceed a threshold critical shear stress (Briaud 2013). While flow velocity and hydrodynamic shear stress do not adhere to a simple relationship, it is conceptually convenient to express the onset of scour by a critical velocity, v_c. For coarse-grained soils, the critical velocity (in m/s) is correlated to the median particle size, D_{50} (in mm), according to:

$$v_c = 0.35 \cdot \left(D_{50}\right)^{0.45} \qquad (6\text{-}1).$$

Note that the units on the constant are m / (s·mm$^{0.45}$)

The critical velocity is not correlated to particle size for fine-grained soils, and Equation 6-1 should not be extrapolated below sand-sized particles. Knowledge about scour of cohesive soils is limited (Hughes 2001). To simplify the assessment of erosion potential, Briaud (2008) categorized soil and rock as shown in Figure 6-3. Six categories are defined based on soil classification, fissuring, and jointing. The zones on the diagram indicate typical ranges of erosion rate for each category based on the water velocity.

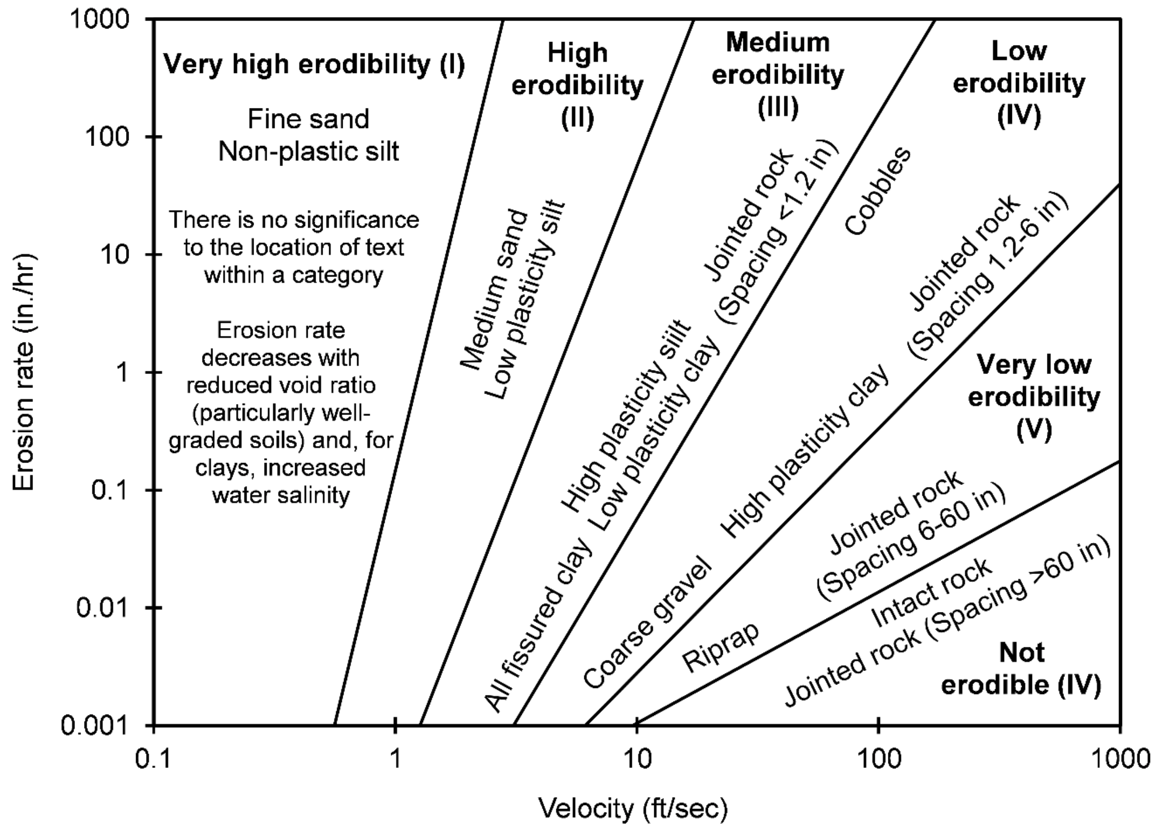


Figure 6-3 Erosion Categories for Soils and Rock Based on Velocity (after Briaud 2008)

The three documents listed below describe the overall process to analyze, evaluate, and remediate scour and stream instability at bridges:

1) Stream Stability and Geomorphic Assessment (HEC-20) (FHWA 2012b): This document describes data collection and analysis procedures to evaluate stream bank and stream bed stability and establishes the level of analysis needed to evaluate scour.

2) Hydrologic, Hydraulic, and Scour Analysis (HEC-18) (FHWA, 2012a): This document describes the hydrologic analysis to evaluate volumetric flow due to water draining from a watershed, the hydraulic analysis to evaluate the depth, velocity, and forces imposed by the flow, and the process to evaluate the components of total scour.

3) Bridge Scour and Stream Instability Countermeasures (HEC-23) (FHWA 2009): This analysis develops an implementation strategy to reduce the likelihood and severity of scour. Countermeasures are often taken for existing foundations in response to scour.

Modeling the fluid dynamics and erosion mechanics of scour problems is a complex undertaking that is typically undertaken by specialists. The U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) developed and maintains the River Analysis System software (HEC-RAS) that models flow hydraulics and sediment transport, among other types of analysis.

Scour is typically considered for two flood conditions: 1) the scour design flood and 2) the scour check flood. In the context of roadways and bridges, both flood conditions are usually more severe than the hydraulic design flood for evaluating inundation and overtopping. For example, according to HEC-18 (FHWA 2012b), if the hydraulic design flood is the 100-yr flood (1% annual probability of occurrence), the scour design flood is the 200-yr flood, and scour design check flood is the 500-yr flood. According to AASHTO (2020), the 100-yr flood should be used for the scour design flood and the 500-yr flood should be used for the scour check flood. The scour design flood is considered for all strength and service limits states while the scour design check flood is considered for the extreme event limit state. In some cases, scour depth does not increase with discharge, so the maximum scour depth for the design scour flood and scour check flood should be the worst case for all floods considered. In other words, an overtopping flood with discharge lower than the design scour flood and scour check flood discharges may produce the most severe scour (FHWA 2021).

UFC 4-151-10 (2012) stipulates that all piles should be designed for a minimum of 5 feet of scour and future dredging while Hughes (2001) suggests that a conservative rule of thumb for piles with Z/b greater than 10 is to assume that the maximum scour depth is double the pile diameter.

The total scour depth directly impacts deep foundation design in the following ways:

1) Unbraced length increases by an amount equal to the scour depth
2) Lateral support lost over the scour depth
3) Side resistance lost over the scour depth
4) Additional water load (LRFD load designated WA) applied to the foundation over the scour depth

Additionally, scour reduces the vertical effective stress due in the soil below the depth of scour over a depth interval of approximately 1.5 times the scour depth. Compared to the original stream bed, the vertical stress may decrease to a depth of 2.5 times the scour depth.

In some conditions, scour holes from adjacent bridge piers can overlap and lead to further deepening and/or widening of the local scour.

When static load testing and/or dynamic testing is used to evaluate foundation performance, it is also important to consider that scour will change the ground support conditions from those present at the time of testing.

The scour risk can be reduced in design by 1) lengthening the foundations to account for the scour depth, 2) lengthening the bridge to reduce the impact of the abutments on the stream channel, 3) modifying the size and arrangement of the piers, and 4) deploying scour countermeasures such as riprap, gabions, articulated concrete block mats, and sheet piles. Over the long term, modifications to the design (1-3) are more reliable than using scour countermeasures (4) alone (FHWA 2018a).

6-2.2.2 Deterioration.

Timber, steel, and concrete are vulnerable to one or more modes of deterioration over time. In particular, steel is susceptive to corrosion, concrete is susceptible to attack by acid and sulfate, and timber is susceptible to biological attack. Reinforced concrete is a composite of steel and concrete and, therefore, shares susceptibilities of both materials. Table 6-3 lists ground and water conditions that pose a heightened risk of foundation deterioration. Elevated temperature, stray electrical currents, and access to oxygen can also increase the risk of deterioration. Conditions that are deemed lower risk for deterioration at the time of construction can become higher risk over time, e.g., through the application of deicing salts or changes to groundwater levels by pumping.

Table 6-3 Conditions that Pose a Heightened Risk of Foundation Deterioration (after AASHTO 2020)

Piles on Land	Piles in Water
• pH less than 5.5 • pH between 5.5 and 8.5 in soils with high organic content • Sulfate concentration greater than 1,000 ppm • Resistivity less than 2,000 ohm-cm • Soils subject to mine or industrial drainage • Landfills or cinder soils • Areas with a mixture of high resistivity soils and low resistivity high alkaline soils • Insects (timber piles)	• pH less than 5.5 • High organic content • Sulfate concentration greater than 500 ppm • Chloride concentration greater than 500 ppm • Mine or industrial runoff • Marine borers and other invertebrates (timber piles) • Piles exposed to wet/dry cycles

Deterioration is a process that occurs over time and cannot be avoided entirely. In design, the goal is to reduce the risks of problematic deterioration to acceptable levels over the service life of the foundation. Broadly, measures to mitigate the impacts of deterioration include the following:

- Select or design the foundation material for durability, including:
  - Selection of steel alloy
  - Concrete mix design
  - Selection of wood species
- Protection of the foundation material, including:
  - Coat steel and concrete in various tar and epoxy coatings
  - Galvanize steel
  - Impregnate timber with preservatives such as creosote (oil-borne), Chromated Copper Arsenate (CCA), and Ammoniacal Copper Zinc Arsenate (ACZA) (both waterborne)
  - Cover timber, steel, or concrete in a plastic sleeve, jacket, or wrap, particularly in tidal and splash zones and at the dredge line
- Include sacrificial material and/or add redundancy in the design, such as:
  - Adequate minimum cover depth of concrete between the environment and steel reinforcement, e.g., 3 inches, and
  - Cathodic protection to steel.

The time rate of metal loss due to corrosion is difficult to forecast and influenced by localized electrochemical conditions that are prone to spatial and temporal variability. In the absence of better information, a metal loss of 0.003 inches per year can be conservatively applied in design for unprotected steel in non-marine environments (FHWA 2016). For marine environments, the rate of metal loss can be significantly higher, e.g., 0.007 inches per year (Coduto et al. 2016). The metal loss is the reduction in thickness of the steel, accounting for corrosion on both sides (Romanoff, 1962). For a pipe pile, the thickness is the wall thickness. Decker et al. (2008) found that the average corrosion rate decreases with time. Figure 6-4 is based on data for non-marine conditions (Decker et al. 2008) and illustrates that an assumed loss rate of 0.003 inches per year is conservative. However, corrosion rates in certain aggressive environments, such as at the splash zone where abrasion can occur, can be higher (FHWA 2016).

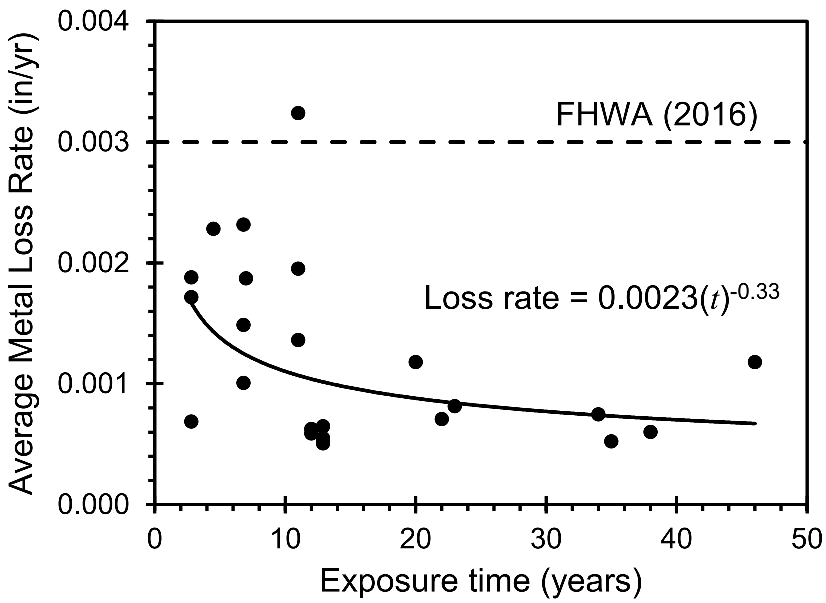


Figure 6-4 Annual Loss of Metal Thickness Versus Exposure Time in Non-Marine Environments (after Decker et al. 2008)

6-2.3 Subsurface Characterization Considerations.

Adequate subsurface exploration must precede the design of a deep foundation. Investigations should include the following:

1) Geological section showing pattern of major strata and presence of possible obstructions, such as boulders and buried manmade objects as well as voids due to karst;
2) Sufficient test data to estimate strength, compressibility, and liquefaction potential of major strata;
3) Determination of probable bearing strata;
4) Evaluation of corrosion potential; and
5) Evaluation of scour potential.

Chapters 2 and 3 of DM 7.1 provide useful guidance for actions performed in the field and in the laboratory to characterize subsurface conditions.

6-2.4 Construction Considerations.

The performance of deep foundations is highly dependent on the installation procedures, quality of workmanship, and installation/design changes made in the field. Thus, inspection of the deep foundation installation by a geotechnical engineer should be required under normal conditions.

This section presents recommendations for minimum spacing between elements and tolerances for placement and alignment.

6-2.4.1 Minimum Spacing.

Guidance for minimum center-to-center spacing between adjacent elements is provided in Table 6-4. Smaller spacing can be impractical from a constructability standpoint due to limitations associated with positioning the equipment, densification of sand that impedes installation, and achievable alignment tolerances as well as group effects on performance (i.e., group efficiency). Minimum spacing guidance is particularly relevant to the discussion of the axial (Section 6-5.5) and lateral (Section 6-6.4) capacity of pile groups.

6-2.4.2 Placement and Alignment Tolerances.

Correct location and alignment of foundation elements is important to minimize the potential for introducing eccentricities not accounted for in design. Eccentricity can introduce additional bending stresses and uneven loading in groups of elements. Additionally, placement and alignment errors can increase the potential for constructability issues and damage to the elements if spacing is too small or if misaligned elements interfere at depth.

The construction tolerances specified by USACE and FHWA for different foundation types are summarized in Table 6-5. The center of each element should be located within the plan location tolerance. The longitudinal alignment refers to the allowable deviation from vertical for most elements or from the planned alignment for batter piles. The pile top elevation should be finished or cut off within the indicated tolerance. The International Building Code requires that deep foundation elements be designed to resist the eccentricity effects of location errors of no less than 3 inches (ICC 2015). The code permits a 10% compressive overload in elements due to location errors.

Table 6-4 Guidance for Minimum Center-to-Center Spacing

Foundation Type	Minimum Spacing Guidance
Driven piles	Minimum spacing is greater of 2.5 ft or s/b = 2.5 (AASHTO 2020) Minimum recommended spacing is greater of 3 ft or s/b = 3.0 (FHWA 2016).
Drilled shafts	Minimum spacing is s/b = 2.5, recommended spacing is at least s/b = 3.0 (FHWA 2018a).
Continuous Flight Auger Piles	Minimum spacing is s/b = 3.0 (FHWA 2007).
Drilled Displacement Piles	Minimum spacing is s/b = 3.0 (FHWA 2007).
Micropiles	Minimum spacing is greater of 2.5 ft or s/b = 3.0 (AASHTO 2020). For micropiles, b is the diameter of the grouted bond zone (FHWA 2005).
Variables: b = element width, s = center-to-center spacing	

Table 6-5 Deep Foundation Construction Tolerances

Foundation Type	Tolerance for:		
	Plan Location	Longitudinal Alignment	Pile Top Elevation
Driven Piles (USACE 1991)	3 to 6 inches	0.25 inches / foot (1H:48V)	Within 1 inch of specified
Vertical Driven Piles (FHWA 2016)	3 inches (bents) 6 inches (capped below grade)	0.25 inches / foot (1H:48V)	Between 1.5 inches above and 4 inches below specified
Batter Driven Piles (FHWA 2016)	3 inches (bents) 6 inches (capped below grade)	0.5 inches / foot (1H:24V)	Between 1.5 inches above and 4 inches below specified
Drilled Shafts (FHWA 2018a)	3 inches for $b \le 2$ ft 4 inches for 2 ft $\le b \le 5$ ft 6 inches for 5 ft $\le b$	1.5% (1H:67V) in soil 2% (1H:50V) in rock	Between 1 inches above and 3 inches below specified
Micropiles (FHWA 2005)	3 inches for pile 0.75 inches for reinforcement	2% (1H:50V)	Between 1 inches above and 2 inches below specified

6-3 FOUNDATION TYPES.

6-3.1 Overview.

Deep foundation elements are principally comprised of one or more of the following materials: timber, steel, crushed stone, grout, and concrete. Deep foundation technologies are summarized in Table 6-6 through Table 6-9. The selection of a particular foundation technology depends on many factors including the intended application, soil and rock conditions, capacity requirements, installation effects (e.g., noise, vibration, soil displacement), material costs and availability, equipment availability, and contractor experience. In the private sector, the client’s comfort with the technology and associated risks may also be a factor.

Broadly speaking, deep foundation technologies can be divided into driven piles and formed-in-place columns. Within each of these categories, deep foundations are distinguished by the amount of soil volume displaced by each element.

Non-displacement elements include the following:

1) Drilled shafts
2) Micropiles

Low- or partial-displacement elements can include the following:

1) Driven piles with a low ratio of cross-sectional area to perimeter, e.g., H-piles and open pipe piles, provided the piles remain unplugged with soil
2) Any pile installed by jetting or pre-boring
3) CFA columns
4) Helical piles
5) Predrilled aggregate piers without ramming or vibration

High- or full-displacement elements include the following:

1) Driven piles with a high ratio of cross-sectional area to perimeter, e.g., timber piles, closed-end pipe piles, tapered piles, and most concrete piles
2) Any driven pile that forms a soil plug and becomes a displacement pile below the depth of plugging
3) Drilled displacement piles (DDP)
4) Aggregate columns – while the installation of aggregate columns often involves drilling, the ramming or vibratory installation methods displace surrounding soil

The effects of soil displacement may be advantageous or detrimental depending on the application, ground conditions, and presence of nearby structures and utilities. The impacts of these effects on shaft and base capacity will be discussed in more detail in Section 6-5, though it suffices to say that soil displacement usually has a positive effect on geotechnical capacity for drained conditions, except for sensitive soils. Soil displacement, particularly associated with driven piles, can also generate positive or negative excess pore pressures. The implications of driving-induced pore pressures are discussed in Section 6-4.1.4.

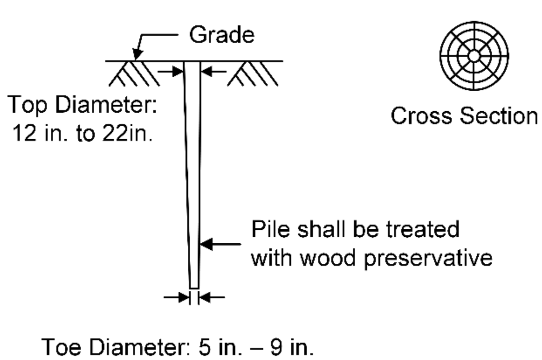
Soil displacement in the form of heave and/or lateral movement can be damaging to adjacent structures, e.g., below-grade walls, buried utilities, abutments, and other foundation elements. When a group of foundation elements is used, the combined soil displacement may be significantly larger than that caused by a single element.

6-3.2 Summaries of Common Deep Foundation Types.

Table 6-6 through Table 6-9 summarize common deep foundation types. These technologies are also used in ground improvement and slope stabilization applications; however, these applications are not within the scope of this chapter. A summary of the aggregate column technology can be found in Figure 1-2.

Table 6-6 Summary of Timber Piles and Steel H-Piles

Pile type	Timber Piles	Steel H-Piles
Typical lengths	15 to 75 ft for Southern Pine 15 to 120 ft for Douglas Fir	15 to 150 ft
Typical factored resistance	20 to 100 kips	80 to 400 kips
Advantages	• Relatively low initial cost • Easy to deliver and handle • Renewable resource • Sequesters carbon • Permanently-submerged piles are resistant to decay • Not susceptible to corrosion	• Broad range of sizes and lengths • Easy to splice • Can be fitted with hardened driving points for penetrating hard layers and some obstructions • Steel often has high recycled content • High load resistance possible
Disadvantages	• Lengths greater than 60 ft difficult to supply in some locations • Difficult to splice • Vulnerable to damage from hard driving, top and base may need protection • Intermittently-submerged piles are vulnerable to decay unless treated	• Unprotected steel is susceptible to corrosion • Despite being the driven pile with highest potential for survival in hard driving conditions, damage still possible from obstructions and uneven rock, e.g. karst
Remarks	• High displacement timber element • Good option as a friction pile, particularly in cohesionless soils • Equipment and materials may be easier to procure in some remote areas than other deep foundation types	• Low displacement steel element, unless plugged • Good option for end-bearing pile on rock • Relatively low skin friction, particularly in cohesionless soils; not good for shaft resistance, but may be an advantage when downdrag is an issue



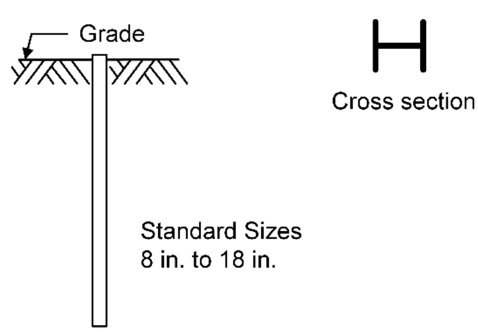
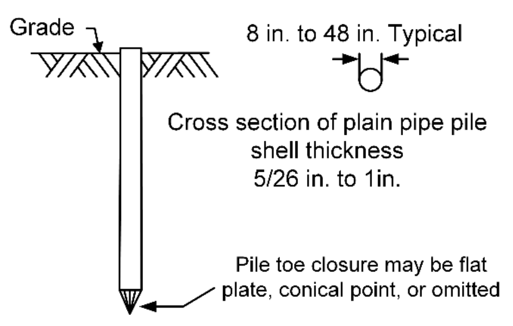


Table 6-7 Summary of Steel Pipe Piles and Concrete Piles

Pile type	Steel Pipe Piles	Precast Prestressed Concrete Piles
Typical lengths	15 to 200 ft	30 to 120 ft
Typical factored resistance	100 to 1,000 kips (unfilled) 100 to 3,000 kips (concrete filled)	100 to 800 kips (square) 200 to 1,200 kips (cylinder)
Advantages	• Like H-piles, broad range of sizes and lengths, easy to splice, steel often has high recycled content, high load resistance possible • Closed-end pipe interior can be inspected after driving • Open-end pipe provides access to clean out base to extend driving • Driving shoes can be used to improve resistance to obstructions	• High corrosion resistance obtainable • High load resistance possible • Rough concrete surface good for frictional resistance • Cylinder piles can provide good bending resistance
Disadvantages	• Unprotected steel is susceptible to corrosion	• Splicing is difficult • Cutting off excess pile is difficult • Handling requires extra care • Damage in hard (compression) and soft driving (tension) possible • Soil displacement can produce unwanted earth movements and pressures
Remarks	• High or low displacement element, sometimes concrete-filled • Provides high bending resistance, including unsupported length • Relatively low skin friction with open end pipe, particularly in coarse-grained soils; not good for shaft resistance, but may be an advantage against downdrag • Closed-end pipe susceptible to buoyancy forces when unfilled.	• High displacement concrete element • Good option for friction piles • Cylinder piles are more common for installations over water • Conventionally-reinforced piles (not prestressed) are rare in North America



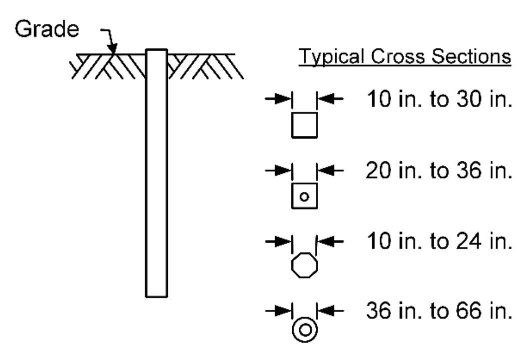
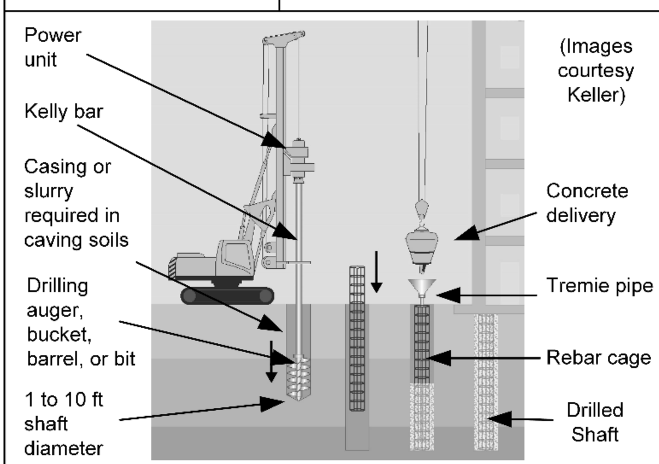


Table 6-8 Summary of Drilled Shafts and Continuous Flight Auger Columns

Pile type	Drilled Shafts	Continuous Flight Auger (CFA)
Typical lengths	20 to 200 ft	30 to 100 ft
Typical factored resistance	300 to 5,000+ kips	100 to 400 kips
Advantages	• High load resistance possible due to rough interface and large base • Possible to inspect cuttings and material at/below base • Installs with low noise and vibration • Simple to modify length during construction • Variety of tooling for excavating through soil and rock • High corrosion resistance obtainable	• Rough interface for good shaft resistance • Installs with low noise and vibration • Simple to modify length during construction • High corrosion resistance obtainable • No open bore hole • Can be installed in low headroom conditions
Disadvantages	• Less redundancy than pile groups • Contractor skill has large influence on quality • Significant mobilization of base resistance may require large settlement, esp. in cohesionless soil • Load tests are difficult and expensive	• Contractor skill has large influence on quality • Augers can overexcavate (mine) loose and/or clean sands and soft soils • Not well suited to hard soil, rock, and obstructions • Not well suited for providing high shear, bending, or uplift resistance
Remarks	• Nondisplacement concrete element • Reinforcement can provide high bending resistance, including unsupported length • Installation may be uncased, cased, or use slurry depending on potential for caving or squeeze • Belling tool can enlarge base area • Barrettes are a special type of shaft with a rectangular base	• Low-displacement concrete or grout element • May or may not include reinforcement • Installation rate can be high • Also known as auger cast-in-place pile



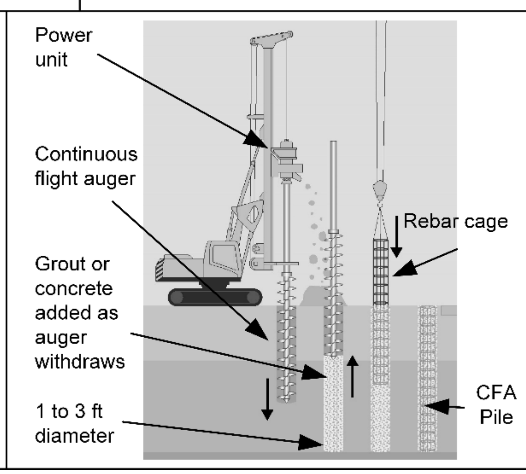
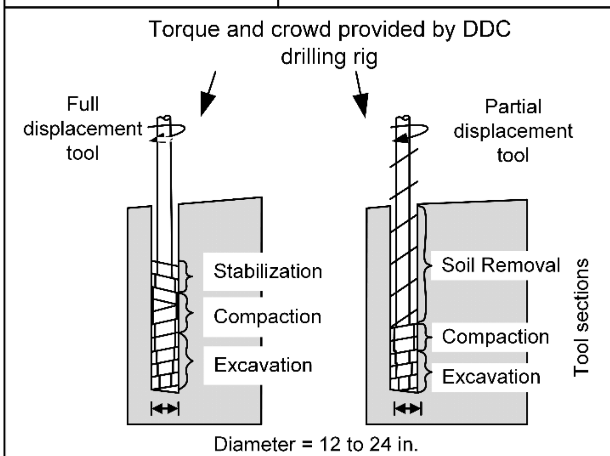
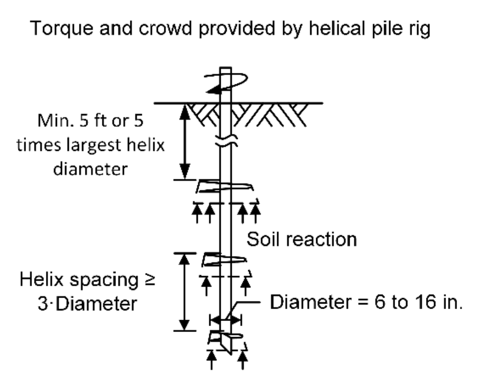


Table 6-9 Summary of Drilled Displacement Columns and Helical Piles

Pile type	Drilled Displacement Columns (DDC)	Helical piles
Typical lengths	20 to 75 ft	10 to 30 ft
Typical factored resistance	75 to 200 kips	20 to 120 kips
Advantages	• Rough interface and soil displacement for good shaft resistance • Installs with low noise and vibration • Simple to modify length during construction • No open bore hole • Fewer issues with overexcavation versus CFA	• Quick installation in any weather and groundwater depth • Can be suitable for compressive and uplift loading • Length adjustable by adding or subtracting prefabricated shaft components • Compact equipment, can be installed in low headroom conditions • Installs with low noise and vibration
Disadvantages	• Not well suited to hard soil, rock, and obstructions • Not well suited for providing high shear, bending, or uplift resistance	• Limited depths • Low bending resistance • Susceptible to corrosion • Not suitable for hard soils, rock, or soil with obstructions • Slenderness poses risk of buckling in soft soils, if liquefaction occurs, and for highly eccentric loadings
Remarks	• High-displacement concrete or grout element • May or may not include reinforcement • Installation rate can be high • Design methods less mature • Also known as rigid inclusions • Several proprietary systems exist, e.g. CMCs	• Low-displacement steel element • Usually six or fewer helices • Good option for underpinning • Installation torque can be monitored to avoid damaging twist of the pile and estimate capacity





6-3.3 Summary of Material Properties.

Table 6-10 provides the mass density and Young's Modulus for steel, concrete, and timber used in piling. Additionally, Table 6-10 includes applicable material specifications.

Table 6-10 Summary of Material Properties of Foundation Materials

Foundation Material		Unit Weight[1], γ (lbs/ft^3)	Young's Modulus[2], E (ksi)	Specifications
Steel		490	29,000	ASTM A572, A588, or A690 ASTM A252, API 5L or 2B For reinforcing steel, ASTM A82, A615, A722, and A884
Concrete[2,3]		150	$1820\sqrt{f'_c}$	ACI 318
Timber[3]	Southern pine[5]	46 (35)[4]	1,500	AWPA UC4A, UC4B, UC4C, UC5A, UC5B, and UC5C ASTM D25
	Douglas fir[5]	47 (31)[4]	1,500	
	Lodgepole pine	38 (27)[4]	1,000	
	Red oak[5]	50 (39)[4]	1,250	
	Red pine[5]	41 (30)[4]	1,280	

Notes:
1 If required, mass density, ρ (slugs/ft^3), is found by dividing unit weight by gravity, g = 32.17 ft/s^2.
2 Modulus of concrete is estimated based on AASHTO (2020) guidance based on f'_c in ksi. Values for modulus of timber are from AWPI (2002).
3 The properties of concrete and timber are influenced by many factors and may differ significantly from the provided values
4 Numbers without parentheses are for creosote preservative, numbers in parentheses are for CCA and ACZA. Values based on wood at 12% moisture content retaining 12 lbs of creosote (pine and oak), 17 lbs of creosote (fir), or 1 lb of CCA or ACZA preservative per ft^3 (USDA 2010).
5 Southern pine applies to loblolly, longleaf, shortleaf, and slash pines. Douglas fir applies to coastal variety. Red oak applies to northern and southern red oak. Red pine applies to US-grown red pine.

6-4 CONSTRUCTION.

The construction processes for deep foundations vary by technology, site conditions, and contractor. Besides consideration of geotechnical and structural performance, the selection of a deep foundation technology may be heavily influenced by construction considerations such as noise and vibration, spatial constraints (e.g., headroom and staging area size), site access, weather, equipment availability and mobilization, limits on work hours, environmental regulations, and contractor experience. This section provides an overview of the basics of deep foundation construction.

6-4.1 Driven Piles.

6-4.1.1 Equipment.

Pile driving operations traditionally utilize a crane to hoist and suspend the pile, hammer, leads, and other accessories (Figure 6-5). Pile leads guide the hammer and pile. *Fixed leads* are attached to the bottom of the crane boom using a spotter apparatus that holds the leads in place. *Swinging leads* hang from the top of the boom and are allowed to swing. The choice of leads is influenced by alignment needs as well as the reach required to position the pile. Alternatively, dedicated pile rigs are specialized equipment that use a telescoping mast instead of a lattice boom and allow faster mobilization and on-site set up. For installation of small- to medium-sized piles on land or near shore, tracked excavators are often configured as pile driving rigs with an attached mast and a hydraulic hammer driven by the excavator's hydraulic pump. When suitable, the use of an excavator-mounted pile driver is faster, more maneuverable, and involves lower mobilization costs than those of a crane-mounted rig.

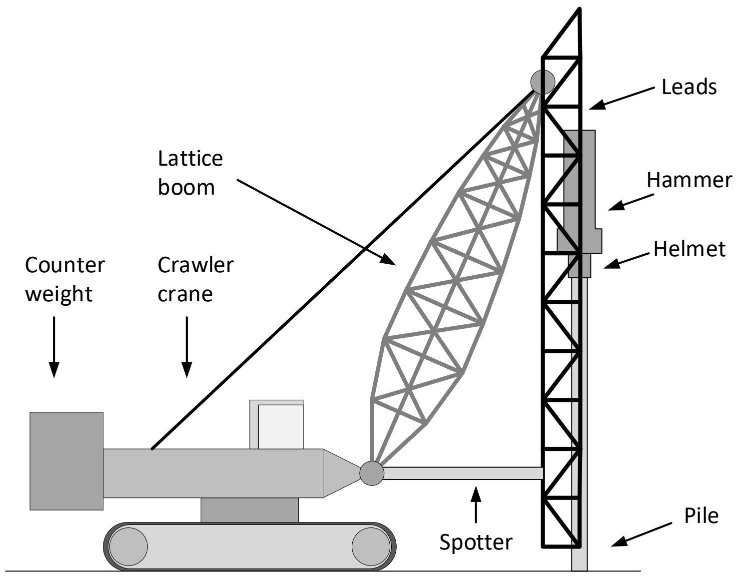


Figure 6-5 Typical Crane-Mounted Pile Driver

Broadly speaking, pile hammers can be classified as either impact or vibratory. The majority of pile driving for deep foundations is performed using an impact hammer. Impact hammers can use compressed air, steam, or pressurized hydraulic fluid to lift and drop a heavy mass to transfer energy to the pile. This energy performs work by advancing the pile deeper into the ground (Figure 6-6a). Single-acting air/steam/hydraulic hammers use a pressurized fluid or gas to lift the ram to the top of the stroke (3 ft is common). A hammer blow is delivered when the ram is allowed to free-fall on the downstroke, strike a steel plate, and transfer energy to the pile as it decelerates. Double-acting and differential hammers also apply pressure on the downstroke of the ram to accelerate the ram beyond gravity alone and allow for higher cycle rates.

Diesel impact hammers deliver energy to the pile through the explosive force from diesel fuel combustion combined with the falling mass of the ram (Figure 6-6b). Similar to a two-stroke internal combustion engine, diesel hammers use the downstroke of a steel ram confined within a cylinder to compress and ignite an air-fuel mixture. The explosion imparts the energy to advance the pile as well as the energy for the upstroke of the ram. Ports in the cylinder allow air to enter on the downstroke and exhaust to exit on the upstroke. Fuel is injected as a liquid or aerosol on the downstroke. Diesel hammers can be challenging to start or operate efficiently when the ground provides low resistance and/or when air temperatures are cold. Diesel hammers are able to deliver maximum power when the ground provides high resistance. Single-acting (open-end) hammers allow the ram to reach maximum rise on the upstroke while double-acting hammers resist the rise of the ram by compressing air within a bounce chamber to increase the cycle rate.

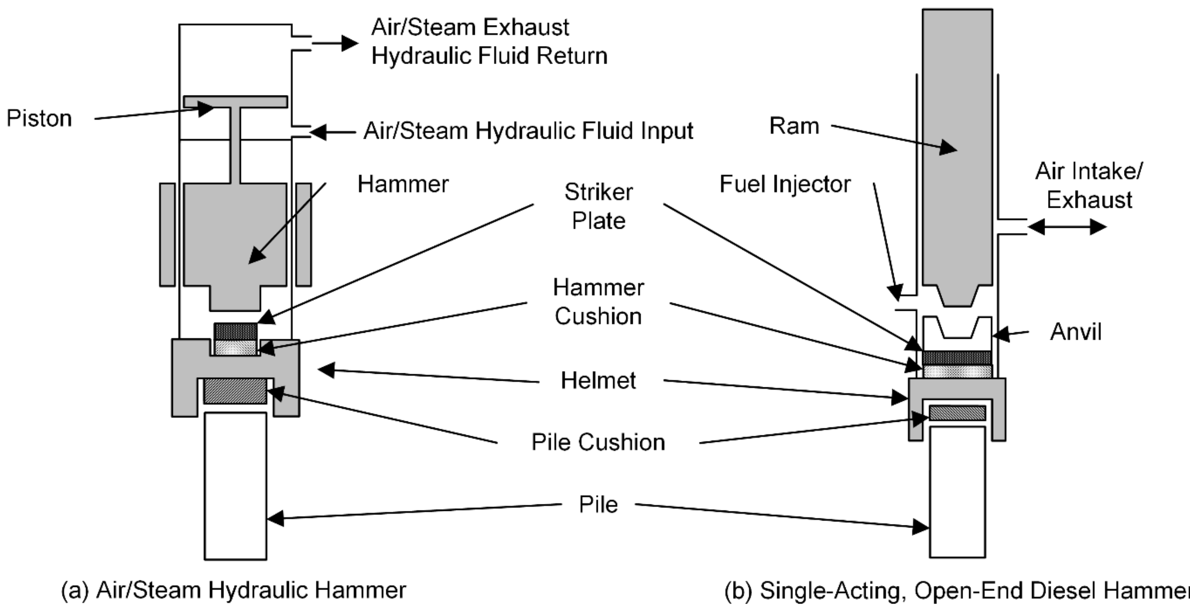


Figure 6-6 Pile Driving Hammers

The drive system is a series of components between the ram and pile that are collectively referred to as appurtenances. These components, listed in order from the ram to the pile, usually include a steel striker plate, hammer cushion (or cap block), and steel helmet (or drive head). Diesel hammers also include a steel anvil between the ram and striker plate as part of the combustion chamber. Modern hammer cushions are typically made from laminates of aluminum, plastic (e.g., nylon), and phenolics (e.g., Micarta) and function to enable efficient energy transfer while mitigating damage to the steel hammer components. The helmet functions to maintain pile alignment within the hammer-pile system and aid in efficient energy transfer. When driving concrete piles, a pile cushion typically made from layers of plywood is used to limit damaging energy transfer between the helmet and pile.

The types and condition of the appurtenances affect the propagation of energy within the hammer-pile system. The pile cushion, in particular, is a rapidly wearing component that has different dynamic properties when it is new (<100 hammer blows) versus when it is at the end of its usable life (often 1,000 to 2,000 hammer blows). This point is especially important when dynamic testing and/or penetration resistance are used to evaluate pile capacity.

Many factors can contribute to the selection of the type and size of the pile hammer. Some of these factors are related to considerations of drivability and driving stresses as discussed in Sections 6-4.2.1 and 6-9. Manufacturers typically provide an energy rating, E_r, to organize hammers by the relative amount of energy they can deliver. The energy rating should not be interpreted as the actual energy delivered to the pile as no hammer and driving system is 100% efficient. Prior to more rigorous evaluation, such as wave equation analysis, the required hammer energy rating in kip-ft can be preliminarily estimated as 7% of the required nominal pile resistance, R_n, in kips (Coduto et al. 2016).

Piles driven to rock and/or through ground containing cobbles, boulders, and/or other obstructions may be fitted with pile toe attachments. For example, damage potential is reduced using driving shoes for H-piles and conical tips for pipe piles. Toe protection for concrete piles exists but is not commonly used in practice.

Sometimes driving aids are used to reduce the potential for pile damage during driving, speed up the installation process, allow for smaller equipment to be used, mitigate heave, and/or mitigate ground vibration. *Predrilling* is a driving aid in which an auger is used to drill a pilot hole for the pile. Sand and gravel soils can be loosened using *jetting* with a high-pressure water nozzle on a probe. *Spudding* is the practice of driving a heavy pile through an obstruction to make a hole for the production pile. These driving aids reduce the axial and lateral load capacity of the pile, and their effects should be accounted for in the design.

Handling piles refers to the processing of positioning the pile in the leads. Handling requires special lifting equipment or a crane hoist line. Sometimes the ability to handle piles will limit their length. In some cases, the bending stresses experienced by piles during handling are higher than the design loading. Concrete piles, in particular, require care when handling and must be lifted from multiple points. Handling piles becomes more difficult as the ratio of the length to the width increases. As a rule of thumb, a maximum of a 40 ft long square concrete pile having a width of 10 inches can be safely handled. Each additional 5 ft of length requires an additional inch of width to be handled without damage (after Salgado 2008).

6-4.1.2 Drivability and Acceptance Criteria.

Drivability refers to the ability of a hammer and drive system to drive the pile efficiently without damaging the pile. Prior to construction, drivability can be assessed using wave equation analysis (Section 6-9.3). However, the installation of test piles prior to installation of production piles is the best way to confirm drivability. To be drivable, the pile must be sufficiently stiff to transmit driving forces necessary to overcome soil resistance and sufficiently strong to withstand the driving-induced stresses. Section 6-7.1 discusses structural limits on stress.

Two limiting conditions exist for pile driving. *Soft driving* conditions occur when driving through soft soil prior to reaching a competent bearing layer. In this case, it is possible to produce damaging tensile stresses in the pile, particularly in concrete piles which have relatively low tensile strength. *Hard driving* conditions occur when driving to refusal on rock or penetrating an obstruction. In hard driving, the hammer can produce damaging compressive stresses in the pile. See Section 6-9.2 for more details about how soft and hard driving conditions affect stresses developed in the pile during driving.

A key parameter to assess drivability is the pile's impedance, I, which is:

$$I = \frac{E \cdot A}{c} \tag{6-2}$$

where:
E = elastic modulus of the pile,
A = cross-sectional area of the pile, and
c = material wave speed.

Impedance is further explained in Section 6-9. Piles with higher impedance are able to transmit more force in the same way a heavy masonry nail can penetrate masonry better than a light finishing nail.

The energy delivered by the hammer and the impact velocity are both important factors for matching a hammer to a pile. Heavier hammers with a lower drop height, or stroke, impart energy to the pile with lower particle velocities induced in the pile. For the same energy, lower impact velocity produces lower driving stresses. Heavier hammers with lower impact velocity also have a longer impact time and tend to transmit energy to the pile with fewer losses. They are also more likely to remain in contact with the pile and overcome reflected compression waves that can cause counterproductive upward bouncing of the pile. However, heavier hammers are often harder to mobilize and require larger equipment. Sometimes, higher driving stresses are needed for the pile to penetrate a stiff layer or obstruction. In these cases, a hammer with a lighter ram and longer stroke is preferred provided that the hammer does not produce damaging driving stresses in the pile.

During driving, records are kept of the installed length and number of blows required to drive each pile, typically in terms of blow count or blows per foot. The blow count can be inverted to find the *set*, which is the amount of permanent penetration per blow. *Acceptance criteria* for pile driving generally refers to the point at which pile driving can be terminated. Common acceptance criteria include driving piles to a target blow count or set, driving piles to practical refusal, and/or driving piles to a specified tip elevation.

Practical refusal is often defined as 120 bpf or 10 blows per inch for three consecutive inches of penetration. *Absolute refusal* is often defined as 5 blows per 1/4 inch (240 bpf equivalent). It must be noted that the blow count is relevant only for the particular hammer and drive system used. Driving to a high blow count using a small hammer may only mobilize a portion of the pile resistance while a large hammer may fully mobilize the pile resistance at a modest blow count.

Target blow counts typically fall in the range of 30 to 120 bpf. Blow counts less than 24 bpf are considered soft driving, and the dynamic methods discussed in Section 6-9 can overpredict nominal resistance. The dynamic methods described in Section 6-9 can underpredict nominal resistance when blow counts exceed 120 bpf.

6-4.1.3 Noise and Vibration.

Pile driving is inherently noisy. Noise levels can range from 80 to 135 decibels. Pile driving noise can exceed noise ordinances and challenge relations with neighbors. Noise levels attenuate with distance, and noise suppression devices are available for some hammers. Driving steel piles tends to generate more noise (ringing) as compared to driving timber and concrete piles. Underwater noise generated by driving piles in water can be detrimental to marine life and bubble curtains are sometimes used to mitigate underwater noise.

Pile driving also induces vibration in soil and rock that can cause settlement. Vibrations can be transmitted to, and can potentially damage, nearby structures. The amplitude of vibration is quantified using the peak particle velocity. Local ordinances may include limits on ground vibration levels. Vibrations with peak particle velocities exceeding 0.5 in/sec can damage structures (Wiss 1981); however, settlement and other negative effects can begin to occur at lower intensities (Lacy and Gould 1985). Low intensity vibrations can also be a nuisance to neighbors or affect nearby operations, such as manufacturing. The frequency of vibrations also influences their impacts, but these effects are beyond the scope of this chapter.

The vibrations generated by pile driving depend on the soils and rock at the site, the pile type, the driving system, installation techniques, the penetration depth of the pile, and distance from the pile. While complete attenuation of vibrations may require many hundreds of feet, damaging vibrations are usually limited to a distance approximately equal to the pile penetration depth or 50 ft, whichever is greater (NCHRP 1997b). Figure 6-7 approximates the relationships between vibration and soil type, hammer energy rating, and distance from the pile. These charts do not capture the specific site response to vibrations, e.g., influences of stiff soil crusts, and should only be used in preliminary assessments of vibration impacts.

Condition surveys and vibration monitoring can reduce the likelihood of damage claims and other bad outcomes, particularly in urban areas. Condition surveys document the condition of nearby facilities before and after construction. Vibration monitoring measures the actual vibrations during pile driving.

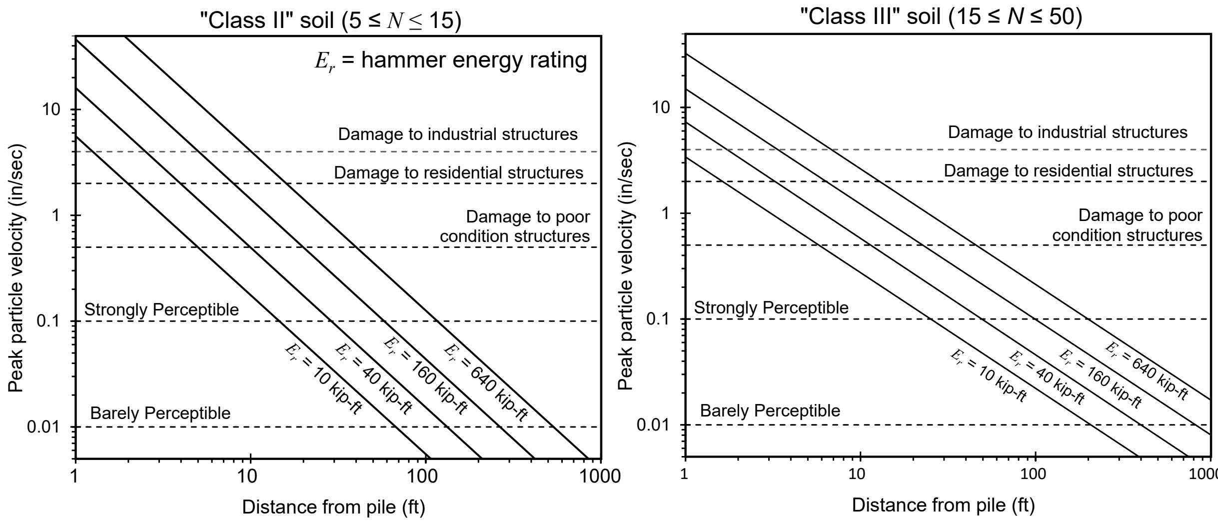


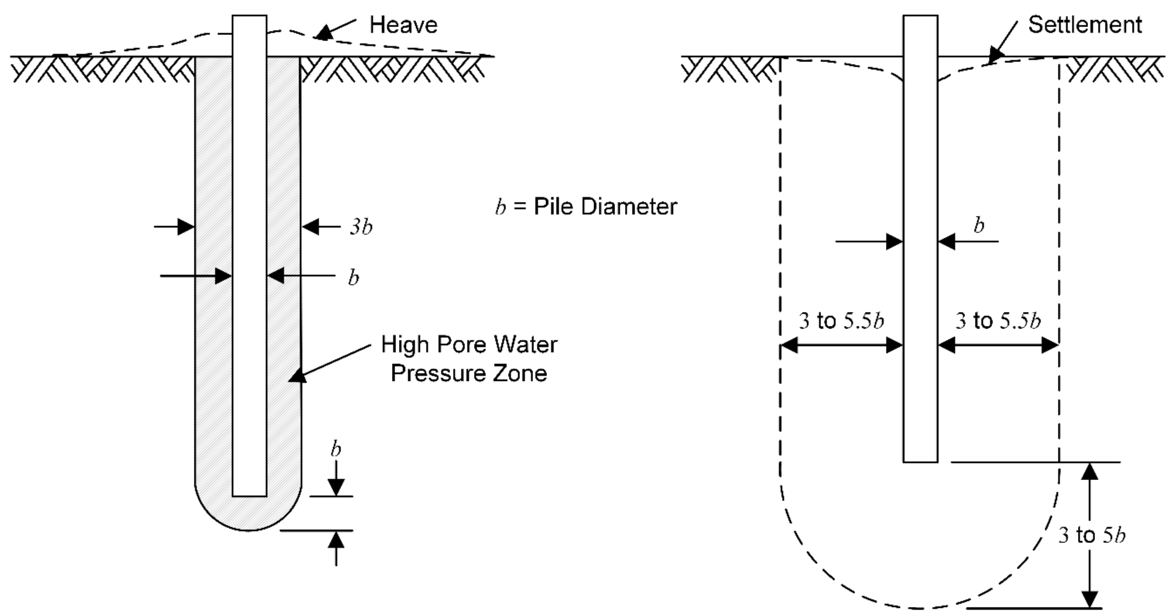
Figure 6-7 Estimated Vibration Level Due to Pile Driving (after Bay 2003)

6-4.1.4 Soil Disturbance and Driving-Induced Pore Pressures.

Pile driving remolds clay soils and can cause volumetric changes and temporary driving-induced pore pressures in all soils. Disturbance effects are more severe as the volume of displaced soil increases. Displacement piles produce greater disturbance than low displacement piles of the same size. The method of installation also influences the severity and spatial reach of disturbance. For example, disturbance can depend on the type of hammer, the use of driving aids, the number of piles, and the pile spacing. As shown in Figure 6-8a, disturbance of clay soils typically produces a zone of heave while disturbance of coarse-grained soils typically produces a zone of settlement (Figure 6-8b).

The initial void ratio of the soil and soil type also influences the impacts of disturbance. Initially, loose to medium dense coarse-grained soils are usually densified by pile driving while dense coarse-grained soils may dilate. Fine-grained soils usually consolidate radially in the vicinity of the pile. The reduction in the soil's volume often does not counter the addition of the pile's volume, particularly in the case of fine-grained soils. Depending on the vertical and lateral boundary conditions, net positive changes in volume can produce heave and/or lateral squeeze of the soil.

Disturbance can impact the soil's shear strength and development of excess pore water pressure. Depending on how quickly the excess pore pressures dissipate, disturbance that leads to densification and compression may generate temporary positive excess pore pressure while disturbance that leads to dilation may generate temporary negative pore pressure. Chapter 7 in DM 7.1 discusses the effects of excess pore pressure and void ratio changes on shear strength in the context of slope stability analysis.



c) Typical Volume and Pore Pressure Changes from Disturbance

Soil Tendency	Short-Term Effects	Long-Term Effects	Typically Occurs in:
Densification / compression	Pore pressure ↑ Undrained shear strength ↓ Pile capacity ↓	Void ratio ↓ Shear strength ↑ Pile capacity ↑	Saturated clay Loose to medium dense silts and fine sands
Dilation / expansion	Pore pressure ↓ Undrained shear strength ↑ Pile capacity ↑	Void ratio ↑ Shear strength ↓ Pile capacity ↓	Dense sands and silts, weak laminated rocks

Figure 6-8 Typical Effects of Disturbance During Driving of Piles (after Broms 1966)

Based on fundamental concepts of effective stress and shear strength, a reduction in void ratio by driving-induced densification will increase long-term shear strength. An increase in void ratio by driving-induced dilation will decrease long-term shear strength. Similarly, a decrease in effective stress from temporary driving-induced positive pore pressures will decrease strength. An increase in effective stress from temporary driving-induced negative pore pressures will temporarily increase shear strength.

While the effects of void ratio changes on shear strength are long lasting, the effects of temporary pore pressure changes on shear strength are temporary. The pile resistance during, and soon after, driving may be different than in the long-term. The term *setup* refers to the increase in pile resistance over time as driving-induced positive pore pressures dissipate. Setup frequently occurs for piles driven in saturated clay and in loose to medium dense silts or fine sands. The term *relaxation* refers to the reduction in pile resistance over time as negative driving-induced pore pressures dissipate. Relaxation can occur for piles driven in dense saturated fine sands, dense silts, and in weak laminated rocks, such as shale.

Setup and relaxation effects usually take a few days to fully manifest. However, effects can sometimes take several weeks. As such, load tests or pile restrikes should be scheduled accordingly to observe the nominal pile resistance without the effects of transient pore pressures.

6-4.1.5 Pile Splicing.

A key decision in pile design is the selection and ordering of piles that are long enough to provide acceptable performance, but not too long to be inefficient. However, sometimes it is not possible or practical to source and/or transport piles at the target length. In other cases, there may be economic advantages to driving shorter piles with smaller equipment and using splices to reach full length. In still other cases, piles can be unexpectedly too short.

Whether planned or unplanned, pile splicing can be used to achieve piles that have necessary length. Steel piles are the easiest to splice and are most often spliced by welding. Preparing the joint surfaces and welding consumes time and requires careful inspection, but when performed correctly, a spliced steel pile can perform as well as an unspliced pile of the same length. Splicing timber piles is difficult and rarely done.

Splicing concrete piles is more difficult and has traditionally been avoided whenever possible because it creates a discontinuity in the prestressed steel and can compromise the capacity and durability of the pile. Furthermore, installing concrete splices is often time consuming, requires specialized equipment and materials, and may be adversely affected by weather and temperature (e.g., epoxy curing). Common concrete splices can be categorized into those that join pile segments with 1) mechanical interlocking end pieces, wedges, or pins, 2) a steel sleeve that fits over the concrete pile segments, and 3) dowels that are secured with epoxy or cement grout. Not discussed here are other niche splicing systems that are usually variants of the three categories listed above. Some splicing options for concrete piles, particularly those with mechanical interlocking pieces, require casting special end pieces into the pile when it is manufactured; therefore, these options are not feasible for unplanned splices.

6-4.2 Drilled Shafts.

Drilled shafts are bored reinforced concrete columns having diameters that typically range from 2.5 to 8 ft and lengths up to 100 ft, though elements up to 12 ft in diameter and 200 ft in length are possible with special equipment. When practical, drilled shafts may be socketed in rock to provide high capacity with small associated settlement. Usually, the diameter of a rock socket is less than or equal to 5 ft, and the length is between 5 and 10 ft, though sockets having larger diameter and length are not uncommon. The diameter of drilled shafts is selected to provide suitable performance. However, shafts may be enlarged to facilitate construction, e.g., to remove rock fragments or match the diameter of the structural column. Compared to driven piles, drilled shafts generally produce fewer disturbance effects, less noise, less vibration and often carry more load per element.

6-4.2.1 Equipment and Methods.

Drilled shafts are constructed using either the dry method or the wet method (Figure 6-9). The *dry method* uses an open shaft without any drilling slurry. The dry method is suitable when the sides and bottom of the open shaft remain stable, and the inflow of water into the shaft is small. Conditions favorable to the dry method include stiff clay and/or rock. Permanent or temporary casing can be used to span problematic zones as discussed below. The dry method is simpler, less expensive, and faster than the wet method.

The *wet method* uses a slurry mixture of water and bentonite or polymer to maintain shaft stability. The wet method is needed when caving along the sides, or heave of the bottom, of an open shaft is possible and/or when the inflow of groundwater is significant and likely to adversely affect the uncured concrete. To provide a stabilizing effect and control water inflow, the head of the slurry inside the shaft is kept higher than the head outside of the shaft. The slurry typically has a viscosity and unit weight greater than water, e.g., bentonite slurry usually has a unit weight of 65 to 70 pcf. The bentonite or polymer additive prevents loss of fluid into the surrounding ground. Bentonite slurry creates a *filter cake* on the sides of the shaft as some of the bentonite is separated from outflowing water. The filter cake is an effective seal but can negatively affect the side resistance of the shaft. Polymer slurry does not create a filter cake. Slurry is usually circulated between the shaft and the holding tank using a pumping system. As the slurry is circulated during drilling it accumulates soil and rock particles that can settle out in the shaft during excavation and create an unsuitable loose layer or become entrapped in the concrete. To avoid these problems, the slurry must be kept clean, or de-sanded, using settling tanks or special de-sanding equipment. When drilling through wet, but otherwise stable ground, the shaft can be simply filled with water to prevent excessive inward seepage. Similar to the dry method, permanent or temporary casing can be used to span problematic zones. If casing can effectively span a problematic zone and control the inflow of water, it is possible to switch to the dry method of construction.

Permanent or temporary casing is frequently used to span soils prone to caving or squeezing, such as saturated sand and very soft soil. In some situations, casing is advanced below the depth of shaft excavation to create a seal in a more stable stratum. Temporary casing is usually pulled during concrete placement, making sure that the head of concrete is above the head of external water. Pulling temporary casing in very soft soils can be difficult. If casing is pulled too soon, the soft soil can intrude into the concrete. If pulled too late, the concrete sets and bonds to the casing. Permanent casing is often used when constructing drilled shafts in water for bridges or other structures, particularly when working from a barge instead of from within a cofferdam. Permanent casing may also be required to span voids created by karstic features or abandoned mines as well as when drilled shafts are socketed into sound rock and high capacity is desired.

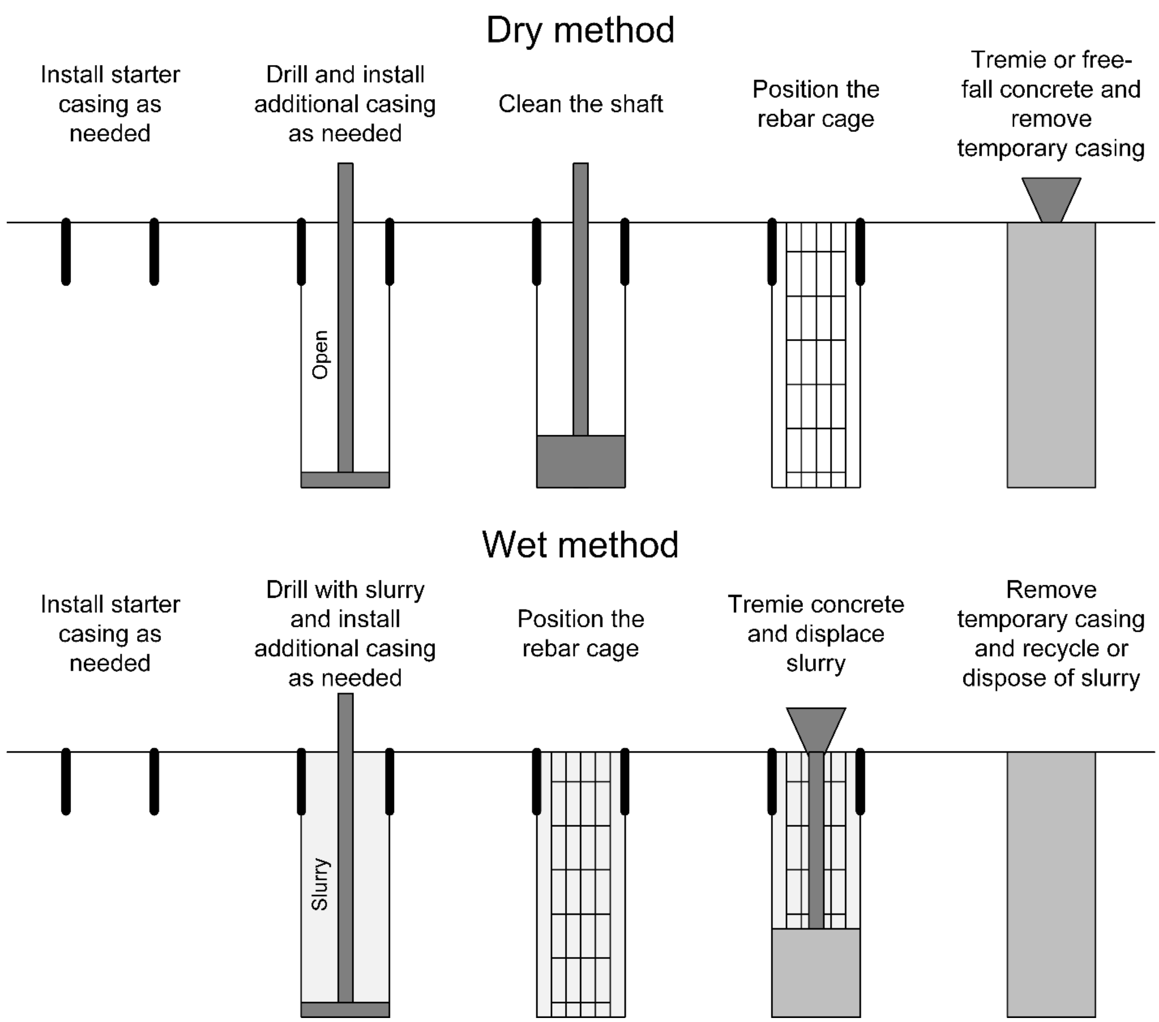


Figure 6-9 Dry and Wet Methods of Drilled Shaft Construction

Most drilled shafts are constructed using hydraulic rotary-drill rigs. The capability of the drill rig is often reported in terms of the maximum torque and downward force, or *crowd*, that can be applied. Drill rigs are usually mounted on a truck or tracked equipment, such as an excavator, crane, or crawler. Some drill rigs, known as top-drive rigs, are mounted directly to casing that is installed prior to drilling. Casing is installed using an impact or vibratory hammer while large diameter casing is sometimes advanced and extracted using oscillator and rotator systems. These machines apply oscillating or continuous torque and crowd to the casing. When this equipment is used, the soil inside the casing is often excavated using a top-drive rig or crane-hoisted buckets.

Rotary drilling tools include augers for soil and rock, drilling buckets for soil, and core barrels for rock. Special rotary tools include an underreamer, or *belling tool*, to enlarge the base of drilled shafts in clay and *muck buckets* for cleaning out the base of the shaft.

Non-rotary drilling tools are also used. Clamshell and grab buckets allow for soil excavation at the base of the shaft. Rock breaker, drop chisel, and impact tools break up rock into fragments that can be lifted by a clamshell or grab bucket. Common impact tools include down-hole hammers, which use one or more pneumatic impact bits, and hammer grabs, which combine the functionality of a rock breaker and clamshell bucket.

A variant of drill shafts, known as barrettes, are diaphragm walls constructed as reinforced deep foundation elements. Barrettes are constructed using non-rotary drilling tools, e.g., hydromill, and the same techniques are used to build diaphragm walls. Unlike conventional drill shafts, barrettes have a rectangular cross section. Barrettes can be constructed using dry or wet methods depending on the ground conditions.

6-4.2.2 Steel Reinforcement and Concrete.

The steel reinforcement used in drilled shafts consists of a fabricated rebar cage formed by concentrically arranged longitudinal bars with transverse reinforcement placed circumferentially around the arrangement of longitudinal bars, often as a hoop or spiral. The cage also includes any centering devices, lifting brackets, and tubing for post grouting and/or nondestructive testing, such as cross-hole sonic logging. The yield strength of the steel is typically between 60 and 100 ksi. The longitudinal reinforcement resists stresses from bending, tension, and compression while the transverse reinforcement resists internal shear and confines the concrete and longitudinal reinforcement. A minimum of six longitudinal bars that are at least No. 5 sized are required by AASHTO (2020). As a rule of thumb, the longitudinal rebar should occupy at least 0.5% of the overall cross-sectional area of the drilled shaft, and the spacing between parallel pieces of longitudinal and transverse rebar should be at least 5 inches or five times the maximum aggregate size in the concrete. Typically, the steel area ratio of longitudinal steel to gross area ranges from 1% to 2%, with 8% being the maximum allowed by AASHTO (2020). Percentages of steel exceeding 4% tend to impede concrete flow around the rebar cage. A minimum 3 inches of concrete cover is required for rebar according to AASHTO (2020). However, greater depths of cover are recommended for larger diameter shafts, e.g., 6 inches for shaft diameters greater than or equal to 5 ft (FHWA 2018a).

Concrete for drilled shafts must satisfy several basic requirements for strength, durability, stability, and workability, which are addressed by the concrete mix design. Concrete is most often placed down the center of the shaft using a free fall method, tremie pipe, or pumping after the rebar cage has been positioned. Free fall introduces concrete at the rising surface of the concrete, while placement by tremie pipe or pumping introduces concrete from the bottom of a pipe, which is positioned sufficiently below the rising surface of the concrete. Concrete mixes are formulated either for free fall or placement by tremie or pumping to target a 28-day strength of 3,000 to 5,000 psi. Higher strengths are targeted in special cases, such as to satisfy seismic design requirements. The cured concrete must be durable in the groundwater chemistry of the placed environment, which may contain salt and acids. During placement, the concrete must remain stable in terms of bleed, which is separation of water from the mix, and segregation, which is separation of the cement paste from the aggregates. The concrete used in drilled shafts must also be able to self-consolidate and flow through the rebar cage without the assistance of vibration. Therefore, concrete placed by free fall usually has a slump of 6 to 7 inches to provide workability, while avoiding segregation, while concrete placed by tremie or pumping usually has a slump of 7 to 9 inches. The concrete must retain workability often for several hours over the duration of placement and retrieval of the casing.

6-4.2.3 Post Grouting.

Post grouting is used to premobilize and improve the base resistance in drilled shafts using pressurized grout delivered after the concrete has been placed and allowed to gain sufficient strength (>2500 psi). The premobilizing effect is achieved by loading and compressing the soil below the base. This leads to smaller post-construction settlement needed to mobilize the base resistance under service conditions. The ground improving effect is achieved by reducing the void ratio of the soil below the base, permeating grout into the soil, and/or creating an enlarged grout bulb that effectively increases the base area.

Post grouting requires installing grout delivery tubing and a distribution device to the reinforcement cage prior to placing the cage in the shaft. The grout distribution device can be a flat jack design, where grout is pumped from tubing placed between a steel plate and rubber membrane. Alternatively, grout distribution can use a sleeve-port design, where grout is pumped through multiple U-shaped circuits that contain perforations which are sealed with rubber sleeves. Grout exits the delivery and distribution system when the internal grout pressure exceeds the confinement provided by the rubber sleeve/membrane and pressure from the earth and groundwater. The grout mix is usually a neat cement with a water-cement ratio of 0.4 to 0.55. As the grout is pumped, it applies an upward-acting force on the drilled shaft and a downward-acting force to the soil below the base. An approximately proportional rise in grout pressure with grout volume is desired as this signifies that the soil below the base is being loaded and compressed. Some upward movement of the shaft, e.g., ½ inch, during post grouting is expected. Significant deviations in the proportionality between grout volume and pressure often indicate a problem, such as a blockage in the grouting system, excessive shaft movement, or hydraulic fracturing of the soil. The achievable grout pressure typically ranges from 100 to 900 psi and is limited by the shaft resistance and weight, overburden pressure at the base, and capabilities of the pumping system.

Methods to incorporate the effects of post grouting into the design of drilled shaft include applying multipliers to the nominal resistance of an equivalent ungrouted shaft or using load transfer t-z methods. Since routine use of post grouting is still relatively recent, design methods that account for post grouting are still evolving. As such, load tests of grouted shafts are particularly valuable to observe the effects of post grouting.

6-4.3 Continuous-Flight Auger Piles.

Continuous-flight auger (CFA) piles, or auger cast-in-place piles, are similar to drilled shafts in that they are bored piles. However, there are a number of significant differences. First, the hole is drilled in one continuous operation and is always supported by augers, which eliminates need for slurry and/or casing. Second, grout or concrete is pumped under pressure through the augers as they are withdrawn. Third, steel reinforcement is pushed into the uncured grout or concrete pile after the augers are withdrawn. The reinforcement commonly extends through only the upper portion of the pile that is subjected to bending.

CFAs are installed with rotary drill rigs typically to depths up to 100 ft using augers that have a diameter ranging from 12 to 36 inches. With the proper equipment, CFAs can be constructed in low headroom conditions and at a batter angle. CFAs can be installed in soil and some weak/weathered rock but cannot be used in hard rock like drilled shafts. CFAs are also not recommended in geologic formations containing voids. A key to good construction quality is balancing the rotation and penetration rate of the augers so that the augers do not excessively rotate and mine soil from beyond the intended limits of the pile. During drilling, the excavated cuttings should ideally be limited to the volume occupied by the auger plus some accommodation for bulking of the disturbed material. This objective can be difficult to achieve in soft clays that tend to squeeze inward and loose clean sands and gravels prone to caving.

After drilling, grout or concrete is pumped at pressure that exceeds the overburden pressure at the bottom of the auger. As grout is pumped, the auger is withdrawn at a rate that compensates for the volume of grout delivered. As the augers are withdrawn, they are either not rotated or rotated slowly in the direction of drilling. These techniques are intended to preserve a seal for grout pumping, retrieve the soil between the auger flights, and prevent the augers from getting stuck in the hole.

The decision to use grout or concrete varies by location, e.g., the US favors grout while the EU favors concrete, and the needs for workability, stability, and durability. Grout tends to retain workability longer than concrete and is more fluid than concrete, which facilitates installation of the reinforcing steel. The mix designs for concrete and grout used in CFAs are similar to that of tremie concrete used for drilled shafts (see Section 6-4.2.2), except that the grout omits the coarse aggregate.

6-4.4 Drilled Displacement Piles.

Drilled displacement piles (DDPs) are similar to CFAs in that a continuous operation is used to drill on the downstroke and pump grout or concrete on the upstroke. Instead of the conventional continuous flight augers used by CFAs, DDPs use special augers that displace soil laterally during drilling. Many variants of the augers, e.g., DeWaal and Omega, can be used to drill DDPs, some of which are proprietary. The primary differences among the augers are the amount of displacement (full or partial), the ability to install reinforcement through a hollow stem prior to grouting, and the shaping of the sides of the hole, e.g., smooth or screw-shaped, as the auger is withdrawn during grouting. Some augers use a sacrificial tip that is left in the hole as the grout or concrete is placed when the auger is withdrawn. In some cases, a process known as amelioration, in which sand or gravel is added to the top of the drill hole, is performed to increase shaft resistance.

One advantage of DDPs over CFAs includes the possibility of greater lateral stress between the pile and the soil under certain ground conditions. The side resistances approach those of driven displacement piles. From the standpoint of constructability, DDPs require less finesse by the operator to balance the rate of rotation and the rate of penetration compared to CFAs. DDPs require greater torque to turn the soil-displacing bit, which is a disadvantage compared to CFAs. They also have greater potential for ground heave and/or lateral squeeze of soft soils due to the volume displaced by the pile.

6-4.5 Aggregate Columns.

Aggregate columns include rammed aggregate piers and stone columns (see Figure 1-2). Aggregate columns are not usually structurally-connected to the superstructure, but they often provide the function of a foundation and meet the definition of a deep foundation ($Z/b \geq 5$) adopted herein. Stone columns up to 100 ft in length can be formed using either vibro-replacement or vibro-displacement.

Vibro-replacement columns, a.k.a wet stone columns, are constructed using a down-hole vibrator and water jet to penetrate the ground. The hole is filled with stone dumped from the top of the hole. A key feature of vibro-replacement is the removal of a portion of the soil as the column is formed. A muddy effluent is created that requires containment, removal, and disposal.

Vibro-displacement columns, a.k.a. dry stone columns, are also constructed using a vibrator except without water jetting, and the soil is displaced by the vibrator rather than removed. Sometimes air jetting or predrilling are required for the dry method. Stone is introduced either from the top, similar to vibro-replacement, or from the bottom using a stone tremie tube attached to the side of the vibrator.

The equipment used to construct vibro-replacement and vibro-displacement stone columns is typically handled and operated using tracked equipment or occasionally a crane. The down-hole vibrators typically have a diameter of 12 to 16 inches and are either electrically or hydraulically powered. Special variants of the vibro-displacement method replace the down-hole vibrator with a vibratory pile hammer, and certain technologies introduce grout with the stone or substitute concrete for the stone.

Rammed aggregate piers are constructed by first drilling a hole with a diameter ranging from 18 to 36 inches and a depth typically ranging from 7 to 35 ft. The pier is formed by introducing lifts of stone into the hole, usually by dumping, and compacting each lift using the ramming action of a special tamper. In addition to compacting the stone, the ramming action of the tamper usually forces some of the stone beyond the drill diameter and below the base of the hole. Special variants of rammed aggregate piers can achieve depths greater than 40 ft. Tracked excavator equipment is most often used to install aggregate columns.

Aggregate piers are most suitable in soils that are not too soft or sensitive and not too stiff or dense. Soft or sensitive soils are prone to excessive volumes of aggregate being required, loss of strength due to the application vibration or ramming, and inward squeezing in the case of the drilled rammed aggregate piers. Stiff or dense soils may be difficult to penetrate with the vibrator. The drilling stage of rammed aggregate pier construction may require temporary casing in soils prone to caving or squeezing.

6-4.6 Micropiles.

Micropiles are bored with a small diameter (<12 inches) and grouted with foundation elements that can be installed in soil and rock to depths up to 200 ft. Greater depths can be achieved with special equipment. Micropiles are very adaptable to drilling in low headroom conditions, hard to access sites, challenging ground conditions, and in close proximity to existing facilities. Micropiles can also readily be installed at a batter angle. Figure 6-10 shows one example of a micropile construction sequence. However, there are many variations to the construction process particularly related to the drilling technique, casing, drilling fluid, grout delivery technique, and number of grouting phases.

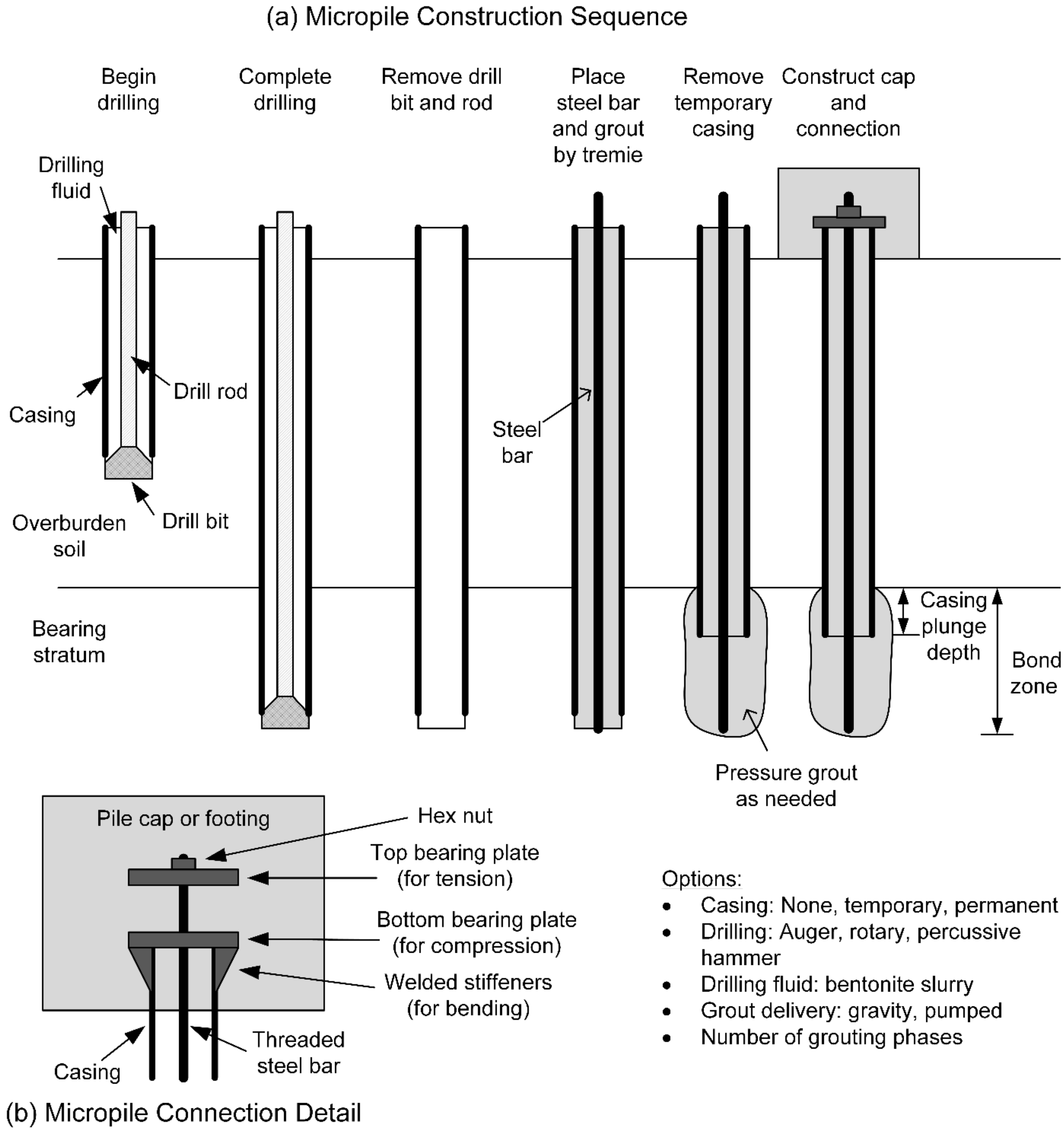


Figure 6-10 Micropiles – (a) Construction Sequence and (b) Connection Detail

Micropile drill rigs are usually mounted on trucks or tracked equipment. Drill rigs usually incorporate a hydraulic power unit to rotate the casing and/or drill rod in the same or opposite directions. Drilling tools are selected to be compatible with the ground conditions and include roller bits, casing with cutter teeth, rock bits, augers, and percussive hammers. Percussive tools, primarily used for rock drilling, may be powered by the rig's hydraulic power unit or a separate air compressor. Percussive force is applied using either a top-drive hammer or down-the-hole hammer. Sonic drilling advances the hole by vibrating the casing and drill rod. The drill hole is usually flushed by water or slurry to remove cuttings, stabilize the hole when casing is not used, and cool drill bits. Compressed air can also be used to flush the hole but should not be used below the groundwater table, especially in sands. Drilling fluids present the need to supply and circulate the fluid as well as manage spoils.

Micropiles are grouted to create a bond zone with the surrounding soil or rock. Bond zone lengths of 5 to 10 ft are common in rock while longer bond lengths are routinely used in soil. The diameter of the bond zone is influenced by the inside diameter of casing that is used, the use of an underreaming bit to enlarge the drill hole below the casing, and the method of grouting. The grout used for micropile construction is most often a neat cement prepared using a water cement ratio of about 0.40-0.50 by weight to achieve typical target compressive strengths of 4,000 to 5,000 psi. As defined by FHWA (2005), Type A micropiles are grouted under gravity only, while Type B micropiles are first gravity grouted and additional grout is added under pressure as the casing is withdrawn. Type C micropiles are first gravity grouted then post grouted under pressure prior to hardening of the initial grout. Type D micropiles are first gravity grouted and then post grouted under pressure one or more times after hardening of the initial grout. The post grouting for Type C and D micropiles does not occur concurrently with removal of casing. Generally, Type A micropiles are used when the bond zone is in stiff clay or rock while Type B, C, and D micropiles are used in soils.

Micropiles are typically reinforced by a steel pipe and/or a centralized steel rebar that carries at least 40% of the load in the element. The casing is often an 80 ksi steel oil field casing (API N-80)[30] with an outside diameter of 5.5, 7.0, or 9.625 inches and approximately a half-inch wall thickness. The rebar is often a large diameter thread bar, e.g., #18 or #20, made from 75 or 80 ksi steel.

Micropiles are commonly installed in groups and tied together within a pile cap. There are a variety of options available for establishing the connection between the micropile and the pile cap that depend on whether the pile cap (or footing) is new or existing and how heavily the pile is loaded in compression, tension, and bending. For example, the inset in Figure 6-10 shows a pile to cap connection for a pile subjected to significant loads in compression, tension, and bending. One or both of the bearing plates and stiffeners may be omitted if not needed.

[30]Typically mill secondary pipe is used because prime pipe is very expensive. Use of mill secondary pipe requires the implementation of coupon tests, typically two per truckload of pipe, because mill certifications are not available for this material.

6-4.7 Helical Piles.

Helical piles, or screw piles, consist of one or more circular steel bearing plates that are formed into a helix shape with a uniform pitch and welded to a central round or square steel shaft. The pitch of the helix is shaped so that the shaft advances the pitch distance in one revolution without excessive soil disturbance. When properly installed, helical piles are low-displacement elements. Typical helix diameters range from 6 to 36 inches, and completed helical piles lengths are mostly 10 to 30 ft; however, greater depths are routinely obtained using larger piles and equipment. Helical piles are usually installed in segments that are connected using bolted couplings. Since helical piles usually involve steel in direct contact with the ground, the components are galvanized to resist corrosion. Many specifications require a minimum embedment depth of five or more times the largest helix diameter between the ground surface and the upper-most helix. Generally, there are no more than 6 helices per pile. Helical piles are not suitable for ground conditions that may damage the shaft or helices, such as hard soils or soils with large gravel or cobbles. Specialty helical piles are grouted along the shaft to increase the strength and stiffness of the pile as well as increase resistance to buckling and corrosion.

Helical piles are installed using hydraulically-power rotary drills that are often small enough to be mounted on a light tracked loader/excavator or a truck. Helical piles are very adaptable to installation in low headroom conditions, hard to access sites, and in close proximity to existing facilities. Helical piles can readily be installed at a batter angle with proper equipment and can be used for resisting tension loads as well as compressive loads. The installation torque is an important parameter to evaluate capacity and is often measured in the field using a variety of qualitative or quantitative torque indicators. These methods include 1) observing the amount of twist in the shaft over some shaft length (qualitative), 2) using torque-limiting shear pins (quantitative at points of pin failure), 3) digital torque indicators (continuous quantitative readings using strain measurements), and 4) differential pressure torque indicators (continuous quantitative readings using the pressure drop through the hydraulic drill).

6-5 GEOTECHNICAL STATIC AXIAL CAPACITY AND SETTLEMENT.

6-5.1 Introduction.

This section presents selected analysis methods for evaluating static axial capacity and settlement of deep foundations. Section 6-8 describes static load testing, and Section 6-9 describes dynamic methods, which provide important refinements to the initial estimates of the anticipated performance of the deep foundations.

6-5.2 Limit States.

6-5.2.1 Strength Limit State.

Static capacity analyses are performed to estimate the nominal resistance (LRFD) or the ultimate capacity (ASD) of a foundation element subjected to compressive or uplift loading. The nominal resistance or ultimate capacity of a foundation element is evaluated by considering the geotechnical strength of the geomaterials and the structural strength of the material(s) that comprise the foundation element. The strength limit state is defined by the extent to which the nominal resistance may be mobilized under the expected conditions over the service life of the foundation. In the LRFD framework, the nominal resistance is reduced by application of resistance factors. In the ASD framework, an allowable (working) value is determined using a factor of safety. In some cases, different factors are applied to the resistances provided by shaft and base. For example, drilled shafts require greater vertical deformation to mobilize base resistance and have greater uncertainty associated with bearing capacity predictions. Thus, the base resistance is assigned a lower resistance factor.

Often, the criteria defining nominal resistance used to develop static capacity analysis methods are not well documented (Fellenius 2021). While this shortcoming may not be significant in routine design, it is worth referring to original sources, particularly on projects with small allowances for settlement. As discussed in Section 6-8, methods such as the Davisson (1972) failure criterion can be applied to interpret load test results to define nominal resistance in a consistent way.

AASHTO (2020) also defines the Extreme Event Limit State, which is a special case of the strength limit state in which survivability rather than satisfactory performance is the intent of the design checks. Examples of extreme events include loads from collisions, blasts, and earthquakes as well as the impacts of scour from severe flooding and liquefaction. Generally, not all extreme event scenarios are assumed to occur simultaneously in design. Consideration of extreme events is outside the scope of this manual.

6-5.2.2 Service Limit State.

The service limit state is defined by the acceptable limits on deformation, e.g., settlement and lateral deflection, over the service life of the foundation. Section 6-5.8 describes some typical limits for settlement and Section 6-6.2 for lateral deflection.

6-5.3 Load Transfer.

The nominal axial resistance in a deep foundation element, R, is developed from shaft resistance, R_s, and/or base resistance, R_b. The contribution of each source of resistance depends upon the mobilization of shear strength at the soil-shaft or rock-shaft interface and the soil or rock at the base. The peak and post-peak strength is influenced by the usual compositional and environmental factors that govern soil behavior with respect to strength. Of particular note is the differential shear movement between the soil and shaft as well as the movement of the base required to mobilize shaft and base resistances. Normally, full mobilization of shaft resistance occurs within a ½ inch of column top settlement (FHWA 2018a); however, mobilization of the base typically requires larger column settlements. Full base mobilization in fine-grained soils may require column settlement of about 4% to 5% of the base, width, or diameter while settlements of about 10% of the base, width, or diameter may be required for columns in coarse-grained soils (FHWA 2018a). Full mobilization of shaft and base resistance usually do not occur simultaneously. For large elements, such as drilled shafts, the settlements required to fully mobilize the base may exceed the service limit state criteria. Post-grouting of drilled shafts, described in Section 6-4.2.3, can be implemented to reduce the settlement needed to mobilize the base resistance. A useful rule of thumb to evaluate the nominal base resistance of drilled shafts without post grouting that considers the displacement required for mobilization of resistance at working loads is to reduce the nominal base resistance by 80%, i.e., use a nominal base resistance equal to 20% of the full value as evaluated by static capacity analysis or load testing (Gregory 2023).[31] Application of this rule of thumb still requires that a factor of safety or LRFD resistance factor be applied to the reduced nominal base resistance. This rule was developed for shafts bearing in sedimentary rock and hard clays, but is considered to be generally applicable to shafts bearing on rock as well as competent clays, sands, and gravels.

Figure 6-11 illustrates the basic concepts of load transfer. Inset (a) shows the case of an end bearing pile where the soil along the shaft is too weak to consider in design, or the bearing stratum is so stiff that the expected displacements are insufficient to mobilize shaft resistance. Inset (b) shows a case that could represent a friction pile in uniform clay that provides uniform unit shaft resistance in the short term with a small contribution of base resistance, i.e., the ratio of R_b/R is small. Inset (c) shows a case that could represent a pile in uniform, coarse-grained soil that provides unit shaft resistance that is proportional to the effective vertical stress and a large contribution of base resistance, i.e., the ratio of R_b/R is large.

Figure 6-11 also shows two hypothetical relationships between axial load applied to the top of the pile and the resulting settlement. When R_b/R is small, the resistance is primarily from the shaft, which mobilizes at small displacements. The condition of plunge is associated with a significant increase in the rate of settlement with respect to additional loading. This results in a large increase in the slope of the curve when load is

---

[31] Personal communication. Gregory developed this rule based on extensive design experience, field testing, and synthesis of the guidance provided by Wyllie (1999) and the findings of Rowe and Armitage (1987a,b).

applied to a pile where shaft resistance is already fully mobilized. When R_b/R is large, the resistance is primarily from the base, which mobilizes at larger displacements. While the rate of settlement with respect to additional loading may increase as the full mobilization of base resistance approaches, plunge usually does not occur if the bearing stratum is coarse-grained soil, stiff clay, or rock. Therefore, as mentioned in Section 6-5.4, the interpretation of the nominal resistance is not always straightforward. In particular, the nominal base resistance is usually estimated by analytical methods developed from load test data where failure requires interpretation by the Davisson or other failure criterion.

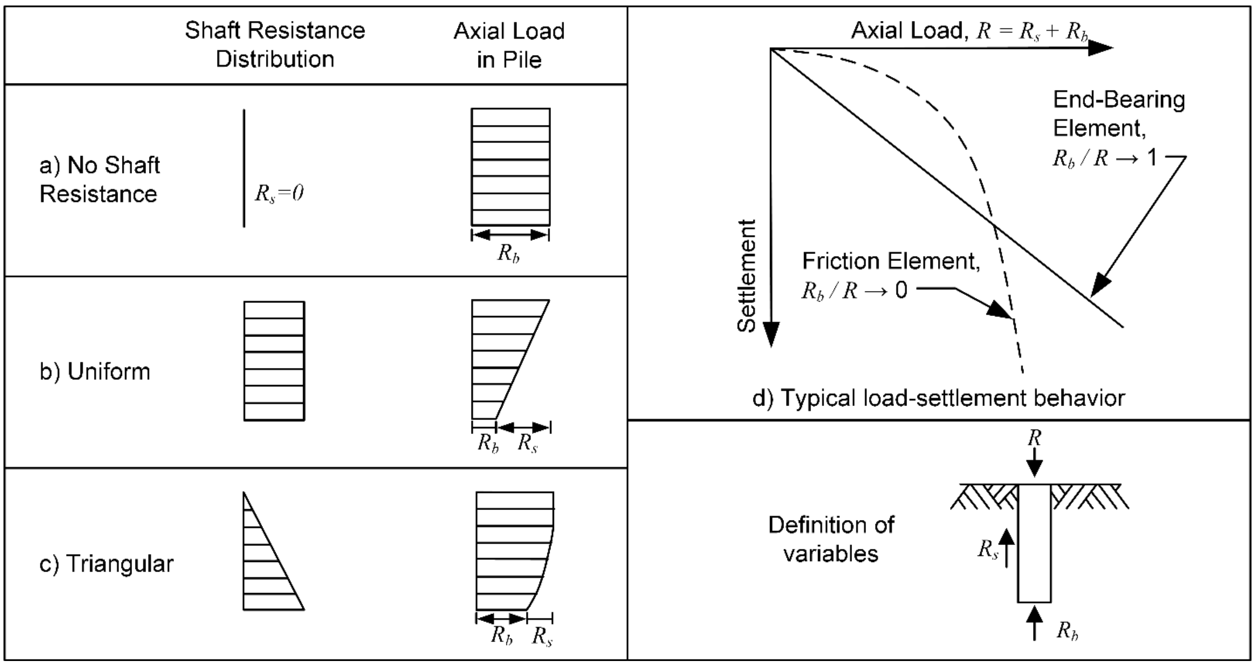


Figure 6-11 Load Transfer Concepts

It is also important to consider that the direction of the displacement of the foundation relative to the soil or rock determines whether load is transferred to or from the element to the soil or rock. Base resistance requires that the foundation element moves downward relative to the bearing stratum. Shaft resistance, i.e., load transferred from the element to the bearing stratum, in compression requires that the foundation element moves downward relative to the surrounding material. Mobilization of uplift resistance along the element shaft requires upward movement of the element relative to the surrounding material (see Section 6-5.6). Relative upward movement of the base does not contribute to uplift resistance by mobilizing shear strength. However, short term resistance can be generated by a suction effect if the rate at which the element moves produces negative excess pore water pressures by exceeding the rate of drainage (Bowles 1996). This suction effect is transient and should not be relied upon in design unless the element is specifically designed to utilize it, as with suction caissons used in offshore applications. A condition known as *negative skin friction*, where load is transferred from the soil to the element, occurs when the soil moves down relative to the element, for example, from consolidation, secondary compression, or vibration-induced densification. Negative skin friction is discussed in Section 6-5.7.

The nominal resistance, R, is the sum of the nominal shaft resistance, R_s, and base resistance, R_b:

$$R = R_s + R_b \quad (6\text{-}3).$$

The nominal shaft resistance is computed by multiplying the unit shaft resistance by the surface area. For heterogenous ground conditions, the shaft can be discretized into multiple segments (i) in which each can be represented by a constant unit shaft resistance and the nominal shaft resistance is:

$$R_s = \sum\left(f_{s,i} A_{s,i}\right) \quad (6\text{-}4)$$

where:
$f_{s,i}$ = unit shaft resistance for segment i and
$A_{s,i}$ = surface area for segment i.

Figure 6-12(a) shows important dimensions for deep foundation elements in sand and clay profiles. In cases where the base of the element is enlarged, it is important to distinguish the diameter used to evaluate the surface area of the shaft, B', versus the diameter used to evaluate the area of the base, B. Figure 6-12 also shows that it is common practice to exclude the upper 5 ft of side resistance, or to the depth of seasonal moisture change or frost depth. This exclusion accounts for the potential for softening and/or gapping of the ground leading to a loss or unexpected reduction of shaft resistance (FHWA 2018a). The potential of softening and/or gaps developing from low confining stress and/or volumetric changes in the soil due to changes in temperature or moisture should be evaluated based on local experience and engineering judgment.

The nominal base resistance is computed by multiplying the unit base resistance, q_b, by the appropriate surface area of the base, A_b, as:

$$R_b = q_b A_b \quad (6\text{-}5).$$

For formed-in-place columns and driven high-displacement piles, the appropriate base area is the full cross-sectional area as illustrated in Figure 6-12(b). For driven low-displacement piles, the appropriate base area is the area of the pile material. In some situations where a soil plug forms, the decision of how to calculate base area may not be obvious.

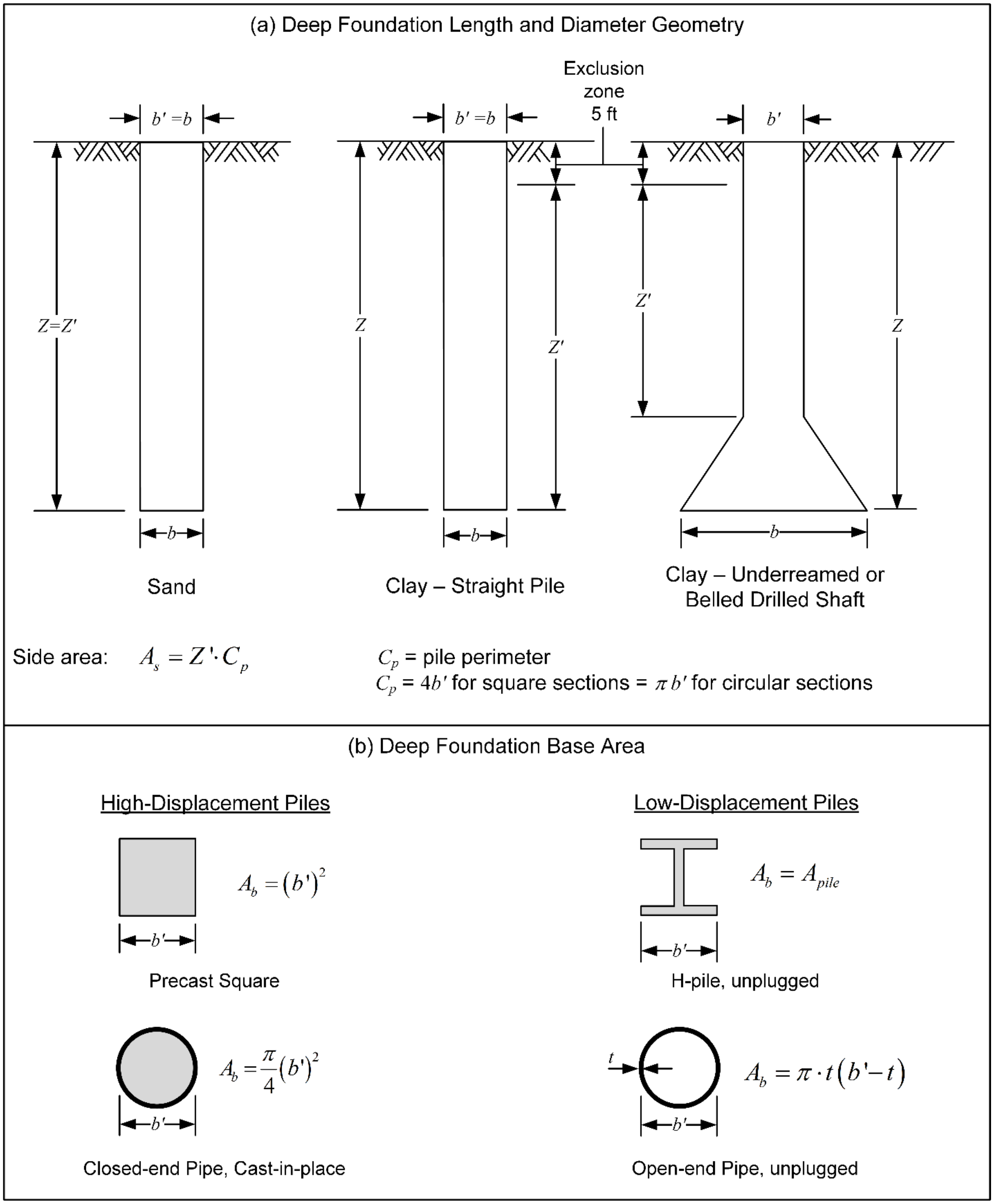


Figure 6-12 Geometry for SCA of Deep Foundations – (a) Length and Diameter and (b) Base Area

The factoring of the nominal shaft and base resistances to reduced (LRFD) or allowable values (ASD) of shaft resistance and base resistance is often dictated by agency practices or code requirements but may be additionally influenced by:

- Consideration of uncertainty in material properties,
  - Variable deposits
  - Weak soils such as soft clay and organics
- Events that have the potential to occur during the service life of the foundation,
  - Scour
  - Seasonal shrink/swell
  - Volume change from temperature changes
  - Volume change from geothermal energy foundations
  - Formation of voids in karst
  - Vibration from natural or manmade sources
  - Liquefaction
  - Impacts of future construction, excavation, or loading
- Costs of a more conservative design, and
- Consequences of unsatisfactory performance.

In some cases, the consequences of uncertain conditions and/or events can be modeled by analytical or numerical analysis, or observed by testing during construction using load testing. However, the actual consequences cannot be precisely known. Therefore, the tools of foundation design have embedded conservatism that, along with engineering judgement, are intended to produce reliable designs. Designers can take efforts to reduce uncertainty through a more robust geotechnical exploration and testing program, performance testing foundation elements via load tests, and working with the entire design team to better estimate the loads applied to the foundation that are expected under normal conditions and possible for abnormal conditions.

6-5.3.1 Limits on Unit Resistances.

Static capacity analysis methods that are at least partially based on empirical observations from load tests may include limits on unit base and shaft resistances. These limits prevent extrapolation of relationships between unit capacity and the input(s) beyond those originally observed by the developers. Such limits may be revised based on site-specific information and engineering judgment.

For coarse-grained soils, some design guidance defines a *critical depth* (USACE 1991) beyond which the unit shaft and base resistances of foundations no longer increase with additional penetration. Other guidance caps the maximum unit resistance based on soil type and relative density (API 2011). The concepts of critical depth and maximum unit resistance are disputed (Fellenius 2021). USACE (1991) recommends limiting unit shaft and base resistances to the value at a depth of $10 \cdot b$ for loose sands and $20 \cdot b$ for dense sands. API (2011) recommends limiting unit shaft and base resistances as the relative density of the soil decreases and/or the silt content increases. For medium dense sand-silt soils, nominal shaft resistance is limited to 1.4 ksf, and nominal base resistance is limited to 60 ksf. For very dense sand soils, nominal shaft resistance is limited to 2.4 ksf, and nominal base resistance is limited to 250 ksf (API 2011).

6-5.4 Static Axial Capacity in Compression for Single Elements.

As stated in Section 6-5.2.1, the factored axial resistance of a deep foundation element is determined by the lesser of the factored structural resistance and the factored resistance provided by the soil and/or rock, which is often referred to as the factored geotechnical resistance. Usually, the geotechnical resistance controls design. Common methods used in practice to evaluate the geotechnical resistance are:

1) Static Capacity Analysis (SCA),
2) Numerical analysis,
3) Dynamic methods, e.g., Wave Equation (WE), dynamic measurements, signal matching, and
4) Trial installation and load testing, e.g., test piles.

As described in Section 6-2.1, the normal process of deep foundation design follows a path of making initial estimates of performance using simple analytical models that are iteratively refined using more sophisticated analyses. In many cases, test pile programs are used to calibrate the analytical models. Load testing and dynamic methods, such as signal matching, are often used to update the design, which is an application of the observational method that is the hallmark of sound decision making in geotechnical engineering.

The Static Capacity Analysis (SCA) methods presented herein should be viewed as a step toward a complete foundation design. In addition to providing an estimate of capacity with relatively little effort and no specialty equipment or software, these simple methods provide a rational means to provide inputs for more sophisticated analyses to estimate capacity and/or assess driveability. In general, the predictive accuracy of SCA methods is low (Jardine et al 2001), and it is usually not clear what criteria was used to define the nominal axial capacity (Fellenius 2021).

While there are many SCA methods for driven piles and formed-in-place columns, only the Beta method for effective stress analysis of capacity and the Alpha method for total stress analysis of capacity are presented here. These methods were selected because there is widespread familiarity with these methods in US practice. In addition, there are versions for both driven pile and formed-in-place columns, and the methods are easy to implement. For continuity with historical tradition, the Beta method is categorized as being applicable to coarse-grained soils while the Alpha method is categorized as being applicable to fine-grained soils. In addition to coarse-grained soils, the Beta method is applicable to any soil in a drained condition, e.g., long-term analysis of capacity in clay soils. The Alpha method is targeted at clay soils and some silts that are routinely represented by the undrained condition in the short term. The Beta and Alpha methods are semi-empirical, meaning that they have been calibrated to load test results. For this reason, the guidance presented herein does not encompass all possible ground conditions.

Drilled displacement piles have not yet reached a state of maturity where specific versions of the Beta and Alpha method are available; however, guidance using results from the SPT and CPT are presented in Section 6-5.4.4. According to Coduto et al. (2016), full-displacement DDPs will have shaft resistance that is at least as high as driven piles and base resistance that is on par with CFAs. Therefore, guidance for estimating the shaft resistance of concrete driven piles and the base resistance of CFAs can be used for full-displacement DDPs. For partial-displacement DDPs that generate some spoils, the shaft resistance is between full-displacement DDPs and CFAs (Coduto et al. 2016).

The design methods for aggregate columns and helical piles are significantly different from driven piles and drilled columns. Design guidance for aggregate columns can be found in FHWA (2017), and guidance for helical piles is provided in Perko (2009).

When using an LRFD framework, AASHTO (2020) recommends the resistance factors provided in Table 6-11. Note that resistance factors have not yet been calibrated by AASHTO for certain analysis methods, e.g., Beta Method for driven piles and deep foundation technologies other than driven piles, drilled shafts, and micropiles. For the extreme limit state, a resistance factor equal to 1.0 can be used for compressive axial loading.

Table 6-11 Recommended Strength Limit State Resistance Factors for Axial Compressive Resistance Evaluated by SCA (AASHTO 2020)

Foundation Technology	Recommended Resistance Factor for Axial Compressive Loading[A]
Driven Piles	0.30 – coarse-grained (cohesionless) soil, Meyerhof SPT method, side and base 0.35 – saturated, undrained (cohesive) soil, Alpha method, side and base
Drilled shafts	0.55 – coarse-grained (cohesionless) soil, Beta method, side 0.50 – coarse-grained (cohesionless) soil, Reese and O’Neill (1989) guidance in Table 6-20, base 0.45 – saturated, undrained (cohesive) soil, Alpha method, side 0.40 – saturated, undrained (cohesive) soil, Equation 6-27, base 0.50 – rock, Equation 6-35, side 0.50 – rock, Equation 6-36, base
Micropiles	0.55 – side resistance using presumptive values 0.50 – rock, Equation 6-36, base

[A] AASHTO (2020) states that resistance factors should be reduced by 20% for single drilled shafts, small pile groups (<5 piles) to account for lack of redundancy, and micropiles in marginal ground conditions.

Table 6-12 provides recommended minimum factors of safety for loading in compression when allowable stress design is used.

Table 6-12 Recommended Minimum Factors of Safety for Compressive Loading

Foundation Technology	Guidance Source	Recommended Minimum Factor of Safety
Driven Piles	USACE (1991)[A]	2.0 – with load tests 2.5 – with dynamic testing 3.0 – other
	UFC (2022)[B]	2.0 – with load tests 2.25 – with dynamic testing and signal matching 3.0 – piles anchored in rock
Drilled shafts	UFC (2022)[B]	2.5 to 4 – drilled shafts anchored in rock
	Coduto et al. (2016)[C]	2.5 – with load tests 3.5 – other
Micropiles	FHWA (2005)[D]	2.0 – with load tests

[A] Values are for "usual" loading; for unusual loading, such as floods, factors of safety may be decreased by factor of 0.75; for extreme loading, such as rare natural disasters, factors of safety may be decreased by factor of 0.57.
[B] Use FS > 3 to limit total and differential settlements to small values. Generally, use FS ≥ 2.5. FS for drilled shafts depends on uncertainties in loading, stratification, and verification testing.
[C] Without load testing, the FS may be reduced by 0.5 for each of the following: uniform ground conditions and extensive site characterization (reduction of 1.0 possible). With load testing, the FS may be reduced by 0.5 for uniform ground conditions and extensive site characterization with an additional reduction of 0.3 possible if the load testing program is very extensive in uniform ground conditions with extensive site characterization.
[D] Load tests should be performed before and during production pile installation, i.e., verification and proof testing. FS should be increased to 2.5 in marginal ground conditions.

6-5.4.1 Shaft Resistance in Drained Conditions – Beta Method.

The Beta method, sometimes referred to as the effective stress method, can be applied to estimate the axial capacity of deep foundations in coarse-grained soils in the short and long term as well as fine-grained soils in long-term, drained conditions. Variants of the Beta method are presented for driven piles (USACE 1991, Fellenius 2021), drilled shafts (Chen and Kulhawy 2002, FHWA 2018a), and other drilled columns (FHWA 2007, Coduto et al. 2016). Other effective stress methods, such as the Nordlund method (Nordlund 1963, 1979), can be adapted to the format of the Beta method.

The Beta method uses the coefficient, β, to relate the effective vertical stress to the unit shaft resistance. The β coefficient is found as:

$$\beta = K \tan\left(\delta\right) \tag{6-6}$$

where:
K = earth pressure coefficient and
δ = interface friction angle between the pile and the soil.

The representative unit shaft resistance (f_s) is evaluated over the shaft or each segment of the shaft by:

$$f_s = \beta \sigma'_z \tag{6-7}$$

where:
σ'_z = average effective vertical stress over the shaft or shaft segment.

The process to find K and δ to determine β consists of evaluating 1) the at-rest earth pressure coefficient according to Jaky (1944) without adjustment for overconsolidation, based on conditions before construction, 2) the ratio of the earth pressure coefficient for the column-soil interface to the at-rest earth pressure coefficient, K/K_0, 3) the effective internal friction angle, and 4) the ratio of the interface friction angle to the internal friction angle, δ/ϕ'. Table 6-13 provides guidance for evaluating K/K_0, and Table 6-14 provides guidance for evaluating δ/ϕ'. The value of ϕ' used in the analysis can be determined from laboratory testing or using empirical correlations, such as those found in Chapter 8 of DM 7.1.

Table 6-13 Ratio of Shaft Friction Earth Pressure Coefficient to At-Rest Earth Pressure Coefficient

Source	K/K_0 [A]	Applicability
Salgado (2008)	See Figure 6-13 (dashed lines)	Nondisplacement columns – drilled shafts[B]
	See Figure 6-13 (solid lines)	Displacement columns – driven concrete piles, closed-end pipe piles, H-piles, and open pipe piles that are plugged[B]
FHWA (2018a)	$OCR^{\sin(\phi')}$	Drilled shafts[C]
Coduto et al. (2016)	0.50 to 0.70	Driven pile installed by jetting
	Similar to driven displacement pile	DDPs

[A] This guidance assumes that $K_0 = 1 - \sin(\phi')$
[B] For partial displacement columns (e.g., CFAs, H-piles, and unplugged open pipe piles), apply judgment to interpolate between the solid and dashed lines in Figure 6-13.
[C] OCR can be found from lab or field tests or estimated using empirical correlations, e.g., with N_{60}. The shaft friction within 7.5 ft of the ground surface should be evaluated using β determined at a depth of 7.5 ft.

Table 6-14 Interface Friction Angle Ratios for Evaluating Shaft Friction

Source	δ / ϕ'	Applicability
Salgado (2008)	0.95	Concrete driven piles
	0.85	Steel driven piles
	1.00	Concrete formed-in-place columns, e.g., drilled shafts CFAs
USACE (1991)	0.90 to 1.00	Concrete driven piles
	0.67 to 0.83	Steel driven piles
	0.80 to 1.00	Timber driven piles
Chen and Kulhawy (2002)	1.00	Drilled shafts
Coduto et al. (2016)	1.00	DDPs

The lateral earth pressure coefficient is influenced by a number of factors related to installation, such as soil displacement and disturbance from predrilling or jetting. Unless explicitly stated, the guidance provided herein does not apply to piles that are jetted, predrilled, or vibrated into place. When a pile is tapered, the perimeter changes along its length. The perimeter change can be handled directly (Nordlund 1963, 1979) or using a series of equivalent uniform segments, each having a different diameter (Fellenius 2021). Unless pile taper is handled directly (Nordlund 1963, Nordlund 1979), the value of K used should not exceed the Rankine passive earth pressure coefficient.

As an alternative to finding K and δ, the coefficient β can be evaluated directly using the empirical guidance provided in Table 6-15 or back calculated from load test results.

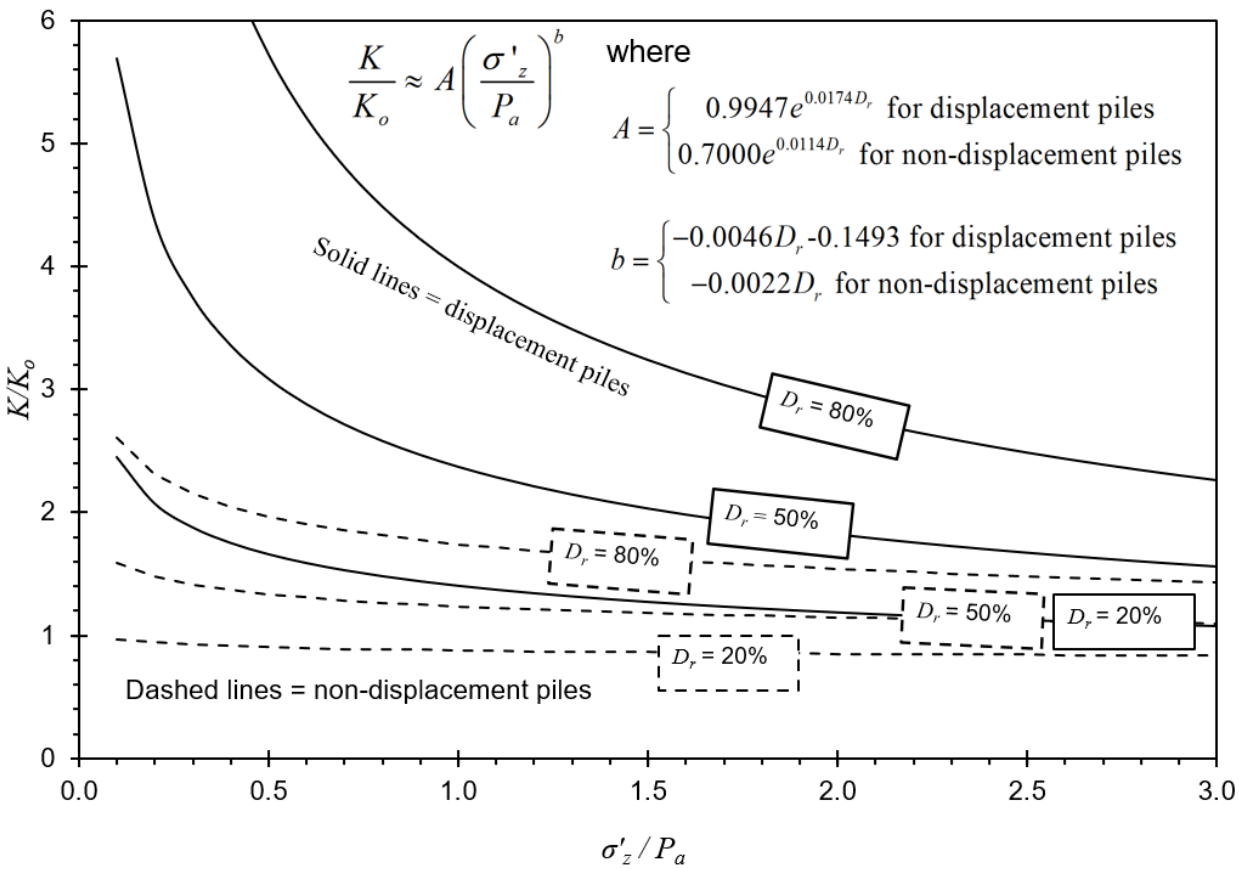


Figure 6-13 Ratio of K/K_0 for Non-Displacement and Full-Displacement Columns (after Salgado 2008)

Table 6-15 Guidance for Estimating β

Source	β	Applicability
Fellenius (2021)	$\beta = 0.15$ for $\phi' = 25°$ $\beta = 0.35$ for $\phi' = 30°$	Driven piles in clay[A]
	$\beta = 0.25$ for $\phi' = 28°$ $\beta = 0.50$ for $\phi' = 34°$	Driven piles in silt[A]
	$\beta = 0.30$ for $\phi' = 32°$ $\beta = 0.90$ for $\phi' = 40°$	Driven piles in sand[A]
	$\beta = 0.35$ for $\phi' = 35°$ $\beta = 0.80$ for $\phi' = 45°$	Driven piles in gravel[A]
FHWA (2007,1999)	$\beta = 1.5 - 0.135 \cdot z^{0.5}$	Drilled shafts[B,C,D], CFAs[C,D]
Rollins et al. (2005)	$\beta = 2.0 - 0.062 \cdot z^{0.75}$	Drilled shafts in gravelly sand[C,E]
	$\beta = 3.4e^{-0.26 \cdot z}$	Drilled shafts in gravel[C,F]
Coleman and Arcement (2002)	$\beta = 5.03 \cdot z^{-0.67}$	CFAs in silts[C,G]
	$\beta = 50.2 \cdot z^{-1.3}$	CFAs in sands[C,G]
Zelada and Stephenson (2000)	$\beta = 1.2 - 0.108 \cdot z^{0.5}$	CFAs in clean sand[C,H]

[A] Guidance based on piles in inorganic alluvium
[B] This version of the Beta Method for drilled shafts has been replaced by the version in FHWA (2018a).
[C] z is the depth in feet below the ground surface to the center of the shaft or subdivided shaft segment.
[D] β limited to $0.25 \leq \beta \leq 1.2$; for soils having an N_{60} value less than 15 bpf, scale β by $N/15$.
[E] β limited to $0.25 \leq \beta \leq 1.8$
[F] β limited to $0.25 \leq \beta \leq 3.0$; e is the base of the natural logarithm = 2.718.
[G] β limited to $0.20 \leq \beta \leq 2.5$
[H] β limited to $0.20 \leq \beta \leq 0.96$

6-5.4.2 Shaft Resistance for Saturated, Undrained Soils – Alpha Method.

The Alpha method is based on an undrained characterization of shear strength and is named for the adhesion factor, α. The unit shaft resistance is also referred to as the adhesion, C_α, between the column surface and the soil. Analogous to the interface friction angle, the adhesion is related to the undrained strength by:

$$f_s = C_a = \alpha S_u \qquad (6\text{-}8)$$

where:
f_s = unit shaft resistance and
s_u = undrained shear strength.

Many authors have presented versions of the Alpha Method for driven piles (Tomlinson 1994, API 1993, Randolph and Murphy 1985, FHWA 2016[32]) and for bored columns (Chen et al. 2011, Salgado 2008). In all forms of the Alpha Method, the values of α are based on empirical observations from load tests that capture installation effects and the properties of the soil-column interface. Depending on the version used, estimates of α may be sensitive to the magnitude of undrained strength, overconsolidation, normalized embedment (Z/b), pile material, installation method, and penetration of overlying soil layers. In general, disturbance of stiff clays by installation lowers adhesion and this effect becomes more pronounced as the undrained strength of the soil increases, meaning that α decreases as s_u increases. The value of α should be limited to values between zero and 1.0.

The effects of embedment length on α are more complex and are addressed in different ways, or ignored altogether, in different versions of the Alpha Method. For example, Tomlinson (1994) recommends reducing α due to the formation of a gap between the shaft and stiff clay near the ground surface. This effect has a more pronounced consequence for shorter piles and discretized pile segments near the ground surface, and thus, the value of α is reduced more at lower ratios of normalized embedment (Z/b). Normalized embedment is defined here as the distance from the ground surface to the bottom of the clay layer, sublayer, or pile, whichever comes first, divided by the pile width or diameter. Doherty and Gavin (2011) describe several versions of the Alpha method that reduce α at greater normalized depths to account for progressive mobilization of shear resistance along the pile length. The length effects described by Tomlinson (1994) are presented here; however, engineering judgment should be exercised for how to consider length effects.

FHWA (2016) provides separate relationships between undrained strength and adhesion for smooth and rough-textured piles, where rough piles exhibit higher adhesion at the same undrained strength. While Tomlinson (1957) observed some influence of pile texture on adhesion, Tomlinson later concluded using additional load test data that pile texture has no discernable effect (Tomlinson, 1970).

The evaluation of unit shaft resistance for driven piles in clay depends in part on the consistency of the clay as described by Tomlinson (1994) and presented in Table 6-16. For piles driven into soft clay, dissipation of driving-induced pore pressures and accompanying consolidation results in adhesion that is at least as high as the undisturbed undrained strength (Tomlinson 1994), corresponding to a value of α equal to 1.0. However, in some situations where the shaft resistance provided by the soft clay

---

[32] The Alpha Method credited to “Tomlinson (1979)” in FHWA manuals first appeared in FHWA (1982) and is based on published guidance by Tomlinson. To the authors’ knowledge, the source “Tomlinson (1979)” does not exist.

is trivial and/or unreliable, the designer may opt to ignore the soft clay's contribution, corresponding to a value of f_s equal to zero.

Table 6-16 Influence of Clay Consistency on α for Driven Piles (Tomlinson 1994)

Clay Consistency	s_u Range (psf)	s_u/P_a Range	Determination of α and f_s
Soft	< 800	<0.38	$\alpha = 1 \rightarrow f_s = s_u$, or $s_u \approx 0 \rightarrow f_s = 0$
Firm (~Medium Stiff)	800 – 1500	0.38 – 0.71	Use curves A and B in Figure 6-14 to determine α.
Stiff	1500 – 3000	0.71 – 1.42	
Very Stiff	3000 – 6000	1.42 – 2.83	

For driven piles in firm to very stiff clay, the relationships between α and normalized undrained strength for the Tomlinson Alpha method (Tomlinson 1994) are depicted in Figure 6-14 as Curves A and B for normalized embedments (Z/b) of 40 and 10, respectively. The pile shaft can be discretized as needed to capture stratigraphic changes and/or shear strength trends with depth (FHWA 2016). For steel H-piles, FHWA (2016) recommends evaluating the shaft area using the outer "box[33]" perimeter rather than the actual perimeter of the flanges and web.

Tomlinson (1994) also presents guidance to estimate α in stiff clay for special cases where the pile penetrates soft clay or sand/gravel before penetrating the stiff clay. The overlying soft clay tends to coat the pile and reduce α while the sand or gravel is pushed into the stiff clay and tends to increase α. These effects are more pronounced near the interface of the stiff clay and the overlying material. The graphical guidance provided by Tomlinson (1994) for overlying soil layers does not compare logically to the case without an overlying layer and is, therefore, not presented herein. A simple approach to account for the effects of soft clay overlying stiff clay based on Tomlinson (1994) is to define a transition zone from the top of the stiff clay along the upper length of pile in the stiff clay equal to 10 times the pile width or diameter. The value of α within this zone can be estimated by

$$\alpha = 0.28\left(\frac{s_u}{P_a}\right)^{-0.44} \qquad (6\text{-}9)$$

where:
s_u = undrained shear strength of the stiff clay layer and
P_a = atmospheric pressure in same units as s_u.

[33] The box perimeter is the smallest rectangular shape that encompasses the H-pile cross section.

If the calculated value of f_s is lower for the transition zone than in the soft clay, the unit shaft resistance from the soft clay layer should be used for the transition zone.

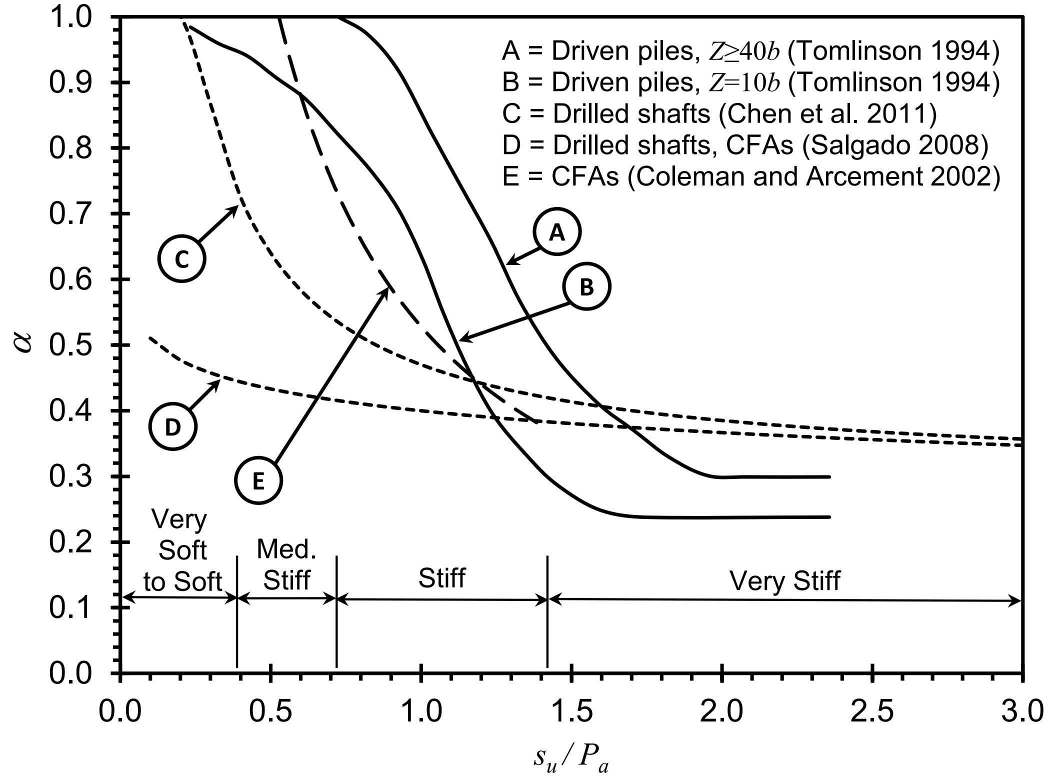


Figure 6-14 Variation of α with Normalized Undrained Shear Strength for Different Deep Foundation Types and Embedments

Equation 6-9 was developed by fitting a power function to the curve proposed by Tomlinson (1994) for penetration of a pile 10 times the width or diameter into stiff clay that underlies soft clay as digitized by FHWA (1993)[34].

Similarly, a simple approach to account for the effects of sand or gravel overlying stiff clay based on Tomlinson (1980) is to define a transition zone from the top of the stiff clay along the upper length of pile in the stiff clay equal to 10 times the pile width or diameter. The value of α within this zone can be assumed to equal to 1.0.

In the cases of overlying soft clay or sand/gravel, values of α below the transition zone are determined as normal using Figure 6-14. Tomlinson (1994) does not give explicit guidance for the cases of soft clay or sand/gravel overlying firm clay; therefore, judgment should be applied to select an appropriate value of α.

---

[34] The Alpha method presented in Tomlinson (1994) also appears in previous publications by Tomlinson, at least as early as 1975.

For drilled shafts, Chen et al. (2011) recommends estimating α as:

$$\alpha = 0.3 + 0.17\frac{P_a}{s_{u,ICU}} \le 1 \tag{6-10}$$

where:
$s_{u,ICU}$ = undrained strength evaluated using an ICU triaxial test and
P_a = atmospheric pressure.

The relationship between α and normalized undrained strength proposed by Chen et al. (2011) is depicted as Curve C in Figure 6-14. Based on guidance provided by Chen and Kulhawy (1993) and Mayne (1985), values of undrained strength evaluated using UC, UU, or DSS tests can reasonably be scaled for the purpose of estimating α as[35]:

$$s_{u,ICU} \approx 1.74 \cdot s_{u,UC} \cdot OCR^{-0.25} \qquad \text{(6-11)},$$

$$s_{u,ICU} \approx 1.68 \cdot s_{u,UU} \cdot OCR^{-0.25} \qquad \text{(6-12)},$$

and

$$s_{u,ICU} \approx 1.43 \cdot s_{u,DSS} \tag{6-13}$$

where:
$s_{u,UC}$ = undrained strength evaluated using an unconfined compression test,
$s_{u,UU}$ = undrained strength evaluated using an unconsolidated undrained triaxial test,
$s_{u,DSS}$ = undrained strength evaluated using a direct simple shear test, and
OCR = overconsolidation ratio.

For drilled shafts and CFAs, Salgado (2008) recommends estimating α for soils with a clay fraction of at least 50% and an OCR between 3 and 5 as:

$$\alpha = 0.4\left[1 - 0.12 \cdot \ln\left(\frac{s_u}{P_a}\right)\right] \qquad \text{(6-14).}$$

For lower values of OCR, Equation 6-14 is expected to produce conservative values. Salgado (2006) indicates that s_u is evaluated using a triaxial test, though the specific type is unspecified. The relationship between α and normalized undrained shear strength proposed by Salgado (2008) is depicted as Curve D in Figure 6-14.

---

[35] Undrained strength ratio calculated using Eqn. 8-20 in DM 7.1 (Jamiolkowski et al. 1985) assuming the fitting parameter, m = 0.8.

Coleman and Arcement (2002) load tested CFAs in mixed alluvial and loessial sand and clay deposits. They found a relationship between α and undrained strength. The relationship (Curve E in Figure 6-14) between α and normalized undrained strength is valid for normalized strengths in the range of 0.24 to 1.42 and is calculated as:

$$\alpha = 0.53\left(\frac{s_u}{P_a}\right) \qquad (6\text{-}15).$$

Comparison of Curves A and B for driven piles and Curves C and D for drilled shafts in Figure 6-14 illustrates the effects of soil displacement and disturbance from pile driving. For medium stiff to stiff clays, remolding and consolidation by pile driving generally produce higher values of α compared to drilled shafts. For stiff to very stiff clays, clay cracking and gap development due to pile driving generally produce lower values of α compared to drilled shafts.

The P2A Method described by the American Petroleum Institute (API) (1993) is a modified version of the Alpha Method by Randolph and Murphy (1985) in which α is calculated as:

$$\alpha = 0.5\left(\frac{s_u}{\sigma'_z}\right)^{-0.5} \text{ for } \frac{s_u}{\sigma'_z} \le 1 \qquad (6\text{-}16)$$

and

$$\alpha = 0.5\left(\frac{s_u}{\sigma'_z}\right)^{-0.25} \text{ for } \frac{s_u}{\sigma'_z} > 1 \qquad (6\text{-}17)$$

where:
s_u / σ'_z = undrained strength ratio with respect to effective vertical stress.

When the undrained strength ratio is less than 0.25, the value of α should be capped at 1.0. As noted by NCHRP (2015), the P2A method was developed using information from large diameter (i.e. ≥ 36 inches) open-end steel pipe piles installed in an offshore environment. Despite the difference in diameter, the API method should also be helpful for designing concrete cylinder piles (Rausche and Webster, 2007).

The API guidance can also be expressed in terms of OCR as:[36]

[36] Undrained strength ratio calculated using Eqn. 8-20 in DM 7.1 (Jamiolkowski et al. 1985) assuming the fitting parameter, m = 0.8.

$$\alpha = 1.07\left(OCR\right)^{-0.4} \text{ for } OCR \le 4.5 \quad (6\text{-}18)$$

and

$$\alpha = 0.73\left(OCR\right)^{-0.2} \text{ for } OCR > 4.5 \quad (6\text{-}19).$$

When the OCR is less than 1.2, the value of α should be capped at 1.0. Coduto et al. (2016) recommend evaluating the side resistance of full-displacement DDPs in the same way as used for driven concrete displacement piles of the same nominal diameter. For partial displacement DDPs, Coduto et al. (2016) recommend interpolating side resistance somewhere between a driven concrete displacement pile and CFA pile.

6-5.4.3 Base Resistance.

Given sufficient displacement for mobilization, unit base resistance, q_b, is usually significantly larger for drained conditions in coarse-grained soils compared to undrained conditions in fine-grained soils. Special considerations need to be accepted and/or addressed to apply bearing capacity theory to deep foundations. These considerations include:

1) Local, or plunging, mode of failure is often more representative of bearing failure of deep foundations rather than the general shear considered by bearing capacity theory (Coduto et al. 2016).
2) The point of bearing capacity failure is usually difficult to define from the relationship of base settlement and load (Fellenius 2021).
3) Bearing capacity theory does not capture the effects of stress release and disturbance of soils below the base, particularly in drilled shafts (FHWA 2018a).
4) Bearing capacity theory does not capture the effects of adjacent elements, e.g. closely-spaced piles in the group.
5) Inputs to bearing capacity theory, e.g. friction angle, tend to have nonlinear effects on bearing capacity. Thus, small changes to inputs may have large impacts on the bearing resistance considered in design.

Due to the limitations of bearing capacity theory, Vesic (1977) states that “in most situations it may be preferable to determine pile point and skin resistances directly from field tests, such as the static (Dutch) cone test, standard penetration test, and the pressuremeter test.” The SPT and CPT-based methods described in Section 6-5.4.4 are often a good alternative, particularly for coarse-grained soils.

Since the ratio of the base width to the depth below the ground surface is usually small, the N_γ term of the general bearing capacity equation is typically eliminated unless an enlarged base is used. For analysis of deep foundations in drained conditions, only the

N_q term is retained. Only the N_c term is retained for short-term analysis of fine-grained soils.

6-5.4.3.1 Base Resistance for Drained Conditions – Semi-Empirical.

Estimates of the N_q factor based on the soil type and friction angle are provided in Table 6-17. The unit base resistance for deep foundation elements ($Z/b \geq 5$) in drained conditions is found by:

$$q_b = N_q \cdot \sigma'_{zD} \quad (6\text{-}20).$$

where:
σ'_{zD} = vertical effective stress at the base elevation.

Table 6-17 Base Resistance Factors for Drained Conditions based on Soil Type and Friction Angle (after Fellenius 2021, Cheng 2004)

Soil Type	Friction Angle, ϕ' (deg)	Bearing Capacity Factor, N_q			
		Fellenius (2021)	Based on Cheng (2004)		
			Z/b = 10	Z/b = 20	Z/b = 40
Clay	25 to 30	3 to 30	12 to 26	10 to 22	8 to 19
Silt	28 to 34	20 to 40	19 to 52	16 to 46	14 to 40
Sand	32 to 40	30 to 150	37 to 168	32 to 152	27 to 139
Gravel	35 to 45	60 to 300	---	---	---

Values for other friction angles and embedment depths can be determined after Cheng (2004) as:

$$N_q \approx 1.2\left(\frac{Z}{b}\right)^{-0.437} \exp\left[6.34\left(\frac{Z}{b}\right)^{0.0486} \tan\phi'\right] \leq 200$$ unless supported by project-specific information

The equation provided in Table 6-17 is based on Cheng's (2004) correction of theory by Berezantev et al. (1961). The latter was also the basis of Nordlund's (1963, 1979) estimates of base resistance.

6-5.4.3.2 Base Resistance for Drained Conditions – Vesic.

Vesic's (1977) bearing capacity theory for driven pile foundations is based on cavity expansion theory. Application to other deep foundation types is up to the designer's judgment. Given the tendency for local shearing, the compressibility of the soil is accounted for using modified bearing capacity factors, N^*_c and N^*_q. The unit base resistance for deep foundation elements ($Z/b \geq 5$) in drained conditions is found by:

$$q_b = N^*_q \cdot \sigma'_m \quad (6\text{-}21).$$

where
σ'_m = mean effective stress at $b/2$ below the pile base elevation.

Assuming K_0 conditions, the mean effective stress is:

$$\sigma'_m = \left(1 - \frac{2}{3}\sin\phi'\right)\sigma'_{zD+b/2} \qquad (6\text{-}22)$$

where:
$\sigma'_{zD+b/2}$ = effective vertical stress at b/2 below the base prior to pile installation and
ϕ' = peak effective friction within proximity of the base.

Vesic's method uses a reduced rigidity index (I_{rr}) and estimates N^*_q by:

$$N_q^* = \left(\frac{3}{3 - \sin\phi'}\right) e^{\left(\frac{\pi}{2} - \phi'\right)\tan\phi'} \tan^2\left(\frac{\pi}{4} + \frac{\phi'}{2}\right) I_{rr}^{\left(\frac{4\sin\phi'}{3(1+\sin\phi')}\right)} \qquad (6\text{-}23)$$

where:
e = base of the natural logarithm and
ϕ' = peak friction angle in radians within proximity of the base.

The impact of compressibility is assessed using the reduced rigidity index, I_{rr}. The tendency for local shear failure increases as the rigidity index decreases. Characterization of the soil within 1 to 2 pile widths of the base is most important for evaluating base resistance by Vesic's bearing capacity theory. These are the soils mobilized to provide resistance to shearing.

For coarse-grained soils, the rigidity index according to Vesic (1977) is equal to:

$$I_r = \frac{E}{(1+2\nu)\sigma'_m \tan(\phi')} \qquad (6\text{-}24)$$

where:
E = Young's Modulus and
ν = Poisson's Ratio.

To account for the volume change required to mobilize shear strength, the rigidity index should be reduced to (Vesic 1977):

$$I_{rr} = \frac{I_r}{1 + I_r \varepsilon_v} \qquad (6\text{-}25)$$

where:
ε_v = volumetric strain from the foundation loading.

For piles bearing in soil, the reduced rigidity index normally ranges from 10 to 500. Assuming one-dimensional elastic compression below the pile, the volumetric strain can be estimated by (Bowles 1996):

$$\varepsilon_v = \frac{(1+\nu)(1-2\nu)\Delta\sigma_{zD+b/2}}{E_s(1-\nu)} \approx F_\nu \frac{q_{b,app}}{E_s} \qquad (6\text{-}26)$$

where:
$\Delta\sigma_{zD+b/2}$ = change in vertical stress at a depth of $b/2$ below the base,
$q_{b,app}$ = estimated applied bearing pressure at the base of the pile, and
F_ν = strain factor based on Boussinesq theory and Poisson's ratio (see Table 6-18).

Table 6-18 Factors for Approximating Volumetric Strain

Pile Shape	Strain Factor, F_ν						
	$\nu = 0.2$	$\nu = 0.25$	$\nu = 0.3$	$\nu = 0.35$	$\nu = 0.4$	$\nu = 0.45$	$\nu = 0.5$
Square	0.59	0.54	0.48	0.41	0.30	0.17	0
Circular	0.63	0.58	0.52	0.44	0.33	0.18	0

6-5.4.3.3 Undrained Base Resistance.

The N^*_c factor is required for short-term analysis of fine-grained soils. For undrained conditions, the unit base resistance for deep foundations is:

$$q_b = N_c^* \cdot s_u \qquad (6\text{-}27)$$

where:
s_u = undrained strength within proximity of the base.

Using Vesic's (1977) approach, the value of N^*_c is found by:

$$N_c^* = \frac{4}{3}\left(\ln I_{rr} + 1\right) + \frac{\pi}{2} + 1 \qquad (6\text{-}28)$$

For undrained conditions, the rigidity index is found by:

$$I_{rr} = I_r = \frac{E_u}{3 \cdot s_u} \qquad (6\text{-}29)$$

where:
E_u = Young's modulus for undrained conditions and
s_u = undrained strength within proximity of the base.

The volume correction is not needed for undrained conditions, which involves no volume change by definition, i.e. $I_{rr} = I_r$.

Methods other than Vesic (1977) are more commonly used to obtain N^*_c for use in Equation 6-22. According to Brinch Hansen (1957), N^*_c is equal to 9 based on bearing capacity theory for typical deep foundations with Z/b of at least 2.5. An exception exists for formed-in-place columns bearing on fine-grained soil having a representative undrained shear strength less than 2 ksf. In this case, interpreting the guidance by FHWA (1999) suggests that N^*_c is a function of I_r:

$$N_c^* = 1.33\left[\ln\left(I_r\right)+1\right] \leq 9 \quad (6\text{-}30)$$

or a function of normalized undrained shear strength:

$$N_c^* = 10.2 - 12.4\left(\frac{0.1}{0.1+{}^{s_u}\!/\!{}_{P_a}}\right) \leq 9 \quad (6\text{-}31).$$

Unlike piles bearing in coarse-grained soils, bearing resistance in clay is often not the dominant contributor to the total nominal axial resistance.

6-5.4.4 SPT and CPT-based SCA Methods.

Many published methods empirically relate shaft and base resistance to the resistances measured by the SPT and CPT (Poulos 1989, Fellenius 2021). In many instances, SPT and CPT-based estimates of base resistance are used in conjunction with estimates of shaft resistance by the Beta and/or Alpha methods. Additionally, certain foundation technologies, such as DDPs, have not yet reached a state of maturity where specific versions of the Beta and Alpha method are available, and presently, designers must rely on SPT and CPT-based SCA methods.

Other *in situ* tests, such as the dilatometer or pressuremeter, can also be used to evaluate axial capacity (Fellenius 2021, Briaud 2013). Presentation of pressuremeter and dilatometer-based methods are beyond the scope of this chapter.

Table 6-19 lists selected methods for estimating shaft friction using SPT blow count, and Table 6-20 lists selected methods for estimating base resistance.

CPT results can also be used to estimate the static axial capacity of deep foundations, e.g., FHWA (1978) or Elsami and Fellenius (1997). The empirical approach developed by the Laboratoire Central des Points et Chausses (LCPC) (Bustamante and Gianesselli,1982) is presented here due to its simplicity and adaptability to a range of deep foundation technologies.

Nominal unit side resistance and unit base resistance are estimated according to the LCPC method as:

$$f_s = \frac{P_a}{k_s}\left(\frac{q_c}{P_a}\right) \leq P_a\left(\frac{f_p}{P_a}\right) \tag{6-32}$$

and

$$q_b = P_a k_t\left(\frac{q_{c,a}}{P_a}\right) \tag{6-33}$$

where:
q_c/P_a = cone tip resistance normalized by atmospheric pressure,
$q_{c,a}/P_a$ = average normalized cone tip resistance in the vicinity of the base (see below),
k_s = side resistance factor (see Table 6-21),
f_p = maximum unit side resistance (see Table 6-22), and
k_t = base bearing factor (see Table 6-23).

The average cone tip resistance in the vicinity of the base is found by averaging resistance values over $1.5 \cdot b$ above and below the base. Values above the base should be discarded until all values fall within 70% to 130% of the average value. Likewise, values below the base should be discarded until all values do not exceed 130% of the average value.

Values of k_s, f_p, and k_t are found using Table 6-21, Table 6-22, and Table 6-23, respectively, based on the categorization of the foundation type and soil conditions. Foundations falling under Group I-A include drilled shafts without permanent casing, CFAs, gravity-grouted micropiles, and barrettes. Group I-B foundations include drilled shafts with permanent casing. Group II-A foundations include driven and jacked concrete piles. Group II-B foundations include driven and jacked steel piles.

Table 6-19 Correlations Between SPT N Values and Nominal Shaft Resistance

Source	f_s (ksf)	Applicability
Meyerhof (1976)[A]	$N_{1,60}$ / 50 ≤ 2 ksf	Driven non-displacement piles in sand
	$N_{1,60}$ / 25 ≤ 2 ksf	Driven displacement piles in sand
Brown (2001)[B]	$0.555+(N_{60}) / 25$	Driven piles in sand and clay.
Briaud (2013)	$0.104(N_{60})^{0.7}$	Driven piles in sand and gravel
NeSmith (2002)[C]	$0.1(N)$ ≤ 3.4 ksf	DDPs in rounded, poorly graded coarse-grained soil with up to 40% fines
	$0.1(N)$ +1 ksf ≤ 4.4 ksf	DDPs in angular, well-graded coarse-grained soil with up to 10% fines

[A] For Meyerhof methods, calculate the overburden-corrected blow count as:

$$N_{1,60} = \left[0.77 \cdot \log\left(\frac{40}{\sigma'_z}\right)\right] N_{60}$$ where σ′z is the effective vertical stress in ksf

[B] Correlation provided for compressive resistance for pile driven with impact hammer and 3 ≤ N_{60} ≤ 50. See original source for other soil, loading, and installation conditions, keeping in mind that SPT N values generally have low reliability in gravelly soils.

[C] N = the uncorrected SPT blow count. Apply judgement to evaluate f_s for intermediate soil conditions.

Table 6-20 Correlations Between SPT N values and Nominal Base Resistance

Source	q_b (ksf)	Applicability
Meyerhof (1976)[A]	$0.8(Z_b/b)(N_{1,60}) \le 6(N_{1,60})$	Reasonably uniform, non-plastic silt
	$0.8(Z_b/b)(N_{1,60}) \le 8(N_{1,60})$	Reasonably uniform sand
Brown (2001)[B]	$3.55(N_{60})(1+F_pA_p / A_b)$	Driven piles with soil plug
Briaud (2013)[C]	$20.9(N_{60})^{0.5}$	Driven piles in sand and gravel
Reese and O'Neill (1989)[D]	$1.2N_{60}$ ≤ 60 ksf	Drilled shafts in coarse-grained soil
Zelada and Stephenson (2000)	$3.4N_{60}$ ≤ 150 ksf	CFA columns in coarse-grained soil
NeSmith (2002)[E]	$3.8(N)$ ≤ 150 ksf	DDPs in rounded, poorly graded coarse-grained soil with up to 40% fines
	$3.8(N)$ +28 ksf ≤ 178 ksf	DDPs in angular, well-graded coarse-grained soil with up to 10% fines

[A] Z_b/b = normalized embedment into bearing stratum. Average $N_{1,60}$ over 3 pile widths below base. When embedment for full base resistance is not achieved, linearly interpolate $N_{1,60}$ with overlying weaker stratum or ground surface. Calculate the overburden-corrected blow count as:

$$N_{1,60} = \left[0.77 \cdot \log\left(\frac{40}{\sigma'_z}\right)\right] N_{60}$$ where σ'_z is the effective vertical stress in ksf

[B] A_p = area of soil plug for open sections; A_b = base area of pile material; F_p = 0.42 for open pipe sections; and F_p = 0.67 for H-piles. To evaluate R_b, apply resulting q_b to A_b.

[C] Average N_{60} over 4 piles widths above and below the base (Briaud and Tucker 1984).

[D] Average N_{60} within two diameters below base.

[E] N = the uncorrected SPT blow count averaged over 4 pile diameters above and below the base. Apply judgment to evaluate q_b for intermediate soil conditions.

Table 6-21 Side Resistance Factor (after Bustamante and Gianeselli 1982)

Soil type	q_c / P_a	k_s			
		Group I		Group II	
		A	B	A	B
Soft clay and mud	<10	30	30	30	30
Moderately compact clay	10 to 50	40	80	40	80
Silt and loose sand	≤ 50	60	150	60	120
Compact to stiff clay and compact silt	> 50	60	120	60	120
Soft chalk	≤ 50	100	120	100	120
Moderately compact sand and gravel	50 to 120	100	200	100	200
Weathered to fragmented chalk	> 50	60	80	60	80
Compact to very compact sand and gravel	> 120	150	300	150	200

Table 6-22 Maximum Unit Side Resistance (after Bustamante and Gianeselli 1982)

Soil type	q_c / P_a	f_p / P_a			
		Group I		Group II	
		A	B	A	B
Soft clay and mud	<10	0.15	0.15	0.15	0.15
Moderately compact clay	10 to 50	0.35 (0.8)	0.35 (0.8)	0.35 (0.8)	0.35
Silt and loose sand	≤ 50	0.35	0.35	0.35	0.35
Compact to stiff clay and compact silt	> 50	0.35 (0.8)	0.35 (0.8)	0.35 (0.8)	0.35
Soft chalk	≤ 50	0.35	0.35	0.35	0.35
Moderately compact sand and gravel	50 to 120	0.8 (1.2)	0.35 (0.8)	0.8 (1.2)	0.8
Weathered to fragmented chalk	> 50	1.2 (1.5)	0.8 (1.2)	1.2 (1.5)	1.2
Compact to very compact sand and gravel	> 120	1.2 (1.5)	0.8 (1.2)	1.2 (1.5)	1.2
Note: Values in parentheses reflect careful construction.					

Table 6-23 Base Bearing Factor (after Bustamante and Gianeselli 1982)

Soil type	q_{ca} / P_a	k_t	
		Group I-A&B	Group II-A&B
Soft clay and mud	<10	0.4	0.5
Moderately compact clay	10 to 50	0.35	0.45
Silt and loose sand	≤ 50	0.4	0.5
Compact to stiff clay and compact silt	> 50	0.45	0.55
Soft chalk	≤ 50	0.2	0.3
Moderately compact sand and gravel	50 to 120	0.4	0.5
Weathered to fragmented chalk	> 50	0.2	0.4
Compact to very compact sand and gravel	> 120	0.3	0.4

6-5.4.5 Micropiles.

Guidance for micropiles used in direct load support applications is provided in FHWA (2005). Due to their small diameter, micropiles develop axial capacity primarily through side resistance developed between the grout and the soil and/or rock in the bond zone. Base resistance is usually neglected; however, for micropiles terminating within hard rock, the procedures for evaluating the base resistance of rock-socketed drilled shafts, described in Section 6-5.4.6.2, can be applied. Given the possibility of high grout-to-ground bond strength, structural capacity often limits micropile capacity.

The nominal side resistance of a micropile bonded in soil or rock can be estimated using:

$$R_s = \alpha_{bond}\left(\pi \cdot b \cdot Z_b\right) \tag{6-34}$$

where:
α_{bond} = nominal unit grout-to-ground bond strength,
b = diameter of the bond zone, and
Z_b = length of the bond zone.

Table 6-24 can be used to make preliminary estimates of α_{bond}, which is sensitive to the grout mix, grout delivery method, and soil/rock properties. Load testing and local experience is most often used to evaluate nominal unit side resistance.

Table 6-24 Typical Nominal Unit Grout-to-Ground Bond Strengths (FHWA 2005)

Soil/Rock Description	Nominal Grout-to-Ground Nond Strength, α_{bond} (psi)			
	Type A	Type B	Type C	Type D
Soft silt and clay	5 to 10	5 to 14	5 to 17.5	5 to 21
Stiff silt and clay	5 to 17.5	10 to 27.5	14 to 27.5	14 to 27.5
Loose to medium dense sand	10 to 21	10 to 27.5	14 to 27.5	14 to 35
Medium to very dense sand	14 to 31	17.5 to 52	21 to 52	21 to 56
Medium to very dense gravel	14 to 38.5	17.5 to 52	21 to 52	21 to 56
Medium to very dense cemented glacial till	14 to 27.5	14 to 45	17.5 to 45	17.5 to 48.5
Soft shale[A]	30 to 80	Types B, C, and D generally not used in rock		
Slates and hard shale[A]	75 to 200			
Limestone[A]	150 to 300			
Sandstone[A]	75.5 to 250			
Granite and basalt[A]	200 to 609			
[A] Rock mass is unweathered with little to moderate fracturing.				

Micropiles are a preferred deep foundation type in karst; however, discontinuities in the rock can cause issues. A conservative option is to drill until a continuous length of competent rock equal to the target length of the bond zone is encountered. A more cost-effective option is to allow for some discontinuous rock to be included within a cumulative length of competent rock equal to the target length of the bond zone. The project specifications should be explicit about the acceptable number and length of any discontinuities allowed within the bond zone.

6-5.4.6 Driven Piles and Drilled Shafts in Rock.

Usually, intact rock provides an excellent material for providing high axial shaft and base resistance with small associated settlement. Due to the high nominal unit resistances relative to soil, the axial capacity of foundations bearing on or in rock may be controlled by the structural capacity of the element (Section 6-7), particularly when the rock is at least moderately strong. While there is not a universal definition of rock strength or hardness used in deep foundation design, Section 1-4 of DM 7.1 presents common ways to describe rock strength, and Section 3-3 of DM 7.1 provides useful information regarding the evaluation of rock strength in the laboratory. The most commonly used measure of rock strength is the unconfined compressive strength test.

Weathered rock and hard soils with $N > 50$ are sometimes referred to as *intermediate geo-materials* (IGM). The capacity of such materials may be better evaluated using methods for soils rather than methods intended for rock. Moreover, existing rock joints, discontinuities, voids, and installation-induced fractures can partially or completely invalidate conventional capacity analyses. In these cases, base and/or shaft resistance may be reduced or neglected entirely depending on the uncertainty of ground conditions, the potential for more discontinuities to develop over the service life, and the consequences of the loss of capacity. When the strength and quality of the rock is variable, careful observations during construction and evaluation of capacity by static load testing and/or dynamic methods become especially important.

6-5.4.6.1 Driven Piles.

According to AASHTO (2020), driven piles bearing on weak rock can be designed using procedures for soil. For driven piles bearing on hard rock, the axial capacity is usually governed by the structural capacity of the element (USACE 1991). Piles driven to rock typically require steel toe protection (Section 6-4.1.2), and it is important to monitor driving stresses using dynamic methods (Section 6-9.4).

6-5.4.6.2 Drilled Shafts.

Drilled shafts socketed in rock can provide high unit shaft and base resistances. However, in karstic conditions, only the shaft resistance may be included in the design.

As described by Kulhawy et al. (2005), the most common model to evaluate the nominal side resistance of a rock socket is:

$$f_s = C \cdot P_a \left(\frac{q_u}{P_a} \right)^n \quad (6\text{-}35)$$

where:
q_u = lesser of the representative unconfined compressive strength of the rock and the compressive strength of the drilled shaft concrete,
C = fitting parameter, and
n = fitting exponent.

For sockets in "normal rock,"[37] Kulhawy et al. (2005) recommend a value of C = 1 and n = 0.5. For rock that is unstable and prone to caving during drilling, FHWA (1999) recommend a value of $C = 0.65\alpha_E$ and n = 0.5, where α_E is the joint modification factor that is found in Table 6-25 based on RQD and whether the joints are closed. Special tooling can be used to groove and roughen the sides of the socket to increase side resistance. In these cases, load testing and local experience should be applied to evaluate the appropriate values of C and n for use in Equation 6-35.

Table 6-25 Joint Modification Factors, α_E, for Unstable Rock (after FHWA 1999)

RQD	Closed joints		Open or filled joints	
	α_E	C	α_E	C
100	1.00	0.65	0.85	0.55
70	0.85	0.55	0.55	0.36
50	0.60	0.39	0.55	0.36
30	0.50	0.32	0.50	0.32
20	0.45	0.22	0.45	0.22

The evaluation of base resistance in rock is complicated by the rock mass condition as compared to the measured strength of an intact rock sample. Using an empirical bearing capacity factor (N^*_{cr}), the unit base resistance is evaluated as:

$$q_b = N^*_{cr} \cdot q_u \quad (6\text{-}36).$$

FHWA (2018a) recommends a value of N^*_{cr} = 2.5 if three conditions are met: 1) the shaft bears on a massive or closed jointed rock extending at least one diameter below the base, 2) there are no voids below the base, and 3) the base can be adequately

---

[37] Normal rock is defined here as relatively massive, unjointed rock, having at least moderate strength.

cleaned prior to placing concrete. If any of these conditions are not met, N^*_{cr} should be evaluated through testing and local experience and application of more sophisticated constitutive models such as the Hoek-Brown failure criterion (Hoek et al. 2002) within numerical analysis, or base resistance should be neglected. Similarly, testing, local experience, and/or numerical analysis may be applied to justify values of N^*_{cr} higher than 2.5. The factored unit base resistance should not exceed the compressive strength of the concrete used for the drilled shaft.

6-5.5 Static Axial Capacity in Compression for Groups of Elements.

Deep foundations are often installed in groups to share the load carrying requirements and provide redundancy. The group behavior of vertically oriented driven piles, drilled shafts, CFAs, DDPs, and micropiles is featured here. Compared to the other foundation technologies, drilled shafts are less commonly installed in groups though adjacent drilled shafts may influence each other.

The minimum recommended center-to-center spacing (s) is three column widths or diameters, which is a consideration for constructability as well as soil-column-soil interaction. Each column has a zone of influence, which is the volume of ground that experiences a change in stress due to installation effects and subsequent load transfer between the column and the ground. When columns are close together, the zones of influence of adjacent columns can overlap. Overlapping zones of influence can have positive or detrimental effects depending on the ground conditions.

The factored axial capacity of the group of foundation elements, $R_{r,g}$, is determined as:

$$R_{r,g} = \min \begin{cases} n \cdot \eta_g \cdot R_r \\ R_{r,gblock} \end{cases} \qquad (6\text{-}37)$$

where:
n = number of columns,
η_g = group efficiency factor,
R_r = factored single column capacity, and
$R_{r,gblock}$ = factored resistance to block failure.

While single element capacity considers the surface area of the column shaft and base, *block failure* considers the shearing resistance of the area along the sides of the group and the base resistance of the projected base area (soil and columns) of the group, as shown in Figure 6-15 where the base dimension, B, is less than or equal to the base dimension, Z. The effect of the group on the capacity of individual columns is captured by the group efficiency factor, η_g. In practice, this factor is usually taken as equal to unity except as noted in Table 6-26. Interpolation can be applied to evaluate η_g for intermediate spacings.

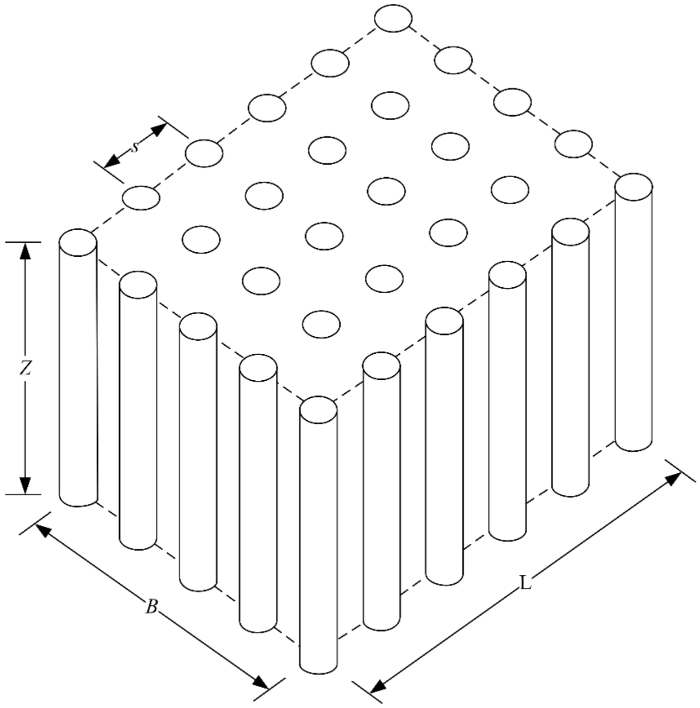


Figure 6-15 Group Geometry

Table 6-26 Group Efficiency Factor for Groups of Elements

Soil Type and Pile Cap Condition	Group efficiency factor, η_g				
	Driven Piles[A]	Drilled Shafts[B]	CFAs[C]	DDPs[D]	Micropiles[E]
Coarse-grained soil and pile cap not in contact with the ground	1.0	0.65 for s/b=2.5 0.80 for s/b=3 1.0 for s/b=4	0.65 for s/b=2.5 1.0 for s/b=6	1.0	1.0
Coarse-grained soil and pile cap in contact with the ground	1.0	1.0	0.65 for s/b=2.5 1.0 for s/b=6	1.0	1.0
Fine-grained soil, s_u< 2 ksf, and pile cap not in contact with the ground	0.65 for s/b=2.5 1.0 for s/b=6	1.0	1.0	0.7 for s/b=3.0 1.0 for s/b=6	0.65 for s/b=2.5 0.70 for s/b=3 1.0 for s/b=6
Fine-grained soil, s_u < 2 ksf, and pile cap in contact with the ground	1.0	1.0	1.0	1.0	1.0
Fine-grained soil, s_u ≥ 2 ksf	1.0	1.0	1.0	1.0	1.0

[A] Minimum spacing is greater of 2.5 ft and s/b = 2.5 (AASHTO 2020); minimum recommended spacing is greater of 3 ft and s/b = 3.0 (FHWA 2016).

[B] Minimum spacing is s/b = 2.5; minimum recommended spacing is greater of s/b = 3.0. If the stability of the shaft is maintained, e.g., by advancing casing ahead of drilled shaft excavation, reductions in coarse-grained soils need not be made (FHWA 2018a).

[C] Minimum spacing is s/b = 3.0. The reductions in coarse-grained soils are likely quite conservative (FHWA 2007).

[D] Minimum spacing is s/b = 3.0 (FHWA 2007).

[E] Minimum spacing is greater of 2.5 ft and s/b = 3.0 (AASHTO 2020). For micropiles, b is the diameter of the grouted bond zone (FHWA 2005).

Block failure should be checked for groups in fine-grained soil and when closely-spaced columns in coarse-grained soils are underlain by weak soil. The nominal resistance to block failure can be estimated as:

$$R_{n,gblock} = 2Z \cdot (B+L) f_{s,1} + B \cdot L \cdot s_{u,2} \cdot N_c \qquad (6\text{-}38)$$

where:
L, B, and Z = dimensions as defined in Figure 6-15,
$f_{s,1}$ = weighted average unit shaft resistance over the depth of column embedment, and
$s_{u,2}$ = average undrained strength from the base to a depth of $2B$ to $3B$ below the base.

When the sides of the pile group are in fine-grained soil, $f_{s,1}$ should be set equal to the average undrained shear strength. When the sides of the pile group are in coarse-grained soils, $f_{s,1}$ equals the average unit shaft resistance as evaluated using an SCA method. In the second term, the depth used to average $s_{u,2}$ should be the value that produces the lower estimate of strength. For pile groups in coarse-grained soils underlain by a weak layer, $s_{u,2}$ equals the undrained strength of the weak layer. The bearing capacity factor, N_c, should be evaluated as (Brinch-Hansen 1957):

$$N_c = 5\left(1+\frac{0.2B}{L}\right)\left(1+\frac{0.2Z}{B}\right) \le 9 \qquad (6\text{-}39).$$

When using an LRFD framework, AASHTO (2020) recommends the resistance factors provided in Table 6-27 for group block failure. For the combined resistance of the single columns, the appropriate resistance factors provided in Table 6-11 should be used.

Table 6-27 Recommended Strength Limit State Resistance Factors for Block Failure (AASHTO 2020)

Foundation Technology	Recommended Resistance Factor
Driven piles	0.60 – fine-grained (cohesive) soil below group
Drilled shafts	0.55 – fine-grained (cohesive) soil below group
Micropiles[A]	0.60 – fine-grained (cohesive) soil below group
[A] AASHTO (2020) states that resistance factors should be reduced by 20% for micropiles in marginal ground conditions.	

6-5.6 Uplift Capacity.

Uplift capacity is needed to resist tensile loads from the superstructure, such as from wind and earthquake loading. Uplift can also result from bending moment that is resisted through a force couple provided by multiple elements.

There are five important concepts to consider when evaluating the uplift capacity of deep foundations: 1) failure in uplift can be abrupt and result in unrestrained movement,

2) the self-weight of the foundation reduces the net uplift force, 3) the base of the foundation does not provide long-term resistance to uplift, 4) the unit shaft resistance in uplift is usually taken to equal the unit shaft resistance in compression even though this may not strictly be true, particularly for cyclic loading, and 5) in pile groups, uplift resistance is limited by the lesser of the combined uplift resistances of the individual elements and the uplift resistance of a block or wedge of soil surrounding the pile group. An important exception to the third point is suction caissons that are explicitly designed to consider suction at the base.

When using an LRFD framework, AASHTO (2020) recommends application of the resistance factors in Table 6-28 to the nominal side resistance found using an appropriate SCA method. For the extreme limit state, a resistance factor equal to 0.8 can be used for uplift loading for all geomaterials.

Table 6-29 provides recommended minimum factors of safety for uplift when using an allowable stress design framework.

Table 6-28 Recommended Strength Limit State Uplift Resistance Factors (AASHTO 2020)

Foundation Technology	Recommended Uplift Resistance Factor[A]
Driven piles	0.20 – coarse-grained (cohesionless) soil, Beta method 0.25 – fine-grained (cohesive) soil, Alpha method 0.50 – group block uplift, all soils
Drilled shafts	0.45 – coarse-grained (cohesionless) soil, Beta method 0.35 – fine-grained (cohesive) soil, Alpha method 0.40 – rock, Equation 6-38 0.45 – group block uplift, all soils
Micropiles	0.55 – presumptive values 0.50 – group block uplift, all soils

[A] AASHTO (2020) states that resistance factors should be reduced by 20% for single drilled shafts and small pile groups (<5 piles) to account for lack of redundancy and micropiles in marginal ground conditions.

For the uplift resistance of a single element, the effective weight of the individual column, $W_{r,e}$, is factored using a minimum dead load factor equal to 0.9 (AASHTO 2020). This approach is less conservative than factoring the effective weight by the resistance factor but is usually acceptable since the weight of the element is usually more certain than the side resistance. When evaluating the weight of the element, the effective material unit weight should be used to account for buoyancy effects regardless of whether a total or effective stress analysis is used. When closed-end pipe piles are driven unfilled below the water table, buoyancy should be checked considering the actual weight of the empty pile. This check confirms constructability for piles subsequently filled with concrete or evaluates the long-term reduction in uplift force if the pile is left unfilled over its service life.

Table 6-29 Recommended Minimum Factors of Safety for Tension Loading

Foundation Technology	Guidance Source	Recommended Minimum Factor of Safety
Driven Piles	USACE (1991)	2.0 – with load tests[A] 3.0 – with dynamic testing[A] 3.0[A]
	UFC (2022)	2.0 – with load tests[B] 3.0 – with dynamic testing and signal matching[B] 3.0 – piles anchored in rock[B]
Drilled shafts	UFC (2022)	2.5 to 4 – drilled shafts anchored in rock[B]
	Coduto et al. (2016)	6.0[C] 4.0 – with load tests[C]
Micropiles	FHWA (2005)	2.0 – with load tests[D]

[A] Values are for "usual" loading; for unusual loading, such as floods, factors of safety may be decreased by factor of 0.75; for extreme loading, such as rare natural disasters, factors of safety may be decreased by factor of 0.57.
[B] Use FS > 3 to limit total and differential settlements to small values. Generally, use FS ≥ 2.5. FS for drilled shafts depends on uncertainties in loading, stratification, and verification testing.
[C] Without load testing, the FS may be reduced by 1.0 for uniform ground conditions and extensive site characterization. With load testing, the FS may be reduced by 1.0 for uniform ground conditions and extensive site characterization, with an additional reduction of 0.5 possible if the load testing program is very extensive in uniform ground conditions with extensive site characterization.
[D] Load tests should be performed before and during production pile installation, i.e., verification and proof testing. FS should be increased to 2.5 in marginal ground conditions.

The combined factored uplift capacity of n individual columns, $R_{r,gu}$, is:

$$R_{r,gu} = \min \begin{cases} n\left(R_{r,s} + W_{r,e}\right) + W_{r,e,cap} \\ R_{r,ublock} \end{cases} \quad (6\text{-}40)$$

where:
$R_{r,s}$ = factored capacity of a single column,
$W_{r,e}$ = factored effective weight of a single column,
$W_{r,e,cap}$ = factored effective weight of the cap, and
$R_{r,ublock}$ = factored uplift capacity of the columns and block calculated as follows.

A practical, conservative method to estimate the uplift capacity of the soil block, $R_{r,ublock}$, associated with the group of columns uses the dimensions and assumed shape shown in Figure 6-16 (Tomlinson 1994, FHWA 2016). The uplift resistance of the block is comprised of the effective weight of the block, $W_{e,g}$, and, in the case of undrained conditions, the contribution of shear strength along the sides of the block. The weight of the foundation and soil between elements are calculated using effective unit weights, regardless of whether a total or effective stress strength analysis is used, to account for buoyancy effects for materials below the water table. Usually, the difference between the unit weight of the foundation material and the soil may be neglected by treating all materials as having the unit weight of soil. The effective weight of the pile cap, W_{cap}, also should account for any expected buoyancy and is included in the weight of the block. The effective weights of the soil block and cap should be left unfactored since the group block resistance factors provided in Table 6-28 are applied to the effective weight and the side resistance for undrained conditions.

For pile groups in coarse-grained soils, the block resistance is the weight of the truncated prism having a rectangular base, shown in Figure 6-16(a), plus the weight of the cap. For a uniform soil profile (with water table at the ground surface or below the block), the volume of the block, V_{block}, is calculated as:

$$V_{block} = B \cdot L \cdot Z + \frac{Z^2}{4}\left(B + L\right) + \frac{Z^3}{12} \qquad (6\text{-}41).$$

For layered soil profiles and/or when the groundwater table is located within the block, the block can be divided into layers. The thickness of each layer should replace Z in Equation 6-41. The plan dimensions B and L should be replaced by the dimensions of the block at the bottom of each layer, calculated using the 4V:1H slope.

For deep foundations in undrained conditions, the effective weight of the block is based on the block geometry shown in Figure 6-16(b) and calculated as:

$$W_{e,g} = B \cdot L \cdot \left(Z_1 \cdot \gamma_m + Z_2 \cdot \gamma_b\right) + W_{cap} \qquad (6\text{-}42)$$

where:
Z_1 = depth of the column group above the water table,
Z_2 = depth of the pile group below the water table,
γ_m= moist unit weight of the soil, and
γ_b = buoyant unit weight of the soil.

The block uplift capacity includes the undrained shear resistance on the sides of the block plus the effective weight of the block and pile cap:

$$R_{n,block} = 2Z \cdot \left(B + L\right) \cdot s_{u,avg} + W_{e,g} \qquad (6\text{-}43).$$

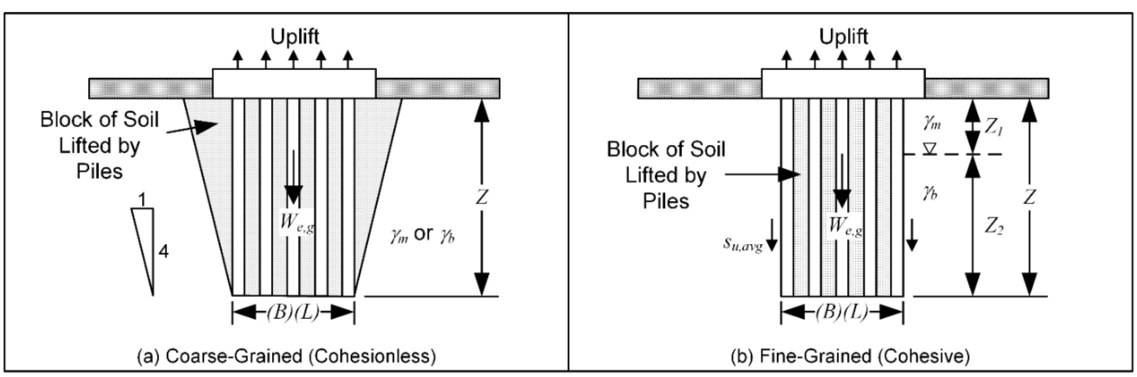


Figure 6-16 Uplift Resistance of Column-Soil Block for Groups of Columns – (a) Coarse-Grained and (b) Fine-Grained Soils

6-5.7 Negative Skin Friction.

Negative skin friction refers to vertical load transfer from the soil to the deep foundation element that occurs when the soil moves down relative to the shaft of the element. The resulting component of the total axial load is called the *drag force*. Negative skin friction requires the reversal of the shaft resistance and is caused by any mechanism that produces settlement in soil, such as consolidation, secondary compression, and vibration-induced densification. Consolidation may be induced by changes in groundwater elevation from dewatering or ground loading during the service life of the foundation. These sources of loading are easy to overlook and are often difficult to predict.

NCHRP (1997a) list conditions that are likely to produce negative skin friction: 1) total ground settlement exceeds 4 inches, 2) post-construction settlement exceeds 0.4 inches, 3) new fill is placed on the ground having a thickness that exceeds 6 ft, 4) the thickness of the compressible soil exceeds 30 ft, and 5) the groundwater table is lowered more than 12 ft.[38] FHWA (2016) states that the stiffness contrast between the piles and the surrounding ground alone is enough to create some amount of drag force; therefore, all designs should consider the possibility of negative skin friction.

When negative skin friction and the resulting drag force occur, the soil moves downward relative to the element until the neutral plane is reached. The *neutral plane* is the elevation along the element at which no relative displacement occurs between the element and the soil. The maximum compressive load in the element occurs at the neutral plane. The position of the neutral plane depends on several factors that are discussed in more detail below and may change over the service life of the foundation. Below the neutral plane, the foundation element moves down relative to the soil, and upward (positive) shaft resistance is developed.

Table 6-30 summarizes the limit states where the the drag force should be included in design. Service limit state calculations are discussed in Section 6-5.8. Inclusion of the drag force in the strength limit state is presented in Section 6-7.4.

Table 6-30 Guidance for Consideration of Down Drag

Design Consideration	Consider Negative Skin Friction and Drag Force?	
	Strength Limit State	Service Limit State
Geotechnical	No (FHWA 2016, 2018a)	Yes, negative skin friction and drag force may increase settlement
Structural	Yes, but it rarely influences the required structural capacity	Yes – location of the neutral plane influences elastic compression

[38] It is important to note that negative skin friction can occur even when none of the conditions are met.

In pile groups, the piles located along the perimeter of the group are exposed to downward movement of the settling ground and associated drag force. In contrast, interior piles are often shielded from drag force since the soil between the piles tends to move with the piles, except near the pile toe (Fellenius 2021). The shielding of interior piles from drag force is more apparent when ground settlement is caused by applied load rather than lowering of the ground water table. Larger pile groups tied together by a stiff cap or raft may experience less settlement due to downdrag than small pile groups and single piles due to support provided to the perimeter piles by the shielded interior piles (Fellenius 2021). The settlement due to downdrag can be nonuniform and lead to structural damage due to differential settlement (Coduto et al. 2016). Methods to mitigate downdrag and drag force are discussed in Section 6-5.8.

As Fellenius (2021) points out, drag force and downdrag settlement are inversely related. An end bearing pile penetrating consolidating ground may experience a large drag force and small downdrag settlement because the neutral plane is located near the base of the column. Conversely, a column floating in consolidating ground may experience a small drag force and large downdrag settlement due to the neutral plane being located further away from the base.

As indicated in Table 6-30, the drag force does not need to be considered for the geotechnical strength limit state. If the axial load approaches the strength limit state, the element will move down relative to the soil, which will fully mobilize positive side resistance along the entire length of the element, removing the effects of the drag force. In other words, the potential for negative skin friction does not reduce the nominal geotechnical axial capacity (Siegel et al. 2014). However, when the ground surrounding the foundation element is settling, the settlement required to mobilize the required geotechnical resistance for service conditions may be intolerably large. While there has historically been debate about whether the drag force should be subtracted from the geotechnical capacity, current FHWA guidance excludes the drag force from geotechnical capacity analysis (FHWA 2018a, 2016).

6-5.8 Settlement.

Settlements are evaluated for the service limit condition. Limits on settlement should be established considering the amount of total and differential settlement that can be tolerated by the structure supported by the foundation. Settlement will also be limited by the operation of the facility, e.g., utility connections, stormwater drainage, and ride quality. The total settlement at the top of the foundation, δ, is equal to:

$$\delta = \delta_e + \delta_s \tag{6-44}$$

where:
δ_e = settlement due to elastic compression of the element and
δ_s = settlement due to compression of the soils supporting the element.

If excessive settlements are estimated, some options include 1) refining the settlement analysis using load tests, 2) resizing the length and/or width of the element(s), 3) exploring other foundation options, 4) increasing the size of the pile group by adding more elements, 5) excluding base resistance and designing only for side resistance, and 6) improving the stiffness of the ground, e.g., by postgrouting drilled shafts.

A few important points about evaluating settlement of deep foundations include the following:

1) Settlements that occur after installation of settlement-sensitive features, e.g., building façade and pavements, are usually more consequential than settlements that occur prior to the installation of sensitive features.

2) Angular distortion is defined as the magnitude of differential settlement divided by the plan-view distance, or span length, over which the settlement occurs. Angular distortion is a useful metric for evaluating whether settlement is likely to be detrimental. Chapter 5 of DM 7.1, NCHRP (1991), and Duncan and Buchignani (1987) list limits on angular distortion for various types of structures. For example, a flexible steel frame structure might be able to tolerate an angular distortion of 0.008 without distress while a concrete block structure might only tolerate an angular distortion 20 times lower, i.e., 0.0004. For multi-span bridges, angular distortion should be limited to 0.004 (FHWA 2016).

3) Estimating the difference in settlement for two foundations is difficult due to the inaccuracies associated with each estimate. When better information is not available, Duncan and Buchignani (1987) recommend estimating differential settlement between two foundations as 75% of the higher estimated settlement for the individual foundations. Later guidance involving Duncan recommends estimating differential settlement between two foundations as 100% of the higher estimated settlement for the individual foundations (NCHRP 1991). Settlements tend to be more erratic for sites with sand, compacted fills, and/or stiff clay profiles.

4) Compression of high coarse-grained permeability soils occurs almost concurrently with applied loading. Compression of low permeability fine-grained soils occurs slowly over time. Since silts and clays also tend to be more compressible than sands and gravels and more susceptible to secondary compression, sites with silt and clay profiles pose greater potential for larger post-construction settlement.

5) The loads included in settlement calculations may depend on the type of settlement being considered. Analyses of immediate settlement and settlement due to compression of coarse-grained soils should consider both permanent and transient loads (Fox 2003). Analyses of consolidation and secondary

compression should consider permanent loads and some reasonable fraction of transient live loads. AASHTO (2020) recommends analyzing settlement of fine-grained soils using the Service I loading condition, excluding transient loads.

6) The settlement at the top of a deep foundation includes elastic compression of the element itself and compression of the soil supporting the element. If the recommended neutral plane concept (Section 6-5.7) is applied, elastic compression of the element that contributes to settlement (δ_e) is above the neutral plane. Likewise, only compression of the soil and rock below the neutral plane should be included in δ_s as contributing to the settlement at the top of the element. For foundations bearing on or in rock, the compression of the rock is usually small enough to ignore.

7) Settlement of single elements can be estimated by developing load-displacement relationships for mobilization of the side and base of the element, evaluating the distribution of axial load in the element, and applying the load-displacement relationships along with consideration of elastic compression of the element itself to estimate movement at the top of the element. Typically, side friction (positive or negative) is mobilized at small displacements, often 0.1 to 0.4 inches, while base resistance mobilizes over larger displacement, often 4% to 10% of the width of the element. Methods to estimate the load transfer movements of single piles include the $t-z$ method (Kraft et al. 1981), which is described succinctly by Coduto et al. (2016), and typically implemented using computer software, and various methods based on elastic theory, as described by Briaud (2013) and Salgado (2008). These methods can be challenging to implement since some of the inputs, particularly those used to evaluate the linear or nonlinear spring stiffness representing mobilization of the base, i.e., the $q-z$ curve, can be difficult to estimate with confidence (Salgado 2008), particularly when relevant load test data is unavailable. Furthermore, the displacement at the top of the element estimated from load transfer relationships does not explicitly include settlement from downdrag. Section 6-5.8.3 describes an empirical load-displacement curve method for estimating settlement of individual drilled shafts.

8) A group of loaded elements should be expected to settle more than a single element carrying the same load as the individual elements in the group (FHWA 2016). This is due to net outcome of group effects. Some effects, such as the stiffening of the soil between the piles, reduces the compression of these soils. However, the dominant effect is the overlapping zones of influence of the individual piles, which results in significant stress change at greater depths.

9) The flexural stiffness of the pile cap ties the elements together and causes all elements to settle uniformly.

6-5.8.1 Elastic Compression of the Foundation Element.

The elastic compression, or elongation, of a foundation element, δ_e, can be found using:

$$\delta_e = \frac{\Delta QZ}{A_p E_p} \qquad (6\text{-}45)$$

where:
ΔQ = average change in load in the element over its length including drag load,
Z = length of the element,
A_p = cross-sectional area of the pile material, and
E_p = Young's Modulus of the pile material.

A more refined estimate of elastic compression can be obtained by discretizing the pile into segments, evaluating the average load for each segment, computing the compression of each segment, and summing the compression of the individual segments. If the neutral plane concept is applied, elastic compression above the neutral plane directly contributes to the settlement of the top of the foundation element while elastic compression below the neutral plane does not directly contribute to the settlement. Elastic compression occurs simultaneously with loading, so only loads applied after construction contribute to post-construction settlement.

For typical service loading conditions, the elastic compression of a concrete and/or steel element is generally small and can sometimes be ignored, particularly when all elements are relatively short and similarly loaded. Elastic compression cannot be ignored when the length and/or loading of the foundation elements varies significantly, particularly over short distances, since potentially damaging differential settlement can occur.

6-5.8.2 Empirical Method for Pile Group Settlement in Coarse-Grained Soil.

The settlement of a pile group in coarse-grained soil will largely occur at the rate of loading. This means that post-construction settlement will be limited to that caused by service loads, unless the site is densified or liquefied by an event, such as an earthquake. Therefore, the settlement of deep foundations in coarse-grained soils is often not a controlling factor and can be appropriately checked using simple methods to see if a more detailed numerical analysis is warranted.

The Meyerhof (1976) method is a simple empirical method that correlates overburden-corrected SPT N values to elastic compressibility. The method applies to pile groups in sand that are not underlain by a more compressible stratum. The method does not explicitly include elastic compression of the piles.

The settlement at the top of the pile group can be estimated by:

$$\delta_s = \frac{\left(\frac{Q_d}{B \cdot L}\right)\sqrt{B}}{\bar{N}_{1,60}} I_f \qquad (6\text{-}46)$$

where:
δ_s = estimated settlement (in inches) at the top of the pile group,
Q_d = unfactored group design load (in kips) for the service limit state,
B and L = pile group dimensions (in feet) as defined in Figure 6-15, and
$\overline{N}_{1,60}$ = average overburden corrected N value within B below the base (Table 6-19).

The influence factor is computed as:

$$I_f = \max \begin{cases} 1 - Z/(12B) \\ 0.5 \end{cases} \qquad (6\text{-}47).$$

where:
Z = length (in same dimensions as B) of the group

For pile groups in silty sand, the settlement estimate from Equation 6-51 should be doubled.

6-5.8.3 Empirical Method for Drilled Shaft Settlement.

The load-displacement curves proposed by Chen and Kulhawy (2002), provided in Figure 6-17, are based on observations from many load tests performed on drilled shafts. This method is intended for preliminary analyses to determine whether settlement will govern the design and a more detailed analysis, such as numerical analysis using computer software, is warranted.

The load-displacement curves are appropriate for drilled shafts in either coarse-grained or fine-grained soil profiles having a diameter between 1 and 6.5 ft, a depth between 16 and 200 ft, and a depth to diameter ratio between 6 and 56. The curves incorporate the composite mobilization of side and base resistances as well as elastic compression of the concrete shaft. The vertical axis of Figure 6-17 is the axial compressive force normalized by the failure threshold. The axial compressive force (ACF) equals the sum of the unfactored applied load and the effective weight of the shaft. Guidance for evaluating the effective weight is provided in Section 6-5.6. The failure threshold (FT) is the axial compressive force corresponding to a displacement normalized by shaft diameter, δ/b, equal to 4%. This force is found by adding the nominal shaft resistance and the nominal base resistance at δ/b equal to 4%, R'_b.

For this method, the nominal shaft resistance should be found by the Alpha Method according to Equation 6-8 for fine-grained soils and by the Beta Method for coarse-grained soils with K/K_0 evaluated according to FHWA (2018a) as provided in Table 6-13.

The nominal base resistance, R_b, should be found according to Equation 6-27 for fine-grained soils and according to Reese and O'Neill (1989) as provided in Table 6-20 for cohesionless soils. The nominal base resistance at δ/b equal to 4% should be found as:

$$R'_b = \begin{cases} R_b & \text{for fine-grained (cohesive) soils} \\ 0.71R_b & \text{for coarse-grained (cohesionless) soils} \end{cases} \quad (6\text{-}48).$$

The equations provided in Table 6-31 approximate the load-displacement curves proposed by Chen and Kulhawy (2002). To estimate settlement, follow these steps:

1) Estimate ACF for the service limit state condition using unfactored loads and the effective weight of the shaft.
2) Apply either the Alpha or Beta method to estimate FT as the sum of R_s and R'_b, as defined above.
3) Compute the ratio ACF / FT.
4) Solve for the value of δ/b using Figure 6-17 or the equations in Table 6-31. Multiply by the shaft diameter, b, to estimate settlement, δ.

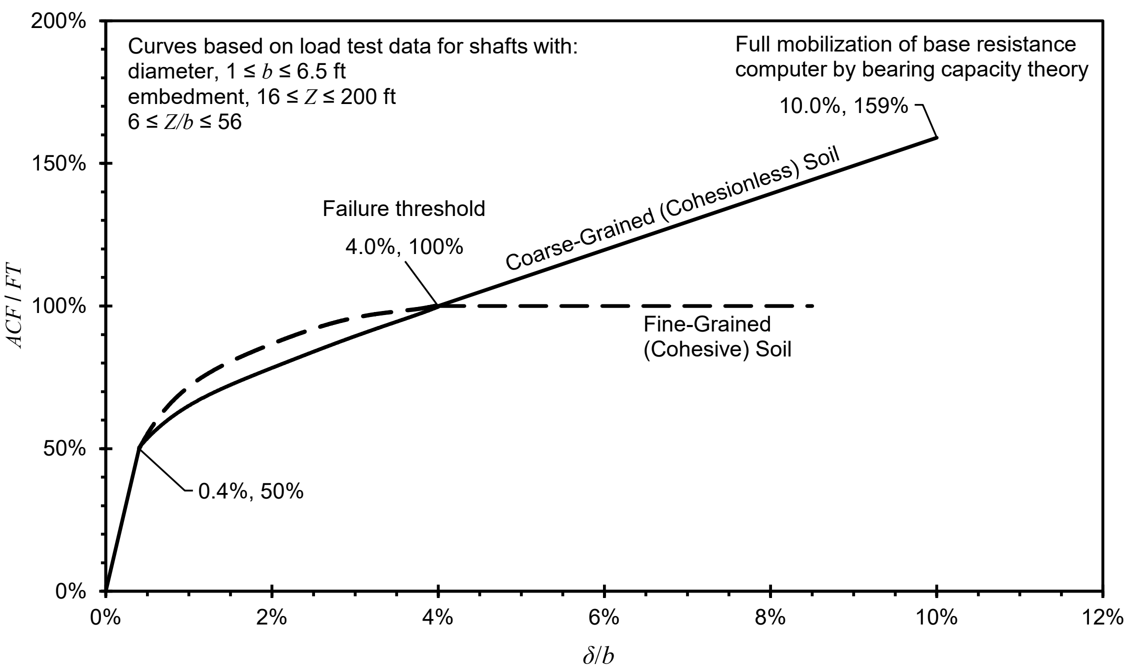


Figure 6-17 Load-displacement Curve for Drilled Shafts (after Chen and Kulhawy 2002)

Table 6-31 Relationships for Normalized Drilled Shaft Settlement vs Normalized Loading

<table>
<tr><th rowspan="2">ACF / FT (%)</th><th colspan="2">Approximate δ / b (%)</th></tr>
<tr><th>Fine-Grained (Cohesive) Soil[A]</th><th>Coarse-Grained (Cohesionless) Soil[B]</th></tr>
<tr><td>0 to 50%</td><td colspan="2">$0.008\left(ACF/FT\right)$</td></tr>
<tr><td>>50% to 90%</td><td rowspan="2">$0.4\% + \dfrac{\left(ACF/FT - 50\%\right)}{50\% - 0.72\left(ACF/FT - 50\%\right)}$</td><td>$0.4\% + \dfrac{\left(ACF/FT - 50\%\right)}{27\% - 0.33\left(ACF/FT - 50\%\right)}$</td></tr>
<tr><td>>90% to <100%</td><td rowspan="2">$0.102\left(ACF/FT\right) - 6.2\%$</td></tr>
<tr><td>100% to 159%</td><td>Large settlements are anticipated</td></tr>
<tr><td>≥159%</td><td>Large settlements are anticipated</td><td>Large settlements are anticipated</td></tr>
<tr><td colspan="3">[A] The fit for fine-grained soils is within ±0.1% of the curve.
[B] The fit for coarse-grained soils is within ±0.1% of the curve, except for $89\% < ACF / FT < 93\%$ where the fit is within ±0.2% of the curve.</td></tr>
</table>

6-5.8.4 Equivalent Footing Method.

Equivalent footing methods use the concept of load spread to estimate settlement of pile groups (Fellenius 1988, FHWA 2016) as well as single piles (Greenfield and Filz 2009). These methods can be applied to a variety of foundation types not bearing on or in rock including driven piles, micropiles, CFAs, DDPs, and groups of drilled shafts. Equivalent footing methods have the following common features:

1) Determine an elevation along the element(s) below which shedding of the applied load from the element(s) will compress the underlying soils,

2) Estimate the change in vertical effective stress using an assumed method of spreading of the applied foundation load, e.g., 2V:1H spread, within the zone of influence defined by the lateral boundaries of load spread, and

3) Estimate soil compression or settlement transferred to the foundation using conventional one-dimensional methods for clay and sand soils.

For the service limit state, the applied foundation load is the unfactored permanent load. For the neutral plane method, drag loads are not added to the permanent load and spread below the elevation of load shedding as discussed in Section 6-5.8.4.2 (Fellenius 1988).

In the basic forms presented here, load spread methods ignore the beneficial stiffening and stress shielding effects that groups of foundation elements usually have on the compressibility of the soils within the group. Procedures to account for these effects can be found in Fellenius (2021) and Greenfield and Filz (2009).

6-5.8.4.1 Empirical Selection of Equivalent Footing.

The depth and dimensions of the equivalent footing with plan-view dimensions of B and L can be selected using the guidance provided in Figure 6-18 and Table 6-32. Some spreading of the load above the equivalent footing depth is considered in some cases. The depth (z_s) represents the depth to the bearing layer(s), Z_b is the depth of embedment in the bearing layer(s), z_1 is the depth below the base of the pile cap to the assumed start of load spreading, and z_2 is the depth interval where load spreading is assumed to occur at 4V:1H. The depth to the equivalent footing is the sum of z_1 and z_2, and load spreading is assumed to occur at 2V:1H below the equivalent footing.

The width, B', and length, L', of the equivalent footing are determined from the dimensions of the group of elements (Figure 6-15), B and L, according to the following equations:

$$B' = B + \frac{z_2}{2} \quad (6\text{-}49)$$

and

$$L' = L + \frac{z_2}{2} \quad (6\text{-}50).$$

FHWA (2016) provides guidance for sizing the equivalent footing for groups that include battered elements. For batter pile groups supported primarily by side resistance, the dimensions B' and L' should be based on the dimensions of the group at a depth equal to the sum of z_s and $2/3 \cdot Z_b$, including the plan area increase due to the batter angle. For battered groups supported primarily by base resistance, the dimensions B' and L' should be based on the dimensions of the group at a depth equal to the sum of z_b and Z_b, including the plan area increase due to the batter angle.

The change in total vertical stress due to the applied load, Q, at a particular depth, z, is estimated by 2V:1H spreading:

$$\Delta\sigma_z = \frac{Q}{(B'+z')(L'+z')} \quad (6\text{-}51)$$

where:
z' = depth below the equivalent footing = $z - z_1 - z_2$.

Other sources of stress change leading to settlement of the foundations should be investigated and incorporated into the calculations if needed. Potential sources of additional stress change include lowering the groundwater table, placement of fill, and overlap of the zones of influence from adjacent foundations. The neutral plane method described in the next section is the preferred approach for incorporating other sources of stress change.

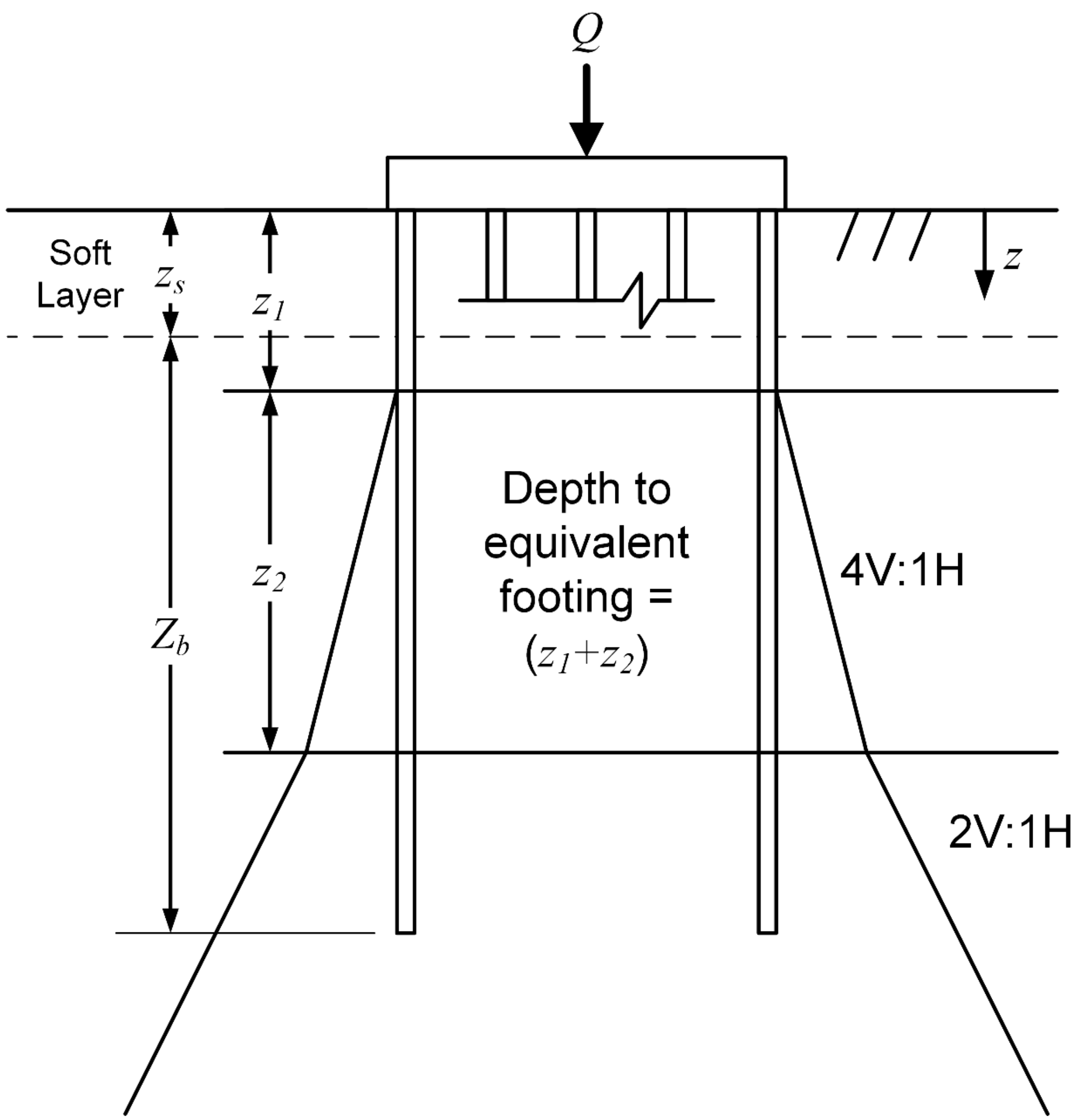


Figure 6-18 Locating the Equivalent Footing

Table 6-32 Guidance for Locating the Equivalent Footing

Columns installed in…	z_1	z_2	Source
Sand or clay, $z_s = 0$	$2Z_b/3$	0	Terzaghi and Peck (1967)
Soft clay over firm clay, z_s = depth to firm clay	$z_s+2Z_b/3$	0	Duncan and Buchignani (1987)
Soft clay over hard clay or sand underlain by soft clay, z_s = depth to hard clay or sand	z_s	0	FHWA (2000)
Clay, $z_s = 0$	0	$2Z_b/3$	
Sand over clay, $z_s = 0$	$2Z_b/3$	$2Z_b/9$	
Layered sand and/or clay, $z_s = 0$	0	$2Z_b/3$	

6-5.8.4.2 Neutral Plane Method.

The neutral plane method described in this section is generally a better approach for locating the equivalent footing since it directly uses the specific loading applied to the element, the side friction, and mobilized base resistance to locate the elevation where load shedding occurs. The neutral plane method can be applied to all cases, not just those where significant drag forces are anticipated.

The neutral plane method rationally considers the applied load, positive and negative skin friction, and the mobilized base resistance to locate the elevation along the element(s) where load shedding leading to foundation settlement begins. The neutral plane method can be applied to a single element as well as groups of elements.

The neutral plane is located using the first five steps of the process described in Section 6-5.7 to evaluate the drag force. For soil profiles that are uniform or become less compressible with depth, the estimated foundation settlement increases as the neutral plane is positioned higher along the element. The assumption of full mobilization of base resistance used to evaluate the drag load for the structural strength limit state is not conservative for settlement calculations.

The more refined estimate of the percentage of base resistance mobilization should be made. Siegel et al. (2013) describe a simpler option and recommend analyzing the problem with a range of different assumed mobilizations of the base, e.g., 0%, 50%, and 100% mobilization. If the conclusion regarding the settlement estimates is not sensitive to the lowest and highest reasonable estimates of base resistance, additional efforts to estimate base mobilization are unlikely to be needed. If the conclusion depends on the assumed base mobilization, calculations can be refined using load transfer-displacement relationships, i.e., t-z and q-z curves, to evaluate the mobilization of the base.

Once the neutral plane has been located, an equivalent footing is positioned at the elevation of the neutral plane, and the settlement analysis can proceed using the equations for one-dimensional compression described in Section 6-5.8.4.3. For a group of elements, the dimension of the equivalent footing is usually taken to equal the dimensions of the group, i.e., $B' = B$ and $L' = L$. For a single element, the dimensions of the footing are equal to the width of the element.

The change in total vertical stress at a particular depth, z, due to the applied load, Q, and any other sources of stress change, $\Delta\sigma_{z,other}$, is estimated by:

$$\Delta\sigma_z = \frac{Q}{(B'+z')(L'+z')} + \Delta\sigma_{z,other} \qquad (6\text{-}52)$$

where:
z' = depth below the equivalent footing to the depth z.

The additional settlement due to $\Delta\sigma_{z,other}$ is the downdrag component of foundation settlement. The magnitude of $\Delta\sigma_{z,other}$ can be found using conventional methods for estimating stress changes at depth, e.g., load spread, Boussinesq, etc.

6-5.8.4.3 Settlement Estimates using the Equivalent Footing.

Once $\Delta\sigma_z$ has been estimated as a function of depth below the equivalent footing, conventional one-dimensional methods can be applied to estimate the compression resulting from the change in stress. For the fully drained condition, the change in effective stress, $\Delta\sigma'_z$, equals the change in total stress $\Delta\sigma_z$. This condition is expected at the time of loading and beyond for high permeability sands and gravels under normal rates of loading. For low permeability materials, the fully drained condition is reached over time. Time rate of consolidation analysis, described in Chapter 5 of DM 7.1 is used to evaluate settlements for partially drained conditions.

For clays and some silts, the compression due to a change in vertical effective stress is found by:

$$\delta_s = H_0 \left[C_{\varepsilon r} \log\left(\frac{\min\left(\sigma'_{z0} + \Delta\sigma'_z, \sigma'_p\right)}{\sigma'_{z0}} \right) + C_{\varepsilon c} \log\left(\frac{\max\left(\sigma'_{z0} + \Delta\sigma'_z, \sigma'_p\right)}{\sigma'_p} \right) \right] \qquad (6\text{-}53)$$

where:
H_0 = initial thickness of the consolidating layer
$C_{\varepsilon r}$ = modified recompression index
$C_{\varepsilon c}$ = modified compression index,
σ'_{z0} = initial effective vertical stress, and
σ'_p = preconsolidation stress.

Elastic compression of coarse-grained soil can be approximated using basic one-dimensional elastic theory according to the following equation:

$$\delta_s = H_0 \left[\frac{(1+\nu_s)(1-2\nu_s)\Delta\sigma'_z}{E_s(1-\nu_s)} \right] \quad (6\text{-}54)$$

where:
ν_s = Poisson's ratio for the soil,
E_s = Young's Modulus for the soil, and
$\Delta\sigma'_z$ = average change in effective vertical stress over the thickness of the sand, H_0.

As described in FHWA (2016), the compression of sand can also be estimated using the nonlinear method proposed by Hough (1959) and later refined by FHWA (2002).

A more refined estimate of the soil settlement can be obtained by discretizing the compressible layer(s) into sublayers, evaluating the average stresses for each sublayer, computing the compression of each sublayer, and summing the compression of the individual sublayers.

Highly compressible deposits may extend a significant depth below the base of the foundation elements. At some depth, the change in vertical stress caused by the applied load becomes sufficiently small to ignore the soil compression. This depth is typically selected where the change in stress is less than 10% of the bearing stress of the equivalent footing.

Figure 6-19 shows that the settlement of the pile and the soil are equal at the neutral plane. The additional pile settlement above the neutral plane is due to elastic shortening of the pile while the additional soil settlement above the neutral plane is the free field settlement due to sources of stress change other than the applied foundation load. Below the neutral plane, the soil settlement is due to the stress changes from the applied foundation load and stress changes from other sources. The difference between the soil and pile settlement at the toe elevation is the pile penetration in the soil. If a q-z curve is defined, an iterative process can be applied, as described by Fellenius (2021), so that the mobilized toe resistance used to locate the neutral plane is compatible with the pile toe penetration.

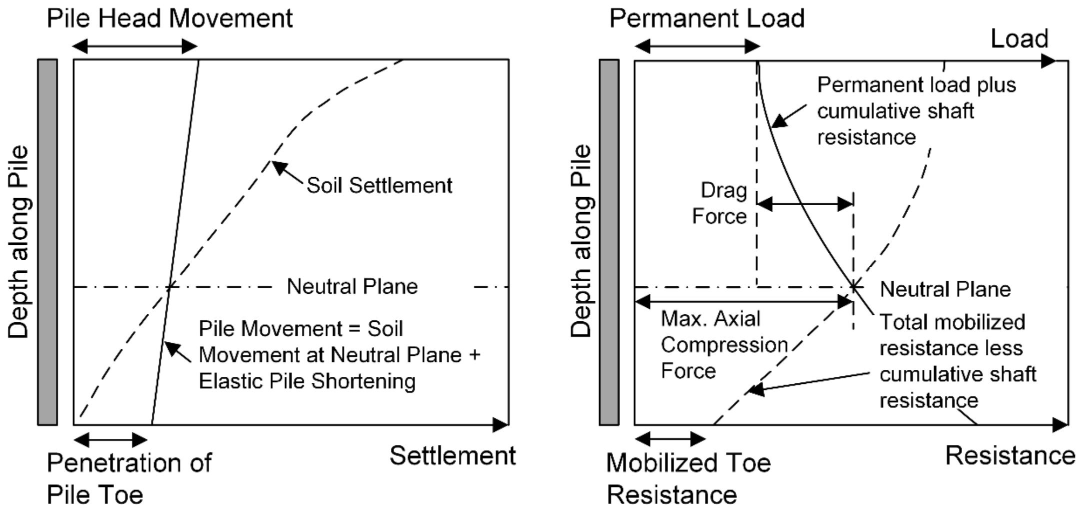


Figure 6-19 Schematic of the Neutral Plane Method for Estimating Settlement

6-5.8.5 Mitigation of Downdrag.

Several measures exist for reducing downdrag and drag force. One approach is to reduce the settlement of the ground that occurs once the columns are installed. This can be accomplished by reducing the total settlement using lightweight fill or ground improvement. Alternatively, consolidation can be accelerated using wick drains, so that a majority of the settlement is complete by the time the columns are installed. Another approach is to intentionally reduce the interface shear strength between the column shaft and soil over some, or all, of the length above the neutral plane. There are many ways to accomplish this. For example, a smooth steel pile can be used instead of a rough concrete column. Columns can be coated in bitumen or epoxy to reduce friction. Columns can also be isolated from the surrounding ground using a slurry or casing.

6-6 GEOTECHNICAL LATERAL CAPACITY.

6-6.1 Introduction.

This section provides guidance for evaluating the lateral capacity of batter and vertical single columns as well as groups of columns. Mainstream contemporary practice has largely migrated to using nonlinear p-y analysis software for evaluating lateral capacity; however, analyses that that can be performed by hand remain valuable as checks of software output and in situations where software is unavailable.

The previous version of this manual contained chart solutions for a linear subgrade reaction analysis of laterally loaded piles originally proposed by Reese and Matlock (1956). The effects of nonlinearity in the lateral load-displacement relationship often have significant effect on the outcome of the analysis (Reese et al. 2004); therefore, the nonlinear Characteristic Load Method (CLM) (Evans and Duncan 1982) is presented in lieu of the linear subgrade reaction charts. As explained below, the CLM method was calibrated to the results of p-y analyses. Since p-y analyses are not fully applicable to short piles that tend to experience base rotation at the strength limit state, the Broms method (1964a,b, 1965), for short free-head piles that are assumed to be rigid, is also presented.

There are a significant number of software offerings available to perform lateral load analysis, including general purpose finite element and finite difference software. LPILE (Ensoft) and RSPile (Rocscience) are popular software options for performing p-y analyses in US practice. Software documentation should be consulted for the details of specific pile-soil models and software usage.

6-6.2 Lateral Loading and Foundation Response.

Sources of lateral loads on foundations include loads transferred by the superstructure from wind, ice, vehicle impacts, ship mooring, moving water, thermal expansion/contraction, earthquakes, and dynamic forces from traffic braking loads and machinery. Additional lateral loads can be directly applied to the foundation from ground displacements due to surface loading, excavation, earthquakes, lateral spreading, landslides, creep, and consolidation in the case of batter piles.

Lateral loading can be static or cyclic. Static loading can be of short duration (uncommon) or sustained. Sustained static loading, e.g., from earth pressures, can cause creep and three-dimensional consolidation of the ground; however, these effects are often not considered for clean sands, overconsolidated clays, and rock. Creep and consolidation due to sustained loading has the effect of softening the relationship between lateral load and deflection. Cyclic loading also softens the load-deflection relationship, particularly in cases where free water is available above a pile in clay. In this case, the cyclic movement of the pile pumps water in and out of the space between the pile and the soil. This effect can lead to significant remolding and erosion of the soil. The selection of input parameters for lateral capacity analysis, e.g., p-y curves, should reflect the nature of the loading for the particular pile and soil conditions (Reese et al. 2004). The discussion herein is limited to relatively simple cases of lateral load and/or moment applied to the top of a column installed in level ground.

Laterally loaded piles fall into two major categories. Relatively s*hort piles* behave as approximately rigid elements that will experience rotation and/or translation of the base at the strength limit state for laterally loaded conditions, which is usually controlled by the geotechnical capacity. Short piles include drilled shafts with a low ratio of length to width, foundations for lighting or sign masts, foundations for communications towers, and foundations bearing on shallow rock. In contrast, relatively *long piles* are slender enough to behave as a flexible member having an essentially fixed base, i.e., no rotation or translation. These include most driven pile, CFA, micropile, and DDP elements. Some drilled shafts can also be considered long piles. The strength limit state for lateral loading of long piles is usually controlled by the structural capacity rather than the geotechnical capacity.

Broms (1965) and Davisson (1970) distinguish between short and long piles based on the ratio of the total length of the element, Z, divided by the *depth to fixity*, Z_f. The definition and methods to calculate the depth to fixity are presented in Section 6-7.2 in the context of buckling.

When Z/Z_f is less than a certain value, the element can be considered a short pile. The response to lateral loading is sensitive to the pile length, but not the stiffness, i.e. the pile can be treated as being infinitely stiff. For elements in undrained fine-grained soil, Broms (1965) characterizes short piles as Z/Z_f less than 2.25 while Davisson (1970) characterizes short piles as Z/Z_f less than $\sqrt{2}$. For elements in coarse-grained soil, Broms (1965) and Davisson (1970) characterize short piles as Z/Z_f less than 1.11.

When the ratio of Z/Z_f is greater than a certain value, the element can be considered a long pile. The response to lateral loading is sensitive to the pile stiffness, but not the length, i.e. the pile can be treated as being infinitely long. For elements in undrained fine-grained soil, Broms (1965) characterizes long piles as Z/Z_f greater than 2.25 while Davisson (1970) characterizes long piles as Z/Z_f greater than $2\sqrt{2}$. For elements in coarse-grained soil, Broms (1965) and Davisson (1970) characterize long piles as Z/Z_f greater than 2.22.

Ratios of Z/Z_f that fall between the criteria for short and long piles are considered intermediate piles, that respond somewhere between a short and long pile. The strength limit state for lateral loading of intermediate piles may be controlled by structural or geotechnical capacity.

6-6.2.1 Limit States for Lateral Capacity Analyses.

Deep foundations that are used to resist lateral loads must consider the strength, service, and extreme event limit states, which are defined in Section 6-5.2. The strength and extreme limit states include consideration of the geotechnical and structural lateral load capacities. The service limit state considers the lateral deflections under service loading conditions. When the modeling capability is available, e.g. LPILE and RSPile, axial loads should be included in the analysis since they influence the maximum flexural capacity as well as lateral deflection. The strength and serviceability limit states should consider the effects of the scour design flood as defined in Section 6-2.2.1.

The preferred way to evaluate the geotechnical strength limit state for vertical piles and drilled shafts is to perform a pushover analysis using the p-y method that reach a state of failure. *Pushover analysis* applies specific combinations of lateral load and/or moment to the top of the pile and predicts the resulting lateral displacement. Pushover analyses that fail to converge or estimate excessive deformations constitute failure. For example, FHWA (2018a) defines deformations that exceed 10% of the width or diameter of the element as failure. Pushover analyses are frequently performed for incrementally increasing magnitudes of applied load and moment up to, and sometimes beyond, the factored values for the strength limit state. This approach is useful to visualize the load-deflection relationship and identify if nonlinear behavior occurs that may indicate the onset of large displacements with additional loading. For example, FHWA (2018a) recommends that the piles be loaded to an amount equal to the factored loads multiplied by the inverse of the resistance factor. For short piles and other conditions that are not well addressed by *p-y* analysis (FHWA 2018b), other methods, such as the Strain Wedge Model (SWM) (Norris 1986, Ashour et al. 1998), may be applied using computer software. The Broms Method for short free-head elements provides a hand solution that is widely used for preliminary analysis. A simple method for evaluating the strength limit state of batter piles is presented in Section 6-6.2.

The structural strength limit state is checked to ensure that factored axial, shear, and moment resistances exceed the factored axial loads, shear loads, and bending moments. The *p-y* method is the preferred analysis method. The nonlinear structural properties of the foundation element, i.e. nonconstant bending stiffness, including the potential for cracking of concrete elements, should be incorporated into the analysis when the software capability is available. The combinations of unfactored axial load (P) and moment (M) that govern the structural strength of the element are depicted on a P-M interaction diagram. A factored interaction diagram is produced by applying a single structural resistance factor that is appropriate for the type of element and design specifications. The combinations of factored loads and moments for each application limit state are plotted on the factored interaction diagram to check whether the combination falls within the acceptable zone defined by the factored diagram. Since axial load can increase moment resistance, both minimum and maximum factored axial loads should be checked. For reinforced and prestressed concrete elements, this step in the design process is used to confirm that the steel area ratio is sufficient and reasonable.

The service limit state is evaluated by ensuring that lateral deflection under service loading conditions is tolerable. The *p-y* method is the preferred analysis method, though the SWM can also be used. The nonlinear structural properties of the foundation element, including the potential for cracking of concrete elements, should be incorporated into the analysis when the capability is available. Limits on lateral deflection depend upon the project requirements but are usually smaller than the tolerable limit of settlement. Lateral deflection limits are often in the range of ¼ to ½ of an inch.

The extreme limit state is evaluated in a similar fashion as the strength limit state using different applied loading and different resistance factors. The Extreme Event II limit state (AASHTO 2020) also includes the effects of the scour check flood as described in Section 6-2.2.1.

Table 6-33 provides recommended lateral resistance factors for driven piles and drilled shafts as presented in FHWA (2018b). These factors are appropriate for all geomaterials and are intended to ensure that the shaft remains ductile beyond the factored design load and provides adequate reserve strength. AASHTO (2020) recommends using appropriately-factored loads with resistance factors equal to 1.0 for driven piles and drilled shafts for all lateral load limit states.

Table 6-33 Recommended Factors for Lateral Geotechnical Resistance (after FHWA 2018b)

Limit State	Resistance Factor
Strength: Pushover of individual deep foundation or single row of elements; top is free to rotate	0.67
Strength: Pushover of multiple-row group; tops are restrained by moment connection to cap	0.8
Service	1.0
Extreme event	0.8

6-6.2.2 Fixity.

Embedment of the pile in a pile cap provides rotational restraint at the top of the pile, which affects the response to lateral loads and displacements. A pile top with zero fixity, or *free head* condition, is allowed to rotate and develops zero moment at the top. In this case, the maximum bending moment usually occurs within 8 to 10 pile diameters of the top. A pile top with full fixity, or *fixed head* condition, is not allowed to rotate and develops maximum moment at the top. The degree of fixity is influenced by whether the pile is tied into a cap as part of a group (increases restraint) and the embedment within the cap (deeper embedment increases restraint).

Commonly, the degree of fixity is unknown. It may be prudent to perform lateral analyses twice, once assuming a free head condition and again assuming a fixed head condition. For a given applied load, the free head condition analysis will estimate larger lateral displacement while the fixed head analysis will estimate larger bending moment.

6-6.3 Lateral Analysis of Batter Piles.

Batter piles are installed at a batter angle measured from vertical that is usually less than 45 degrees (1H:1V). Typical batter angles fall between 1H:12V and 1H:3V (FHWA 2018b). Batter piles usually consist of driven piles or micropiles. Pile batter angle can be considered in p-y analyses.

Lateral capacity can be conservatively approximated by assuming that the piles only carry axial load as depicted in Figure 6-20. This assumption combined with practical limitations on batter angle regulates the lateral capacity of a particular pile. Normally, a pile with a battered alignment is much stiffer laterally compared to the same pile with a vertical orientation. This means that for the same earthquake or blast-induced lateral deflection, batter piles transmit much greater load and moment to the structure compared to the same number and type of vertical piles. Batter piles should also be used cautiously in cases where consolidating ground exerts a drag force on the pile (USACE 2012). Unlike a vertical pile where the drag load from 1D settlement is axial to the pile, a batter pile will experience bending moment due to the drag force.

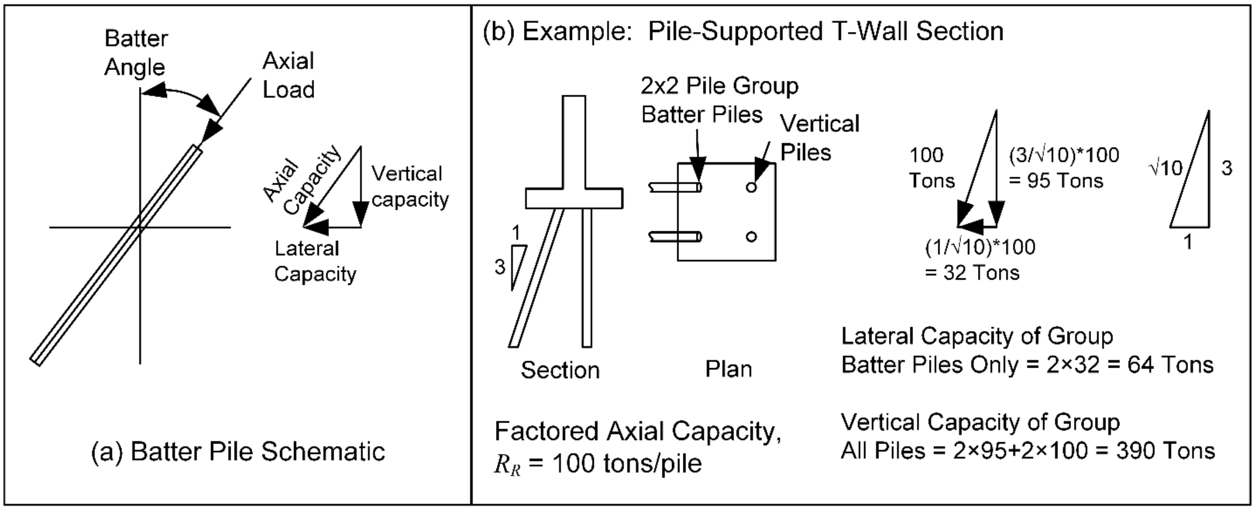


Figure 6-20 Axial Capacity of Batter Pile

6-6.4 Lateral Analysis of Single Vertical Piles.

Lateral loads and moments applied to vertical piles are resisted by the flexural stiffness of the pile and mobilization of resistance in the surrounding soil as the pile deflects. For long piles, consideration of the flexibility of the pile is very important for proper modeling of the soil and pile response. For short piles, pile flexure is small enough to be ignored and a rigid pile can be assumed.

6-6.4.1 Broms' Analysis of Rigid Short Free-Head Piles.

The ultimate geotechnical lateral capacity of short piles can be estimated using ultimate load solutions, such as the one proposed by Broms (1964a,b, 1965). Broms' analysis treats the pile as a rigid body and ignores the axial load in the pile. Separate analyses are provided for uniform undrained and drained soil profiles. There is currently no guidance for applying the Broms Method within an LRFD framework. Broms (1965) recommends scaling the lateral dead load applied to the top of the pile, $P_{t,dead}$, by a factor of 1.5 and the applied lateral live load, $P_{t,live}$, by a factor of 2.0. Since the moment applied at the top of the pile can equivalently be expressed as the product of the applied load and a height of the line of action above the ground line, the same factors apply to the moment. Therefore, the ultimate load, $P_{t,ult}$, and moment, $M_{t,ult}$, applied to the top of the pile can be found by:

$$P_{t.ult} = 1.5P_{t,dead} + 2.0P_{t,live} \tag{6-55}$$

and

$$M_{t.ult} = 1.5M_{t,dead} + 2.0M_{t,live} \tag{6-56}$$

where:
$M_{t,dead}$ = applied moment from dead load and
$M_{t,live}$ = applied moment from live load.

Broms (1965) recommends factoring the shear strength parameters used in the analyses as follows:

$$s_u^* = 0.75s_u \tag{6-57}$$

and

$$\phi'^* = \tan^{-1}\left(0.75\tan\phi'\right) \tag{6-58}$$

where:
s_u = undrained shear strength and
ϕ' = effective stress friction angle.

The pile capacity is checked by comparing the actual pile length to the minimum length calculated from the analysis. If the actual length equals or exceeds the minimum length, the applied load and/or moment to the top of the element should not exceed the geotechnical lateral capacity. If the minimum length exceeds the actual length, the applied load and/or moment should be reduced, and/or the pile should be lengthened.

6-6.4.1.1 Short Pile in Undrained Soil Conditions.

For an element in undrained soil conditions, application of the ultimate load and moment to the top of the pile produces the simplified earth pressure, shear, and moment diagrams shown in Figure 6-21. The minimum length of the pile (Z_{min}) includes an exclusion zone of $1.5\cdot b$ at the top of the pile, a length (f) that resists the applied load, and a length (g) that creates a couple to resist the applied and induced moment. The length of pile required to resist the lateral load:

$$f = \frac{P_{t,ult}}{9\cdot s_u^*\cdot b} \tag{6-59}$$

where:
b = width or diameter of the pile.

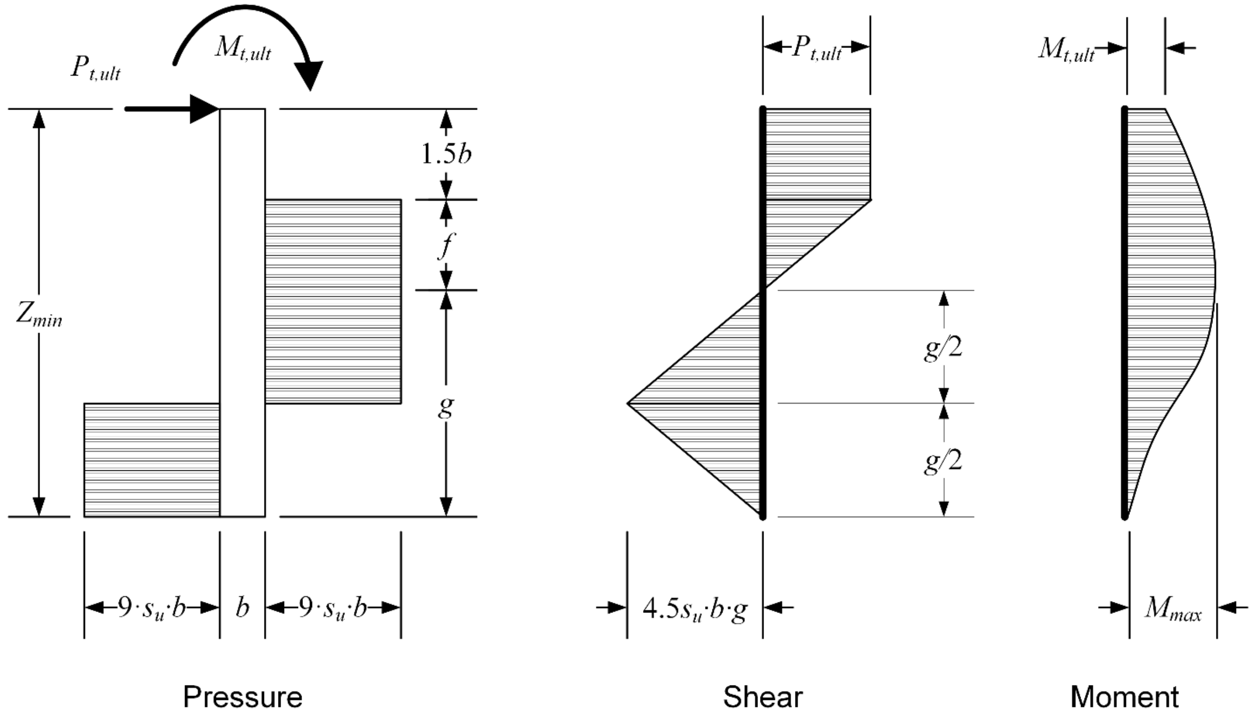


Figure 6-21 Earth Pressure, Shear, and Moment Diagrams for Broms Method in Undrained Soil Conditions (after FHWA 2010)

Once f has been determined, an expression for g can be derived by summing moments:

$$g = \sqrt{\frac{M_{t,ult} + P_{t,ult}\left(1.5 \cdot b + 0.5 \cdot f\right)}{2.25 \cdot b \cdot s_u^*}} \tag{6-60}$$

The minimum length is then calculated as:

$$Z_{min} = 1.5 \cdot b + f + g \tag{6-61}$$

6-6.4.1.2 Short Pile in Drained Soil Conditions.

For an element in drained soil conditions, application of the ultimate load and moment to the top of the pile produces the earth pressure, shear, and moment diagrams shown in Figure 6-22. The passive soil resistance, P_P, from Rankine theory is assumed to be developed along the entire pile length. This is multiplied by an empirical factor equal to three to account for three-dimensional effects and earth pressures acting on the nonpassive side, resulting in:

$$P_P = \frac{3}{2} b \cdot \gamma' \cdot K_P \cdot Z_{min}^2 \tag{6-62}$$

where:
γ' = effective unit weight of the soil, and
K_P = Rankine passive earth pressure coefficient determined using ϕ'^*.

As shown in Figure 6-22, Broms approximates the lateral reaction force on the toe as a concentrated load. For the applied ultimate load and moment, a minimum pile length is required to develop the countering resistance. The minimum required pile length is found by summing moments about the toe and rearranging to:

$$Z_{min} = \left[\frac{2\left(P_{t,ult} \cdot Z_{min} + M_{t,ult}\right)}{b \cdot \gamma' \cdot K_P} \right]^{1/3} \quad (6\text{-}63).$$

Because Z_{min} is on both sides of the equation, an iterative process is required when both $P_{t,ult}$ and $M_{t,ult}$ are nonzero, a.k.a flagpole loading. An initial value must be assumed for Z_{min} and adjusted until the solution converges.

The maximum moment for the ultimate condition occurs at a depth, f, below the pile top where the shear force is zero, which can be determined by:

$$f = \sqrt{\frac{2P_{t,ult}}{3 \cdot b \cdot \gamma' \cdot K_P}} \quad (6\text{-}64).$$

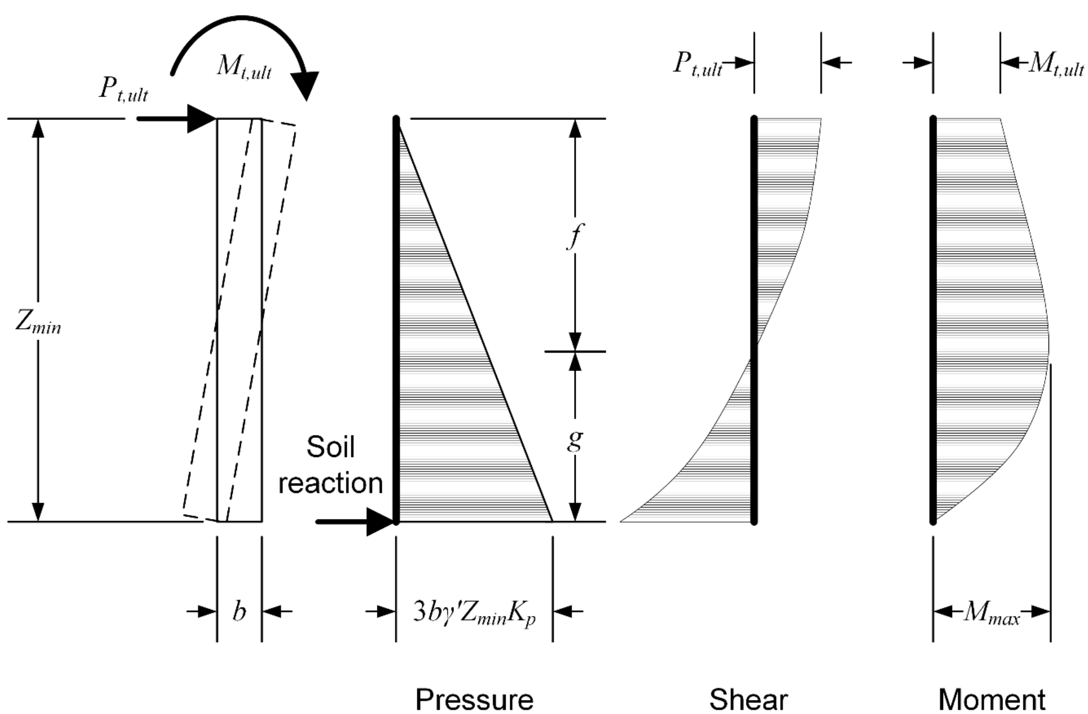


Figure 6-22 Earth Pressure, Shear, and Moment Diagrams for Broms Method in Drained Soil Conditions (adapted from FHWA 2010)

The maximum moment is found by summing moments about the location of zero shear, as:

$$M_{max,ult} = M_{t,ult} + P_{t,ult} \cdot f - \left(\frac{b \cdot \gamma' \cdot f^3 \cdot K_P}{2} \right) \quad (6\text{-}65).$$

The dimension g is equal to Z_{min} minus the dimension f.

6-6.4.2 *p-y* Analyses.

Numerical p-y analyses (FHWA 1984, 1986) relate load (p) and deflection (y) by discretizing the pile into elements that are connected to the surrounding ground by springs and sliders, as shown in Figure 6-23. Common procedures to define p-y relationships are semiempirical and calibrated based on load test data, e.g., p-y relationships for piles in soft clay proposed by Matlock (1970). The stiffness of the pile elements in bending, the stiffness of the springs, and load required for displacement of the sliders interact to produce the load-deflection and load-moment response of the model.

Contemporary pile-soil spring models are generally nonlinear; however, it is possible to specify linear springs, if desired, to compare to the results from a linear subgrade reaction analysis. The stiffness of a linear pile-soil spring does not depend on how much it is compressed whereas the stiffness of a nonlinear spring does depend on how much it is compressed. If a slider is present, then plastic yield in the soil can be considered. These analyses are performed almost exclusively using commercial software such as LPILE and RSPile. The appendix to FHWA (2018b) provides a good summary of the commonly used p-y models.

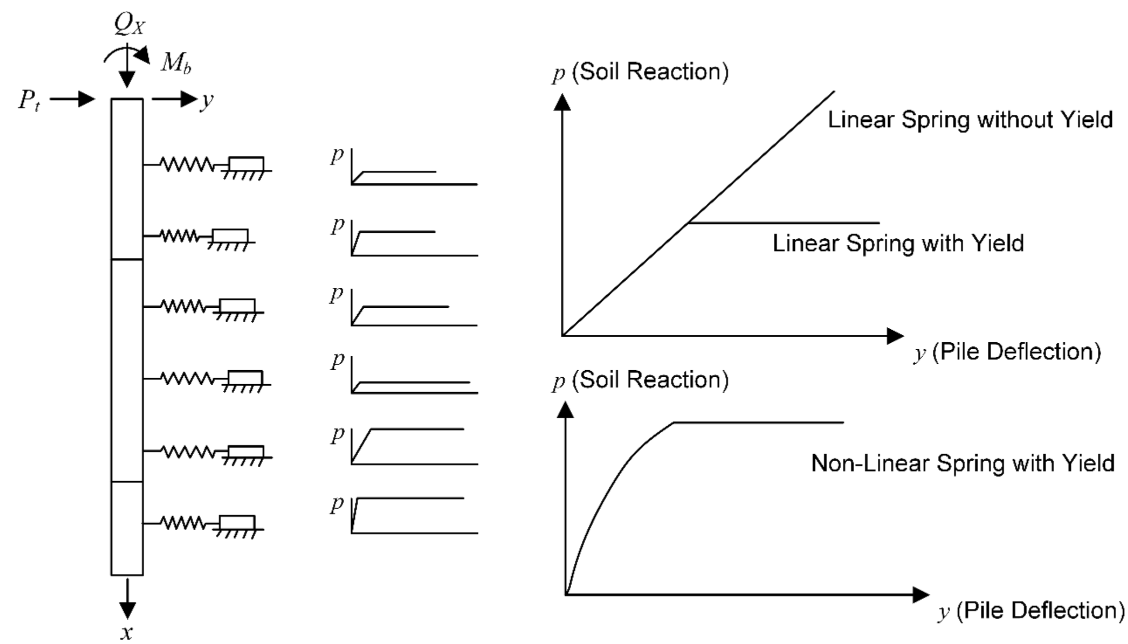


Figure 6-23 *p-y* Relationships

6-6.4.3 Characteristic Load Method.

Duncan et al. (1994) described parametric studies using LPILE and expressed the results in terms of "characteristic load" and "characteristic moment."[39] The resulting Characteristic Load Method (CLM) is simpler than *p-y* analyses and does not require special software. This approach can be used as a standalone option when computer software is not available or as a check of computer analyses. The CLM can be applied to single elements as described in this section and groups of elements as described in Section 6-6.4. The CLM is directly applicable to long piles in uniform ground conditions. For pile lengths less than $18b$ in clay and $14b$ in sand, consult Duncan et al. (1994) to confirm that the CLM is a suitable approach. Since the upper length of pile is the most important for the lateral response, the CLM is expected to perform acceptably well in nonuniform ground conditions that can be approximated as uniform within 8 to 10 pile widths of the pile top (Duncan et al. 1994).

The CLM estimates the lateral deflection at the top of an element due to an applied ground line load, P_t, and/or moment, M_t. The CLM does not consider the effects of applied axial load on the response of the foundation element to P_t and/or M_t. The characteristic load, P_c, and moment, M_c, are the basis for the dimensionless relationships used in the CLM and are found by applying the appropriate equations

[39] In this context, an applied load or moment equal to the characteristic load or moment will generate a normalized pile deflection equal to a constant value for a particular soil type and fixity.

provided in Table 6-34. The pile is assumed to have constant linear bending stiffness, i.e. nonlinear effects from concrete cracking are not considered. If high bending moments are anticipated, the moment of inertia of the pile (I_p), may be reduced by a factor of 0.4 to 0.5 as an allowance for cracking in concrete elements (Duncan et al. 1994). The bending moment estimated by a CLM analysis considering an uncracked section can provide insight into whether the moments are sufficiently close to the cracking moment of the section to warrant the reduction.

Table 6-34 Equations for Characteristic Parameters (Clarke and Duncan 2002)

Soil	Characteristic Parameter	Equation
Clay	P_c	$P_c = 7.34b^2\left(E_pR_I\right)\left(\frac{s_u \cdot p_{m,avg}}{E_pR_I}\right)^{0.68}$
	M_c	$M_c = 3.86 \cdot b^3\left(E_pR_I\right)\left(\frac{s_u \cdot p_{m,avg}}{E_pR_I}\right)^{0.46}$
Sand	P_c	$P_c = 1.57b^2\left(E_pR_I\right)\left(\frac{\gamma' b \cdot \phi' K_p p_{m,avg}}{E_pR_I}\right)^{0.57}$
	M_c	$P_c = 1.33b^3\left(E_pR_I\right)\left(\frac{\gamma' b \cdot \phi' K_p p_{m,avg}}{E_pR_I}\right)^{0.40}$

b = diameter or width of the element, E_p = Young's Modulus of the element, ϕ' = friction angle (in degrees), $K_P = \tan^2(45 + \phi'/2)$

$p_{m,avg}$ = weighted average p-multiplier when CLM is applied to pile groups as described in Section 6-6.5. Use Mokwa (1999) equations in Table 6-38. For single piles, use $p_{m,avg}$ =1.

R_I = the ratio of the moment of inertia of the pile section, I_p, to the moment of inertia of a solid circular section, I_{circ}. R_I is calculated as:

$$R_I = \frac{I_p}{I_{circ}} = \left(\frac{64}{\pi \cdot b^4}\right)I_p$$

NCHRP (1991) presents a method for evaluating R_I for composite sections of concrete and reinforcing steel. Table 6-35 summarizes values of R_I for a circular concrete section having a Young's modulus equal to 3,500 ksi, reinforced with steel having an Young's modulus of 29,000 ksi, and a combined cross-sectional area of 1% to 8% of the gross area of the section. The reinforcing steel is assumed to have 3 inches of concrete cover. If the values of R_I from Table 6-35 are used, the Young's modulus for the concrete should be used to calculate P_c and M_c.

The shear strength parameter values and Rankine passive earth pressure coefficient, K_P, used to calculate P_c and M_c should be based on representative values over a depth of $8 \cdot b$ because the soils near the top of the element are most important for lateral resistance.

Table 6-35 R_I Values for Circular Reinforced Concrete Section

Steel Area Ratio	R_I values for Reinforced Concrete Sections with Various Diameters			
	b = 18 in.	b = 24 in.	b = 30 in.	b = 36 in.
1%	1.06	1.07	1.09	1.09
2%	1.11	1.14	1.16	1.18
4%	1.21	1.27	1.31	1.34
8%	1.38	1.50	1.58	1.63
Assumptions: E_{steel} = 29,000 ksi, E_{conc} = 3500 ksi, 3 inches cover				

The applied load and moment are normalized by the characteristic load and moment, respectively, and the lateral deflection at the top of the element, y_t, is normalized by the element width. The dimensionless parameter values are related by power functions having values for the constant, a, and exponent, n, given in Table 6-36 and are calculated as:

$$\frac{y_t}{b} = a\left(\frac{P_t}{P_c}\right)^n \tag{6-66}$$

$$\frac{P_t}{P_c} = \left(\frac{1}{a}\frac{y_t}{b}\right)^{\frac{1}{n}} \tag{6-67}$$

$$\frac{y_t}{b} = a\left(\frac{M_t}{M_c}\right)^n \tag{6-68}$$

and

$$\frac{M_t}{M_c} = \left(\frac{1}{a}\frac{y_t}{b}\right)^{\frac{1}{n}} \tag{6-69}$$

Table 6-36 Constants for Load and Moment Deflection Equations (after Brettmann and Duncan 1996)

Soil Type	Ratio	Fixity	a	n
Clay	P_t/P_c	Free	50.0	1.822
		Fixed	14.0	1.846
	M_t/M_c	N/A	21.0	1.412
Sand	P_t/P_c	Free	119.0	1.523
		Fixed	28.8	1.500
	M_t/M_c	N/A	36.0	1.308

When P_t or M_t equals zero, straightforward application of Equations 6-66 through 6-69 enable the deflection at the top of the element to be estimated. When both P_t and M_t are nonzero, a process of nonlinear superposition must be followed, as described below and illustrated in Figure 6-24. In this process, the deflection due to applied load, y_{tp}, is distinguished from the deflection due to applied moment, y_{tm}.

The nonlinear superposition involves seven steps:

1) Estimate y_{tp} due to P_t using Equation 6-66.

2) Estimate y_{tm} due to M_t using Equation 6-68.

3) Estimate the equivalent load (P_m) that produces y_{tm}. Substitute P_m for P_t in Equation 6-67.

4) Estimate the equivalent moment (M_p) that produces y_{tp}. Substitute M_p for M_t in Equation 6-69.

5) Combine P_t and P_m to estimate the deflection due to load and moment, y_{tpm}, using Equation 6-66.

6) Combine M_t and M_p to estimate the deflection due to moment and load, y_{tmp}, using Equation 6-68.

7) Average the deflection estimates.

The maximum moment in the element occurs at the top of the element for 100% fixity and a depth below the top for 0% fixity. Using the appropriate coefficients provided in Table 6-37, the maximum moment due to the application of P_t can be estimated as:

$$\frac{M_{\max}}{M_c} \approx a\left(\frac{P_t}{P_c}\right)^n \qquad (6\text{-}70).$$

Refer to Duncan et al. (1994) for the procedure to estimate the maximum bending moment when P_t and M_t are both nonzero.

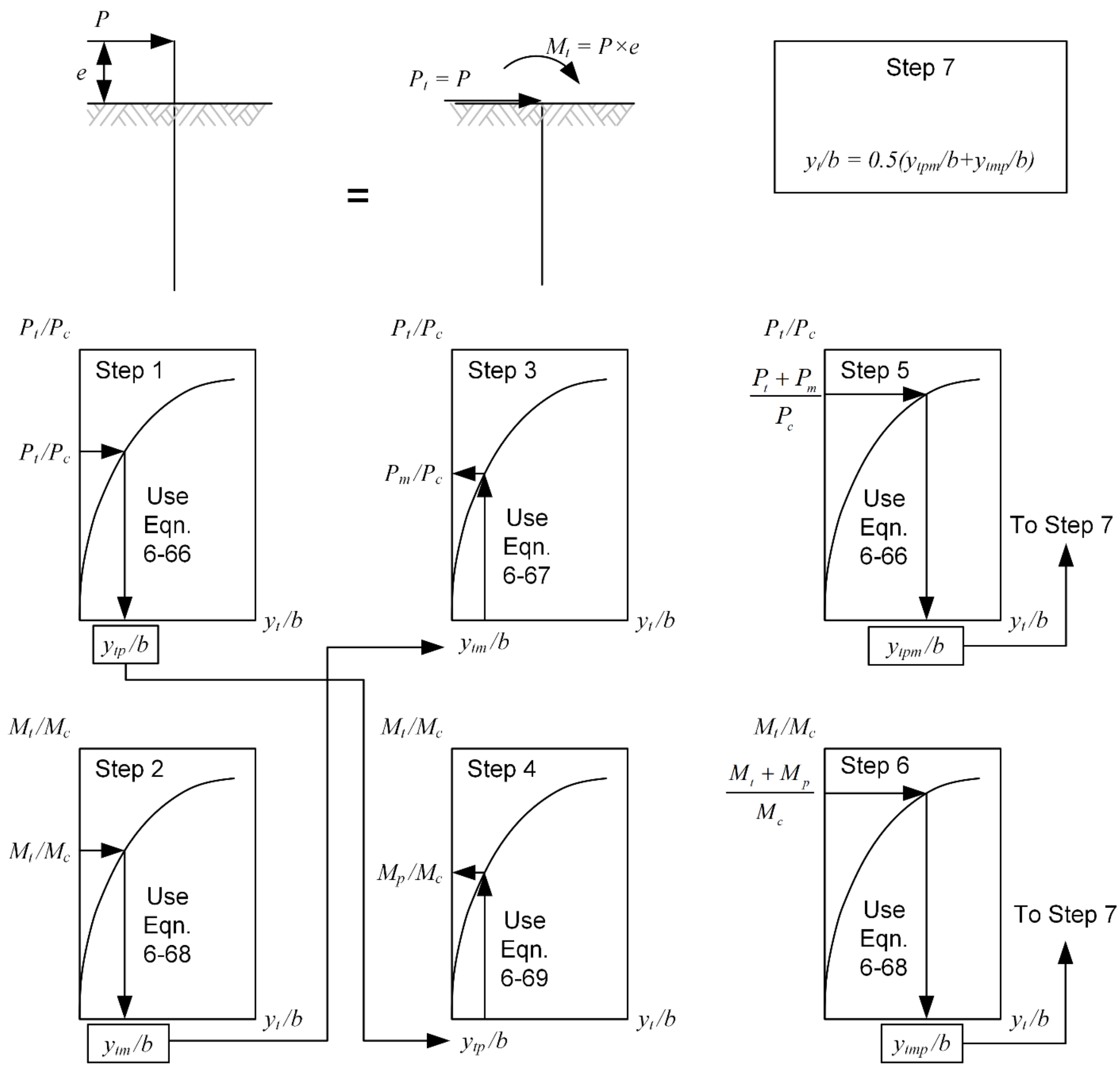


Figure 6-24 Nonlinear Superposition Process to Estimate Deflection

Table 6-37 Coefficients for Estimating the Maximum Moment

Soil	**Fixity**	***a***	***n***
Clay	Free	0.855	1.288
	Fixed	0.782	1.249
Sand	Free	4.28	1.384
	Fixed	2.64	1.300

Duncan et al. (1994) do not provide guidance for factoring loads and resistances for evaluating the strength limit state. An approach similar to the one proposed by Broms (1965), described in Section 6-6.4.1, to factor up applied loads and moments and factor down shear strength can be used for this purpose. The lateral deformation criterion of 10% of the element width or diameter (FHWA 2018a) can be used to define failure.

6-6.5 Groups of Vertical Piles.

Three important issues govern considerations of the lateral capacity of a pile group:

1) Pile-soil-pile interaction – At the same load per pile, lateral deflections and moments in groups are larger than for single piles because of interaction with adjacent piles through the soil in between. Piles in the corner of a group tend to carry more lateral load than piles in the center of a group, and trailing rows of piles, as defined in Figure 6-25, have significantly less lateral resistance than the lead row.

2) Interaction between the piles and the cap – The stiffness of the pile affects the distribution of loads and moments from the pile cap to individual elements. For elements with some fixity, lateral displacement will cause the cap to rotate and change the loads and moments in the elements.

3) Lateral capacity of the pile cap – If the pile cap is embedded in the ground and is protected from scour and other factors that weaken or remove the surrounding ground, there can be significant passive resistance developed between the cap and the ground to counteract lateral loads (Duncan and Mokwa 2001a).

Items 1 and 2 are group effects that are typically addressed by considering the fixity of the pile group in the cap and through the use of p-multipliers to reduce the force, p, at a particular deflection, y, in the p-y curves. A significant body of experimental and analytical work described in FHWA (2018b) explores appropriate p-multipliers to use for design. For the pile spacing parallel to the direction of loading, pile-soil-pile interaction becomes insignificant at and beyond a center-to-center pile spacing of $6{\cdot}b$ (Mokwa 1999). For a single row of piles spaced perpendicular to the direction of loading, pile-soil-pile interaction becomes insignificant at and beyond a center-to-center pile spacing of $5{\cdot}b$ (FHWA 2018b). Since it is not advisable to install elements closer than $3{\cdot}b$, the primary focus is on values for p-multipliers, p_m, for spacing between $3{\cdot}b$ and $6{\cdot}b$.

AASHTO (2020) guidance, extrapolated to a pile spacing of $6{\cdot}b$, is provided in Table 6-38. Separate p-multipliers exist to account for liquefied soil. The terminology for rows of elements used by AASHTO (2020) is graphically defined in Figure 6-25. Be aware that different sources may use different terminology. Only small sensitivity of p-multipliers to soil type and rate of loading have been observed, and these effects are usually ignored (FHWA 2018a). Alternatiavely, equations for p-multipliers proposed by Mokwa (1999) are also provided in Table 6-38.

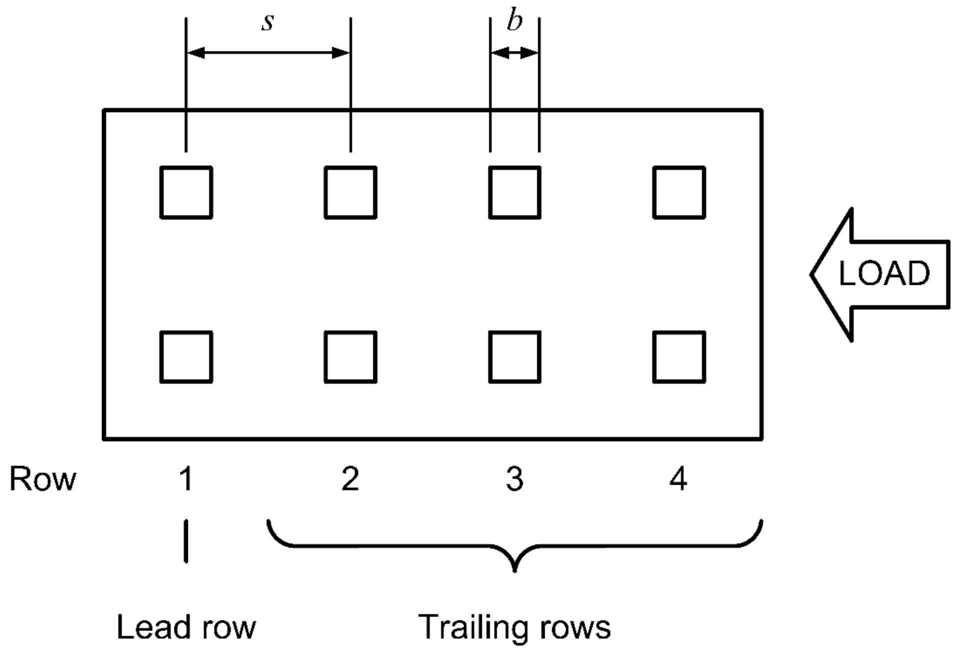


Figure 6-25 Geometry for a Group of Foundation Elements Subjected to Lateral Load

Table 6-38 p-Multipliers to Account for Group Effects in Design (after AASHTO 2020, Mokwa 1999)

Row	AASHTO (2020) p-multiplier, p_m			Mokwa (1999) p_m Equations
	s/b = 3	s/b = 5	s/b > 6	
1	0.80	1.00	1.00	$p_m = 0.06(s/b) + 0.64 \leq 1$
2	0.40	0.85	1.00	$p_m = 0.11(s/b) + 0.34 \leq 1$
3	0.30	0.70	1.00	$p_m = 0.14(s/b) + 0.16 \leq 1$
4 and higher	0.30	0.70	1.00	$p_m = 0.16(s/b) + 0.04 \leq 1$

The lateral resistance of the pile cap can be addressed through application of earth pressure theory and a load-displacement relationship for mobilization of passive resistance. Passive resistance can be neglected or reduced in design due to the potential for loss of soil around the cap due to factors such as scour and future excavation. Shearing resistance on the sides and base of the pile cap are typically neglected, and the passive resistance is partially offset by active pressure acting on the trailing side of the cap (Coduto et al. 2016). Passive resistance is most accurately estimated using log spiral earth pressure theory with correction for 3D effects (Duncan and Mokwa 2001, Mokwa 1999); however, Rankine theory provides a conservative estimate that may be reasonable in some cases. Mokwa (1999) and Duncan and Mokwa (2001) present a hyperbolic load-displacement relationship for mobilization of passive resistance. Assuming that full passive resistance is mobilized at a lateral displacement equal to 4% of the height of the pile cap (Mokwa 1999) and the failure ratio is equal to 0.85 (Duncan and Mokwa 2001), the mobilized passive resistance can be estimated as:

$$\frac{P_{P,mob}}{P_{P,ult}} = \left(\frac{y}{0.85y + 0.006H_{cap}} \right) \leq 1 \qquad (6\text{-}71)$$

where:
$P_{P,mob}$ = mobilized passive resistance,
$P_{P,ult}$ = fully-mobilized passive resistance,
y = average lateral movement of the pile cap, and
H_{cap} = height of the pile cap in the same length units as the lateral deflection.

Lateral analyses for groups of foundation elements can be performed in a number of ways:

1) Commercial software, e.g., LPILE, developed for single elements with p-multipliers applied to the p-y relationships. This approach empirically accounts for pile-soil-pile effects but does not address interactions between the piles and the cap and lateral resistance provided by an embedded cap. One option is to perform analyses for each row of elements with different p-multiplier values (Brown and Bollmann 1993). A simpler option is to use a weighted average value of p-multiplier, $p_{m,avg}$, for all rows, which implicitly assumes that all piles carry the same lateral load. This is not actually the case since the p-y relationship of each pile, or at least each row, is different and the lateral deflection at the top of all of the piles is approximately the same. A solution is to scale the average maximum calculated moment by a factor to account for the peak value in the group, e.g., for elements at the corners in the lead row. The moment scaling factors recommended by Brown et al. (2001) are 1.20 for s/b equal to 3, 1.15 for s/b equal to 4, 1.05 for s/b equal to 5, and 1.00 for s/b equal to 6.

2) Purpose-built commercial software developed for groups of elements, e.g., GROUP and RSPile. This approach empirically accounts for pile-soil-pile effects, interactions between the piles and the cap, and lateral resistance provided by an embedded cap.

3) General finite element or finite difference codes, e.g., ABAQUS and PLAXIS.

4) Clarke and Duncan (2002) proposed an adapted version of the CLM described in Section 6-6.4.3 that empirically accounts for pile-soil-pile effects and lateral resistance provided by an embedded cap. The adapted CLM for pile groups uses a weighted average of the p-multipliers proposed by Mokwa (1999) for the number of rows in the pile group. The weighted average p-multiplier is applied to the characteristic load and moment applied to the top of the pile as shown in Table 6-38. The spreadsheet PileGroup2 (Robinette and Duncan 2005) applies the CLM for pile groups for the case of loads applied to the pile cap. The case where both lateral load and moment are applied to the pile cap is not able to be modeled using the CLM as currently formulated.

All of the approaches listed above are capable of analyzing simple problems to a reasonable degree of accuracy where a lateral load is applied to a group of elements that is either fixed or pinned within a pile cap. In cases where complex loads and/or moments are applied to pile caps, the problem should be approached using either purpose-built commercial software or numerical modeling software.

6-7 STRUCTURAL CAPACITY.

This section introduces structural design concepts that are useful for the geotechnical design engineer. Readers seeking detailed aspects of structural design should consult design manuals that are specific to the type of foundation, relevant codes (e.g., IBC), and specifications (e.g., ASTM, ACI, AASHTO).

At the most basic level, structural design of a foundation within an LRFD framework includes the following:

1) Determining factored loads for the limit state under consideration,
2) Assigning trial foundation dimensions and properties,
3) Checking axial resistance in compression and tension,
4) Checking shear and moment resistance,
5) Checking resistance for combined axial and loads and moments,
6) Designing to meet demands for steps 3, 4, and 5 as well as constructability and efficiency, and
7) Designing splices, connections, joints, and pile caps.

6-7.1 Allowable Stresses.

Stresses in the foundation element must remain sufficiently below levels that will cause structural damage over the life cycle of the foundation. For all types of foundations, this includes the stresses that the element may experience during normal conditions and during extreme events. For driven piles, stresses during handling and driving are also important. Timber and steel piles are generally tolerant of stresses that arise during typical handling and lifting by a crane; however, concrete piles are susceptible to damage by improper handling, such as using an insufficient number or spacing of pickup points.

6-7.1.1 Driving Stresses.

Driving stresses are estimated during design using a wave equation analysis, which is discussed in Section 6-9.3, and are monitored during construction using high-strain dynamic measurements, as discussed in Section 6-9.4. The high strain rate and short duration of driving-induced stresses allow limits to be set closer to the strength limit state as compared to static design. AASHTO (2020) LRFD resistance factors for driving stresses are provided in Table 6-39. Limiting values for driving stresses, σ_{dr}, are presented in the following sections for steel, concrete, and timber piles. Excessive dynamic stresses during driving can be mitigated through careful selection of the hammer, hammer settings, and pile cushion in the case of concrete piles.

Table 6-39 AASHTO (2020) Resistance Factors During Pile Driving

Pile type	Resistance Factor for Pile Driving, φ_{da}
Steel piles	1.0
Concrete piles	1.0
Timber piles	1.15

6-7.1.1.1 Steel Piles.

Driving stresses for steel piles are limited by the yield strength, f_y. The yield stress for common steel pipe piles and H-piles is provided in Table 6-40. Tensile driving stresses are generally below levels that approach the yield strength. AASHTO (2020) specifications limit compressive stresses to:

$$\sigma_{dr} \leq \varphi_{da}\left(0.9 f_y\right) \tag{6-72}$$

Table 6-40 Yield Stress and Driving Stress Limit for Common Steel Piles

Steel Pile Type	Designation or Grade	Yield Stress, f_y (ksi)	Maximum σ_{dr} (ksi)
Pipe piles	ASTM A-252 Grade 2	35	31.5
	ASTM A-252 Grade 3	45	40.5
	ASTM A-252 Grade 3 (Mod)	50 to 80	45 to 72
H-piles	A-36	36	32.4
	ASTM A-572-50	50	45
	ASTM A-572-60	60	54

6-7.1.1.2 Concrete Piles.

Concrete piles are susceptible to damage by compressive and tensile stresses developed during driving. The compressive stresses are assumed to be carried by the concrete, which has a design strength in compression, f_c', typically between 3 and 8 ksi. In current practice, nearly all concrete piles are prestressed in compression to some amount, f_{pe}, typically 0.5 to 1.0 ksi, that is always substantially below f_c'. The longitudinal steel reinforcement is assumed to be responsible for resisting most, but not all, tensile stresses.

AASHTO (2020) specifications limit maximum compressive driving stresses to:

$$\sigma_{dr,comp} \leq \varphi_{da}\left(0.85 f_c' - f_{pe}\right) \quad \text{(6-73).}$$

AASHTO (2020) specifications limit maximum tensile driving stresses to:

$$\sigma_{dr,tensile} \leq \varphi_{da}\left(0.095\sqrt{f_c'} + f_{pe}\right) \quad \text{(ksi)} \quad \text{(6-74).}$$

6-7.1.1.3 Timber Piles.

For timber piles, AASHTO (2020) specifications limit maximum compressive and tensile stresses to the limit found by:

$$\sigma_{dr} \leq \varphi_{da}\left(2.6 f_{cto}\right) \quad \text{(6-75)}$$

where:
f_{cto} = reference value for compressive strength parallel to the wood grain.

Engineering properties for timber can be found in the *Wood Handbook* (USDA 2010). Values of f_{cto} for typical woods used for timber piles are listed in Table 6-41.

Table 6-41 Allowable Stresses Parallel to the Grain for Treated Timber Graded in Accordance with ASTM D25 (AWPI 2002)

Species	f_{cto} (ksi)	Maximum σ_{dr} (ksi)
Southern pine	1.20	3.59
Douglas fir	1.25	3.74
Lodgepole pine	1.15	3.44
Red oak	1.10	3.29
Red pine	0.90	2.69
Southern pine applies to loblolly, longleaf, shortleaf, and slash pines. Douglas fir applies to coastal variety. Red oak applies to northern and southern red oak. Red pine applies to US-grown red pine.		

6-7.1.2 Structural Resistance for Static Design.

When structural capacity of driven piles and drilled shafts is evaluated within an LRFD framework, AASHTO (2020) recommends the LRFD resistance factors provided in Table 6-42. Factored resistances in axial compression (P_r), flexure (M_r), and shear (V_r), must exceed the factored applied axial load (P_u), moment (M_u), and shear load (V_u). Combined axial loading and flexure is handled using interaction equations and/or diagrams to check that stresses and strain from combined loading are sufficiently below the strength limit. The details of the required design checks can be found in design manuals for specific foundation types.

When structural capacity of driven piles and drilled shafts is evaluated within an ASD framework, Table 6-43 provides allowable stresses for materials used in deep foundations as recommended by IBC (ICC 2015).

Table 6-42 Resistance Factors for Structural Strength Limit State (AASHTO 2020)

Foundation Material	Condition	Pile Type	Resistance Factor[A]
Steel (driven piles)	Axial compression – Good driving conditions	H-piles Pipe piles	0.60 0.70
	Axial compression – Potentially damaging driving conditions	H-piles Pipe piles	0.50 0.60
	Combined axial and flexural for undamaged piles	Axial – H-piles Axial – Pipe piles Flexure – Both types Shear – Both types	0.70 0.80 1.00 1.00
Concrete/grout and steel (micropiles)	Compression -	Cased & uncased	0.75
	Tension	Cased & uncased	0.80
Concrete and steel (driven piles and drilled shafts)	Tension controlled[B,C]	Reinforced concrete Prestressed concrete	0.90 1.00
	Compression controlled[B]	Reinforced concrete Prestressed concrete	0.75 0.75
	Shear	Any type	0.90
Timber	Compression parallel to grain Tension parallel to grain Flexure Shear	Any type	0.90 0.80 0.85 0.75

[A] AASHTO (2020) states that resistance factors should be reduced by 20% for single drilled shafts, small pile groups (<5 piles) to account for lack of redundancy, and micropiles in marginal ground conditions.
[B] Refer to AASHTO (2020) for guidance to interpolate between tension and compression-controlled sections based on strain limits for combined axial and flexure loading.
[C] Tension is assumed to be resisted by the reinforcing steel only.

Table 6-43 Recommended Allowable Stresses for Typical Foundation Materials (ICC 2015)

Material	Condition	Maximum Allowable Stress
Concrete or grout in compression	Cast-in-place with permanent casing that is mandrel driven and not included in design resistance	$0.40f'_c$
	Cast-in-place in a pipe, tube, other permanent casing, or rock	$0.33f'_c$
	Cast-in-place without a permanent casing	$0.30f'_c$
	Precast nonprestressed	$0.33f'_c$
	Precast prestressed	$0.33f'_c$ to $0.27f_{pe}$
Nonprestressed reinforcement	Compression	$0.40f_y \leq 30$ksi
Steel in compression	Cores within concrete-filled pipes or tubes	$0.50f_y \leq 32$ ksi
	Pipes, tubes, or H-piles with justification[A]	$0.50f_y \leq 32$ ksi
	Pipes and tubes for micropiles	$0.40f_y \leq 32$ ksi
	Other pipes, tubes, or H-piles	$0.35f_y \leq 16$ ksi
	Helical piles	$0.60f_y \leq 0.50\ f_u$
Nonprestressed reinforcement in tension	Within micropiles	$0.60f_y$
	Other conditions	$0.5f_y \leq 24$ ksi
Steel in tension	Pipes, tubes, or H-piles with justification[A]	$0.50f_y \leq 32$ ksi
	Other pipes, tubes, or H-piles	$0.35f_y \leq 16$ ksi
	Helical piles	$0.60f_y \leq 0.50\ f_u$
Timber	In accordance with ANSI/AWC NDS	

Variables: f'_c = compressive strength of concrete or grout, f_{pe} = effective prestress, f_y = yield strength of steel, f_u = tensile strength of steel
[A] With substantiating data to justify higher allowable stresses, e.g., geotechnical investigation and load tests.

6-7.2 Buckling.

Foundation elements act as structural columns and are theoretically vulnerable to buckling. A basic Euler-type analysis of buckling due to axial load considers an unbraced column with pinned end supports. When the end conditions are not both pinned, an effective length factor is used to scale the actual unbraced column length up or down to an equivalent effective length with pinned conditions on both ends. Guidance for the effective length factor is provided by FHWA (2016) and UFC 4-151-10 (UFC 2012) since the restraint provided by the ground and the pile cap do not translate to theoretical end conditions in a straightforward way. From these sources, the smallest recommended effective length factor is equal to 0.65 for the case where pile embedment and the top connection provide significant rotational and translational restraint. The largest value is equal to 2.0 for the case where the ground and top connection provide little restraint against rotation and the top provides little restraint against translation. Buckling is primarily a concern for unbraced piles in air, water, and/or liquefied soil.

In addition to the unbraced length in liquids, the lateral support provided by the ground may be insufficient to brace the element for some depth into the ground. The embedded length of the element that contributes to the total unbraced length is known as the depth to fixity, Z_f (Davisson and Robinson 1965). This length can be found for elements in uniform undrained soil conditions by:

$$Z_f = \sqrt{2}\left(\frac{E_p I_p}{b \cdot k_h}\right)^{0.25} - \qquad (6\text{-}76)$$

where:
E_p = elastic modulus of the pile (F/L^2),
I_p = moment of inertia of the pile (L^4),
b = pile width (L), and
k_h = coefficient of horizontal subgrade reaction (F/L^3).[40]

The moment of inertia should be for the weak axis (FHWA 2018b), unless bending is only expected in the strong direction. For undrained conditions modeled by constant k_h, the product of pile width, b, and k_h, is assumed to equal the elastic modulus of the soil, E_s, (AASHTO 2020) and can be estimated as a function of undrained strength:

$$E_s = b \cdot k_h = C \cdot s_u \qquad (6\text{-}77)$$

where
C = constant depends on overconsolidation and soil mineralogy.

Davisson (1970) recommends C of 67, which is very low and may underestimate the support provided by the soil. The value of C can also be determined by correlations, such as the one presented in Figure 5-30.

For groups of piles, the value of E_s is affected by neighboring piles when the normalized spacing, s/b, is less than 8. For s/b equal to 3, E_s should be reduced to 25 percent of the value for a single pile (AASHTO 2020). Interpolation should be applied for s/b between 3 and 8.

Coarse-grained soils become stiffer with depth. The horizontal subgrade modulus ($b \cdot k_h$) can be modeled as increasing at a rate, n_h. The parameter n_h can be estimated using Table 6-44 from AASHTO (2020). For elements in coarse-grained soils, the depth to fixity can be estimated as:

[40] Dimensions are provided for this equation for clarity: F = force and L = length.

$$Z_f = 1.8\left(\frac{E_p I_p}{n_h}\right)^{0.2} \quad (6\text{-}78)$$

Table 6-44 Rate (n_h) of Increase in Subgrade Modulus with Depth for Sands (AASHTO 2020)

Density	n_h (ksi/ft)	
	Dry or moist	Submerged
Loose	0.417	0.208
Medium	1.110	0.556
Dense	2.780	1.390
Note the mixed units for n_h.		

UFC 4-151-10 (UFC 2012) provides guidance for the depth to fixity for piling used for waterfront construction. For soft fine-grained soils and loose sands, the depth to fixity can be assumed to range from 8 to 12 ft, with the upper end of the range applying to elements in soft clay having a flexural rigidity (EI) greater than 1010 lbs-in^2. For other ground conditions, the depth to fixity can be assumed to equal 5 ft.

When p-y analysis is applied (Section 6-6.4.2), soil-pile interaction is evaluated directly, and the depth to fixity concept is not needed. Coduto et al. (2016) criticizes the depth to fixity concept for ignoring the soil resistance above the fixity point.

Despite the theoretical possibility of buckling, there is little to no evidence of deep foundation buckling occurring under realistic field conditions (FHWA 2016, Coduto et al. 2016). According to Section 1810.2.1 of IBC (ICC 2015), “Any soil other than fluid soil shall be deemed to afford sufficient lateral support to prevent buckling of deep foundation elements and to permit the design of the elements in accordance with accepted engineering practice and the applicable provisions of this code.” During driving, there is some potential for buckling, which can be mitigated by managing hammer energy during initial driving and/or by providing temporary lateral support (Coduto et al. 2016).

6-7.3 Considerations for Pile Caps.

FHWA (2016) describes background information needed to develop a preliminary size of a pile cap and directs readers to a manual published by the Concrete Reinforcing Steel Institute (Mays 2015) for detailed design guidance according to ACI (2014).

The minimum pile cap width can be established based on the width and length of the pile group at the top of the piles (Figure 6-15) plus twice the minimum distance between the edge of the pile and the edge of the cap. For driven piles and micropiles, AASHTO (2020) stipulates a minimum edge of pile to edge of cap distance of 9 inches. Minimum spacing between elements is provided in Table 6-4 for different foundation types.

The minimum thickness of the pile cap can be established based on the minimum embedment of the piles into the cap plus the structural depth, which includes a minimum 3-inch clear space between the top of the pile and the reinforcement. For driven piles and micropiles, AASHTO (2020) requires that the undamaged top of piles extend a minimum of 12 inches into the cap or 6 inches if the pile is attached to the cap by embedded bars or strands. FHWA (2016) recommends using Equation 5-81 to make an initial estimate of the cap thickness:

$$t_{cap} = \frac{P_{ui}}{12} + 30 \quad (6\text{-}79)$$

where:
t_{cap} = estimate of cap thickness (in inches) and
P_{ui} = factored maximum single pile axial load (in kips).

Structural analysis checks should be performed to confirm adequate resistance for several modes of failure in the cap including two-way punching shear, one-way beam shear, and bending.

6-7.4 Design for Drag Force.

The concepts of negative skin friction and the associated drag force are discussed in Section 6-5.7. In most cases, the drag force is insufficient to exceed the structural capacity of the element, especially considering the high stresses that occur during pile driving. In fact, the drag force can act to prestress the column which reduces the elastic compression due to live loads (Fellenius 2021).

However, as indicated in Table 6-30, it is prudent to include the drag force in the structural strength limit state. The drag force is evaluated by the following six steps:

1) Select the foundation element type, width, and length for the analysis.

2) Characterize the nominal side and base resistances using an appropriate SCA method. Keep in mind that lower unit side friction from lower α and β is conservative for resistance, while higher unit side friction from higher α and β is conservative for negative skin friction. When side friction is evaluated using an effective stress method, such as the Beta method, Seigel et al. (2013) demonstrate analytically that unit side friction increases due to the increases in vertical stress. Nominal side and base resistances should be evaluated considering the vertical effective stress profile that includes stress change(s) producing settlement.

3) Characterize the axial displacement required to mobilize side and base resistances. Typically, only small relative movements, e.g., 0.1 inch, between

the column and ground are needed to fully mobilize side resistance. Larger movements are usually needed, e.g., 4% to 10% of the column width, to fully mobilize the base. A conservative approach for evaluating the drag force is to assume that enough relative displacement occurs to fully mobilize side friction and base resistance. A more sophisticated approach is to use static analysis software that accounts for the relationships between axial displacement and side friction, known as *t-z* curves, and the relationship between axial displacement and base resistance, known as a *q-z* curve.

4) Develop a diagram similar to Figure 6-26 that shows the axial load and resistance versus depth along the element. The resistance curve (Curve A in Figure 6-26) is created by plotting the mobilized base resistance from Step 3 at the base elevation and adding the cumulative positive skin friction (side resistance) as a function of depth along the length of the element. If side and base resistances are assumed to be fully mobilized, the resistance curve will pass through the nominal geotechnical resistance at the elevation of the top of the element. The load curve (Curve B in Figure 6-26) is created by plotting the unfactored permanent load on the element at the top of the element and adding the cumulative negative skin resistance (drag load) as a function of depth along the length of the element.

   Transient loads are not included at the top of the pile since these loads are assumed to temporarily compress the pile and reverse the skin friction. For the short interval of time that the transient load acts on the pile, positive skin friction is mobilized below the top of the pile over a length that develops enough shaft resistance to counter the transient load. When the transient load is not acting on the pile, the pile rebounds and the skin friction again becomes negative. Therefore, when the transient load is applied to the pile, the drag force is reduced by an equal amount.

5) Locate the neutral plane and the estimated maximum load in the pile, Q_{np}, at the intersection of the load and resistance curves. Note that increasing the permanent load applied to the top of the pile causes the neutral plane to occur at a higher elevation, with the limiting case being where the applied load equals the nominal geotechnical resistance and there is no neutral plane. Conversely, the neutral plane will be located near the interface of the column and the bearing layer for an end-bearing column bearing in a stratum that is much stiffer than the compressible soil.

6) Check the structural limit state by comparing the factored axial structural capacity, P_r, to the factored permanent load and the drag force. The applied permanent load, Q_d, excluding live load, should be factored by the appropriate load factor, γ_p, equal to 1.25 according to AASHTO (2020). The drag force (DF)

is equal to the difference between the maximum load identified in Step 5 and Q_d. FHWA (2016) reports that at least one state transportation agency uses a load factor equal to 1.10 for the drag force, as shown in:

$$1.25 \cdot Q_d + 1.10\left(Q_{np} - Q_d\right) \leq P_r \tag{6-80}$$

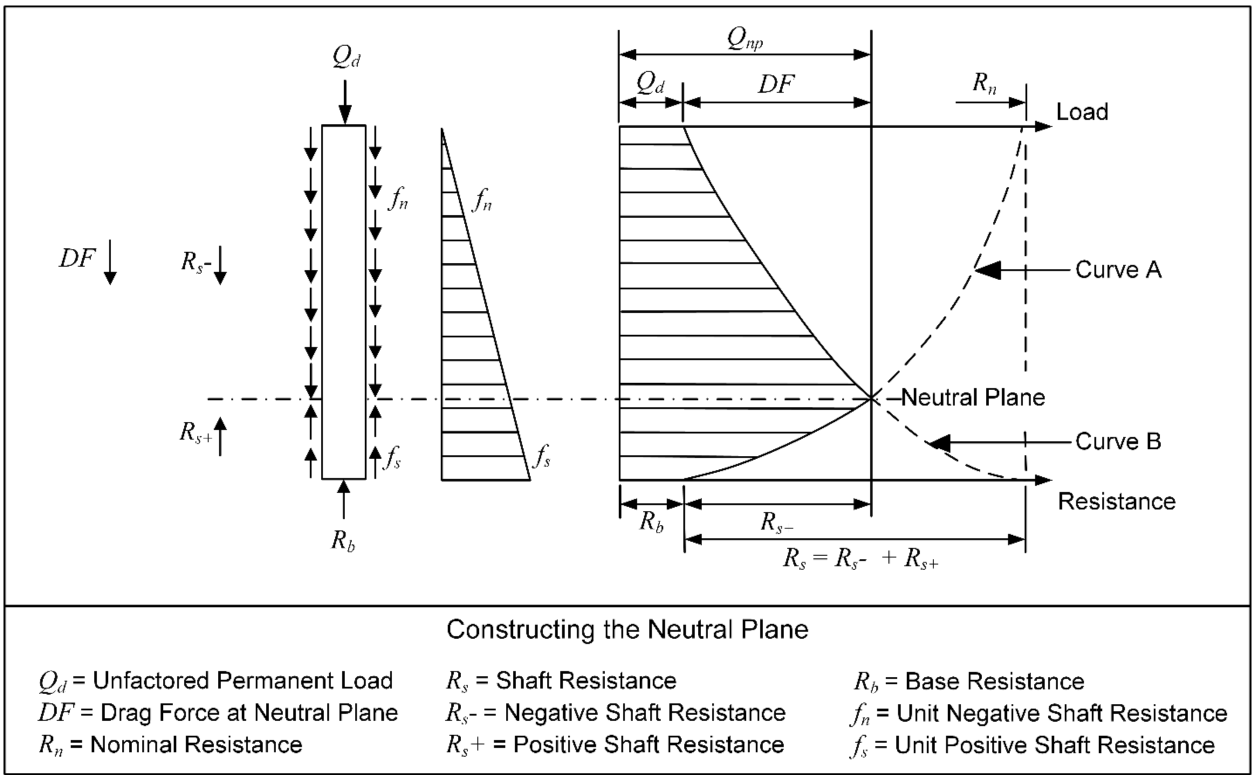


Figure 6-26 Locating the Neutral Plane

6-8 STATIC LOAD TESTING.

6-8.1 Introduction.

Static load testing provides the most direct way to assess the performance of deep foundations. As discussed in Section 6-8.2, different types of load tests can assess performance in axial compression, axial tension, and lateral loading. The loading used in load tests can be applied incrementally (most common) or to achieve a constant rate of deflection, and some tests are designed to apply cyclic loading. Load testing performed as part of a test pile program prior to construction guides the selection of installation criteria and element length and provides an opportunity to refine the design for constructability and economic efficiency. Load testing performed on production elements during construction provides proof that the tested foundation is adequate, i.e., “proof test,” and, in some cases, allows for additional refinements to element lengths and installation criteria.

Procedures for axial compressive load tests are described in ASTM D1143, procedures for axial tensile load tests are described in ASTM D3689, and procedures for lateral load tests are described in ASTM D3966. Section 6-8 focuses on conventional axial load testing where load is applied to the top of the element. The interpretation of conventional axial compressive load tests is described in Section 6-8.3.

Static load tests require engineering oversight as well as personnel and equipment time to mobilize/demobilize the loading testing equipment and to set up and perform the test. The return on the investment of performing load tests is an increase in confidence in the expected foundation performance that is reflected in higher resistance factors or lower factors of safety. Table 6-45 provides recommended resistance factors when static load testing is applied as part of the design and/or construction phases of the project, which may also include dynamic testing and/or wave equation analysis (Section 6-9). Additionally, load tests may reveal ground conditions that are better, or worse, than what was considered in design.

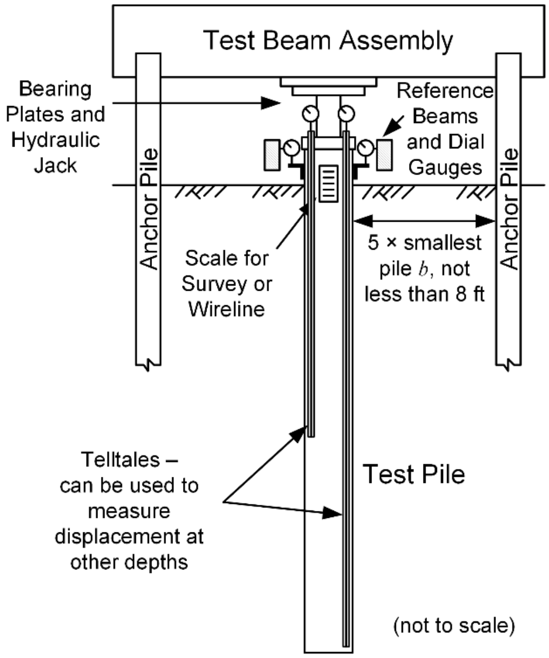
6-8.2 Axial Load Tests.

Conventional axial load tests, sometimes referred to as top-down tests, apply compressive or tensile loads to the top of the element, or a group of elements, using a hydraulic jack and measure the axial displacement at the top of the element. Testing a single element is more common than simultaneously testing a group of elements. To apply the load, the hydraulic jack requires a stiff reaction beam or load frame as illustrated in Figure 6-27(a). Movement of the reaction beam is typically resisted by two or more reaction elements installed around the test element at a sufficient distance away to mitigate pile-soil-pile interaction. ASTM D1143 requires a clear distance of at least 5 times the largest pile width or 8 ft, whichever is greater. In a compression test, the reaction elements resist movement of the reaction beam by uplift resistance. In a tension test, however, the reaction elements are put into compression. A kentledge load test uses a weighted platform instead of reaction elements for compression testing; however, this type of test is limited by the amount of weight that can safely be positioned over the test element.

Table 6-45 Recommended Strength Limit State Resistance Factors for Axial Loading based on Static and Dynamic Testing

Foundation Technology	Recommended Resistance Factor for Axial Loading[A,B]
Driven Piles in compression (FHWA 2016)	0.80 – at least one load test along with dynamic testing[C] of at least 2% of production piles or two piles, whichever is greater 0.75 – at least one load test without dynamic testing 0.75 – dynamic testing[C] of 100% of production piles 0.65 –dynamic testing[C] of at least 2% of production piles or two piles, whichever is greater 0.50 – Wave equation analysis
Driven Piles in tension (FHWA 2016)	0.60 – at least one load test 0.50 – dynamic testing[C]
Drilled shafts in compression (FHWA 2018a)	0.70 – at least one load test
Drilled shafts in tension (FHWA 2018a)	0.60 – at least one load test
Micropiles in compression (AASHTO 2020)	Same as driven piles, but limited to 0.70
Micropiles in compression (AASHTO 2020)	Same as driven piles, but limited to 0.70

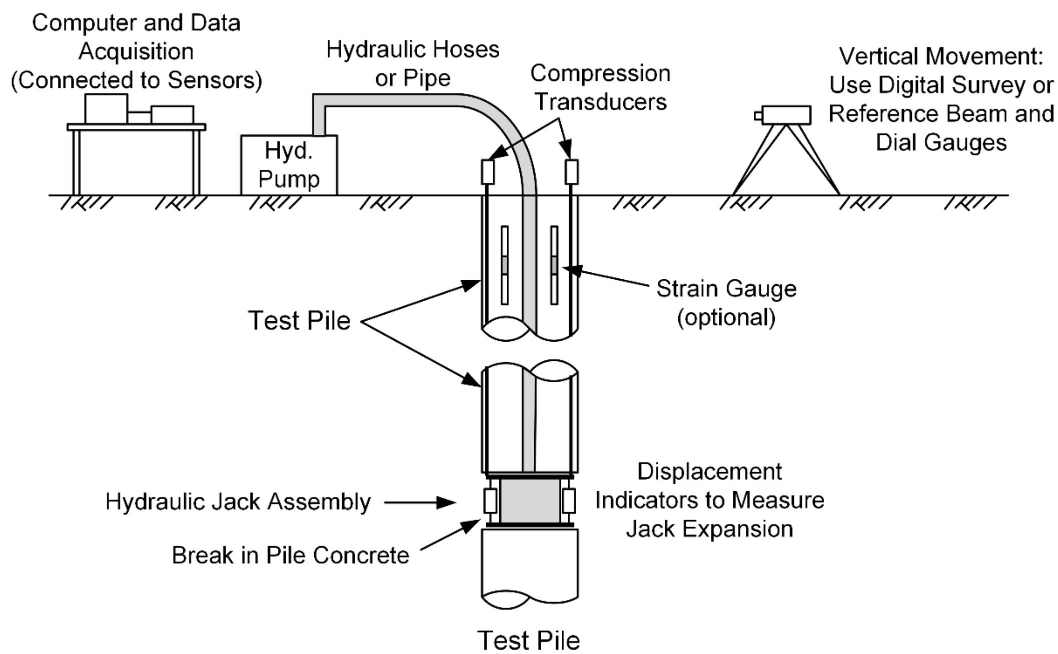
[A] AASHTO (2020) states that resistance factors for single drill shafts and small pile groups (<5 piles) should be reduced by 20% to account for lack of redundancy
[B] Minimum number of tests is on a per site condition basis.
[C] Dynamic testing is evaluated for restrike conditions and includes signal matching analysis.



Test Procedure Details for Compressive Loading (ASTM D1143) and Tensile Loading (ASTM D3689)

	Quick Test Procedure A	Maintained Load Test Procedure B
Test Increments	5% of Failure Load (FL) up to FL	25% of FL up to 200% of FL (150% for group)
Time per Increment	4 to 15 min	2 hr or displacement rate < 0.01 in./hr
Readings	At end of increment	At end of increment
Failure Load Hold	Hold FL longer to check creep behavior	Hold at least 12 hr & up to 24 hr. If fails, then hold until displacement equals 0.15b
Unload	5 to 10 decrements, equal duration	Decrements at 25% of max load, hold 1 hr each
Total Time	2 to 6 hr	About 2 days

(a) Schematic of Top-Down Axial Load Tests and Test Procedure Details



(b) Schematic of Bi-Directional Axial Load Test

Figure 6-27 Schematics of Top-Down and Bi-Directional Axial Load Tests (after ASTM D1143, ASTM D3689, ASTM D8169)

Displacement at the top of the tested element is measured using dial gauges and/or linear variable displacement transducers (LVDTs). Displacements are measured relative to one or more reference beams that are supported independently of the load frame and not significantly affected by ground movements. Redundant measurement methods, such as a scale, mirror, and wire system, and/or optical survey methods, are included as good practice to provide a backup or to confirm the function of the primary measurement devices. The shape of the resulting load-displacement relationship at the top of the element can infer the distribution load along the shaft and base of the test element. As shown in Figure 6-11, an element that develops axial capacity primarily from side resistance tends to mobilize resistance at smaller displacement and plunge more distinctly as compared to an element with large base resistance. In some cases, telltales and/or strain gauges are installed on the test element prior to testing to provide additional measurements of displacement or strain. These additional measurements are needed to make a good estimate of the transfer of load between the element and the ground through shaft and base resistance.

Standard procedures for compressive loading (ASTM D1143) and tensile loading (ASTM D3689) are summarized in Figure 6-27(a). Variations of the Maintained Load Test described in ASTM D1143 reload the test element to failure (Procedure C) or load/unload the element using a shorter 1-hour duration for each load level (Procedure D).

Bi-directional load testing is an alternative used when a conventional load frame and reaction elements are impractical due to high anticipated element capacity and/or challenging site conditions, e.g., foundations in deep water. Standardized procedures for performing a bi-directional load test are described in ASTM D8169. This type of testing is primarily applied to test drilled shafts; though, it is also occasionally applied to CFAs and large diameter steel pipe piles. As shown in Figure 6-27(b), the loading equipment for bi-directional testing consists of one or more expendable hydraulic pancake jacks, e.g., an Osterberg Cell, positioned at or near the bottom of the test element. The jacks are supplied with pressurized hydraulic fluid through lines extending to the top of the element. Once the concrete in the test element has gained sufficient strength, the test can be performed by gradually expanding the jack and separating the test element into upper and lower sections.

In a bi-directional test, each section of the element provides the reaction for the other. The displacement of the jack moves the upper section upward and the lower section downward. Movement of the upper section is resisted by the buoyant weight of the element, the side resistance along the upper section, and any additional surface loading placed on top of the element to assist with the mobilization of base resistance. Movement of the lower section is resisted by the side resistance along the lower section and base resistance. The jack is located in the element at the location where the anticipated resistances to the upward and downward movement of the test element are equal. The load applied to the upper and lower sections of the test element is typically measured using pressure applied to the jack. Displacements are measured using expendable LVDTs and telltales. Strain gauges are sometimes embedded in the test element to estimate load transfer. Once the test is completed, the jack is filled with grout, and the element can be included in the foundation.

6-8.3 Interpretation of Axial Compressive Load Tests.

Interpretation of proof tests not taken to failure are generally limited to confirming that the magnitude and time rate of settlement do not exceed specified limits, e.g., 0.01 inches per hour. For load tests taken to failure, the interpretation of the load at failure, P_n, can be difficult.

Many methods to interpret load tests have been proposed, and three methods are permitted by the International Building Code, with additional methods permitted by approval of the building official (ICC 2015). This section describes two of the methods permitted by the IBC: the Davisson Offset Limit Method (Davisson 1972) and the Brinch Hansen 90% Criterion (Brinch Hansen 1963). Two additional methods, the Brinch Hansen 80% Criterion (Brinch Hansen 1963) and Corps of Engineers Method (USACE 1991), are also described. For driven piles and micropiles, AASHTO (2020) specifies the Davisson method for elements having a width of 24 inches or less and a modified version of the Davisson method for larger elements. For drilled shafts, AASHTO (2020) defines failure as plunging of the test shaft or displacement of the top of the shaft equal to 5% of the diameter. The failure loads interpreted by different methods should not be expected to agree.

Table 6-46 provides the equations and requirements for interpretation of the failure load from static load test data. Figure 6-28 illustrates the usage of each method for a hypothetical load test with a “true” failure load of 400 kips at a corresponding settlement of 1.2 inches. The curve shown perfectly follows a Chin-Kondner hyperbolic relationship (Chin 1978) in which the failure loads interpreted using the Brinch Hansen 80% and 90% criteria are approximately the same. The pile considered in the example is an 80-ft long, 24-inch diameter steel pipe with a 0.5-inch wall thickness.

The Brinch Hansen criteria usually produces a higher, and arguably more realistic, interpretation of the failure load as compared to the Davisson method (Coduto et al. 2016). Fellenius (2021) asserts that the Brinch Hansen 80% criterion is often close to the “true” ultimate resistance.

Table 6-46 Interpretation of Failure Load from Static Load Tests

Criterion	Interpretation of data	Interpreted P_n (Figure 6-28)
Davisson Offset Limit (Davisson 1972)[A]	P_n equals the intersection of data and $\delta = \frac{PZ}{A_p E_p} + 0.15\,in. + \frac{b}{120\,in.}$	Point A
Brinch Hansen 80% Criterion (Brinch Hansen 1963)[B]	P_n and δ_n satisfy $\frac{\delta \text{ at } P = 0.8P_n}{\delta_n \text{ at } P = P_n} = 0.25$	Point B
Brinch Hansen 90% Criterion (Brinch Hansen 1963)[B]	P_n and δ_n satisfy $\frac{\delta \text{ at } P = 0.9P_n}{\delta_n \text{ at } P = P_n} = 0.50$	Point C
USACE (1991)	P_n is the average of three estimates: 1: P = the intersection of data and δ_n = 0.25 in. 2: P = the intersection of tangents from early and late portions of data 3: P = point on data where the instantaneous slope equals 0.005 in./kip	Point D Point E Point F

[A] All length units must be consistent; inches are presented here.
[B] The hyperbolic relationship that approximately satisfies both the Brinch Hansen 80% and 90% criteria is provided below. The synthetic load test data in Figure 6-28 was generated using the hyperbolic relationship with P_n = 400 kips and δ_n =1.2 inches.

Chin-Kondner hyperbolic relationship for the example: $\frac{P}{P_n} = \frac{\delta/\delta_n}{0.91\cdot\delta/\delta_n + 0.09}$

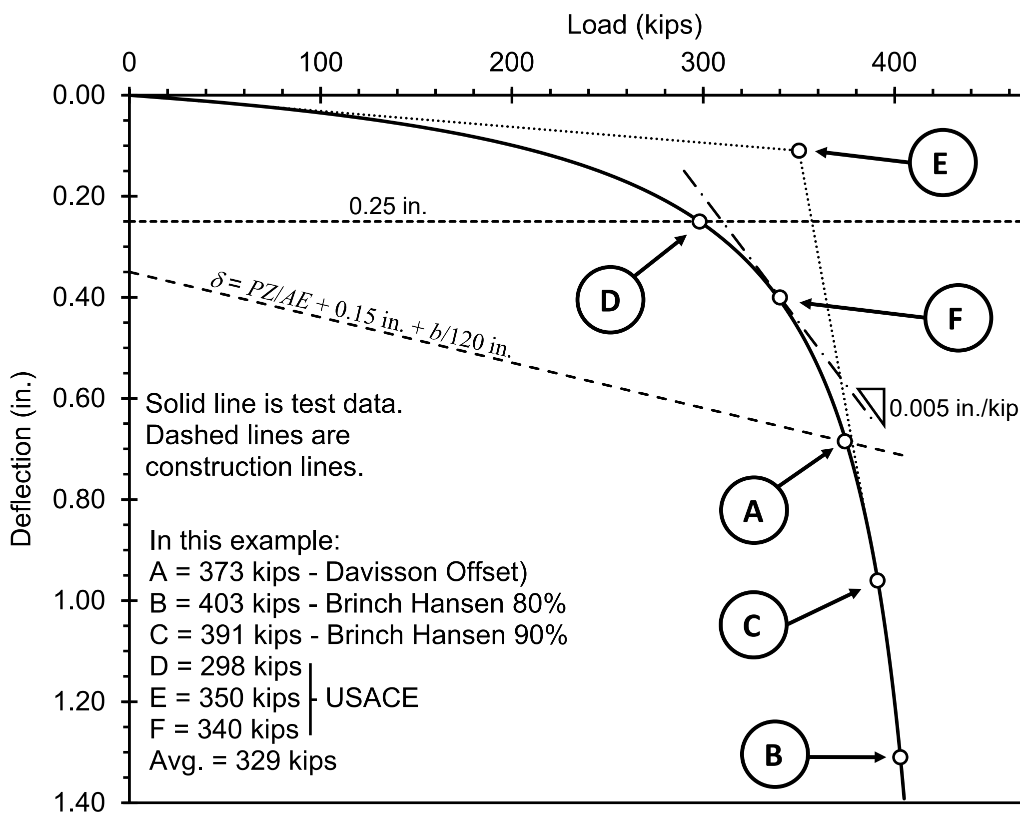


Figure 6-28 Interpretation of Failure Load from Static Load Tests

6-9 DYNAMIC METHODS OF ANALYSIS AND TESTING.

6-9.1 Introduction.

This section is focused on the use of actual or modeled hammer impacts applied to the top of a foundation element to evaluate a variety of aspects that are important to foundation design and construction. Dynamic methods are primarily associated with driven piles; however, some dynamic methods can also be applied to bored piles. While most of the attention in this section is given to methods for driven piles, some of the methods that can be applied to bored piles are also briefly discussed.

Counting the number of hammer blows for a particular pile penetration, e.g., blows per foot (bpf) or blows per inch (bpi), is the most simple and fundamental dynamic method to inform engineering and construction decision-making related to pile foundations. The inverse of the blow count is the set per blow. In the late 19th century, the relationship between set and pile resistance was formalized in the first popular dynamic formula known as the Engineering News Formula. This semi-empirical formula estimates nominal resistance by dividing the theoretical potential energy of the hammer (the product of hammer weight and drop height) by the observed permanent set plus an empirical value to account for factors, such as elastic rebound. As use of the Engineering News Formula and other dynamic formulas became widespread in the 20th century, their inadequacies became well documented. These inadequacies include treating the pile as a rigid body that transfers energy without losses, ignoring inefficiencies in the hammer and drive system components, and errors in isolating the static resistance from the observed resistance, which includes a dynamic component.

Furthermore, dynamic formulas do not provide a means to assess potentially damaging driving stresses and are not well suited to evaluating setup or relaxation effects, which are best observed within the first few hammer blows of a restrike. Due to these shortcomings, dynamic formulas are not recommended as a primary means of evaluating pile resistance. In situations where no other options are available or to provide an approximate check of other methods, dynamic formulas can be useful when applied with appropriate factors of safety or resistance factors, particularly when the analyst has knowledge that is specific to a particular combination of site, pile, and driving system.

The advent of dynamic methods based on wave mechanics provided a rational way to evaluate the nominal static resistance of the pile, driving stresses, and performance of the hammer and driving system. Table 6-47 summarizes dynamic methods commonly used in driven pile design and construction, including whether the methods are primarily applied during design or during installation of the piles. Implementation of these methods requires specialized software and/or hardware in addition to prerequisite knowledge and training. Presentation of the background knowledge and usage of the software and hardware is beyond the scope of this manual; however, a brief overview of wave mechanics is provided in Section 6-9.2, and key information about the methods referenced in Table 6-47 is provided in the Sections 6-9.3 through 6-9.6.

As discussed in Section 6-8.1, frequent use of dynamic methods during construction, e.g., testing 2% or more of all production piles, often permits higher LRFD resistance factors to be used in design. This can especially be true when dynamic methods are used together with static load testing and/or rapid load tests. While testing adds cost and time to the construction process, the ability to reduce uncertainty, and design less conservatively, often yields overall savings in cost and/or time.

Dynamic methods are more likely to overpredict nominal resistance when the blow count is less than 24 bpf and underpredict nominal resistance when blow count exceeds 120 bpf. Observing the nominal capacity requires a hammer that delivers sufficient energy to mobilize the resistance along the sides and base of the pile.

Table 6-47 Common Dynamic Methods Based on Wave Mechanics

Method	Primarily used… during design	during test installation[B]	during production installation[C]	Used to evaluate…	Comments
Wave equation analysis of pile driving (WEAP) See Section 6-9.3	x			Nominal resistance as related to pile penetration	• Theoretical behavior based on inputs for the hammer, drive system, pile, and soil
	x			Driveability[D]	
	x	x	x	Preferred hammer and cushion design[E]	
Case Method[A] See Section 6-9.5		x	x	Nominal resistance	• Output evaluated in real time for every hammer blow
		x	x	Hammer and driving system performance	
		x	x	Driving stresses and pile integrity	
Signal matching[A] See Section 6-9.6		x	x	Nominal resistance	• Involves additional computation based on dynamic measurements • Performed on selected hammer blows for a particular time and penetration • More refined than Case Method
		x	x	Hammer and driving system performance	
		x	x	Driving stresses and pile integrity	

[A] Uses dynamic force and velocity measurements from PDA or similar device
[B] Commonly, a high percentage of test piles are tested during initial driving and restrike
[C] Commonly, a specified subset of production piles is tested, restrikes are performed as needed to address changes and/or concerns
[D] Driveability includes evaluating hammer energy and driving stresses
[E] The selection of a hammer and cushion is often refined as the project progresses from design to construction

6-9.2 Wave Mechanics Basics.

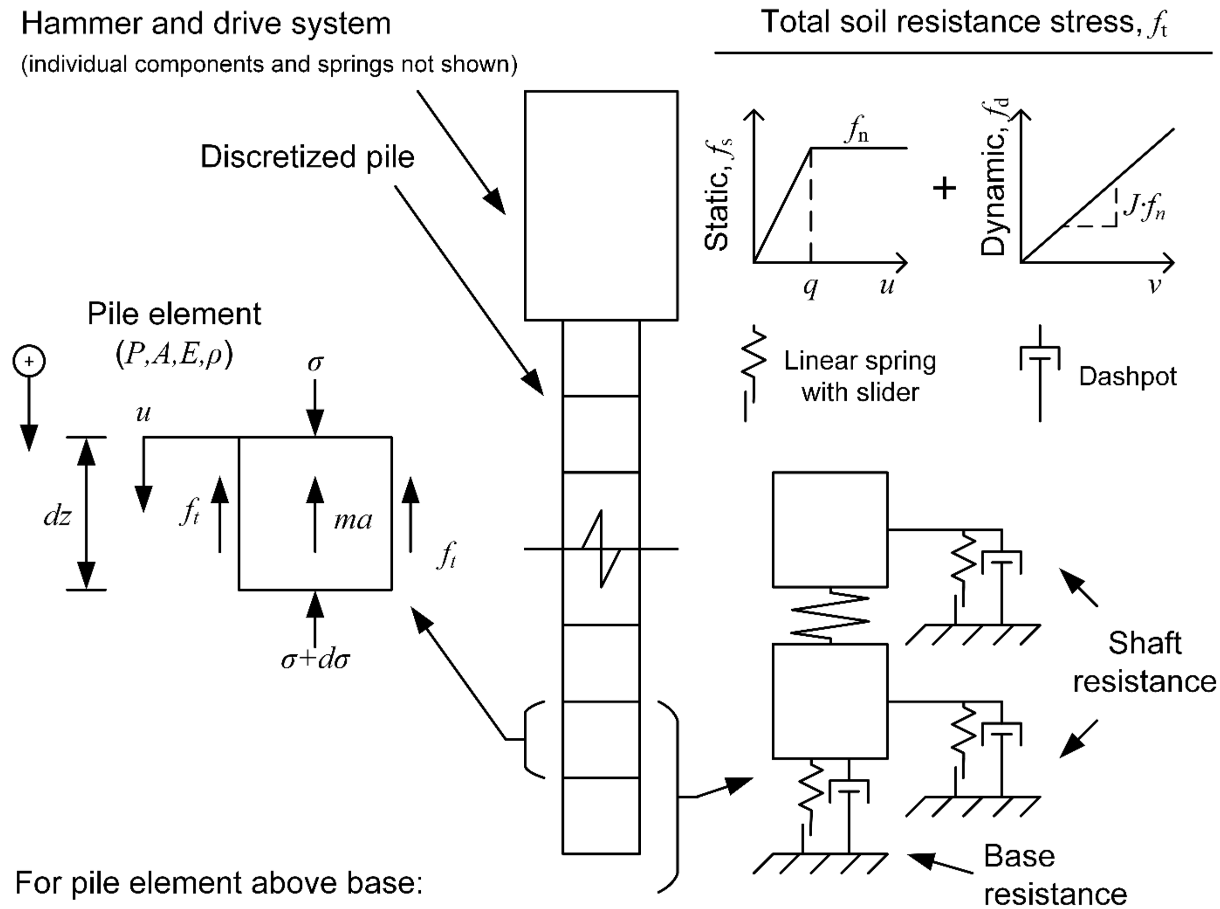
A hammer impact on the top of a pile generates a time-dependent force that propagates down the pile at the wave speed of the pile material. The wave equation is the governing differential equation that describes such one-dimensional wave propagation. The basics of wave mechanics are defined and presented in Figure 6-29. The impact force generates normal stresses in the pile that are proportional to the axial strain for an elastic material. The local axial strain is equal to the change in local displacement of the pile material with respect to position along the pile. Thus, shortening or lengthening the pile produces strain while uniformly moving the pile does not produce strain. The total resistance to local displacement is comprised of the inertial force and the static and dynamic components of the resistance provided by the material (soil) surrounding the pile. The resistances can be modeled using linear springs and dashpots, as shown in Figure 6-29, or nonlinear springs and dashpots that are available in commercial software.

To apply wave mechanics to estimate the nominal geotechnical static resistance, the inertial force and dynamic resistance must be removed. Usually, there is less uncertainty associated with removing the inertial forces from the pile-soil model as compared to removing the dynamic soil resistance.

The inputs to the hammer-pile-soil model depend on which implementation of wave mechanics is being used, i.e., wave equation analysis, Case Method, or signal matching. The specifics of the driving system, pile, and ground conditions also affect the inputs. The Case Method and signal matching utilize measurements of force and velocity near the top of the pile, as discussed in Section 6-9.4, while wave equation analysis does not. Guidance for selection of parameters used to define the behavior of the hammer and driving system, e.g., cushion, are available in textbooks, design manuals, and software user manuals. Guidance for selecting values for the wave speed, damping, and quake values is shown in Figure 6-29 and as follows:

- Wave speed – The wave speed of a steel pile is approximately 16,800 ft/sec while the wave speed of a concrete pile typically increases with the compressive strength and is typically in the range of 10,000 to 13,000 ft/sec. The wave speed is many times faster than the particle velocity.
- Quake – *Quake* is defined as the displacement where the soil starts to yield plastically. Values are required for the side and base of the pile. A typical value for side quake is 0.1 inches. The typical range is 0.04 to 0.4 for base quake (lower end for rock).
- Damping – Typical values for the Smith damping factor range from 0.05 to 0.2 s/ft for side resistance (lower end for sands, higher end for clays) and 0.15 s/ft for base resistance. The Smith damping model computes dynamic resistance as the product of the damping factor, pile velocity, and mobilized static resistance. The Smith viscous damping model uses the fully-mobilized static resistance in place

of the mobilized static resistance. The dynamic side resistance is proportional to the pile velocity in the Smith viscous damping model while it follows a nonlinear relationship in the Smith damping model. The Case Method uses a different approach to evaluate the dynamic side resistance that involves a dimensionless damping coefficient having a typical range of 0.1 to 1.0 (lower end for sands, higher end for clays).



For pile element above base:

$$\sum F = \sigma A - (\sigma + d\sigma)A - f_t p dz = \rho A dz \frac{d^2u}{dt^2} = ma$$

where: $\sigma = E\varepsilon = E\dfrac{-du}{dz}$ $\quad v = \dfrac{du}{dt}$ $\quad a = \dfrac{d^2u}{dt^2}$ $\quad c = \dfrac{dz}{dt} = \sqrt{\dfrac{E}{\rho}}$ $\quad I = \dfrac{EA}{c}$ $\quad \dfrac{d^2u}{dt^2} = c^2\dfrac{d^2u}{dz^2} - f_t\dfrac{p}{EA}$

1D Wave equation w/o soil resistance: $\dfrac{d^2u}{dt^2} = c^2\dfrac{d^2u}{dz^2}$

The impact force delivered to the pile top:

$$F_{top} = \sigma_{top}A = E\varepsilon_{top}A = E\frac{du_{top}}{dz}A = E\frac{du_{top}}{dt}\frac{dt}{dz}A = Iv_{top}$$

Variables: Perimeter, p; Area, A; Elastic modulus, E; Mass density, ρ; Mass, m; Displacement, u; Time, t; Particle velocity, v; Acceleration, a; Wave speed, c; Damping*, J; Quake, q; Impedance, I

*There are different ways to obtain the dynamic resistance. Smith viscous damping is applied here, in which a damping factor is multiplied by the fully-mobilized nominal soil resistance

Figure 6-29 Definition Sketch for Wave Mechanics Basics

For a single wave traveling through an infinitely-long uniform pile without side resistance, the force in the pile and the particle velocity are proportional according to the impedance, as defined in Figure 6-29. Increasing the pile cross section area, elastic modulus, and/or mass density increases the impedance. Piles with higher impedance transmit impact force with lower associated particle velocity and driving stresses. Resistance along the sides and base of the pile from the soil reflect some of the wave force. Impedance changes, including the end of the pile itself, also reflect some of the wave force. The creation of multiple waves traveling in the pile by reflections disrupts the proportionality between the force in the pile and the particle velocity.

Figure 6-30 illustrates cases of a pile without side resistance having one of two extreme end conditions. The free-end case, which approximates a pile in very soft ground, illustrates the potential for damaging tensile stresses in the pile. This is particularly important for concrete piles because the tensile strength of concrete is lower than the compressive strength. The fixed-end case, which approximates an end-bearing pile installed through very soft ground, illustrates the potential for damaging compressive stresses in the pile.

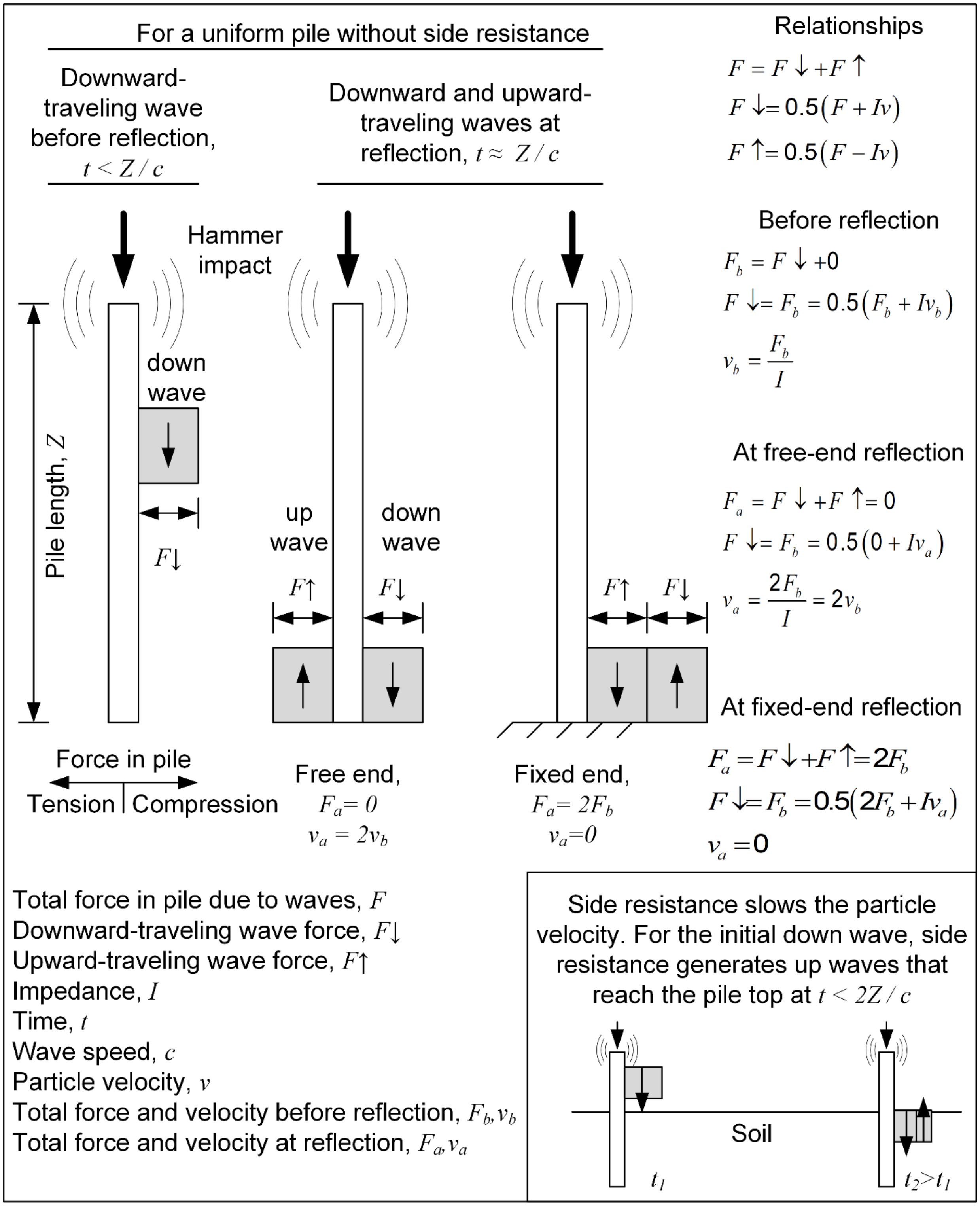


Figure 6-30 Forces in Pile Due to Downward and Upward-Traveling Waves

6-9.3 Wave Equation Analysis of Pile Driving.

Wave equation analysis of pile driving (WEAP) (Smith 1960) is performed using software, such as GRLWEAP, to model the hammer-pile-soil system. The analysis applies the finite difference method to solve for the velocity, acceleration, and forces along the pile at any moment in time. Table 6-47 lists typical uses of WEAP and at what points during the project analyses are typically performed.

A primary use of WEAP is to develop a relationship between the blow count or set and the nominal pile resistance. By itself, an estimate of a pile's nominal resistance made by static capacity analysis does not indicate the type of hammer system that will be suitable nor what driving criteria will be necessary to achieve a target resistance. Inputs to WEAP software include the type and length of pile, the components of the hammer and drive system, the nominal axial resistance, the distribution of resistance along the shaft and base of the pile, and values of damping and quake. Inputs for the hammer and drive system as well as values of quake and damping are usually assigned with guidance from the software. The WEAP analysis computes nominal resistance versus the required blow count or set for the specified parameters. The graphical output of this type of analysis is a called a *bearing graph*. For analyses that include a variable stroke hammer, such as an open-end diesel hammer, the WEAP analysis shows the combination of stroke and blow count that corresponds to the resistance. An inspector's chart analysis plots blow count versus stroke for a particular resistance. A lower stroke requires more blows to reach the target resistance than the same hammer with a higher stroke.

A second primary use of WEAP is to perform a driveability analysis in which the goal is to select a hammer system and pile that can efficiently drive the pile without causing damage to the pile. The key feature of a driveability analysis is the iterative application of WEAP to evaluate blow count, capacity, stresses, and hammer performance over a range of pile penetration depths. The output of a drivability analysis includes plots of the calculated blow count versus depth. Driveability analyses are commonly repeated once the actual driving equipment has been selected by the contractor to refine the plan for hammer settings (e.g., fuel delivery or stroke) and cushion selection.

It is important to emphasize that the outputs of a WEAP analysis, e.g., bearing graph, are only valid for the specific hammer-pile-soil model. Changing any component of the driving system, e.g., cushion, or hammer setting requires a new analysis to be performed.

6-9.4 High-Strain Dynamic Measurements.

Observations of the actual hammer-pile-soil system in action allow designers to overcome some of the limitations of wave equation analysis associated with model uncertainty, such as dynamic soil properties and hammer system performance. These observations typically include using a pair of strain transducers and a pair of accelerometers mounted in a diametrically opposed manner near the top of the pile. Using a pair of instruments mitigates some of the effects of uneven application hammer energy to the pile. The strain transducers are used along with the pile's area and modulus to measure force in the pile. Single integration of the accelerometer output with respect to time provides the velocity of the pile while double integration provides displacement.

Equipment is required for sensor excitation, data acquisition, data logging, and data processing. One commercially available product is the Pile Driving Analyzer (PDA). The sensors are connected to the PDA by a cable or transmitted wirelessly.

Wave traces are plots of measured force and velocity versus time over the duration of the hammer impact. Typically, velocity is multiplied by the pile impedance to match force since force is proportional to velocity for a single wave traveling along the pile (see Section 6-9.2). The time required for the wave to travel from the instrumentation to the base and back is equal to $2Z'/c$ as indicated in Figure 6-31. As shown, the wave traces can be interpreted to infer the resistance provided along the sides and base of the pile. Wave traces can also be interpreted to assess pile integrity. Bending or cracking of the pile introduces impedance changes that create wave reflections that appear in the wave traces.

Records of force and velocity versus time obtained for each hammer blow initial driving and/or restrike are processed in real time within the PDA using the Case method (Section 6-9.5) to estimate nominal static resistance. Force and velocity records are also able to be processed in real time within the PDA to compute energy transfer, driving stresses, factors related to pile integrity, and hammer stroke. Selected force and velocity records from hammer blows at the end of initial driving or restrike are further processed using signal matching analysis (Section 6-9.6).

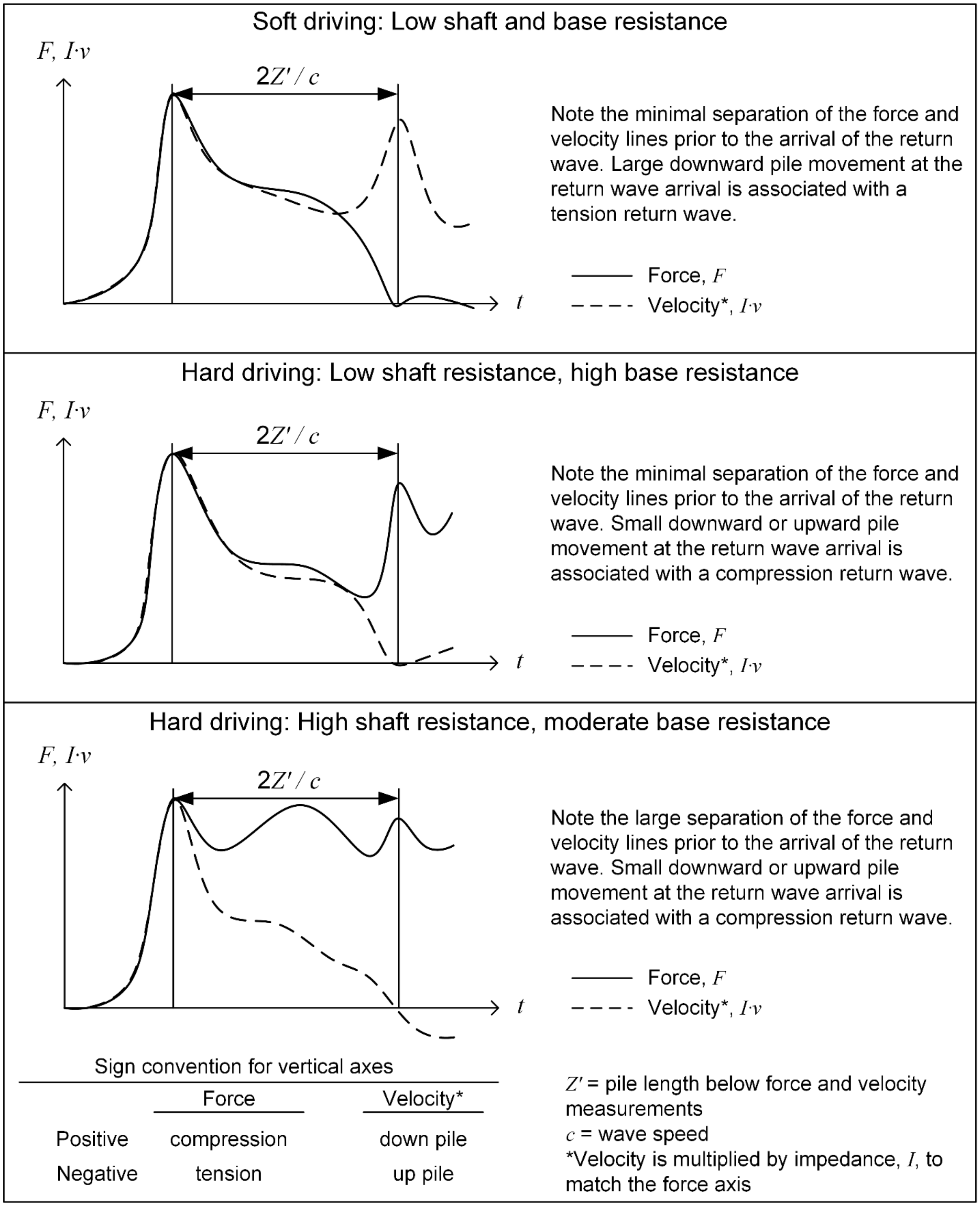


Figure 6-31 Typical Force and Velocity Records for Different Resistance Conditions

6-9.5 Case Method.

High-strain dynamic measurements of force and velocity versus time for each hammer blow (Section 6-8) are interpreted in real-time onboard the PDA using the Case Method to assess static nominal resistance. The Case Method uses a closed-form solution for wave propagation. The Case Method estimates the total pile resistance using measurements of force and velocity when the peak of the initial downward-traveling hammer impact wave reaches the instruments ($t = 0$) and when the reflected impact wave returns to the instruments as an upward-traveling wave ($t = 2Z'/c$). Z' is the distance between the instruments and the end of the pile. A single Case damping coefficient, which is different than the Smith damping factor, is multiplied by the interpreted velocity of the pile base and impedance to remove the dynamic component of the resistance and isolate the static resistance.

There are several variants of the Case Method applied within the PDA, e.g., RMX and RSP. The engineer must be familiarized with these methods to decide which method is most appropriate. FHWA (2016) provides additional description of these methods.

6-9.6 Signal Matching.

High-strain dynamic measurements of force and velocity versus time for a selected hammer blow (Section 6-8) can be processed using special software, such as CAPWAP, to assess static nominal resistance. Often, analysis of a hammer blow at the end of initial driving is compared to an analysis of a hammer blow at the beginning of restrike to evaluate set-up or relaxation effects. Signal matching uses the same application of wave mechanics as WEAP and is thus more rigorous than the Case Method. The measured force record for the downward-traveling impact wave (down wave) is used in the signal matching software in place of the hammer model used in WEAP. The wave equation is applied in the signal matching software with the down wave force record using reasonable estimates of the side and base resistance distribution, quakes, and damping factors to compute the force record at the instrument location due to the upward-traveling reflected impact wave (up wave). The software compares the computed up wave force record for the up wave to the measured up wave force record and adjusts the side and base resistance distribution, quakes, and damping factors until the match quality cannot be improved.

CAPWAP assesses match quality using the match quality parameter, MQ, that increases with greater deviation between the computed and measured up wave force assessed at multiple points in time in the hammer blow record. MQ also increases with greater deviation between the measured and computed blow count (GRL 2013). The final match achieves the lowest value of MQ. Analyses performed using different initial trial parameter values may produce a different final match; however, careful application of signal matching has a proven track record of producing good estimates of static capacity and back-calculated model parameter values. The back-calculated model parameter values can be used to refine WEAP and the Case Method for site-specific conditions.

6-9.7 Rapid Load Tests.

The rapid load test, also known as force pulse load test, is another type of field test that is primarily used to evaluate nominal geotechnical axial compressive resistance. However, variations of the test have been applied to evaluate the lateral load response of single elements and groups of elements. Rapid load tests are used on a variety of deep foundation types. Unlike static load tests, rapid load tests do not require reaction elements or large reaction weights to apply large forces to the test element. Instead, rapid load tests use a comparatively smaller reaction mass that is often accelerated upward by ignition of a solid propellant. The mass can also be dropped onto cushioning material or a spring positioned between the mass and the test element. For the test that uses an upward accelerated mass, such as a Statnamic test, the combustion gas pressure generated by the propellant to overcome the inertial force of the reaction mass applies a force to the test element. In both test types, the force is imparted to the test element for a longer duration than high-strain dynamic testing described in Section 6-9.4 but for a far shorter duration than static load testing described in Section 6-8. The duration of the force pulse is many times longer than the time required for the stress wave to pass through the test element. Consequently, the effects of wave propagation on the forces in the element are small. However, the applied load is dynamic, and inertial and damping effects are important.

ASTM D7383 describes standardized procedures for rapid load tests. The test element is instrumented with a load cell to measure the force pulse over time. Usually, the element is also instrumented with accelerometers and strain gauges in a similar manner as with high-strain dynamic testing. Additional instrumentation is sometimes used including displacement transducers at the top of the test element and one or more expendable accelerometers located along the length of the test element.

The Unloading Point method (UP) (Middendorp, 1992) is the most common method to analyze static axial resistance from the results of a rapid load test. This method models the test element as a rigid mass, i.e., wave propagation effects are ignored, that is connected to the soil by a non-linear soil spring and a viscous damper. The specifics of this method can be found in the original source and FHWA (2016).

In some cases, the assumption that the test element behaves as a rigid mass is not valid. One case is when the test element has high base resistance and the acceleration, velocity and displacement at the top of the element are significantly different than at the base. Another case applies to long slender piles where wave propagation effects become significant. Both of these cases are addressed using modifications to the Unloading Point method. To address the influence of high base resistance, the Modified Unloading Point method (MUP) (Justason 1997) is applied in which accelerometers are included at the top and bottom of the test element and the response of the pile is modeled as a rigid mass using the average of the measured accelerations. To address the problems with long slender piles, the Segmental Unloading Point method (SUP) is applied in which a number of accelerometers are positioned along the test element (Mullins et al. 2002). The response of the pile is modeled as a series of rigid segments using the measured acceleration corresponding to each segment. Other methods, such as the Sheffield method (Holscher et al. 2012), are used to address loading rate effects for elements in fine-grained soils.

Due to the faster rate of loading in rapid load tests as compared to static load tests, NCHRP (2006) recommends reduction factors for axial capacities estimated using the UP, MUP, and SUP methods applied to the results of Statnamic tests. The loading rate reduction factors for elements in rock, sand, silt, and clay are equal to 0.96, 0.91, 0.69, and 0.65, respectively. Studies by Weaver and Rollins (2010) and Brown and Powell (2013) propose lower reduction factors for elements in fine-grained soil. Weighed loading rate reduction factors can be determined and applied in mixed soil profiles based on the percentage of nominal resistance provided by each layer (FHWA 2016). FHWA (2016) suggests that reduction factors similar to those applied to Statnamic tests are applicable to rapid load tests performed using cushioned drop weight systems. Note that the loading rate reduction factor is applied in addition to the LRFD resistance factor or ASD factor of safety.

AASHTO (2020) does not provide strength limit state resistance factors for geotechnical resistance based on rapid load tests. FHWA (2016) cites a study by McVay et al. (2003), which is summarized in Table 6-48.

Table 6-48 Strength Limit State Resistance Factors for Axial Loading based on Rapid Load Testing (after McVay et al. 2013, FHWA 2018a)

Pile	Bearing Conditions	Recommended Resistance Factor
Redundant driven piles	Rock and coarse-grained soil	0.70
	Mixed layers of sand, clay, and/or rock[A]	0.60
Nonredundant driven piles	Rock and coarse-grained soil	0.60
	Mixed layers of sand, clay, and/or rock[A]	0.50
Redundant drilled piers[B]	Relatively uniform ground conditions	0.65

[A] Rapid load tests not recommended in fine-grained soils without calibration to a static load test.
[B] FHWA (2018a) recommends lowering resistance factors for non-redundant shafts, sites with high variability, and/or when uncalibrated rapid load tests.

The primary benefit of a rapid load test is the ability to apply a large load with a less expensive and less complicated loading system than a static load test. The cost and time saving benefits often increase on projects with multiple tests. Additionally, unlike bi-directional load tests, rapid load tests can be performed on existing elements.

The main drawbacks of rapid load tests include 1) uncertainty associated with accounting for loading rate effects, particularly in fine-grained soils and/or using cushioned drop weight systems, 2) less accumulated knowledge and experience with rapid load tests as compared with static load tests, 3) the applied force pulse must overcome the static and dynamic ground resistance which can overstress the element, 4) insufficient displacement of the top of the element, i.e., less than 3% of element width, can result in overprediction of capacity (FHWA 2016), 5) conventional interpretation of rapid load tests only determine the total nominal resistance and not the distribution of shaft and base resistance (Coduto et al. 2016), and 6) the availability and mobilization of rapid load test equipment may be challenging in some locations.

6-10 INTEGRITY TESTING.

Integrity testing is used to detect and evaluate damage and/or defects in a deep foundation element. Most integrity tests are nondestructive, with drilling and coring as notable exceptions. Some nondestructive tests require advanced planning and preparation to provide access to the necessary portion(s) of the element. Additionally, integrity tests require specialized equipment and training to perform, and integrity testing using high-strain dynamic measurements requires mobilization of a pile hammer. This section provides a brief overview of some of the most common methods used to perform integrity testing.

Integrity testing using high-strain dynamic measurements is primarily used for driven piles while crosshole sonic logging, thermal integrity profiling, and gamma-gamma testing are primarily applied to drilled shafts.

6-10.1 High-strain Dynamic Measurements.

The Case Method can be applied using high-strain dynamic measurement to evaluate pile integrity. The Beta Method developed by Rausche and Goble (1979) interprets the force and velocity measurements to detect changes in impedance that indicate changes in the cross-sectional area along the element. The pile integrity factor, Beta, abbreviated as BTA, is reported by the PDA to quantify the severity of damage. A BTA equal to 1.0 indicates no damage while a BTA less than 0.8 indicates damage. As the BTA value decreases, the severity of the damage increases.

6-10.2 Low-strain Dynamic Measurements.

The sonic echo and impulse response methods are the most common of several low-strain dynamic measurement methods used to assess foundation element integrity. These methods do not require access tubes in the tested element and can therefore be used without prior preparation of the element. The sonic echo test involves striking the element with a hand-held hammer and recording the initial downward-traveling compression wave and return upward-traveling compression or tension waves using a geophone that is temporarily glued to the top of the element. Concrete defects or anomalies in cross-sectional area, i.e., necking or bulging, create impedance changes that will cause early reflection of the wave energy, i.e., $t < 2L'/c$. Additionally, the type of impedance change infers the type of anomaly. For example, an increase in cross-sectional area due to a bulge will increase impedance that will create a reflected compression wave. A decrease in cross-sectional area due to necking will decrease impedance that will create a reflected tension wave. The impulse response method is similar to the sonic echo method except that results are analyzed in the frequency domain instead of the time domain.

A limitation of the low-strain dynamic measurement methods is that the strength of the return waves is sometimes too weak to be properly interpreted, particularly when the element is long relative to its width and/or when the element is bearing in rock. Additionally, the resolution of the method is often insufficient to detect small anomalies, particularly near the base of the element.

6-10.3 Cross Hole Sonic Logging.

Cross hole sonic logging requires at least two embedded access tubes installed in the tested element. An acoustic source is lowered down one tube while a receiver is simultaneously lowered down another tube to the same depth as the source. The distance between the source and receiver divided by the time between emission and detection of the acoustic signal gives the compression wave speed of the concrete. Reduced compression wave velocity below a baseline value indicates reduced concrete quality. Standardized procedures for cross hole sonic logging are provided in ASTM D6760. Cross hole tomography is a variation of cross hole sonic logging that includes placing the source and receiver at different depths to obtain a three-dimensional representation of the tested element. A primary limitation of cross hole sonic logging is that only the portions of the element between access tubes can be tested.

6-10.4 Thermal Integrity Profiling.

Thermal integrity testing uses embedded temperature-sensing cables, or multiple access tubes, and a thermal probe to monitor the temperature of the curing concrete. The temperature profile can be interpreted to infer the geometry and concrete quality of the tested element in the following ways: 1) localized low temperature zones indicate the potential for defective concrete, 2) comparisons of local temperature at a particular elevation to the overall average temperature are used to infer the radius and concrete cover at the elevation, and 3) comparison of temperature at diametrically opposite measurement locations are used to infer the cage alignment. Standardized procedures for thermal integrity profiling are provided in ASTM D7949. A primary limitation of thermal integrity profiling is that it can only be performed while the exothermic chemical reaction of cement hydration is still occurring at a significant rate.

6-10.5 Gamma-Gamma Logging.

Gamma-gamma logging requires one access tube installed in the tested element. During the test, a single probe with a gamma ray source and detector is lowered down the access tube. A portion of the gamma rays emitted by the source is reflected back to the probe, i.e., backscatter, and are encountered by the detector. An approximately linear correlation exists between the time rate of gamma ray detection (counts per second) and the density of concrete. A primary limitation of gamma-gamma logging is the security and logistics required to transport, handle, and store the radioactive source. Additionally, the test can only detect anomalies within a radius of several inches of the access tube.

6-11 PROBLEM SOILS AND DEEP FOUNDATIONS.

Chapter 1 provides a summary of many types of problem soil conditions that can affect the design of foundations and earth structures. Table 6-49 summarizes important conditions for the design of deep foundations in problem soils.

Table 6-49 Problem Soil Considerations for Deep Foundations

Soil Type	Primary Considerations for Deep Foundations
Soft Clays, Organic Soils, Peat, and Muskeg	• These soils generally provide poor shaft and end bearing resistance • Settlement of these soils from other loading, such as embankments, and/or lowering of the water table can cause a drag load and downdrag settlement of deep foundations. • Aggregate piers may be unsuitable because of a tendency for excessive lateral compression. • Drilled shafts may require temporary casing to prevent squeezing of the shaft during drilling. • CFA piles may experience inward squeezing, resulting in inconsistent pile diameter. • Displacement piles (driven or drilled) can cause heave and/or lateral soil displacement from the additional volume of the piles added to the ground.
Fissured Stiff Highly Plastic Clays and Soft Shales	• Clay fissures and cracks can reduce deep foundation skin friction. Foundation installation methods, e.g. pile driving, can produce cracks in stiff clays. • Stiff near surface clays are prone to having poor contact with deep foundations, and thus low skin friction, due to the formation of gaps during installation, shrink/swell, and freeze/thaw. • Driven piles in soft shales are susceptible to a loss in geotechnical resistance after driving known as relaxation.
Loess and Other Collapsible Soils	• Inundation settlement of collapsible soil can introduce a drag force and downdrag settlement.
Sensitive Clays	• Cyclic softening reduces geotechnical resistance, particularly lateral resistance.
Loose Sands	• Drilled shafts will likely require temporary casing to prevent collapse of the shaft during drilling. • CFA piles may experience caving, resulting in inconsistent pile diameter. • Aggregate piers may require temporary casing during the drilling stage. • Post-construction densification of loose sand can introduce a drag force and downdrag settlement. • Liquefaction of loose sand increased the unbraced length of deep foundations, may introduce high lateral forces, and temporarily eliminates the geotechnical resistance within the liquefied zones. • Excessive foundation settlement may be required to mobilize base resistance in loose sand

Glacial Till	• Gravel, cobble, and boulder content of the till is the major consideration for deep foundations.
	    o These can obstruct pile driving and/or cause misalignment of piles. Pile toe attachments can help prevent damage.
	    o Drilled shafts can have difficulty drilling through large boulders, particularly when encountered partially in the alignment of the shaft. Special tooling may be required in tills containing large boulders.

Expansive Soils and Rock	• Low skin friction is possible over the depth of soil that is susceptible to shrink/swell.
Dredged Soils	• Dredged soils should be considered as soft or loose for design of deep foundations (see comments above)
Low Plasticity and Nonplastic Silts	• Squeezing and caving can also occur in these silty soils, especially when saturated. Temporary casing will likely be required for drilled foundations.
Municipal Solid Waste	• The electro-chemical properties of the waste may lead to deterioration of deep foundations, e.g. corrosion of steel piles. Elevated temperatures within the waste accelerate deterioration. • Obstructions within the waste may damage or deflect foundations during installation • Decomposition of waste can introduce a drag force and downdrag settlement

6-12 NOTATION.

Variable	Definition
a	Acceleration in wave mechanics calculations
A	Total or "gross" cross-sectional area of a pile
A_b	Area of pile base
A_p	Cross-sectional area of the pile material
$A_{s,i}$	Shaft area for a pile segment
b	Pile diameter
b'	Enlarged pile base diameter
B	Width of pile group (smaller plan dimension)
B'	Width of equivalent footing (smaller plan dimension)
c	Wave speed in a pile material
C	Fitting paramer for shaft resistance of drilled shafts
C_α	Adhesion
$C_{\varepsilon c}$	Modified compression index
$C_{\varepsilon r}$	Modified recompression index
D_{50}	Median particle size
D_r	Relative density
E	Young's modulus
E_p	Young's modulus of pile material
E_r	Energy rating of a pile driving hammer
E_u	Young's modulus of soil for undrained conditions
F	Force in pile in wave mechanics calculations
F_a	Force in pile after reflection
F_b	Force in pile before reflection
f'_c	Compressive strength of concrete or grout
f_n	Unit negative shaft resistance
f_p	Maximum unit wide resistance
f_{pe}	Effective prestress

Variable	Definition
$f_{s,i}$	Unit shaft resistance for a segment
f_u	Ultimate tensile strength of steel
f_y	Yield strength of steel
FS	Factor of safety
g	Acceleration due to gravity
I	Pile impedance
If	Influence factor
I_p	Moment of inertia of pile
I_r	Rigidity index
I_{rr}	Reduced rigidity index
J	Damping in wave mechanics calculations
K	Earth pressure coefficient
K_0	Coefficient of at-rest earth pressure
k_h	Coefficient of horizontal subgrade reaction
K_P	Coefficient of passive earth pressure
k_s	Side resistance factor
k_t	Base bearing factor
L	Length of pile group (larger plan dimension)
L'	Length of equivalent footing (larger plan dimension)
M_c	Characteristic moment
$M_{t,dead}$	Applied moment from dead load
$M_{t,live}$	Applied moment from live load
M_{ult}	Ultimate moment
n	Fitting parameter for shaft resistance of drilled shafts
N	Standard Penetration Test blow count – uncorrected
$N_{1(60)}$	Standard Penetration Test blow count corrected for overburden and efficiency
N_{60}	Standard Penetration Test blow count corrected for efficiency
N_c, N_q	Bearing capacity factors

Variable	Definition
n_g	Group efficiency factor
N^*_c, N^*_q	Bearing capacity factors modified to account for compressibility and local shear
N^*_{cr}	Bearing capacity factor for unit base resistance of rock
OCR	Overconsolidation ratio
p	Pile perimeter in wave mechanics calculations
P_c	Characteristic load
P_n	Load at failure in
$P_{P,mob}$	Resultant force from mobilized passive resistance
$P_{P,ult}$	Resultant force from fully mobilized passive resistance
P_r	Factored axial structural capacity
$P_{t,dead}$	Applied dead load
$P_{t,live}$	Applied live load
$P_{t,ult}$	Ultimate load
P_{ui}	Factored maximum single pile axial load
P_a	Atmospheric pressure
q	Quake in wave mechanics calculations
q_b	Unit base resistance
q_c / P_a	Cone tip resistance normalized by atmospheric pressure
$q_{c,a} / P_a$	Average cone tip resistance normalized by atmospheric pressure
Q_d	Applied permanent axial load
Q_{np}	Maximum axial load in pile at neutral plane
q_u	Unconfined compressive strength
R, R_n	Nominal axial pile resistance
R_b, R'_b	Base resistance
$R_{n,block}$	Block uplift capacity
$R_{r,g}$	Factored axial capacity of pile group
$R_{r,gblock}$	Factored resistance to block failure
$R_{r,gu}$	Combined factored group uplift capacity

Variable	Definition
$R_{r,s}$	Factored single column capacity
$R_{r,ublock}$	Factored uplift capacity of piles and block
R_s	Shaft resistance
R_{s-}	Negative shaft resistance
R_{s+}	Positive shaft resistance
s_u	Undrained shear strength
$s_{u,UC}$	Undrained shear strength evaluated using the unconfined compression test
$s_{u,DSS}$	Undrained shear strength evaluated using the direct simple shear test
$s_{u,ICU}$	Undrained shear strength evaluated using the isotropically consolidated undrained triaxial test
$s_{u,UU}$	Undrained shear strength evaluated using the unconsolidated undrained triaxial test
s^*_u	Factored undrained shear strength
t	Time in wave mechanics calculations
t_{cap}	Pile cap thickness
u	Pile displacement in wave mechanics calculations
v	Particle velocity in wave mechanics calculations
v_a	Particle velocity at reflection
v_b	Particle velocity before reflection
v_c	Critical velocity for scour
V_{block}	Volume of frustum
$W_{e,g}$	Effective weight of pile group block
W_{re}	Factored effective weight of a single column
y	Lateral deflection of pile or pile cap
y_{tm}	Deflection of pile top due to applied moment
y_{tp}	Deflection of pile top due to applied load
z_s	Depth to bearing layer
z_1	Depth below the base of the pile cap to the assumed start of load spreading
z_2	Depth interval where load spreading is assumed to occur
z'	Depth below the equivalent footing

Variable	Definition
Z	Pile length
Z'	Pile length below strain and acceleration measurements
Z_f	Depth to fixity
α	Adhesion factor
α_{bond}	Nominal unit grout to ground bond strength
α_E	Joint modification factor
β	Beta method coefficient to account for shaft friction and lateral earth pressure
δ	Interface friction angle
δ	Total settlement
δ_e	Elastic settlement of pile
ΔQ	Average change in load in an element over its length
δ_s	Settlement due to compression of soil supporting a pile
γ	Total unit weight
γ', γ_b	Bouyant or effective unit weight of soil
γ_m	Moist unit weight of soil
ε_v	Volumetric strain from foundation loading
ϕ'	Effective stress friction angle
$\phi'*$	Factored effective stress friction angle
φ_{da}	Resistance factor for pile driving
ν	Poisson's ratio, s subscript indicates soil
ρ	Mass density
σ'_m	Mean effective stress at b/2 below the pile base elevation
σ'_p	Preconsolidation stress
σ_{zD}	Vertical stress at the base elevation (total or effective depending on the case)
σ'_z	Average vertical effective stress

6-13 SUGGESTED READING.

Topic	Reference
Driven piles	FHWA. 2016. *Design and Construction of Driven Pile Foundations. Geotechnical Engineering Circular No. 12, FHWA-NHI-16-009*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.
Drilled shafts	FHWA. 2018. *Drilled Shafts: Construction Procedures and Design Methods, Geotechnical Engineering Circular No. 10, FHWA-NHI-18-024*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.
Continuous flight auger (CFA) columns	FHWA. 2007. *Design and Construction of Continuous Flight Auger Piles, Geotechnical Engineering Circular No. 8, FHWA-HIF-07-03*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.
Micropiles	FHWA. 2005. *Micropile Design and Construction. Reference Manual for NHI Course 132078: FHWA-NHI-05-039*. U.S. Department of Transportation, Federal Highway Administration, Washington, DC
Drilled displacement piles (DDP)	FHWA. 2007. *Design and Construction of Continuous Flight Auger Piles, Geotechnical Engineering Circular No. 8, FHWA-HIF-07-03*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.
Helical piles	Perko, H. A. 2009. *Helical Piles: A Practical Guide to Design and Installation*. Wiley, Hoboken, NJ.
Aggregate columns	FHWA. 2017. *Ground Modification Methods Reference Manual – Volumes I and II, Geotechnical Engineering Circular No. 13, FHWA-NHI-16-009*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

CHAPTER 7. PROBABILITY AND RELIABILITY IN GEOTECHNICAL ENGINEERING

7-1 INTRODUCTION.

7-1.1 Scope and Purpose.

This chapter introduces the basic principles of statistics and probability required to understand and begin to use these concepts in geotechnical engineering. Sources of uncertainty in geotechnical design and methods for quantifying that uncertainty are discussed. Applications of probabilistic principles are presented, including use of probability to understand and interpret laboratory and field-testing data, methods to calculate reliability indices, a review of common risk assessment procedures, and discussion of hazard analyses. In many sectors, LRFD is used to design retaining walls and foundations. The probabilistic basis of LRFD is explained to help engineers connect this approach to other design procedures. A primary purpose of this chapter is to familiarize the engineer with common applications of probability in geotechnical engineering. In many cases, additional study would be required to implement these applications fully.

7-2 PRINCIPLES OF STATISTICS AND PROBABILITY.

This section reviews basic principles of statistics and probability to provide a foundational understanding for discussions of uncertainty, reliability, and risk assessment. Deeper treatment of statistics and probability in the context of civil engineering can be found in textbooks, such as Ang and Tang (1975) and Benjamin and Cornell (1970).

The methods presented in this chapter are based on sets of observations or measurements, which are referred to as a *sample*. Every sample comes from a *population*, which is the set of all outcomes for the property being measured for a particular experiment or situation. This terminology can be confusing because geotechnical engineering also uses sampling terminology in field and laboratory testing. The common geotechnical use of the term sample is related to the more rigorous statistical definition. The distinction between the sample and population depends on how the population is defined as illustrated in the following examples. The scope of the population differs in each example.

- The liquid limit below a particular shallow foundation is required for a forensic case. The corresponding population might be defined as the liquid limit at all locations within a Shelby tube of the soil from below the foundation. In this case, the sample might be a set of ten liquid limit tests on soil taken from different locations in the Shelby tube. In reality, the Shelby tube is itself a sample of the soil below the foundation.

- The undrained shear strength of a clay layer at a particular site must be characterized for a foundation design. The population is the undrained shear strength at all locations within the clay layer. The sample might be a set of 30 UU triaxial compression tests on individual Shelby tube specimens of the clay.
- A researcher desires to develop a general relationship for the adhesion of piles in clay using the α method (see Section 6-5.4.2). As a general relationship, the population may be defined as all piles installed in clay or could be restricted to a particular type of pile or stratigraphy. The sample used to develop the relationship might be adhesion measurements from 200 load tests on piles installed in clay.

7-2.1 Statistics.

For a given sample of measured data, any function of the sample data is referred to as a statistic. The most common statistics provide measures of either the central tendency or the spread (a.k.a., dispersion) of the data (Baecher and Christian 2003). Common statistics used to describe a data set and the equations for these statistics are summarized in Table 7 1. It is common to use different symbols to distinguish between statistics from the population and those obtained from a sample. For example, the population mean (average) and variance (mean-squared deviation from the mean) are commonly represented by μ and σ^2 while the sample mean and variance are $\overline{x}$ and s^2.

The definitions of statistical terms used in this chapter are provided in Table 7 1. The reader may need to refer back to this table when these terms are used later in the chapter.

7-2.2 Methods of Plotting Data.

In order to be interpreted usefully, sample observations are usually plotted. While many types of plots can be used (e.g., scatter plots, pie charts, area plots, etc.), the most common means of graphically representing sample data are box and whisker plots, histograms, and cumulative distribution plots. These are readily available in most spreadsheet applications and statistical software tools.

7-2.2.1 Box and Whisker Plots.

A *box and whisker* plot is a depiction of the mean, median, specified percentiles, and extreme values. Two examples are provided at the bottom of Figure 7-1(a) and (b). The box portion is bounded by a lower and upper percentile, usually $x_{0.25}$ and $x_{0.75}$, with a line indicating the median or $x_{0.5}$. A marker or line is plotted at the mean value. The whiskers are lines that extend out to bars at specified percentiles or at the maximum and minimum values,[41] indicating the meaningful range of the data.

Table 7-1 Common Statistics

Statistic	Symbol	Definition	Equation or comments
Sample Mean	$\bar{x}$	Arithmetic average of n items in a sample from a population	$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$
Population Mean	μ	Arithmetic average of all N items in the population, or expected value, $\mathrm{E}(X)$, of the variable.	$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$
Median	$x_{0.5}$	Value for which half of the data are smaller and half larger	Cumulative distribution at the median, $F_X(x_{0.5}) = 0.5$
Mode	NA	Most frequent value in the data	
Maximum	x_{max}	Highest observed value	
Minimum	x_{min}	Lowest observed value	
Range	r_X	Difference between the highest and lowest values	$r_x = \lvert x_{max} - x_{min} \rvert$
Percentile	x_P	Value for which a fraction, P, of the data are smaller	Cumulative distribution at the median, $F_X(x_P) = P$
Sample Variance	$\mathrm{Var}_X = S_X^2$	Second moment of the sample data about the mean	$Var_X = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2$
Sample Standard Deviation	S_X	Root-mean-square value of the difference between the sample data and the mean, or square root of the variance	$S_X = \sqrt{Var_X} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$
Sample Covariance	$\mathrm{cov}(x, y)$	Measure of the tendency of two variables (x, y) to vary together	$\mathrm{cov}\left(x, y\right) = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)$
Sample Correlation Coefficient	r_{xy}	Covariance normalized by the standard deviations of the variables, such that $-1 \le r_{xy} \le 1$.	$r_{xy} = \frac{\mathrm{cov}\left(x, y\right)}{S_x \cdot S_y}$
Population Variance	$(\sigma_X)^2$	Second moment of the population about the mean	$\sigma_X^2 = E\left[\left(X - \mu\right)^2\right] = E\left(X^2\right) - \mu_X^2$
Population Standard Deviation	σ_X	Root-mean-square value of the difference between the sample data and the mean, or square root of the variance	$\sigma_X = \sqrt{\sigma_X^2} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \mu\right)^2}$
Coefficient of Variation	COV_X	Standard deviation divided by the mean. Relative measure of dispersion commonly used in geotechnical engineering	$COV_X = \frac{S_X}{\bar{x}}$ or $COV_X = \frac{\sigma_X}{\mu_X}$
Notes: Expected value is the sum of all possibilities of a variable multiplied by the probability of that value. For discrete variables, $\mathrm{E}(X) = \Sigma x \cdot \mathrm{P}(x)$. For continuous variables or functions, see Table 7-3. $(n - 1)$ is used in the equations for variance and standard deviation to produce an unbiased estimate.			

[41] In some cases, outliers may be identified using appropriate statistical methods. Such observations are plotted individually beyond the bounds of the whiskers.

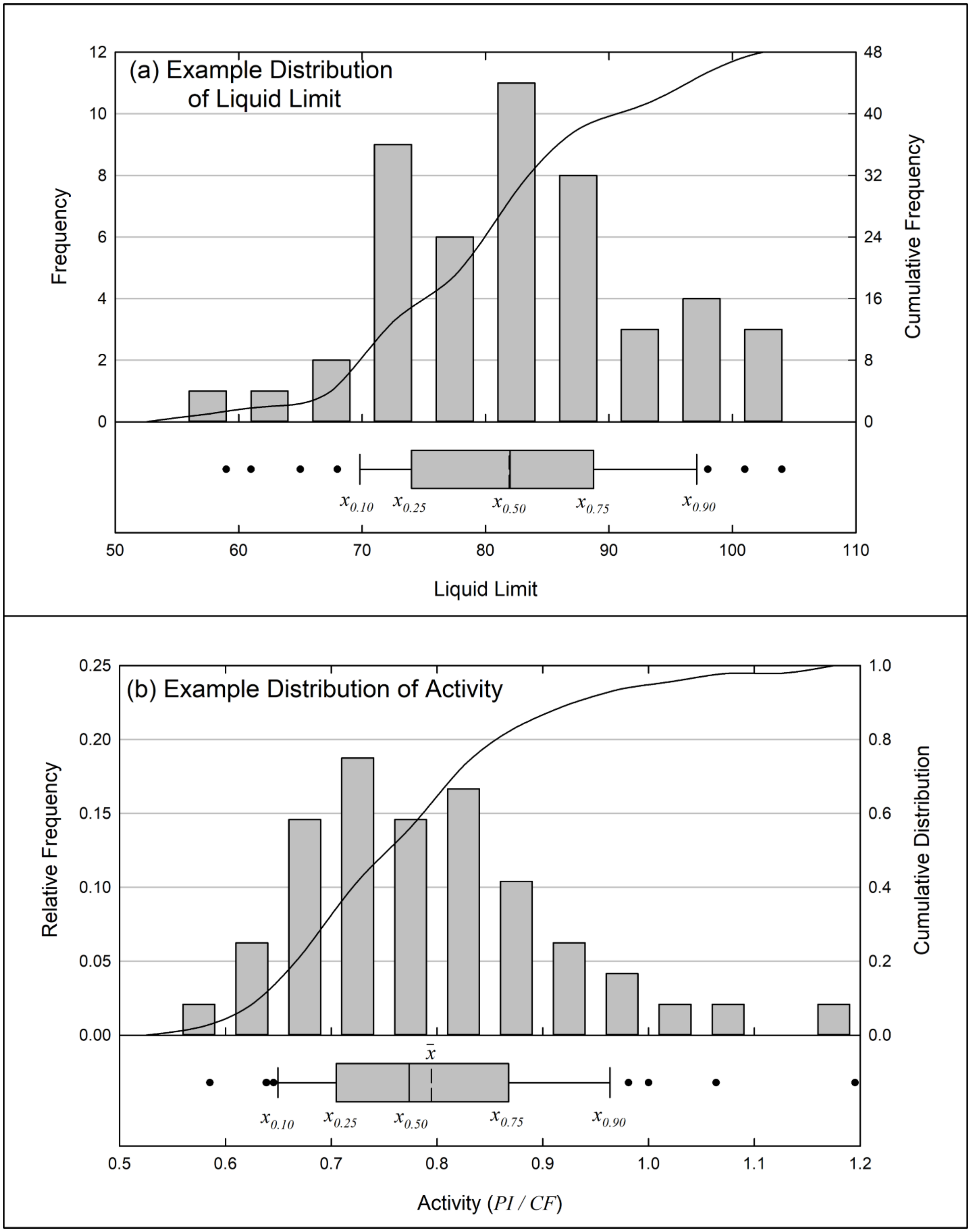


Figure 7-1 Example Statistical Plots Illustrating Important Definitions.

7-2.2.2 Histograms.

The range of a property can be divided into equal intervals or bins, and the number of observations from a sample within each interval can be counted. A *histogram* is a bar graph with the intervals on one axis (typically the x-axis). The frequency or number of observations for each interval is represented by a bar of the appropriate height. The total height of the bars is equal to the number of observations in the sample. If the frequency for each interval is divided by the number of observations in the sample, the histogram plots relative frequency and the sum of the heights of the bars is equal to 1.0. The histograms in Figure 7-1 provide examples of both types of plots.

Histograms are useful for visual interpretation of the statistics of a sample. In Figure 7-1(a), the mean and median liquid limit are both 82 while the mode also corresponds to the interval of 80 to 85. This indicates that the distribution is relatively symmetric about the mean. In contrast, the example of clay activity in Figure 7-1(b) is *skewed*, meaning that the peak or mode of the sample is not at the middle of the range of observations. In this case, the mode is lower than the median while the mean is higher than the median. The observations have a long upper tail, which is referred to as positive skew.

7-2.2.3 Cumulative Distributions.

The *cumulative distribution* shows the number of observations that are less than or equal to a particular value (or interval). The cumulative values are found by progressively summing the number of observations from each interval starting at the lower end of the data. Examples of cumulative distributions are shown by the monotonically increasing curves in Figure 7-1.

7-2.3 Probability.

As discussed at length by Baecher and Christian (2003), the term *probability* can have many definitions. In one sense, probability refers to the relative frequency of an event. Thus, the probability of an event can be thought of as the number of times an event occurs divided by the total number of trials, usually for a large number of trials. This frequentist approach cannot be used for (1) unique occurrences, (2) conditions that cannot be statistically sampled, or (3) direct inference to probabilities on states of nature (Baecher and Christian 2003). In the other sense, probability refers to the degree of belief that an event will occur. This definition of probability can apply to unique occurrences but may be subjective. Further philosophical discussion of the meaning of probability is beyond the scope of this manual.

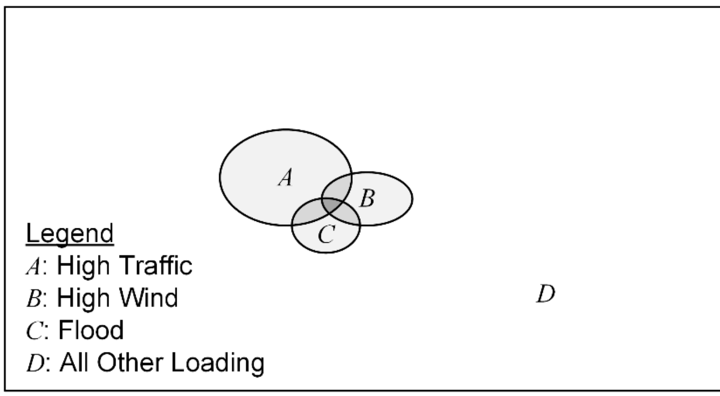
7-2.3.1 Concepts and Terminology.

In order to understand applications of probability to geotechnical engineering, it is necessary to understand the language of probability. Table 7-2 lists common terminology and provides a general description of the meaning of the terms.

Table 7-2 Probabilistic Terminology (after Ayyub and McCuen 2016, Baecher and Christian 2003)

Terminology	Description
Set	Collection of outcomes. May be discrete or continuous. May be finite or infinite in number.
Subset	Collection of outcomes within a set.
Sample space, S (a.k.a. outcome space)	Set of all possible outcomes for a particular experiment or situation.
Sample points	Individual outcomes within the sample space.
Null set, Ø	Set containing no outcomes.
Event	Subset of the sample space. An event containing no sample points is the null set. An event containing all the sample points is a certain event.
Union, ∪	Subset of outcomes in either A or B (for events A and B).
Intersection, ∩	Subset of outcomes in both A and B (for events A and B).
Complement, $\bar{A}$	Subset of outcomes not in event A.
Overlapping events	Events which intersect. Events A and B are overlapping if $A \cap B \neq Ø$.
Mutually exclusive events	Events which are completely separate. Events A and B are mutually exclusive if $A \cap B = Ø$.
Collectively exhaustive events	A set of events that completely comprise the sample space. Events A and B are collectively exhaustive if $A \cup B$.
Partition	A set of collectively exhaustive and mutually exclusive events. The sum of the probabilities of the events in a partition must equal 1.0.
Probability of event, $P(A)$	Probability that event A occurs with $0 \leq P(A) \leq 1$.
Conditional probability, $P(A\|B)$	Probability that event A occurs given the fact that event B occurs.
Independent events	Events for which the probability of one event is not changed by knowing that the other event occurs. For independent events A and B, $P(A\|B) = P(A)$ and $P(B\|A) = P(B)$.
Dependent events	Events for which the probability of one event is changed by knowing that the other event occurs. For dependent events A and B, $P(A\|B) \neq P(A)$ and $P(B\|A) \neq P(B)$.
Permutation, $P_{r\|n}$	Number of outcomes possible by picking r items from n possibilities where the order of the items matters (i.e., HTH is different from HHT). $P_{r\|n} = n! / (n - r)!$
Combination, $C_{r\|n}$	Number of outcomes possible by picking r items from n possibility where the order of the items does not matter (i.e., HTH is the same as HHT). $C_{r\|n} = n! / [n!\ (n - r)!]$
Binomial coefficient	Alternate notation for combination: $\binom{n}{r} = C_{r\|n} = \frac{n!}{r!(n-r)!}$
Note: The descriptions are intended to be correct but not necessarily rigorous definitions of each term.	

Figure 7-2 illustrates some of these probabilistic concepts in the context of bridge foundation loading. The sample space represents a range of loading conditions for a bridge foundation. Events A, B, and C are extreme loading conditions while Event D represents all other loading conditions. The possibility of combined high traffic, high wind, and flood loading is represented by the overlap of A, B, and C (i.e., $A \cap B \cap C$) and is illustrated by the dark shaded area. Representative probability calculations are also summarized in Figure 7-2. Event D is seen to be the complement of the extreme loadings for the Figure 7-2 example. The probability of the complement of an event is equal to unity minus the probability of the event. Thus, the probability of all other loading conditions is equal to unity minus the probability of the union of A, B, and C.



Sample Space, S, for Bridge Foundation Loading

$$S = A \cup B \cup C \cup D$$

$$D = \overline{A \cup B \cup C}$$

Dark shaded area is: $A \cap B \cap C$

Probability of Sample Space: $P(S) = 1$

Probability of A or B: $P(A \cup B) = P(A) + P(B) - P(A \cap B)$

Probability of A or B or C: $P(A \cup B \cup C) = P(A) + P(B) + P(C) - P(A \cap B) - P(B \cap C) \ldots$
$- P(C \cap A) + P(A \cap B \cap C)$

Probability of D: $P(D) = 1 - P(A \cup B \cup C)$

Figure 7-2 Sample Space, Events, and Probability Calculations.

7-2.3.2 Random Variables.

Engineering applications most often are concerned with outcomes that are real numerical values. In this case, a *random variable* (RV) can be used to map every outcome in the sample space to the real line as depicted in Figure 7-3. The mapping may be one-to-one or one-to-many but maintains the probability rules for complements, unions, and intersections. Random variables may be either discrete or continuous. A discrete RV can only take on particular values, usually integers. An example of a discrete RV might be the number of floods larger than a given size at a location in one year. For continuous RV, any value within the range of possible outcomes is valid.

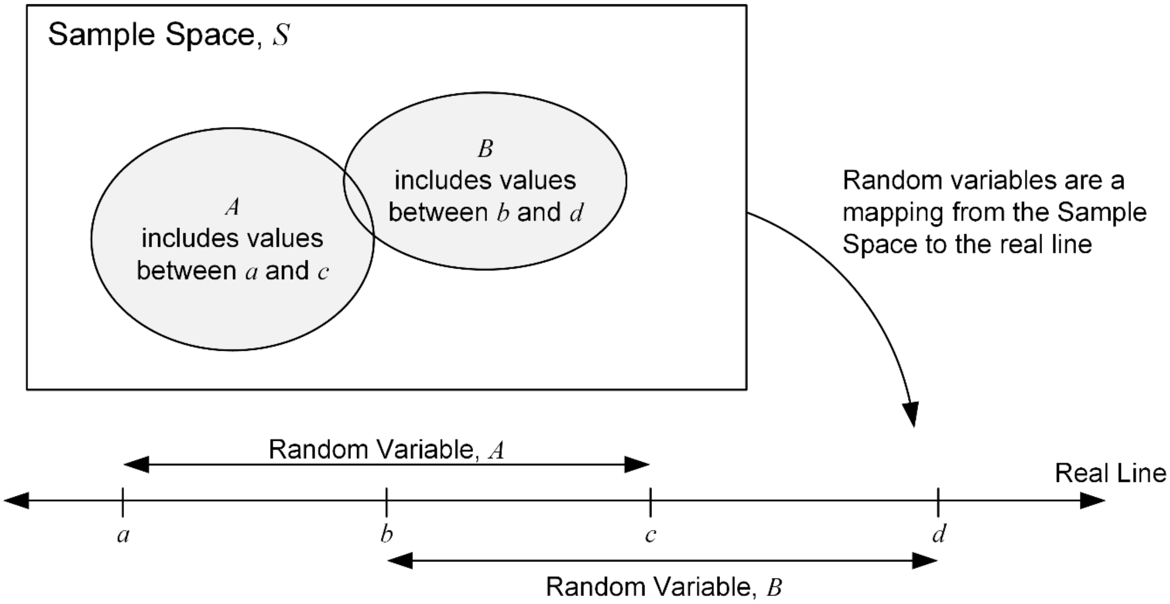


Figure 7-3 Use of Random Variables to Relate Sample Space to the Real Line

7-2.3.3 Probability and Cumulative Distributions.

For discrete RV, probabilities are represented by a *probability mass function* (PMF), which relates probability, $P_X(x_i)$, to particular values of x_i. For each x_i, the PMF provides the probability that the random variable X takes on the value x_i. The *cumulative mass function* (CMF) is defined as the probability that X is less than or equal to x_i or:

$$F_X\left(x_i\right) = P_X\left(X \le x_i\right) = \sum_{j=1}^{i} P_X\left(x_i\right) \qquad (7\text{-}1).$$

Other important properties of discrete random variables are summarized in Table 7-3. Examples are found in Figure 7-4(a) and (c). The left bars of each histogram represent the PMF while the right bars represent the CMF. The CMF bar for each x_i is equal to the previous value of the CMF plus the current value of the PMF. In other words, the PMF is the difference between the CMF for the current and previous values of x_i.

For continuous RV, the probability functions use the term density rather than mass. The *cumulative density function* (CDF) is the probability that X is less than or equal to x_0, which is calculated as:

$$F_X\left(x_0\right) = P\left(X \le x_0\right) = \int_{-\infty}^{x_0} f_X\left(x\right) dx \qquad (7\text{-}2).$$

The integral in the CDF is analogous to the summation for the CMF. The CMF and CDF are both non-decreasing functions as the RV increases.

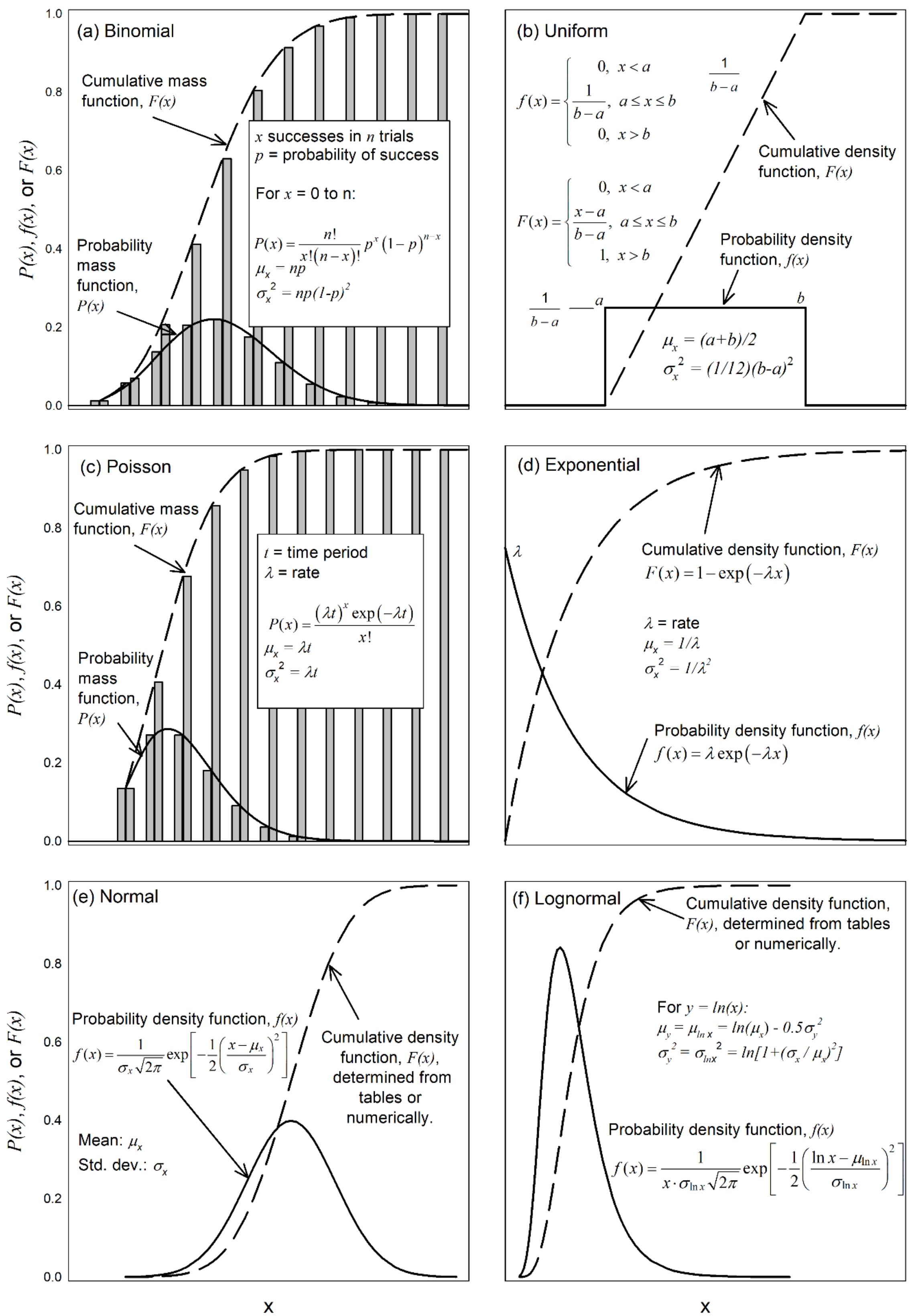


Figure 7-4 Common Types of Distribution

Probabilities of continuous RV are represented by a *probability density function* (PDF), $f_X(x)$. Similar to the PMF, the PDF is the rate of change of the CDF, or its first derivative, such that:

$$f_X(x) = \frac{d}{dx} F_X(x) \qquad (7\text{-}3).$$

This is illustrated by the uniform distribution in Figure 7-4(b). The uniform CDF increases linearly from 0 to 1 over the interval $[a, b]$. The value of $f_X(x)$ is equal to the slope or derivative of the CDF. For continuous RV, probabilities are defined only over an interval:

$$P(x_1 \le X \le x_2) = \int_{x_1}^{x_2} f_X(x)\,dx \qquad (7\text{-}4).$$

While the PDF has a value at particular values of X, the probability of a particular value of X is zero.[42] Properties of continuous random variables are summarized in Table 7-3.

Table 7-3 Properties of Random Variables

Distribution Properties	Type of Distribution	
	Discrete	**Continuous**
Total probability and cumulative values at extremes	$0 \le P_X(x_i) \le 1$, $\sum_{i=1}^{n} P_X(x_i) = 1$ $F_X(x_i) = 0$ for $x < x_1$ $F_X(x_i) = 1$ for $x > x_n$	$P(-\infty \le X \le \infty) = 1$ $F_X(-\infty) = 0$ $F_X(\infty) = 1$
First moment about the origin (mean)	$\mu_X = \sum_{i=1}^{n} x_i P_X(x_i)$	$\mu_X = \int_{-\infty}^{\infty} x \cdot f_X(x)\,dx$
Second moment about the mean (variance)	$\sigma_X^2 = \sum_{i=1}^{n} (x_i - \mu_X)^2 P_X(x_i)$	$\sigma_X^2 = \int_{-\infty}^{\infty} (x - \mu_X)^2 \cdot f_X(x)\,dx$
k^{th} moment about the mean	$M_k = \sum_{i=1}^{n} (x_i - \mu_X)^k P_X(x_i)$	$M_k = \int_{-\infty}^{\infty} (x - \mu_X)^k \cdot f_X(x)\,dx$
Expected value, E	$E[g(x_i)] = \sum_{i=1}^{n} g(x_i) P_X(x_i)$	$E[g(x)] = \int_{-\infty}^{\infty} g(x) \cdot f_X(x)\,dx$
Notes: The standard deviation is the square root of the variance (σ_X) The population mean (μ_X) can be replaced by the sample mean ($\bar{x}$) for calculations based on a sample rather than the entire population.		

[42] A physical object with a known density must have thickness in order to have a mass. The interval is the thickness required to have mass in probabilistic terms.

The probability functions (PMF or PDF) are often described by their moments about the origin or about the mean, which are analogous to area moments from mechanics. The mean is first moment about the origin, analogous to the center of gravity. The variance is the second moment about the mean, analogous to the moment of inertia. The third and fourth moments about the mean are referred to as the skew and kurtosis, respectively. These moments can be calculated from the PMF or PDF using the equations provided in Table 7-3.

Table 7-3 also defines the *expected value* ($E[\cdot]$), which is found by multiplying any function by the PMF or PDF over the full range of the random variable. The expected value is a linear operator and can be distributed algebraically through expressions. The expected value of a constant is the constant. The mean is the expected value of x or $E[x]$, which can be found by substituting x for $g(x)$.

Any function may serve as a PMF or PDF provided that the properties in Table 7-3 are satisfied. Six common distributions are plotted in Figure 7-4 along with equations for the PMF and CMF or PDF and CDF, if available. More information on each of these distributions follows:

- Binomial – discrete distribution that results from repeated experiments with each being a Bernoulli trial (i.e., two outcomes – success or failure) with constant probability, p, for each trial. The binomial distribution uses the binomial coefficient and is useful for modeling the probability of a specified number of events (e.g., floods, earthquakes, etc.) in a certain time period.
- Uniform – continuous RV with equal probability over the specified range and zero probability outside of the interval $[a, b]$.
- Poisson – discrete distribution commonly used to model the occurrence of a random event in a continuous dimension of time or space as a limiting case of the binomial distribution. The three stochastic processes represented by the Poisson distribution are (1) the number of events in a time interval, (2) the intensity of an event, and (3) the separation of the events in time or space. The second and third processes can be continuous rather than discrete.
- Exponential – continuous distribution related to the third Poisson process of time between events. The exponential function is described by a single parameter, λ, which is related to the rate and is the value of the PDF at $x = 0$. The mean of the exponential function is also referred to as the recurrence or return period.
- Normal (a.k.a., Gaussian) – symmetric, bell-shaped, continuous distribution that fits well to the distribution of many naturally occurring properties. The mean and standard deviation are conveniently the parameters of the PDF. The notation $N(\mu_X, \sigma_X)$ is often used as shorthand for the normal distribution. The CDF cannot be expressed in a closed form equation and must be read from tables or determined numerically. Modern spreadsheets and statistics packages can easily provide the normal CDF. The addition of more than one normally distributed RV

results in another normally distributed RV. When RV with any type of distribution are added together, the resulting distribution will tend to be normal as the number of RV increases. This explains the wide natural occurrence of the normal distribution.

- Lognormal – skewed continuous distribution related to the normal distribution via a transformation ($y = \ln x$), which can be used to determine CDF values. The lognormal distribution does not allow negative values, which is convenient for many engineering properties. Lognormal distributions result from the multiplication of many RV with any type of underlying distribution.

7-3 UNCERTAINTY IN GEOTECHNICAL ENGINEERING.

Uncertainty refers to a condition that is completely or partially unknown, indefinite, indeterminate, or unverified (Baecher and Christian 2003). In the context of geotechnical engineering, soil and rock properties are uncertain because of natural variation in space, and possibly time, and because measurements and interpretations are required to determine these properties. Calculated values, such as settlement, bearing capacity, and lateral earth pressure, may be uncertain because of the uncertainty of both input parameters and the analytical or numerical models used.

7-3.1 Sources of Uncertainty.

Uncertainty in geotechnical engineering occurs mostly within two groups, which sometimes overlap. *Natural variability* (a.k.a., *aleatory* or *external* uncertainty) occurs from physical randomness and describes variability at various locations at the same time, or variations in both time and space. On the other hand, *knowledge uncertainty* (a.k.a., *epistemic* or *internal* uncertainty) occurs from a lack of knowledge, such as data, information, or understanding. As pointed out by Baecher and Christian (2003), the latter manifests most prominently in geotechnical engineering in site characterization, determination of soil and rock parameters, and selection of appropriate engineering models. Geotechnical engineering must also interact with social and economic factors, which may add uncertainties related to operations and decision-making. These are outside the scope of this chapter.

7-3.1.1 Inherent Soil and Rock Variability.

Soil and rock inherently exhibit natural variability as a result of the complex natural processes by which these materials have reached their current location and condition. Inherent variability can apply to both stratigraphy and soil properties within a particular stratum as illustrated in Figure 7-5. The thickness of every soil layer varies spatially, and the soil properties, such as composition, packing, and stress state, vary within each layer. Characterization of these variations is necessarily limited, which, in reality, produces knowledge uncertainty. However, from a practical standpoint, inherent, natural variability is usually considered *stochastic*, which simply refers to a random variation in time or space.

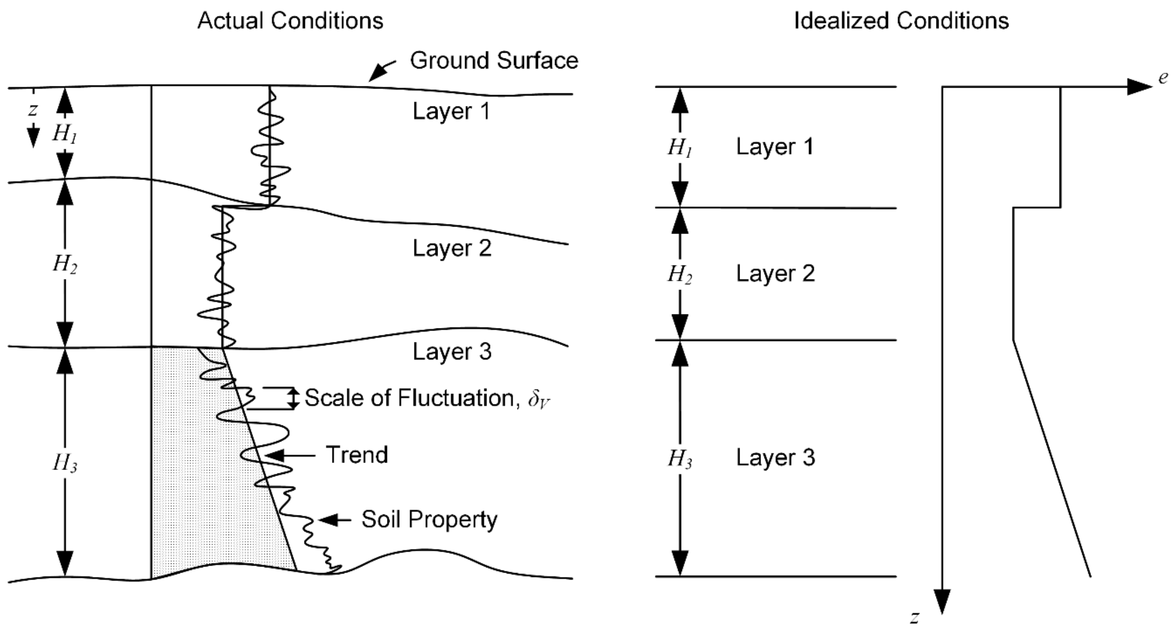


Figure 7-5 Uncertainty in Characterization of Actual Field Conditions (after Phoon and Kulhawy 1999a)

The degree of inherent variability depends heavily on the geologic and environmental history. For example, coarse-grained alluvial deposits have high spatial variability as a result of the rapid changes that occur in stream morphology. In contrast, varved fine-grained lacustrine deposits have low variability in the horizontal direction and high, but predictable, variability vertically across the varves.

Figure 7-6 summarizes the available data for the inherent variability of various soil and rock properties and parameters. The gray bars and dots indicate the range and mean of reported COV, respectively, for each property. The COV normalizes the standard deviation with respect to the mean. Wide gray bars indicate a wide variation in the level of uncertainty for the particular property. The range of mean values of each geotechnical property is provided. For soils with properties outside these ranges, the COVs may differ.

While care was taken to isolate inherent variability from measurement error as much as possible, these values likely contain some uncertainty caused by the measurement technique. Because of the complexity of separating sources of uncertainty, there is a bias towards higher values of COV. The engineer should be aware that the true inherent variability may be lower than as represented by the data in Figure 7-6.

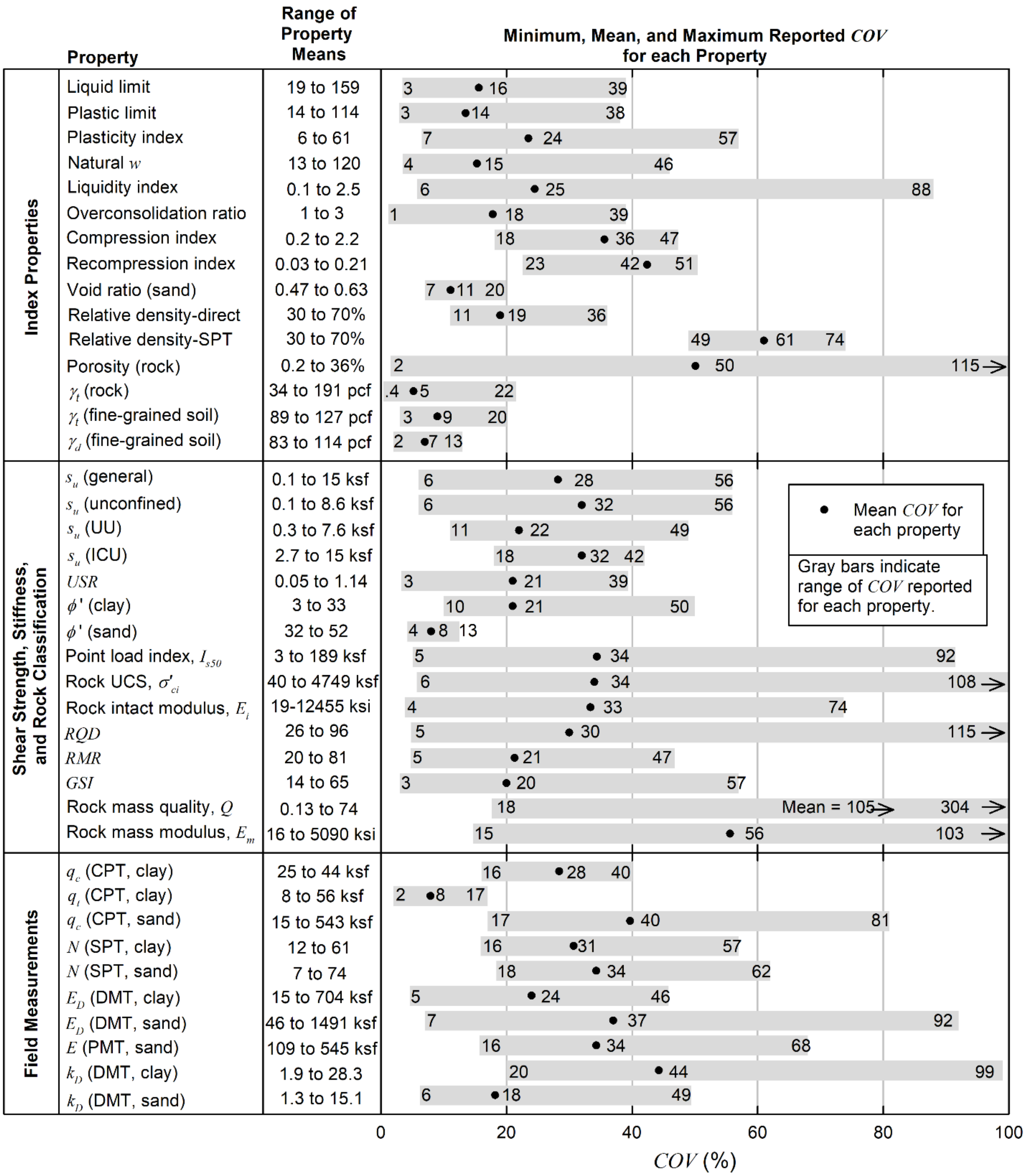


Figure 7-6 Typical Inherent Variability
(after Phoon and Kulhawy 1999a, Guan et al. 2021)

7-3.1.2 Measurement Error.

According to Phoon and Kulhawy (1999a), measurement error can be attributed to equipment effects, operator or procedural problems, and random testing effects. In general, these components of measurement cannot be separated. VandenBerge et al. (2020) used simulation to show that well-calibrated equipment should result in $COV(\phi')$ less than 1%. It appears likely that most laboratory testing error results from operator and procedural testing error, including soil disturbance.

Determination of laboratory measurement errors requires cross-laboratory testing of the same soil, which has been performed by a few studies and by ASTM for a small number of test methods. Field measurement errors have been studied for various types of equipment by Kulhawy and Trautmann (1996). The available data on laboratory and field measurement errors are summarized in Figure 7-7. In general, the measurement uncertainty is lower than the inherent variability. Some of the highest measurement variability occurs for the SPT and the plasticity index.

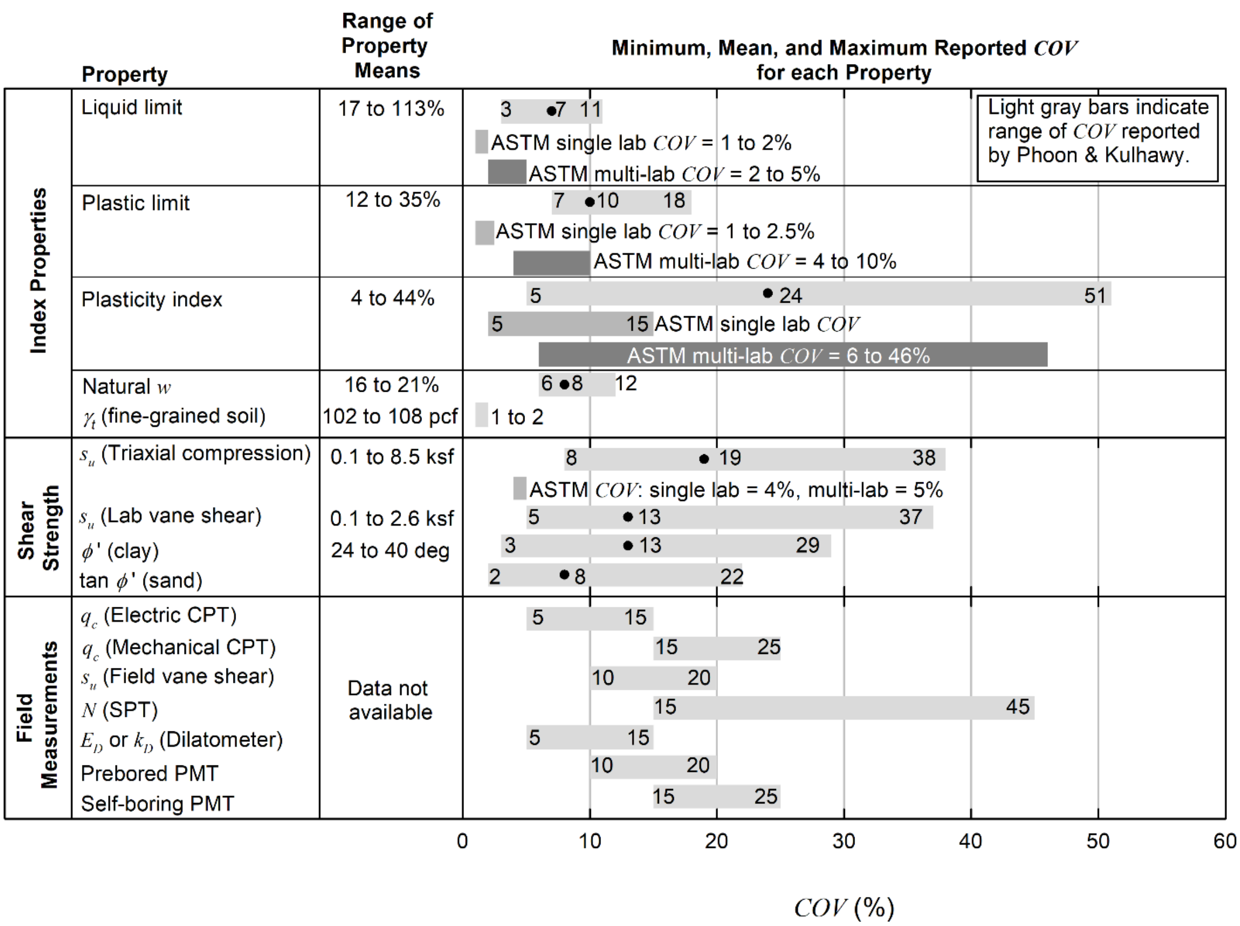


Figure 7-7 Typical Measurement *COV* (after Phoon and Kulhawy 1999a, ASTM D1586, ASTM D2216, ASTM D4318)

7-3.1.3 Transformation Uncertainty.

Phoon and Kulhawy (1999b) point out that the geotechnical parameters are often obtained by *transformation* from a more easily measurable property to that required for design through the use of empirical correlations,[43] such as those found in Chapter 8 of DM 7.1. Empirical correlations are based on observation and contain error, which adds an additional source of uncertainty into the assessment of geotechnical parameters.

When an empirical correlation is developed, transformation uncertainty is determined from the residual error between the supporting data and the empirical trend, which can either be expressed in terms of coefficient of variation or standard deviation. For example, Phoon and Kulhawy (1999b) provide examples of correlations for s_u from corrected vane shear tests (COV of 7.5 to 15%), from corrected tip resistance (COV of 29 to 35%), and from SPT (COV of 15%). Ching and Noorzad (2021) summarize the uncertainty in common empirical correlations for soil and rock properties.

7-3.1.4 Model Uncertainty.

The previous three sections dealt with uncertainties in the determination of geotechnical parameters. A related source of uncertainty is the selection of a shear strength model (e.g., linear vs. nonlinear) or a constitutive theory (e.g., Duncan-Chang vs. Cam Clay). None of these theories or models perfectly represent soil behavior, and each will cause uncertainty.

Uncertainty can also be introduced by the analytical or numerical approach selected to calculate design values. For example, consider the scenarios illustrated in Figure 7-8. The calculated bearing capacity will vary depending on which theory is used (i.e., lower bound, upper bound, etc.), and all of the theories contain empirical components. Similarly, the calculation of lateral earth pressure requires assumptions that lead to uncertainty in the calculated values.

Some calculation methods are much less certain than others. Estimates of settlement magnitude from consolidation calculations can be quite accurate, if the clay has low inherent variability and can be well-characterized. In contrast, estimates of sand compression from SPT blow counts will have much higher uncertainty. The greater uncertainty results from the empirical nature of the latter prediction method as well as the greater inherent variability of most sand deposits.

Unfortunately, little information is available on model uncertainty, especially for theoretical solutions. Where an analytical method is empirically based, the COV of the

[43] Empirical correlations are based on the statistical concept of correlation in which probability distributions of two or more random variables are dependent on each other. See Section 7-3.2.

model can be estimated from the errors between the observed data and the trend, similar to Phoon and Kulhawy's (1999b) approach for transformation uncertainty. Additional examples in which model uncertainty is considered can be found in McGuire and VandenBerge (2017).

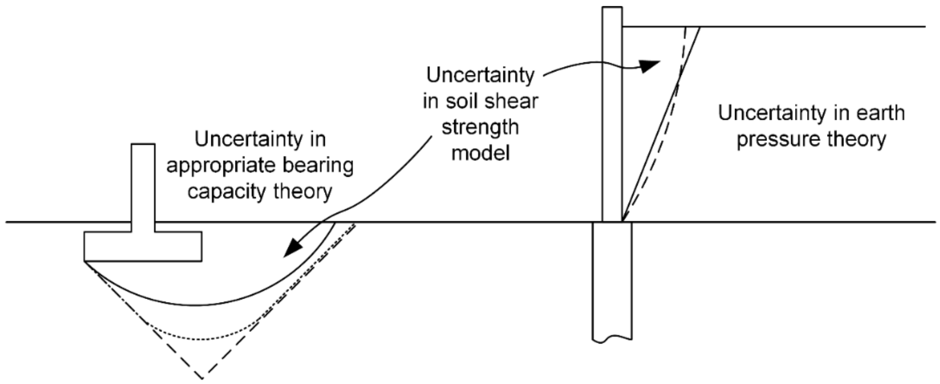


Figure 7-8 Model Uncertainty Examples

7-3.1.5 Combined Uncertainty Effects.

Figure 7-9 is a schematic illustration of how various sources of uncertainty combine to affect a geotechnical prediction. The example in the figure assumes that a soil layer with spatial variability is sampled at discrete locations. At these points, its properties may differ from the overall trend. Measurement of a desired property is made using sampling and/or testing, which introduces additional error. In many cases, the measured property must then be transformed into a useful engineering parameter.

Using a first-order approximation about the mean, the COV of the desired parameter can be estimated as

$$COV^2(\theta) = COV_w^2 + COV_e^2 + COV_t^2 \quad (7\text{-}5)$$

where:
θ = generic geotechnical parameter
COV_w = coefficient of variation of inherent variability,
COV_e = coefficient of variation of measurement error, and
COV_t = coefficient of variation of transformation.

One or more engineering parameters are used in an analytical model, which may have uncertainty of its own, to predict a desired outcome, such as settlement, bearing capacity, or factor of safety. The predicted outcome will be uncertain as depicted by the distribution at the bottom of Figure 7-9. The methods used to evaluate this uncertainty in engineering predictions are the subject of Section 7-4.2 on reliability analysis.

Figure 7-9 and Equation 7-5 are not intended to imply that the various sources of uncertainty in geotechnical parameters can easily be separated. This is especially true for inherent variability and measurement error. Such separation may be necessary for rigorous consideration of uncertainty, particularly if the effects of correlation described in the next section are considered. However, for many applications and simplified reliability analyses, the selection of a combined *COV* for each parameter is appropriate.

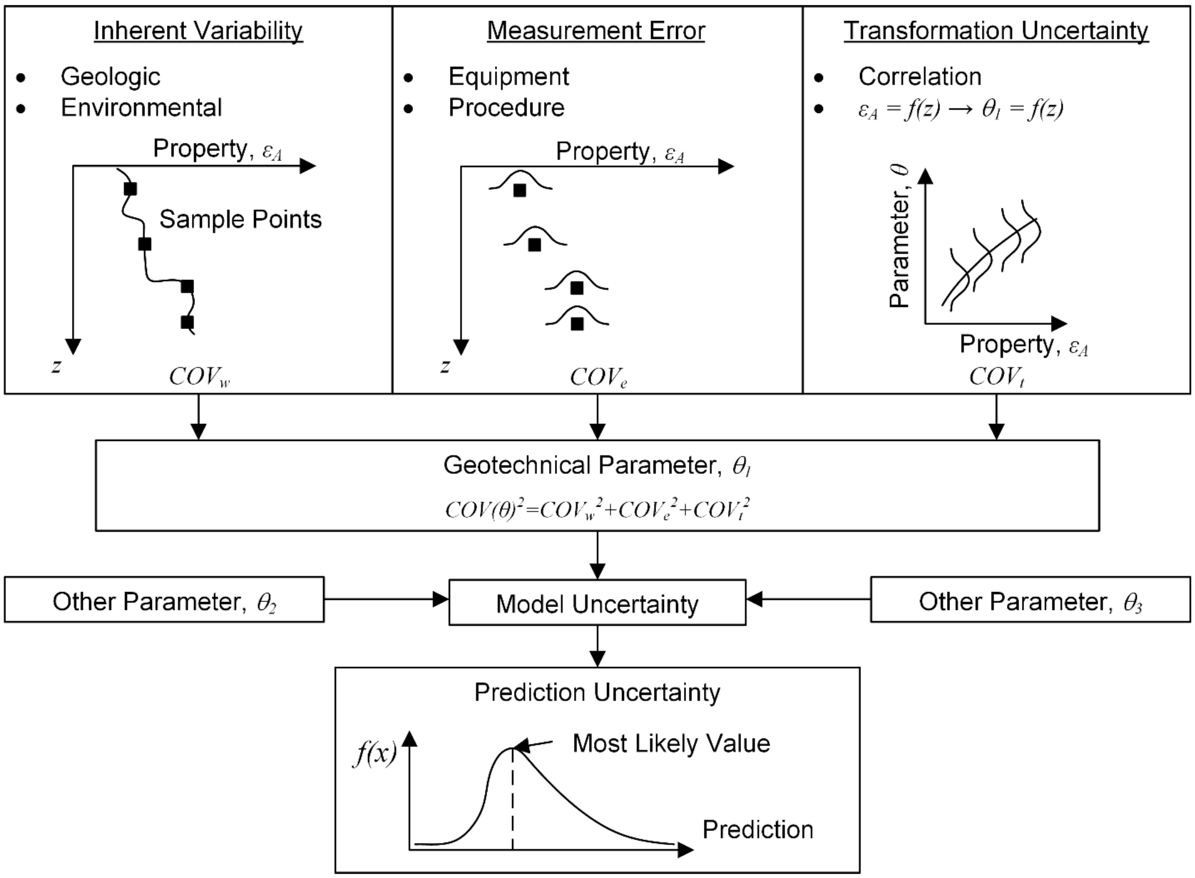


Figure 7-9 Combined Effects of Uncertainty on Geotechnical Design

Table 7-4 contains typical values of *COV* for a variety of geotechnical parameters. The values can be assumed to contain the combined effects of inherent, measurement, and transformation uncertainty. The values have been divided into categories for low, moderate, and high uncertainty, corresponding approximately to the lower, middle, and upper thirds of the reported *COV* values for each parameter. These values provide a rational means of accounting for the engineer's knowledge of site conditions, subsurface exploration techniques, and the use of transformations (if appropriate). For example, if a retaining wall is being planned at a site with an excellent site investigation and relatively uniform clay soils (i.e., low uncertainty), a *COV* of 25% would be appropriate for the undrained shear strength from laboratory tests. Continuing this example, the effective friction angle for the wall's sand backfill may be estimated based on the expected compaction, and a *COV* of 16% might be selected due to the high uncertainty associated with this estimate.

Table 7-4 Typical Combined COV for Common Geotechnical Parameters (after Phoon and Kulhawy 1999a,b; Sleep and Duncan 2014, FHWA 2001, Guan et al. 2001)

Property		Typical COV based on Uncertainty Level (%)		
		Low[A]	Moderate[B]	High[C]
Soil Index Properties	Unit weight	4	8	12
	Natural water content	10	15	25
	Liquid limit	10	15	25
	Plastic limit	10	15	25
	Void ratio (sand)	10	15	20
	Relative density (direct measurement)	15	20	30
	Relative density (from SPT)	50	60	70
Soil Compressibility, Hydraulic Conductivity, and Shear Strength	Compression index	25	35	45
	Recompression index	25	35	45
	Preconsolidation stress	15	20	30
	Overconsolidation ratio	10	20	30
	Coefficient of consolidation	40	50	60
	Coefficient of hydraulic conductivity (saturated)	75	80	85
	Coefficient of hydraulic conductivity (unsaturated)	150	180	210
	Effective stress friction angle (sand)	8	12	16
	Undrained shear strength (from laboratory tests)	25	40	50
	Undrained strength ratio (USR)	20	30	40
Field Measurements	SPT blow count (clay)	15	30	45
	SPT blow count (sand)	25	35	45
	CPT cone tip resistance (clay)	20	30	35
	CPT corrected cone tip resistance (clay)	5	10	15
	CPT cone tip resistance (sand)	25	40	55
	Dilatometer modulus (clay)	15	25	35
	Dilatometer modulus (sand)	30	50	70
	Dilatometer lateral earth pressure coefficient (clay)	15	30	40
	Dilatometer lateral earth pressure coefficient (sand)	20	45	70
	Vane shear test undrained shear strength	15	25	35
	Pressuremeter modulus (sand)	15	35	55
Rock Properties	Unit weight	1	5	10
	Porosity	25	50	75
	Point load index	15	35	55
	Unconfined compressive strength	15	35	55
	Intact modulus	20	35	50
	Rock mass modulus	30	55	80
	Compression wave velocity	5	15	25

COV was assumed to follow a normal distribution. The standard deviation of COV was estimated by the reported range and number of studies for each parameter (see Baecher and Christian 2003 Table 3.2). In order to limit the implied accuracy, values were rounded to regular intervals.

[A] Mean COV minus one standard deviation – use for well-characterized or relatively homogeneous site conditions

[B] Mean COV – use for typical site characterization and/or geologic variability

[C] Mean COV plus one standard deviation – use for limited characterization and/or highly variable soil conditions

7-3.2 Effects of Correlation on Uncertainty.

7-3.2.1 Correlation between Parameters.

Geotechnical parameters are often correlated with each other (i.e., covariance is non-zero – see Table 7-1), which means that the two parameters do not vary independently. For example, when c' and ϕ' are used to characterize shear strength, the values are negatively correlated. As c' increases, ϕ' decreases for a given soil and condition. The variation of undrained shear strength with depth is another example. Undrained strength is a function of effective stress, which depends on the soil unit weight. Thus, the undrained shear strength should be positively correlated to the unit weight.

Geotechnical applications of probability theory should account for correlation between parameters, if possible. The inclusion of correlation typically requires that additional terms be added to the calculation of the variance of the solution, which can substantially complicate the analysis.

7-3.2.2 Autocorrelation.

Within the ground, soil and rock properties vary spatially from point to point and/or with time at the same point. This is true even after removing the effects of geologic trends, such as layering or increasing stress with depth. *Autocorrelation* refers to the correlation of a soil or rock property with the same property at a different point in space or time (Baecher and Christian 2003). The amount of autocorrelation observed varies with the distance between the two observation points and the variability of the soil or rock. If the distance is zero, the two observation points are identical, and the correlation is perfect (r = 1). As the distance increases, the properties at the two points are no longer identical, and the correlation decreases (r approaches zero). The distance within which the property is significantly correlated with itself (perhaps $|r| \geq 0.1$) is referred to as the *correlation length* (Fenton and Griffiths 2008). Further discussion involves the topics of random field theory and geostatistics, which are beyond the scope of this manual.

Autocorrelation is sometimes presented in terms of the *scale of fluctuation* (δ_v for vertical and δ_h for horizontal) shown in Figure 7-5. The scale of fluctuation is the distance over which the soil properties are strongly correlated. Soils deposited in horizontal layers can have very different values of δ_v and δ_h. When δ_v is large, the soil properties are well-correlated and change less rapidly. As δ_v approaches zero, the properties become uncorrelated and can change rapidly. For small δ_v relative to the slip surface or structure passing through the soil, the uncertainty in the soil properties will tend to average out. A simplified method of considering the scale of fluctuation is found in Vanmarcke (1977). More rigorous consideration of fluctuation may require the use of the random finite element method (Fenton and Griffiths 2008).

7-3.3 Designing for Uncertainty.

Many different approaches have been taken in geotechnical engineering to address the uncertainties discussed in previous sections.

Design may implicitly account for uncertainty using a factor of safety. In this case, the design is approached in a *deterministic* manner, meaning that the calculations are based on a single value selected for each geotechnical parameter. Uncertainty is accounted for solely in the selection of a factor of safety, usually lumped into a single factor. The effects of uncertainty in the individual parameters or loads on the overall design cannot be determined. An alternative to this approach will be discussed further in Section 7-4.5, which describes load and resistance factor design.

In contrast, *stochastic* approaches explicitly consider the uncertainty associated with the design. In particular, reliability analysis provides an alternative to deterministic design that explicitly includes uncertainty as summarized in Section 7-4.2. Additional information about the probability distribution of the key geotechnical parameters must be determined or estimated to complete a reliability analysis. Duncan (2000) advocates for the use of reliability analysis alongside conventional design using factors of safety. The use of factor of safety provides continuity with past experience while the reliability analysis allows geotechnical engineers to more directly understand the impact of uncertainty on their designs. Reliability analysis is also used to inform estimates of probability for risk assessments.

Both the deterministic and stochastic approaches to geotechnical design seek to establish an appropriate level of conservatism that is in balance with direct costs (FHWA 1987). Many times, this is accomplished using specified factors of safety based on past experience.

Risk is the product of the probability of an adverse event multiplied by its consequence, which is often expressed in terms of fatalities or monetary cost. The cost of failure can be quantified and compared to the cost of designing a more conservative facility. In some cases, risk must be compared to either acceptable or tolerable levels. *Acceptable risk* can be defined as “a state of risk which stakeholders are willing to accept” while *tolerable risk* refers to a state of risk that society will tolerate because of the broader benefit (Timchenko et al. 2021). If risk is considered explicitly during design, the level of conservatism required in the design can be selected more rationally.

7-4 APPLICATIONS.

The purpose of this section is to help the engineer understand common uses of statistics and probability in geotechnical engineering and begin to use these methods. In particular, these sections should provide sufficient background to interpret reliability analyses, risk assessments, and hazard analyses performed by others. In addition, the basis of LRFD is discussed and compared with ASD to elucidate LRFD.

7-4.1 Evaluation of Field and Laboratory Data.

Principles of statistics and probability can be used to both plan and analyze field and laboratory data. The following sections describe a few specific applications but are not a comprehensive list.

7-4.1.1 Selection of Geotechnical Parameters.

Geotechnical designs can be separated into three basic approaches with respect to the selection of parameters (i.e., c' and ϕ', s_u, k, γ, etc.). In the first approach, the design calculations are deterministic and based on a single estimate of each required parameter. Often, this approach implicitly recognizes uncertainty by the selection of test specimens or results that represent conservative conditions, especially when limited testing is performed. For example, specimens from the softest clay layers may be selected for the determination of compressibility. Another example is the *one-third rule*, which chooses a design parameter such that one-third of the data lies to the conservative side of the selected parameter (USACE 2001). Such practices introduce bias that may be appropriate for deterministic analysis.

The second approach is to use deterministic analysis for ranges of values for the important parameters. The ranges for each parameter are selected from the results of field or laboratory testing, or based on engineering judgment. This approach also implicitly recognizes uncertainty in the parameters but does not attempt to explicitly consider probability.

The third approach explicitly considers the probability distribution of the geotechnical parameters, likely for use in a reliability analysis (see Section 7-4.2). In this case, distribution statistics (usually the mean and standard deviation) of each parameter must be determined. In most cases, the type of distribution is also required for each parameter. For nearly all geotechnical projects, the sample sizes are small from a statistical viewpoint. Many parameters are selected based on the results of three or fewer tests (e.g., s_u from UU tests or c' and ϕ' from direct shear tests). In this case, the measured parameter(s) can be assumed to represent mean conditions unless correlations indicate the parameter(s) are unusually high or low. The COV for very small samples must be selected based on typical values (Table 7-4). As the sample size increases, improved estimates of the mean and standard deviation can be obtained directly from the data.

The standard deviation of a parameter can also be estimated using the so-called *n-sigma rule*. This method leverages the fact that 99.7% of all values fall within a range of three standard deviations above and below the mean for a normally distributed RV. The highest conceivable value (HCV) and lowest conceivable value (LCV) of the variable should be separated by a distance of six standard deviations (i.e., n = 6), resulting in:

$$\sigma = \frac{HCV - LCV}{n} \qquad (7\text{-}6).$$

Because of a tendency to under- or overestimate the HCV and LCV, n is sometimes taken to be 3 or 4 in order to produce a conservatively high estimate of σ. An example of this approach is provided in Appendix B.

Three examples of geotechnical parameter selection are provided in Figure 7-10. In the first example, SPT blow counts are presented. For deterministic analyses using N as an input, an N of 21 might be selected or a range of 15 to 25 may be evaluated. Alternatively, a lognormal distribution has been fit to the N values, which could be used for a probabilistic analysis. The second example examines similar data for undrained shear strength. The drained strength data for the third example is presented in shear-normal stress space. The data is interpreted using a fixed adhesion (a') and stochastic ϕ'. For more information on fitting probability distributions to data, see Baecher and Christian (2003) or Ayyub and McCuen (2016).

7-4.2 Reliability Analysis.

Probabilistic principles can be applied to determine the reliability of a geotechnical design problem. *Reliability* is the probability that the design will perform in a satisfactory manner. This concept can also be stated in a negative sense as the *probability of unsatisfactory performance* (a.k.a., *probability of failure*), P_u. The reliability and the probability of unsatisfactory performance sum to unity.

In order to estimate reliability, a design problem is written in terms of a *limit state function*, $g(X)$, of random variables (X). Positive values of $g(X)$ correspond to satisfactory performance while negative values represent unsatisfactory performance or failure. Limit state functions are commonly written in terms of a safety margin or a safety factor as illustrated in Figure 7-11. The safety margin is the difference between the capacity and the demand, resulting in a negative value if demand exceeds capacity (Cornell 1969). For example, the predicted settlement for a foundation can be subtracted from the maximum allowable settlement. In the safety factor approach, the limiting safety factor of 1 is subtracted from the capacity divided by the demand (Rosenblueth and Esteva 1972). An example of this case would be foundation bearing capacity divided by the applied stress minus one.

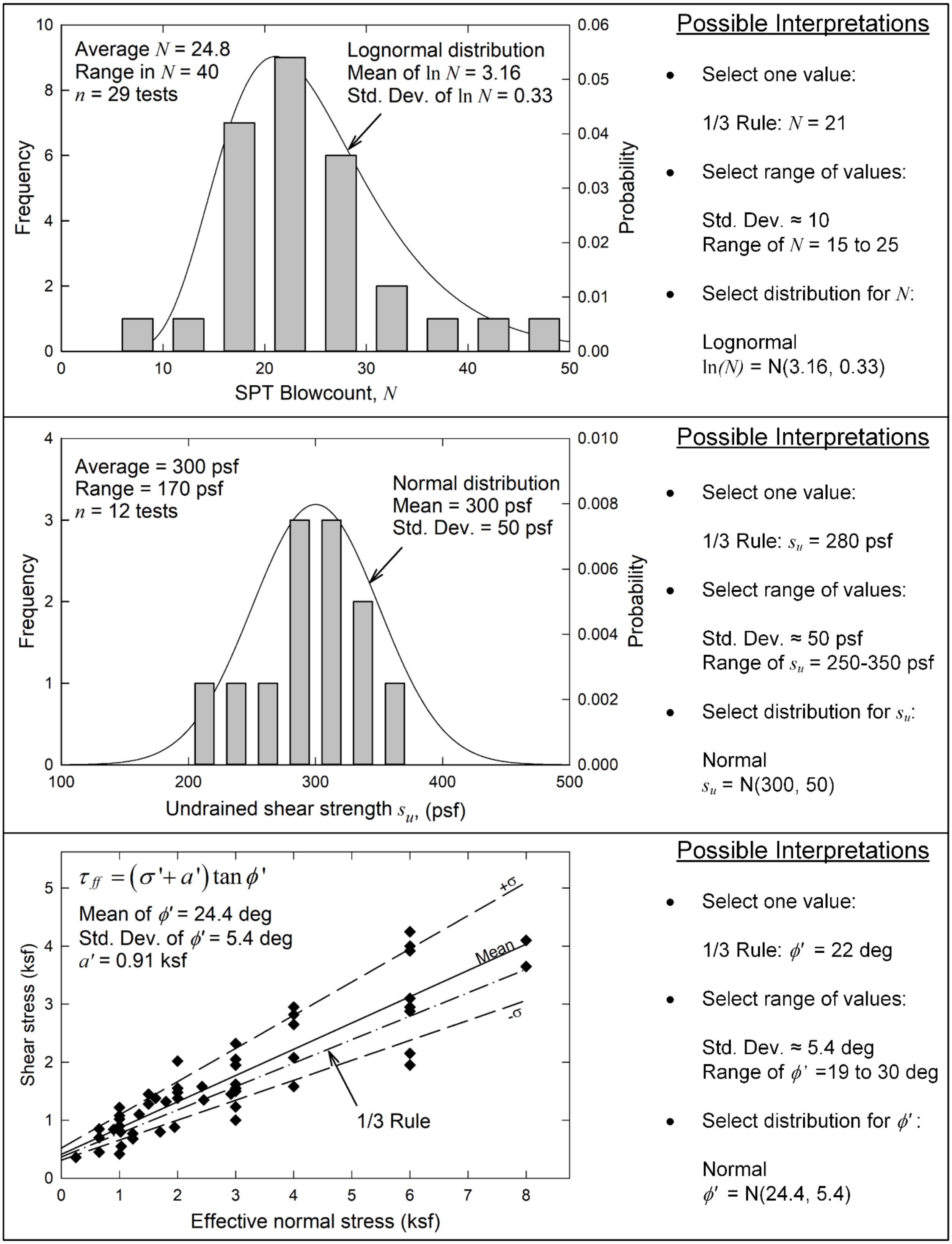


Figure 7-10 Parameter Selection Using Probabilistic Concepts

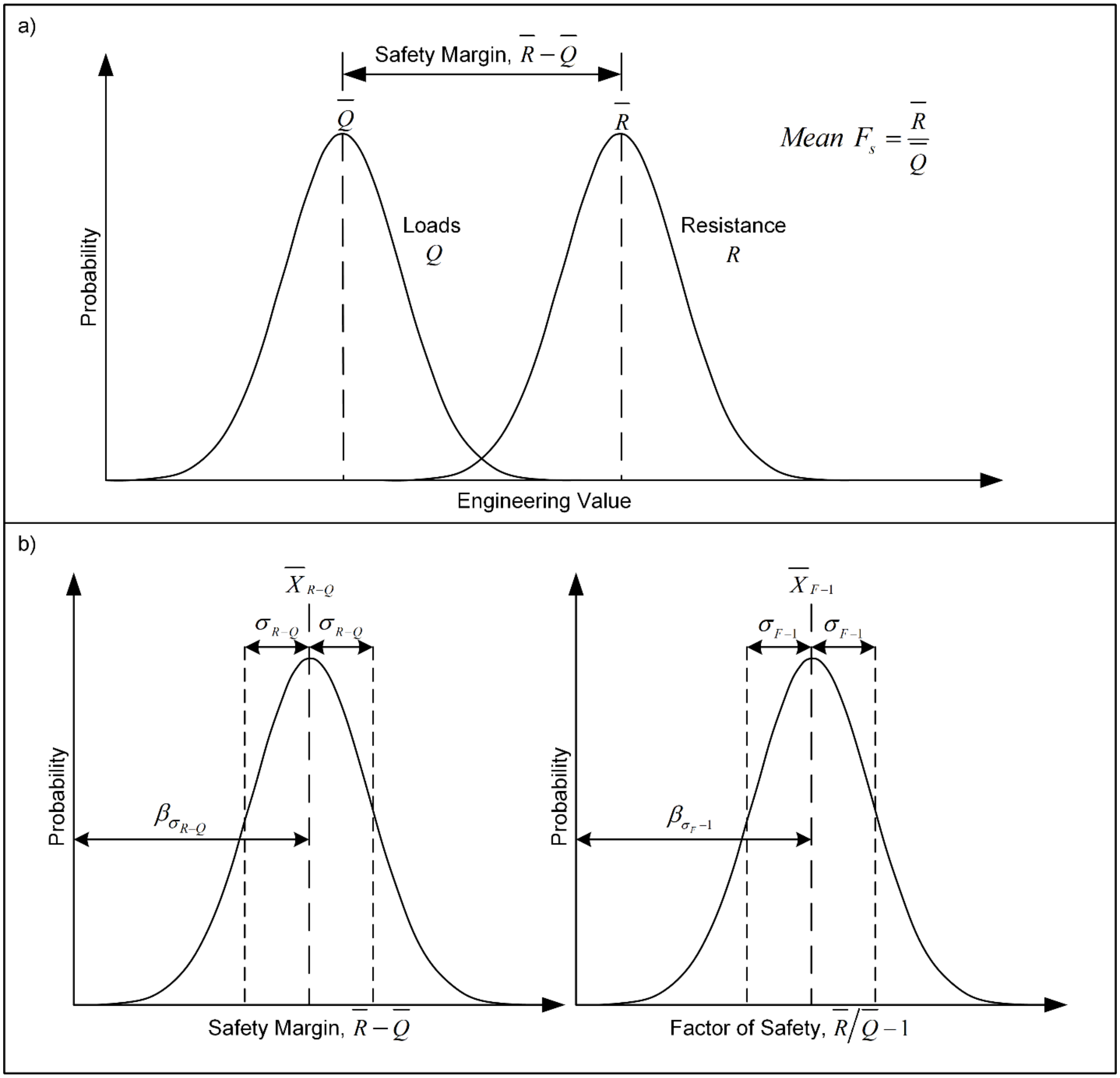


Figure 7-11 Example Distributions for (a) Load and Resistance and (b) Safety Margin and Factor of Safety Formulations

Once the design problem has been written as a limit state, the mean, $\mu_{g(X)}$, and standard deviation, $\sigma_{g(X)}$, of $g(X)$ must be determined. Differences in reliability analysis approaches lie mostly in the method and level of approximation involved in calculating these values. The results of limit state function will have a probability distribution that results from the distributions of the input random variables and their interactions within the limit state function. The level of difficulty associated with determining $\mu_{g(X)}$ and $\sigma_{g(X)}$ depends on the complexity of the design problem, the number of random variables, and probability distributions of those variables.

The *reliability index* (β) can be generically defined as the number of standard deviations that separate the mean design condition from a state of failure as shown in Figure 7-11 (Cornell 1969). If the problem is defined using a limit state function, then

$$\beta = \frac{\mu_{g(X)}}{\sigma_{g(X)}} \qquad (7\text{-}7).$$

The value of β calculated for a specific problem will depend on the method used to determine the mean and standard deviation of $g(X)$. Transformations of the limit state function (e.g., use of logarithms) may also result in changes in the value of β. Thus, the reliability index can vary depending on how it is defined. Because of the uncertainty in the statistics of the input parameters, geotechnical reliability analyses produce values of β that are also uncertain (USACE 2020).

The reliability index provides a relative measure of the reliability of the solution but not the probability of unsatisfactory performance. The value of P_u can be estimated from β based on the distribution of the results of the limit state function. Usually the distribution of $g(X)$ is not known and must be assumed. The normal and lognormal distributions are common assumptions for the distribution of the results of $g(X)$.

Approximate methods are appropriate for application of reliability analysis to real-world problems. It is important to bear in mind the uncertainty involved in describing the probability distributions of geotechnical parameters, which will affect the calculated values of $\mu_{g(X)}$ and $\sigma_{g(X)}$. Four methods are considered in this section and summarized in Table 7-5: (1) first order, second-moment, including the so-called Taylor series approximation, (2) point estimate method, (3) Hasofer-Lind, and (4) Monte Carlo simulation. These methods can accommodate correlated random variables; however, only uncorrelated solutions are presented in this section. A detailed example of the four methods is provided in Appendix B.

7-4.2.1 First-Order, Second Moment Method.

The first-order, second moment (FOSM) method uses only the mean (μ_{Xi}) and variance (σ_{Xi}) of the random variables to define β. The mean of the limit state function is simply the function evaluated at the mean values of the parameters, or:

$$\mu_{g(X)} = g\left(\mu_{X_1}, \mu_{X_2}, ...\mu_{X_n}\right) \qquad (7\text{-}8)$$

where:
n = number of random variables.

The variance of $g(X)$ for uncorrelated variables can be approximated by keeping only the first-order terms as:

$$Var\left(g(X)\right) = \left(\sigma_{g(X)}\right)^2 = \sum_{i=1}^{n}\left(\frac{\partial g(X)}{\partial X_i}\right)^2 \left(\sigma_{X_i}\right)^2 \tag{7-9}$$

where all the derivatives are evaluated at the mean values of the random variables.

Table 7-5 Reliability Analysis Methods

Method	Requirements	Advantages	Disadvantages
First-Order, Second Moment (FOSM)	• $g(X)$ must be explicit • $g(X)$ must be differentiable	• Requires only mean and standard deviation of the random variables, X_i, rather than full probability distribution	• Ignores higher order effects • Variant with respect to form of $g(X)$ • Requires differentiation • Must assume the probability distribution of $g(X)$ to determine P_u
Approx. Derivative Method of FOSM	• $g(X)$ can be evaluated at specific values of X_i • $g(X)$ must be evaluated $2n$ times	• Does not require an explicit function for $g(X)$ • Can be easily implemented in a spreadsheet	• Assumes linearity of the derivatives of $g(X)$ • Ignores higher order effects • Variant with respect to form of $g(X)$ • Must assume the probability distribution of $g(X)$ to determine P_u
Point Estimate (multiple RV)	• $g(X)$ can be evaluated at specific values of X_i • X_i must have symmetric distributions • $g(X)$ must be evaluated 2^n times	• Does not require an explicit function for $g(X)$ • Can be easily implemented in a spreadsheet • Often more accurate than FOSM and Taylor Series	• Large number of calculations required when the number (n) of RV is large • Less accurate for $g(X)$ that cause a large change in the distribution
Hasofer-Lind	• $g(X)$ must be explicit	• Calculates an invariant value of β with a geometric interpretation • Can be implemented in a spreadsheet (Low and Tang 1997) • Accommodates nonlinearity in $g(X)$	• Assumes linearity of the standardized $g(X)$ to determine P_u • Requires some programming experience or special software • Difficult for variables that are not normally or lognormally distributed
Monte Carlo Analysis	• $g(X)$ can be evaluated at specific values of X_i in a computer program • Random values of X_i based on probability distributions	• Full probability distribution can be accommodated for each variable • Provides direct estimates of $\mu_{g(X)}$ and $\sigma_{g(X)}$ • Provides direct estimate of P_u	• Large number of trials can be required to determine P_u for some problems • Requires programming experience or special software

The derivatives required for the FOSM method are not always easy to obtain. In addition, the limit state function for some problems cannot be written explicitly in terms of the random variables. For example, the limit state function for a slope stability analysis generally can be written only as $g(X) = F - 1$, where F is calculated by a numerical procedure. To alleviate this difficulty, the derivatives can be estimated using central differences about the mean (e.g., Duncan 2000, Wolff et al. 2004).[44]

Very small increments are typically used to estimate derivatives by central difference. However, in order to simplify the calculations and capture possible nonlinearity in $g(X)$, the increment can be set equal to the standard deviation of each random variable. Thus, for each random variable, $g(X)$ is evaluated at values of x_i that are one standard deviation (σ_{Xi}) above and below the mean (μ_{Xi}) with all other variables at their mean values. This results in a central difference (Δg_1) of:

$$\Delta g_1\left(X\right) = g\left(\mu_{X_1} + \sigma_{X_1}, \mu_{X_2} ... \mu_{X_n}\right) - g\left(\mu_{X_1} - \sigma_{X_1}, \mu_{X_2} ... \mu_{X_n}\right) \tag{7-10}$$

for the first random variable. A similar definition is used for the other variables. Using these central differences, the variance of $g(X)$ is estimated as:

$$\left(\sigma_{g(X)}\right)^2 = \sum_{i=1}^{n}\left(\frac{\Delta g_i\left(X\right)}{2}\right)^2 \qquad \textbf{7-11.}$$

The mean value of $g(X)$ is evaluated using Equation 7.8. When $g(X)$ is defined using the safety factor format, a logarithmic distribution of the factor of safety is logical and the reliability index becomes:

$$\beta_{LN} = \frac{\mu_{\ln(g(X))}}{\sigma_{\ln(g(X))}} = \frac{\ln\left(\mu_{g(X)}\right) - 0.5\ln\left(1 + COV_g^2\right)}{\left(\ln\left(1 + COV_g^2\right)\right)^{0.5}} \qquad \textbf{7-12}$$

where:
COV_g = coefficient of variation of the limit state function = $\sigma_{g(X)} / \mu_{g(X)}$.

7-4.2.2 Point Estimate Method.

The point estimate method was introduced by Rosenblueth (1975). According to Baecher and Christian (2003), this method is based on the premise that continuous random variables can be converted to equivalent discrete RV, usually with just two

---

[44] This method is sometimes referred to as the Taylor Series approach. However, the entire FOSM approach is based on a Taylor Series approximation. This method is distinguished by the numerical method used to determine the derivatives for Equation 7-9.

points. If those points and the associated probabilities (or weights) are chosen properly, the moments of the continuous distribution are maintained. These discrete RV are used to approximate the distribution of the limit state function.

While Rosenblueth (1975) proposed additional cases, the most common case used in geotechnical engineering allows $g(X)$ to be a function of n symmetric RV as illustrated for two RV in Figure 7-12. The limit state function is evaluated for 2^n cases with each RV either one standard deviation above or below the mean. The mean of $g(X)$ is calculated by:

$$\mu_{g(X)} \approx \sum_{i=1}^{2^n} P_i \cdot g(X)_i \qquad (7\text{-}13)$$

where:
P_i = weighting factors (equal to 2^{-n} for uncorrelated RV) and
$g(X)_i$ = limit state function evaluated for each of i cases.

The variance of $g(X)$ can be found as:

$$\sigma^2_{g(X)} \approx \sum_{i=1}^{2^n} P_i \cdot \left(g(X)_i\right)^2 - \left(\sum_{i=1}^{2^n} P_i \cdot g(X)_i\right)^2 \qquad (7\text{-}14).$$

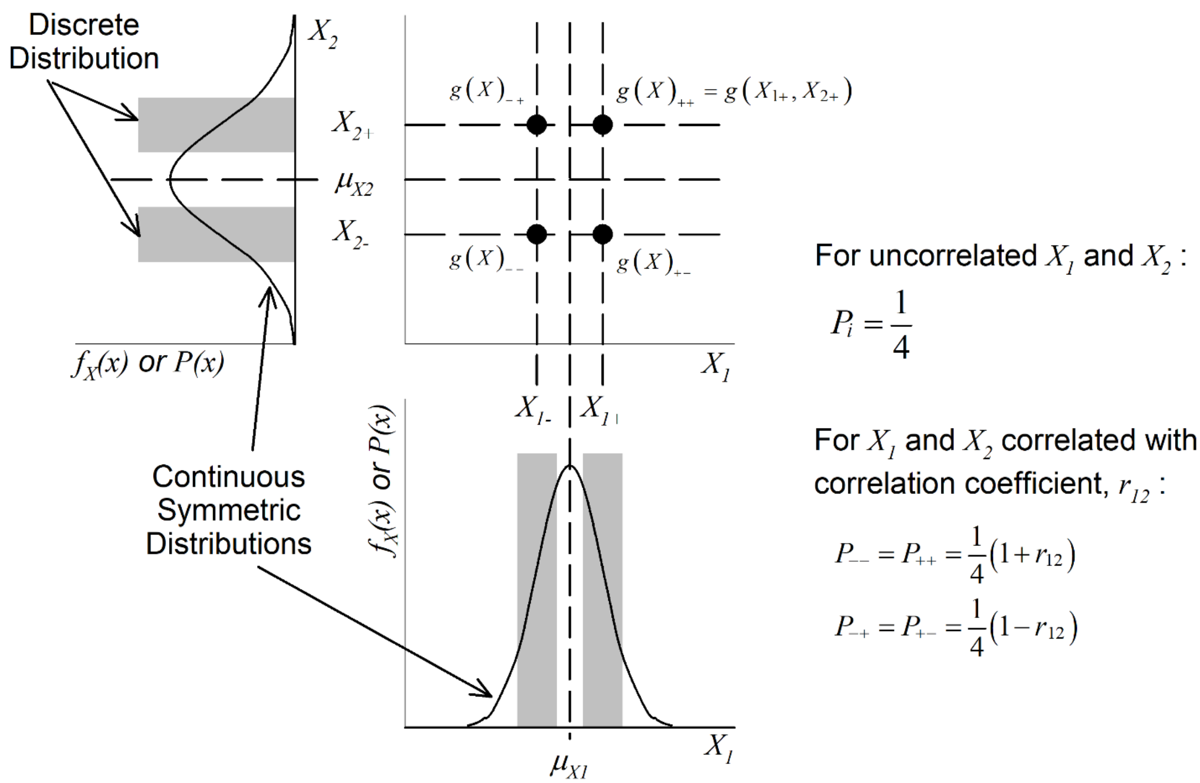


Figure 7-12 Point Estimate Method for Two Random Variables (after Baecher and Christian 2003)

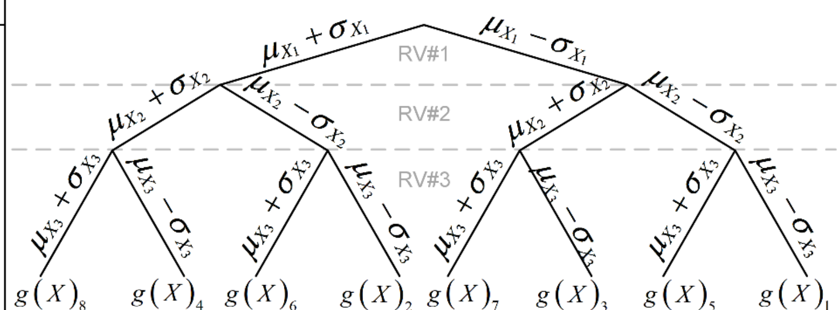
Figure 7-13 provides guidance for the combinations of plus or minus one standard deviation that make up each case for up to four RV. The cases are also illustrated in a branching format for eight cases required for three RV.

The point estimate method can accommodate correlation between the RV by changing the weighting factors. The equations for correlated P_i for two RV are shown in Figure 7-12 as an example. The method for determining weighting factors for additional correlated RV can be found in Baecher and Christian (2003) or Wolff et al. (2004).

The point estimate method cannot accurately approximate moments beyond the mean and variance (Baecher and Christian 2003). This is rarely a practical concern for reliability analysis. The method works best when the coefficients of variation of the random variables are relatively low. Inaccuracies have been shown to occur when $g(X)$ results in substantial change in the form of the probability distribution (i.e., normal to lognormal) and when $g(X)$ is highly nonlinear. Christian and Baecher (1999) provide additional guidance on the errors that may result for the point estimate method.

# Calcs	Case	# of RV (n) 1	2	3	4
2	1	-	-	-	-
	2	+	-	-	-
2^2 = 4	3	-	+	-	-
	4	+	+	-	-
2^3 = 8	5	-	-	+	-
	6	+	-	+	-
	7	-	+	+	-
	8	+	+	+	-
2^4 = 16	9	-	-	-	+
	10	+	-	-	+
	11	-	+	-	+
	12	+	+	-	+
	13	-	-	+	+
	14	+	-	+	+
	15	-	+	+	+
	16	+	+	+	+

Illustration of Calculations for n = 3



$$\mu_{g(X)} \approx \sum P_i g(X)_i$$

$$\sigma^2_{g(X)} \approx \sum P_i \left(g(X)_i\right)^2 - \left(\sum P_i g(X)_i\right)^2$$

For uncorrelated X_i:

$$P_i = \frac{1}{2^n}$$

Figure 7-13 Guides for Application of the Point Estimate Method (after Harr 1987)

7-4.2.3 Hasofer-Lind Method.

The magnitude of the reliability index calculated by the first three methods can depend on how the limit state function is formulated. In other words, the safety margin and factor of safety definitions will result in different values of β. In order to overcome this limitation, Hasofer and Lind (1974) proposed a geometric interpretation of the reliability index. In their method, the value of β is defined as the shortest distance between the origin and the limit state function when all of the random variables are transformed into standard normal space. The Hasofer-Lind approach can be used most easily when the random variables are normally or lognormally distributed both of which can be easily transformed into standard normal space. An equivalent tail approximation method is described in Ayyub and McCuen (2016) for non-normal variables.

The Hasofer-Lind method is illustrated for the case of two random variables in Figure 7-14. Each random variable is first transformed to an equivalent standard normal distribution (i.e., N(1,0)). The joint probability distribution for two uncorrelated variables is represented by circles centered on the origin in two-dimensions (Figure 7-14(b)). The point where the transformed limit state function comes closest to the origin corresponds to the *design point* for the analysis. This point can be found using a variety of numerical or iterative procedures. The distance between the design point and the origin is equal to β or the number of standard deviations separating the limit state function from the origin. The value of β is determined directly because the variables have been transformed to have a unit standard deviation.

The standard normal distribution is typically used to calculate P_u from β, which assumes that the limit state function is linear in the standard normal space. The potential error associated with this assumption is illustrated in Figure 7-14(c). The Hasofer-Lind method can also accommodate correlated random variables. The circles in Figure 7-14(b) become ellipses. A readily implementable spreadsheet solution to the Hasofer-Lind method is described by Low and Tang (1997), which includes the ability to consider correlated RV.

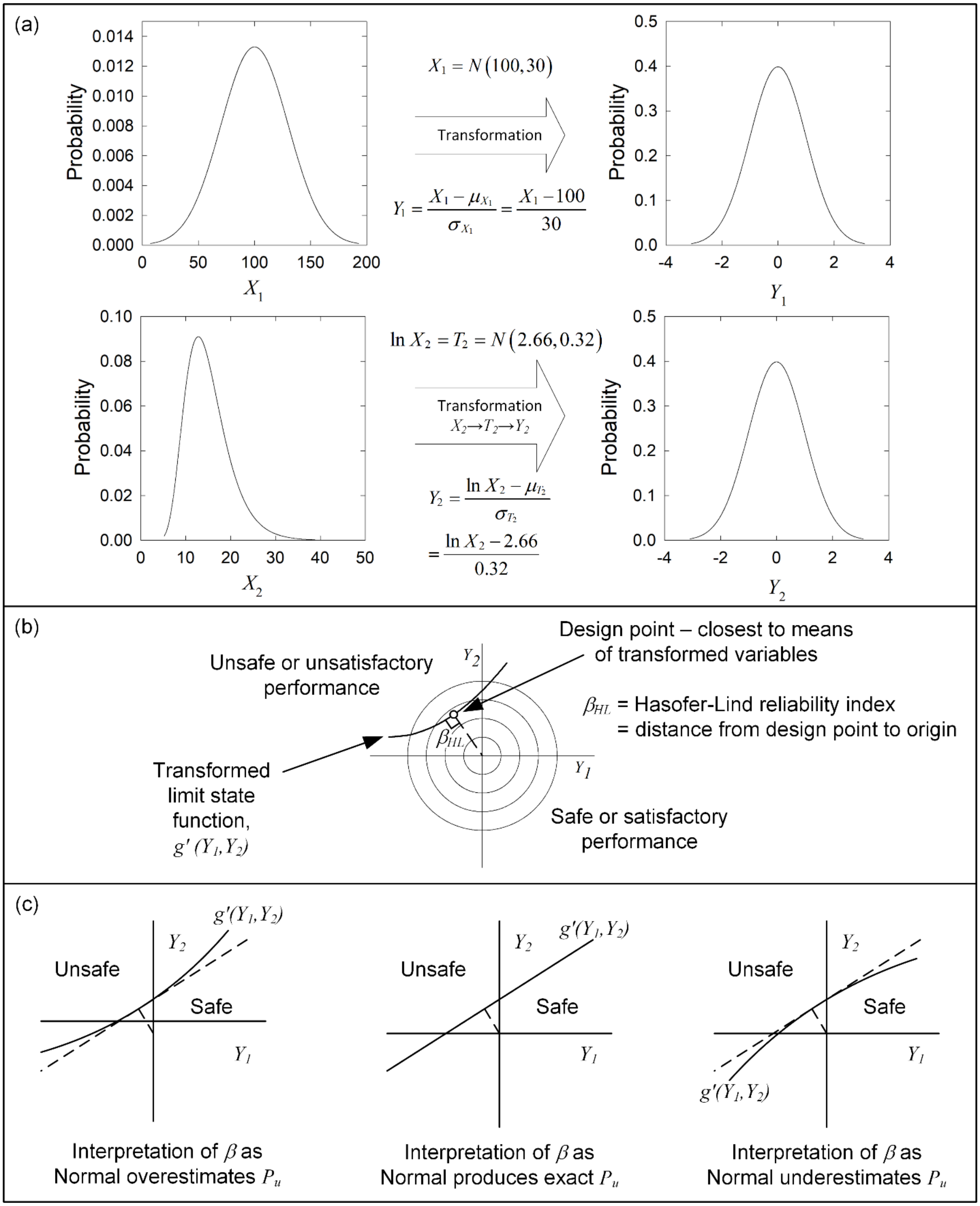


Figure 7-14 Hasofer-Lind Reliability Index Concept for Two Random Variables

7-4.2.4 Monte Carlo Simulation.

Monte Carlo simulation calculates the limit state function for a number of trials that is sufficiently large to define the probability of unsatisfactory performance. For each trial, Monte Carlo uses random number generation to select values from the probability distributions of each random variable in the design problem. The selected values are used to determine the value of $g(X)$ for that trial. If the value of $g(X)$ is negative, a failure is recorded. The number of failures divided by the total number of trials defines the probability of failure. The Monte Carlo process is repeated until the value of P_u remains stable as the number of trials increases.

Monte Carlo simulation can define the probability distribution of the limit state function. A value of $g(X)$ is generated for every trial, providing data to which a probability distribution can be fit. Limit state functions that are mostly addition and subtraction tend toward a normal distribution while those which use multiplication and division tend to be lognormally distributed.

The number of trials required for a Monte Carlo simulation depends on the problem being investigated and the information desired from the simulation. A common approach is to progressively increase the number of trials in the Monte Carlo simulation until the value of P_u is approximately constant. An example plot is provided in Figure 7-15.

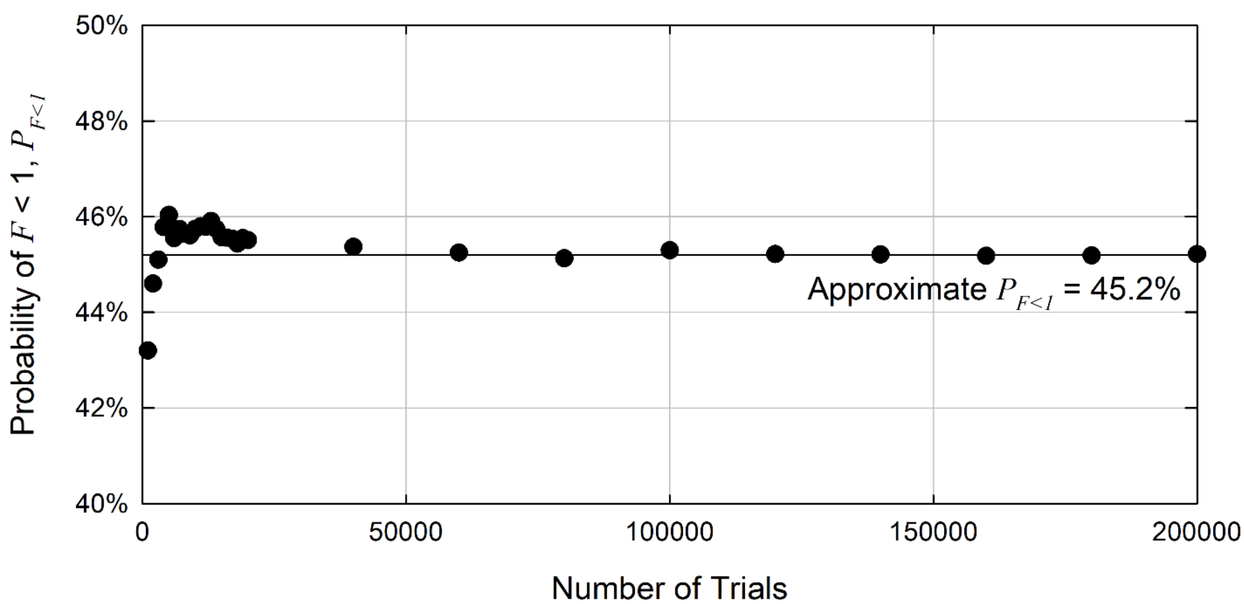


Figure 7-15 Convergence of Monte Carlo Simulation with Increasing Trials

The number of trials required to obtain simulated estimates of the mean and standard deviation can also be determined from Figure 7-16, based on the desired level of confidence and acceptable error in the estimates. If the acceptable error in the estimates of the mean and standard deviation is 10%, the required number of trials is in the range of 100 to 1000. In order to reduce the error to about 1%, the number of trials increases one-hundredfold to a range of 10,000 to 100,000. In order to estimate the probability of extreme events, the required number of trials is at least 100,000. In general, the number of trials should be sufficient so that the event of interest occurs many times (perhaps 10 to 100) in the simulation. For example, the simulation of a system with a reliability index of β = 4.26 (P_u = 0.0001) would require at least 10^6 trials.

The aforementioned requirements apply to simulations performed with random sampling implemented in a brute-force manner. In many cases, it may be necessary to reduce the number of trials in order to save computational effort as discussed in Baecher and Christian (2003). The *importance sampling* and *controlled variates* methods use a function that correlates well with the likely distribution of the solution. This concentrates the search in the area of interest. *Correlated sampling* is useful for comparing more than one design alternative. It recognizes that some random variables, such as those representing the soil conditions, can be used for assessment of all the design alternatives. *Stratified sampling* concentrates sampling in the regions that most affect the estimated variance. This approach can still lead to a large number of sampling points. The *Latin hypercube* method is a randomized approach that reduces the number of trials in a stratified simulation.

Monte Carlo methods rely on random number generators to simulate random variables. The quality of the simulation depends on the quality of the random numbers. Engineers should be aware of the random number generator used by their software and the limitations imposed. The use of more than one type of random number generator is encouraged (Baecher and Christian 2003).

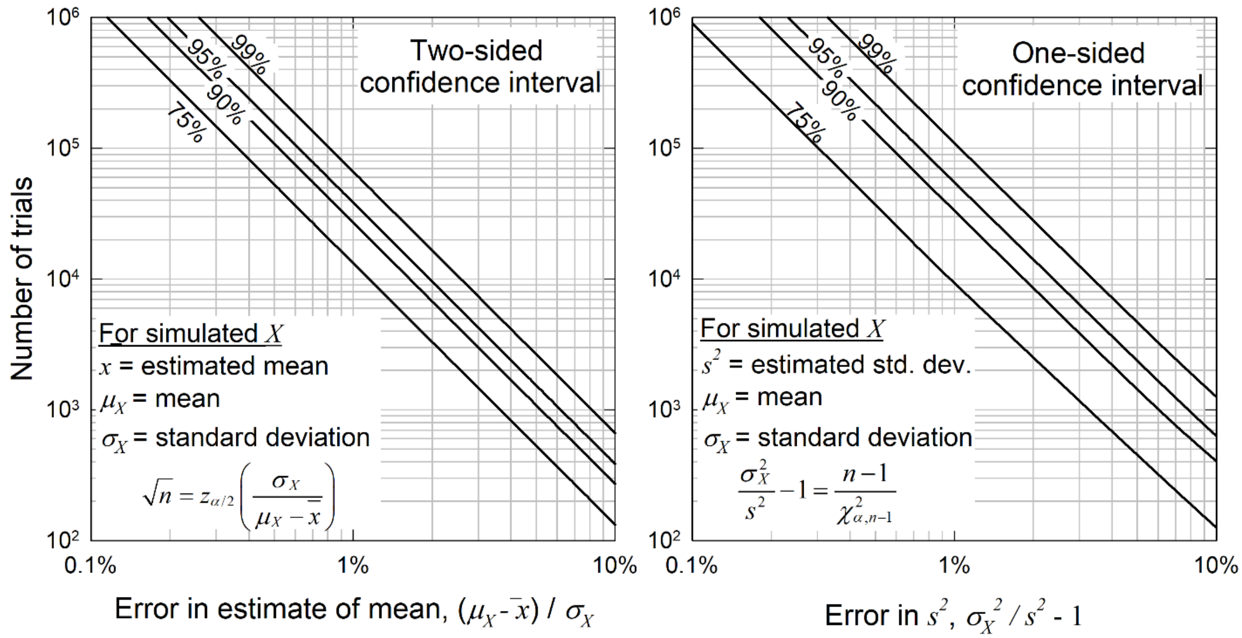
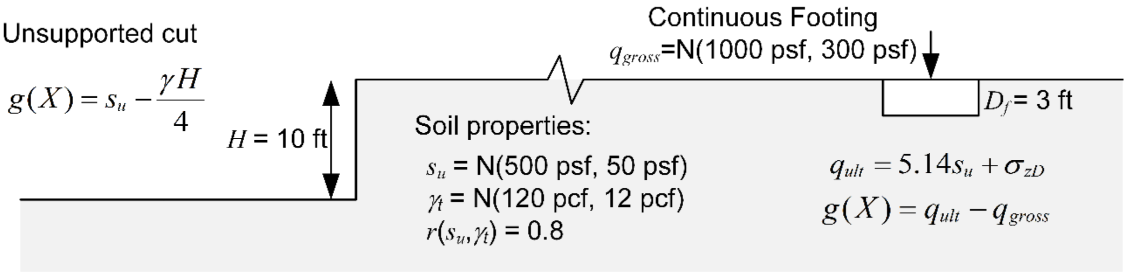


Figure 7-16 Monte Carlo Simulation Trial Number Requirements

7-4.2.5 Effect of Correlation on Reliability Analysis.

Correlation between parameters can either increase or decrease the reliability index. The influence of correlation depends on whether the correlation is negative or positive, and on the effect that each parameter has on the solution. An example of this is provided in Figure 7-17. If undrained shear strength is positively correlated to unit weight, the correlation will reduce the uncertainty in the factor of safety for an unsupported cut. This causes the reliability index to increase as a result of the inverse relationship between a driving force related to γ_t and a resistance (s_u). In contrast, the correlation will increase the uncertainty in the bearing capacity because both parameters (γ_t and s_u) are used to determine the resistance.



Use the First-Order, Second Moment Method (see Section 7.4.2.1) to find β.

Unsupported Cut (H is deterministic)

First, ignoring correlation between s_u and γ_t:

$$\sigma_{g(X)}^2 = \left(\frac{\partial g}{\partial \gamma_t}\right)^2 (\sigma_{\gamma_t})^2 + \left(\frac{\partial g}{\partial s_u}\right)^2 (\sigma_{s_u})^2$$

$$\sigma_{g(X)}^2 = \left(\frac{10\,ft}{4}\right)^2 (12\,pcf)^2 + (1)^2 (50\,psf)^2 = 3400\,psf^2$$

$$\mu_{g(X)} = 500 - \left(\frac{120\,pcf\,(10\,ft)}{4}\right)$$

$$\mu_{g(X)} = 200\,psf$$

$$\sigma_{g(X)} = 58.3\,psf$$

$$\beta = \frac{200}{58.3} = 3.43$$

Considering correlation between s_u and γ_t:

$$\sigma_{g(X)}^2 = 3400 + 2r(\gamma_t, s_u)\left(\frac{\partial g}{\partial \gamma_t}\right)\left(\frac{\partial g}{\partial s_u}\right)(\sigma_{\gamma_t})(\sigma_{s_u})$$

$$\sigma_{g(X)}^2 = 3400 - 2400$$

$$\sigma_{g(X)}^2 = 1000\,psf^2$$

$$\sigma_{g(X)} = 31.6\,psf$$

$$\beta = \frac{200}{31.6} = 6.33$$

Considering correlation increased β by about 85%.

Bearing Capacity (D_f is deterministic)

$$\sigma_{g(X)}^2 = \left(\frac{\partial g}{\partial \gamma_t}\right)^2 (\sigma_{\gamma_t})^2 + \left(\frac{\partial g}{\partial s_u}\right)^2 (\sigma_{s_u})^2 + \left(\frac{\partial g}{\partial q_{gross}}\right)^2 (\sigma_{q_{gross}})^2 + 2r(\gamma_t, s_u)\left(\frac{\partial g}{\partial \gamma_t}\right)\left(\frac{\partial g}{\partial s_u}\right)(\sigma_{\gamma_t})(\sigma_{s_u})$$

$$\sigma_{g(X)}^2 = 66049\,psf^2 + 11664\,psf^2 + 90000\,psf^2 + 14803\,psf^2$$

$$\mu_{g(X)} = 5.14(500\,psf) + (120\,pcf)(3\,ft) - 1000\,psf = 1930\,psf$$

Without correlation (first two terms): $\sigma_{g(X)}^2 = 167713\,psf^2$, $\sigma_{g(X)} = 409.5\,psf$, $\beta = \frac{1930}{409.5} = 4.71$

With correlation (all three terms): $\sigma_{g(X)}^2 = 182516\,psf^2$, $\sigma_{g(X)} = 427\,psf$, $\beta = \frac{1930}{427} = 4.52$

Considering correlation decreased β by about 4%.

Figure 7-17 Example of Correlation Effects on Geotechnical Analysis

7-4.2.6 Use of Reliability Analysis.

The utility of reliability analysis is the ability to understand and quantify the effects of uncertainty in the input parameters on the design. Reliability analysis can accompany traditional design and can also be incorporated in risk assessments. Duncan (2000) provides multiple examples of the application of reliability analysis to the design of foundations, retaining walls, and slopes.

Traditional deterministic design can be supplemented by reliability analysis. The reliability index and/or probability failure deepen the meaning of a particular factor of safety or other geotechnical calculation. For example, two shallow foundation designs may have factors of safety of 2.5 and 3, respectively. However, if the former design is based on more certain information, the respective reliability indices might be 4 and 3. Even if the estimates of β are approximate, the relative magnitude suggests that the first design is more reliable despite the lower factor of safety. The probability of failure can also be used to help individuals without geotechnical background understand the impact of changing the factor of safety or completing additional site characterization.

The probability of failure estimated from reliability analysis can also provide a useful input to larger scale risk assessments, which are discussed in the following section. The event trees used by these assessments have branches that can be filled using reliability analysis rather than relying solely on expert judgment.

7-4.3 Risk Assessment.

Risk assessment quantifies and describes the nature, likelihood, and magnitude of risk in a systematic, evidence-based manner. The performance of geotechnical structures and systems as a function of the applied loads is referred to as a *system response function*. For a given situation, risk assessment often involves determining the probabilities of unsatisfactory performance (e.g., failure, excessive settlement, etc.) over a time frame, as well as the consequences of those events. Sources of these probabilities include analytical reliability analyses, observations of past frequencies, and expert opinion (USACE 2020).

The combination of probability and consequences can be compared to specific criteria, such as F-N charts, or used for comparing multiple structures or systems. The example F-N chart in Figure 7-18 allows calculated risk to be compared to societal standards imposed by a regulatory agency (USACE 2014). In this case, the estimated probability and loss of life can be plotted, and subsequent action is based on the zone of the chart. Improvement plans are evaluated by assessing the resulting changes in probability and/or consequences (USACE 2020). Timchenko et al. (2021) have produced F-N charts in terms of both fatalities and cost, which compare geotechnical activities to other types of risk. Their study defined the low-risk threshold as either $10,000 per year (2020 US dollars) or 0.001 fatalities per year.

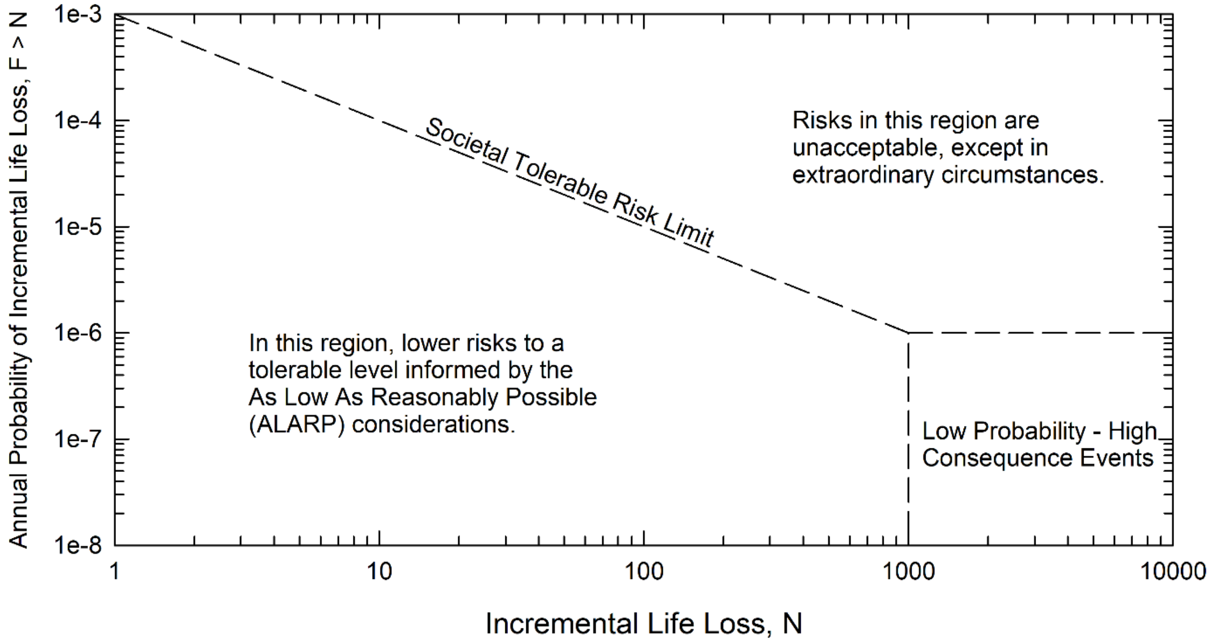


Figure 7-18 Example F-N Chart

Risk assessments require estimates of P_u over a defined time frame. The P_u calculated from reliability analysis typically starts with the assumption of a particular loading condition. Thus, the likelihood of the loading condition within the defined timeframe must be included. For example, levee stability following a flood may depend on the height of the flood. In this case, the time frequency can be incorporated by considering the return period of the particular flood level being analyzed.

Event trees, such as those shown in Figure 7-19, are another risk assessment tool, which help to evaluate complex chains of conditional probabilities. An event tree starts with an initiation event with a specified probability. At each intermediate node, the event tree will branch into two or more possible outcomes. At each node, the sum of the branch probabilities must equal 1.0. The final branches terminate at end nodes with a unique sequence of events or pathway. The probability for each pathway can be calculated by combining (i.e., multiplying) the probabilities for each branch. Fault trees are an alternate method used in risk assessment. Fault trees start from outcomes of interest and assess the events required to reach those outcomes (USACE 2020).

The *decision tree* is a similar risk assessment tool that combines probabilities with consequences in a graphical form (Baecher and Christian 2003). Decisions are made at some branches between options with different costs (or consequences). The other nodes represent possible events with associated probabilities and consequences.

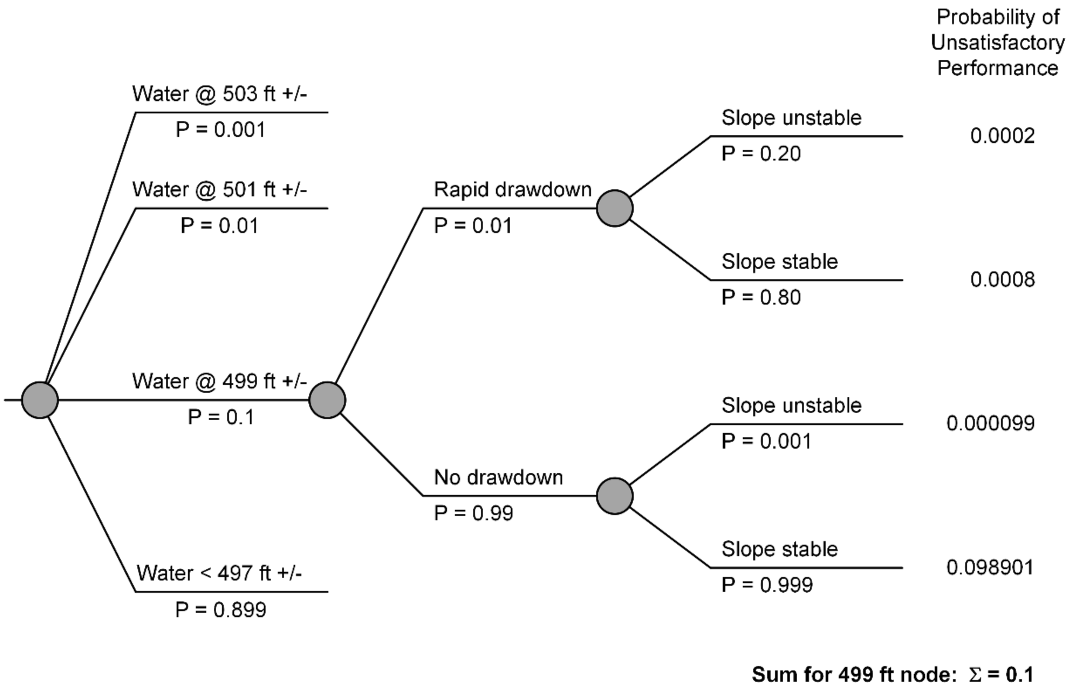
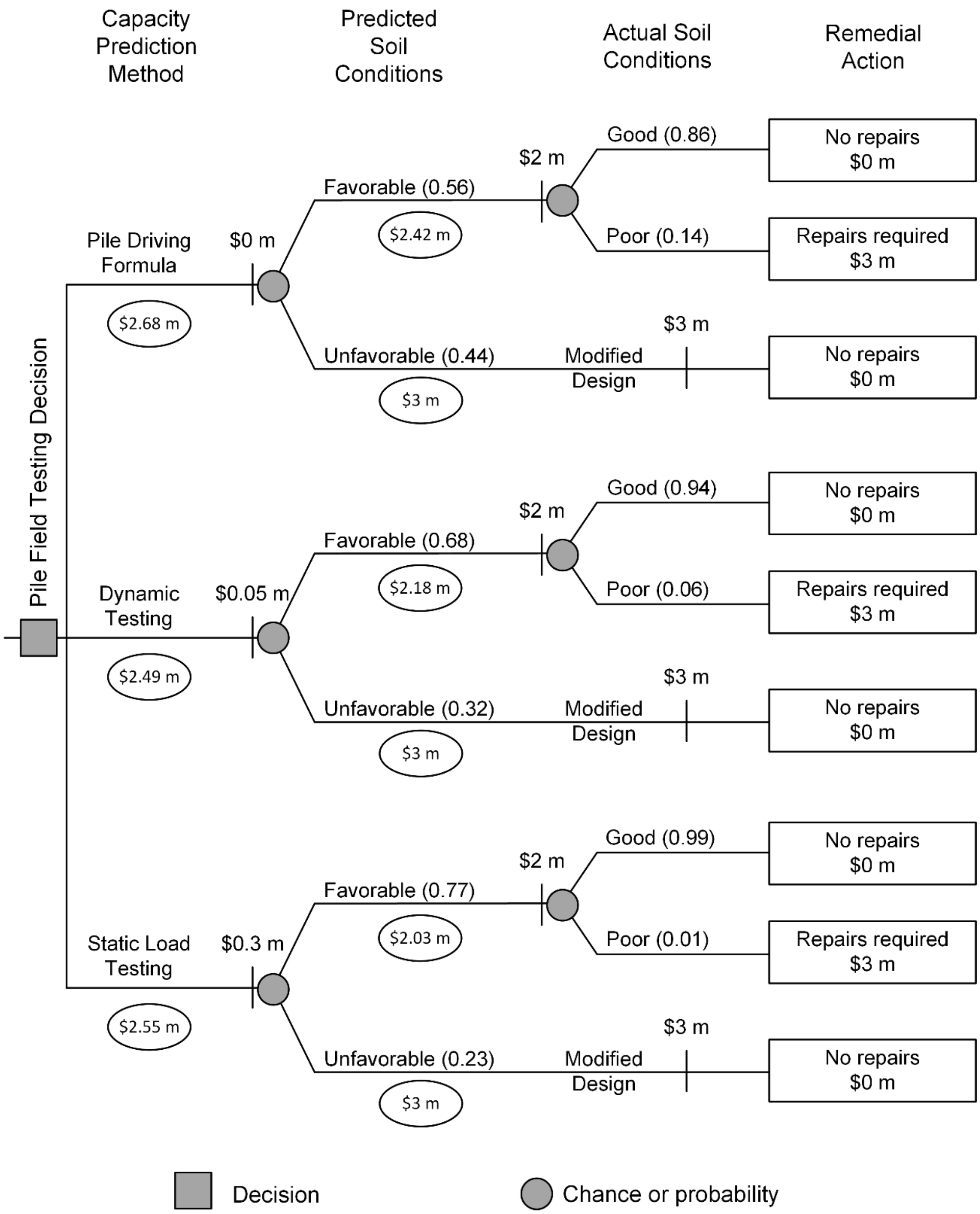


Figure 7-19 Example Event Tree (after USACE 2020)

An example decision tree for three pile testing methods is provided in Figure 7-20. In this example, a “normal” design is used if favorable soil conditions are predicted, while a more expensive modified design is used for unfavorable conditions. If a normal design is used for cases where soil conditions are actually poor, costly repair is required. For the values in this example, the higher uncertainty of the driving formula results in a higher risk. On the other hand, the increased cost of the static load testing exceeds the benefit of the decreased uncertainty about the soil conditions for this example.

7-4.4 Hazard Analysis and Return Periods.

In the context of civil engineering, a *hazard* is a condition that has the potential to cause damage to or loss to personnel, equipment, or property (DoD, 2021). All of these losses can limit the usefulness of a structure or system. A *hazard function* defines the probability that an event occurs (per time) assuming that the event has not occurred up to the given time. Many events related to geotechnical engineering, such as earthquakes and floods, are assumed to have a constant hazard function and are referred to as Poisson processes. An increasing hazard function implies that the likelihood of the event increases with time. A decreasing hazard function implies that the likelihood of the event decreases with time (USACE 2020).



Underlying probabilities
Soil conditions: P(good) = 0.8, P(poor) = 0.2
Prediction:
Formula: P(correct) = 0.6, Dynamic: P(correct) = 0.8, Static: P(correct) = 0.95

Figure 7-20 Example Decision Tree (after Baecher and Christian 2003)

Many hazards are natural processes that create uncertainty in the loading applied to geotechnical structures. The *return period* or *mean recurrence interval* (R) for these events can be estimated based on historical data. The *rate of exceedance* (λ), which is an annual value if R is expressed in years, can be calculated as:

$$\lambda = \frac{1}{R} \quad \textbf{(7-15).}$$

The effect of hazards on engineering design is often characterized in terms of the loading parameters that result from the hazard. Databases of these engineering parameters, including those related to seismic and climatic hazards, can be accessed through government agencies and professional organizations, such as USGS, NOAA, and ASCE.[45] The databases provide values of R or λ for particular magnitudes of loading parameters, such as a level of peak ground acceleration, a 24-hour rainfall, or a wind speed, as illustrated in Figure 7-21(a) to (c). As the magnitude of the hazard increases, the annual probability of exceedance decreases (i.e., larger hazards are less common). This relationship is referred to as a *hazard curve*.

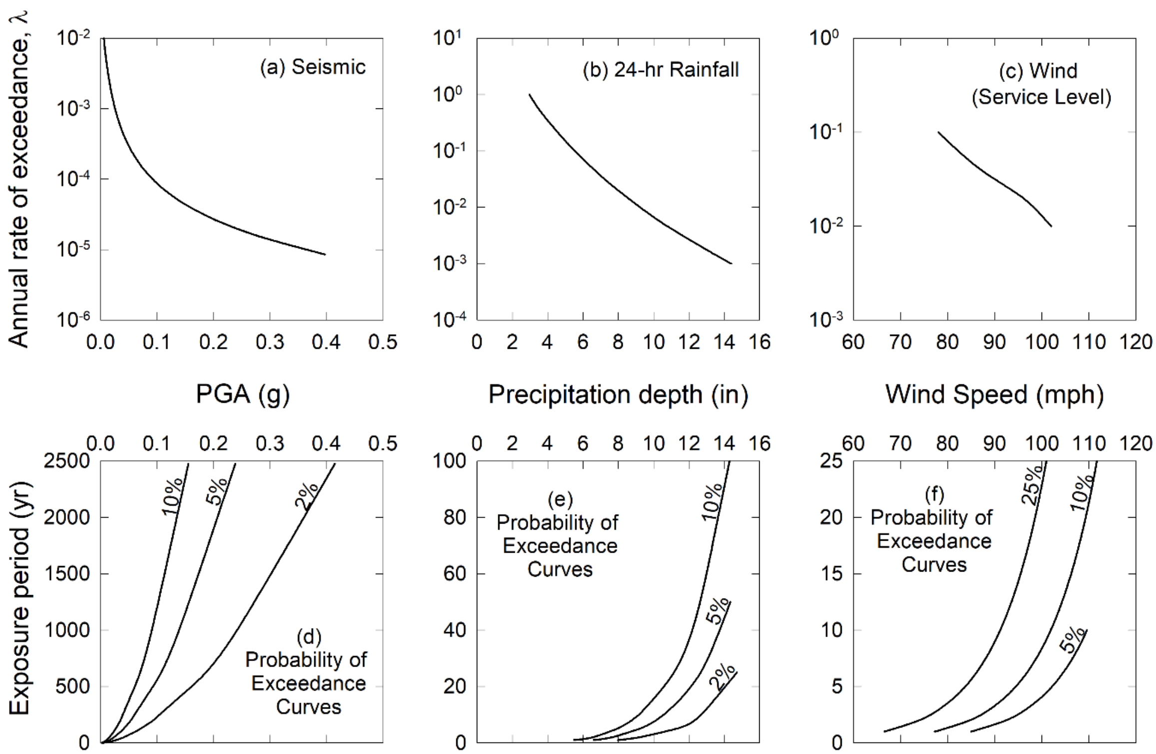


Figure 7-21 Example Hazards for an Eastern US Site – (a) to (c) Hazard Curves and (d) to (f) Probability of Exceedance Curves

---

[45] These resources have migrated primarily to the internet and are regularly updated. For this reason, specific links or citations have not been included herein.

In many cases, a particular value of the loading parameter is required in the design. Commonly, an *exposure period* (T_R) is selected, which is the length of time being considered in the design. A threshold probability of exceedance ($P(Y>y^*)$) is also selected. The value of $\lambda(y^*)$ which produces this probability can be found as:

$$\lambda\left(y^*\right) = -\frac{\ln\left(1 - P\left(Y > y^*\right)\right)}{T_R} \quad (7\text{-}16)$$

where:
Y = random variable representing loading parameter of interest and
y^* = value of Y that results in the desired probability of exceedance.

Once $\lambda(y^*)$ has been determined, the corresponding value of the loading parameter can be determined from the hazard curve. This process can be repeated for other exposure periods and probabilities of exceedance, allowing the loading parameter to be plotted against the exposure period as in Figure 7-21(d) to (f). For example, events with a probability of exceedance of 10% in 50 years have $\lambda(y^*)$ of 2.1×10^{-3} yr^{-1}, which corresponds to R of 475 years. Using the hazard curve, the 24-hour rainfall (Figure 7-21(b)) with this rate is about 12.6 inches.

In the case of seismic analysis, a hazard curve may represent the combined effects of multiple seismic sources and is developed using a process called *probabilistic seismic hazard analysis*. Each source will have a different distance or range of distances to the project site as well as different annual distribution of earthquake magnitude. These variations are used to predict the probability distribution of the desired loading parameters for each site. The effects from each site are combined to determine the probability that the loading parameter is greater than a given value. This information can be expressed as a hazard curve, similar to Figure 7-21(a).

7-4.5 Load and Resistance Factor Design (LRFD).

Load and resistance factor design (LRFD) is an application of reliability analysis, which separately factors both loads and resistances using probabilistically calibrated factors. LRFD uses the concept of limit states to define conditions in which a structure (used generically in this section) no longer performs its intended function. *Ultimate limit states* are those pertaining to collapse or safety. In geotechnical engineering, ultimate limit states are related to the shear strength of the soil, such as bearing capacity or slope stability. *Service limit states* are those pertaining to functionality or the ability of the structure to remain useful. Settlement criteria are a common geotechnical service limit state. Some LRFD codes, such as the AASHTO Bridge Design Code, define multiple types of ultimate and service limit states that must be considered in a particular design.

The ultimate limit state design equations and methodology for LRFD are compared in Table 7-6 to allowable stress design (ASD), multiple load and resistance factor design

(MRFD), and full reliability-based analysis. With the exception of full reliability analysis, all of the methods apply factors in some combination to the nominal loads (Q) and/or the nominal resistances (R). Progressing from ASD to MRFD, the factors are applied in greater specificity, which allows more flexibility to consider uncertainty but requires additional effort in both design and development of the appropriate factors.

Table 7-6 Comparison of Ultimate Limit State Design Methodologies (after Kulhawy 2017)

Method	Design Equation	Method for Calibrating Factors	Example
ASD	$Q_n \leq \frac{R_n}{F}$	Appropriate F is selected by experience with similar calculation method and conditions. Uncertainty in both load and resistance is lumped into a single factor.	Common approach to many foundation and retaining wall designs.
LRFD	$\sum \gamma Q_n \leq \varphi R_n$	Statistics of load and lumped resistance along with load factors are used to determine the φ required to achieve a particular value of β_t.	AASHTO (2020) driven pile design uses a single φ for static capacity analysis.
Multiple LRFD (MRFD)	$\sum \gamma_i Q_{n,i} \leq \varphi_i R_{n,i}$	Statistics of loads and load factors are used to determine the resistance factors for various components of resistance that are required to achieve β_t. Different values of φ may be considered for different soil conditions or levels of uncertainty.	AASHTO (2020) drilled shaft design uses separate φ for side and tip resistance, recognizing differences in uncertainty associated with each.
Full Reliability Analysis	$\beta_{calc} > \beta_t$	The probability distributions for loads and resistances (or underlying geotechnical parameters) are determined directly. Methods from Section 7-4.2 are used to determine β_{calc}.	Design-specific methodology. Not codified.
Notation: Q_n = nominal load (or stress), R_n = nominal resistance (or stress), F = factor of safety γ = load factor, φ = resistance factor, β_{calc} = calculated reliability index, and β_t = target reliability index.			

7-4.5.1 Components of LRFD.

The basic concept of LRFD is illustrated in Figure 7-22 in which the loads and resistances are shown along the same scale. The unfactored (nominal) loads are the lowest and plot at the left while the unfactored resistances are highest and on the right. These loads and resistances are those determined using the calculation approaches specified by the LRFD design code.

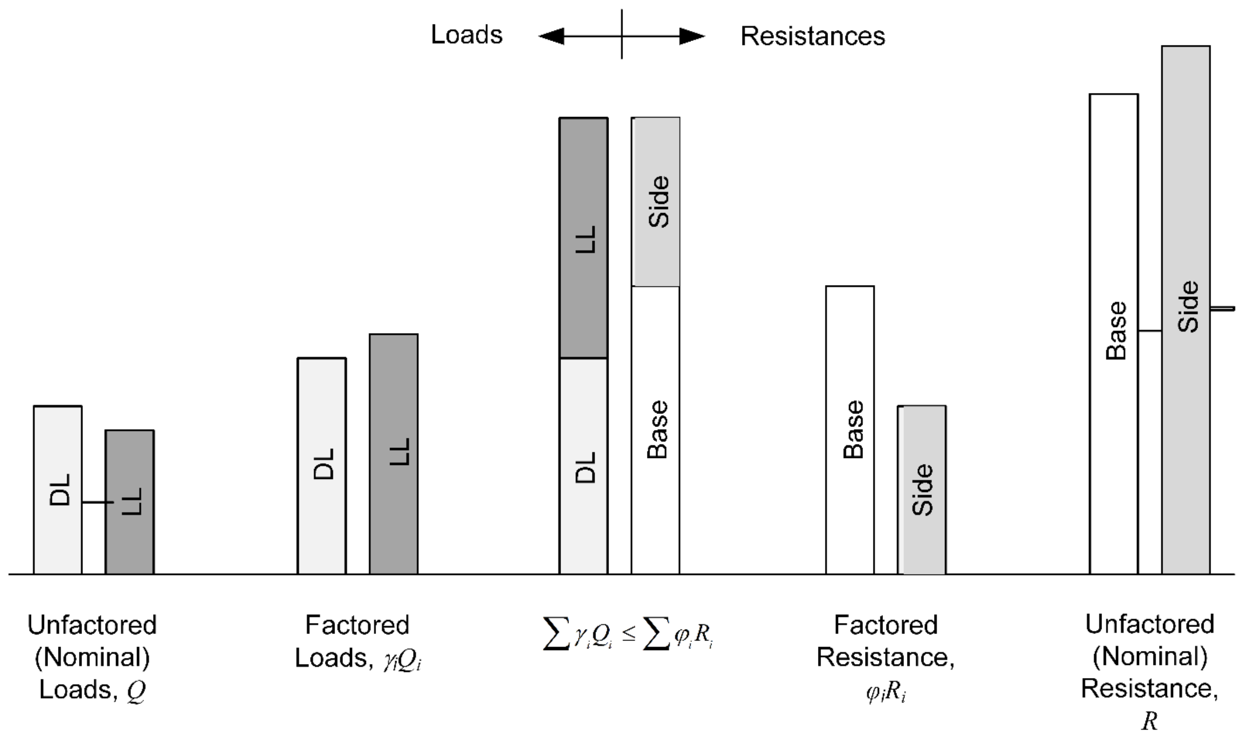


Figure 7-22 LRFD Concept (after FHWA 2001)

In order to account for uncertainty in load, the loads are multiplied by *load factors* (γ_i) that are greater than one to produce factored loads that are larger than the nominal values. Specific load factors are used for each type of load because of differences in the uncertainty associated with each type of load. Similarly, the resistances are multiplied by *resistance factors* (φ_i) that are less than one and produce lower factored resistances. The selection of appropriate values of γ_i and φ_i is the critical step in the development of an LRFD procedure or code.

The design equation for LRFD requires the sum of the factored loads to be less than or equal to the sum of the factored resistances, which is shown conceptually in the middle of Figure 7-22. This inequality is checked for each limit state that must be assessed for the structure or design. The details of the limit state will dictate the values of the loads, resistances, and factors. In other words, these values may change for each limit state considered.

7-4.5.2 LRFD Calibration.

The method used to determine the appropriate values for load and resistance factors is referred to as *calibration*. An engineer using LRFD does not perform this calibration but will benefit from understanding the general calibration process. Early efforts at calibration used direct fitting of the load factors (γ) and resistance factors (φ) to generate similar designs as those produced by ASD. An example of this approach is provided in

Table 7-7. While the direct fitting approach separates the uncertainty in load from the uncertainty in resistance, it is not based on reliability theory.

Table 7-7 Resistance Factors based on Fitting Directly to ASD rather than Reliability Theory (after FHWA 2001)

Factor of Safety	Resistance Factor, φ			
	$Q_D / Q_L = 1$	$Q_D / Q_L = 2$	$Q_D / Q_L = 3$	$Q_D / Q_L = 4$
1.5	1	0.94	0.92	0.90
2	0.75	0.71	0.69	0.68
2.5	0.60	0.57	0.55	0.54
3	0.50	0.47	0.46	0.45
3.5	0.43	0.40	0.39	0.39
4	0.38	0.35	0.34	0.34

Notes:
Load factors assumed to be: γ_D =1.25 and $\gamma_L = 1.75$.
Variables: Q_D = dead load, Q_L = dead load, γ_D = dead load factor, and γ_L = live load factor

Current LRFD codes, such as ACI, AISC, and AASHTO, are calibrated to achieve a consistent reliability across a broad range of design scenarios (Nowak 1995, Kulhawy 2017). The process used to develop LRFD codes starts with the selection of a set of representative structures. Statistical data is gathered for both load and resistance parameters, from which the cumulative distribution functions for load and resistance are defined. Reliability analysis is then completed, typically in a simplified form, to adjust γ and φ to result in a specific target value of β. Commonly, the load factors are first selected so that the factored load has a predetermined probability of exceedance (Nowak 1995). LRFD codes are periodically updated as new information and methods become available.

The calibration process uses the mean and coefficient of variation of the loads and resistances. The mean values of load and resistance may differ from the nominal values calculated by a particular design method. This difference is referred to as *bias*. For example, mean dead loads tend to be a few percentage points higher than the design values because structural members are slightly overbuilt. The calibration process uses bias factors (λ), which are the mean value divided by the nominal value, to incorporate this difference in the reliability analyses used for calibration.

The simplifications introduced in the LRFD calibration process produce designs that *on average* meet the target β. Improvements to the calibration can be made by using multiple load or resistance factors to separate sources of uncertainty. For example, many codes employ multiple resistance factors for loads, such as dead, live, seismic, and wind loads. In a few cases, codes may separate geotechnical resistance into multiple types of resistance, such as tip and side resistance for piles. Future improvements to LRFD may include development of ranges of φ that depend on the expected variability of the site-specific resistance.

The calibration process is specific to each design methodology or model of resistance (e.g., Meyerhof bearing capacity for shallow foundations or the α method for deep foundations). For this reason, resistance factors are methodology specific, and careful attention must be given to selecting the appropriate φ for the design method used. The commentary section of the design codes often provides helpful information about the particular calibration process that was used (Kulhawy 2017).

7-4.5.3 Use of LRFD in Geotechnical Engineering.

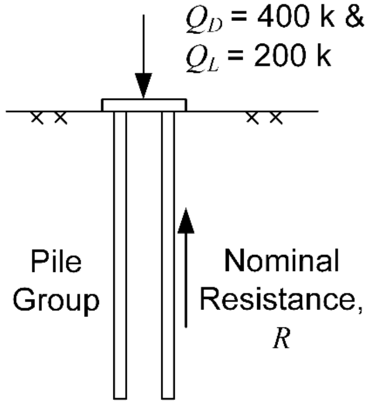
The discussion herein is intended to provide the engineer with an understanding of the LRFD process and its basis in reliability analysis. Specific values of γ and φ are intentionally not included in this chapter, because they are code-dependent and can change as codes are updated. The most recent version of the appropriate code should be used. For example, the AASHTO LRFD Bridge Design Specifications apply LRFD to most of the design procedures covered in this manual. FHWA's Geotechnical Engineering Circulars on various foundation and retaining wall topics also provide excellent guidance on the application of LRFD.

Some types of geotechnical design have many different methods for determining resistance. LRFD facilitates the comparison of the reliability of these methods. An example is provided in the context of pile design in Figure 7-23. The generic resistance factors used in this example range from 0.1 to 0.9. The former represents a method that is very uncertain or unreliable. In contrast, the high value of 0.9 represents a method for predicting resistance with very low uncertainty. In this way, LRFD can be especially useful for deep foundations because of the large range of methods available for predicting the resistance.

To some extent, engineers can use differences in load factors to understand the uncertainty associated with loading. Larger load factors are typically associated with live loads, which have higher uncertainty. The load factors for extreme events may be close to 1.0. In this case, the lower load factor recognizes the small probability of occurrence associated with such events.

While LRFD can theoretically be used for any analysis involving load and resistance, some problems are poorly suited to this approach. This is especially true for cases, such as slope stability, where the primary load and the primary resistance are both functions of the soil's self-weight. If a load factor is applied to the soil unit weight, the stresses within the slope will change, which changes the shear strength (except for undrained analysis). A better alternative for slope stability is to complete reliability analyses using the methods described earlier in this chapter.

LRFD Pile Design Example



A pile group is being designed to resist a nominal dead load of 400 k and a nominal live load of 200 k. Load factors of γ_D = 1.25 and γ_L = 1.75 are determined. The factored load is calculated to be:

$$\sum \gamma_i Q_i = (1.25)(400\ k) + (1.75)(200\ k) = 850\ k$$

Preliminary Design with Static Capacity Analysis

A static capacity method is used to provide preliminary sizing for the piles. The method indicates a nominal group capacity of 2500 k. The resistance factor for the method is indicated to be 0.35. The factored resistance is:

$$\sum \varphi_i R_i = (0.35)(2500\ k) = 875\ k$$

The factored resistance is greater than the factored load so the preliminary design is satisfactory.

Dynamic Evaluation of Resistance

The engineer examines the available dynamic methods for determining pile resistance. The driving formula is disregarded as unreliable based on its low resistance factor (φ = 0.1). Dynamic testing is selected, which has a resistance factor of 0.65. Using dynamic testing, the group resistance is determined to be 2000 k. The factored resistance is calculated to be sufficient as:

$$\sum \varphi_i R_i = (0.65)(2000\ k) = 1350\ k$$

Static Load Testing

In order to further evaluate capacity, static load testing is completed, resulting in a group resistance of 2250 k. The resistance factor for this method is 0.9, indicating a factored resistance of:

$$\sum \varphi_i R_i = (0.9)(2250\ k) = 2025\ k$$

Based on this information, the pile group may be redesigned to more efficiently carry the factored load of 850 k.

Figure 7-23 LRFD Pile Design Example

7-5 NOTATION.

Variable	Definition
a, b	Limits of uniform distribution
a'	Tensile stress intercept of the Mohr Coulomb failure envelope
CF	Clay fraction
$cov(x,y)$	Covariance of variables x and y
COV_X	Coefficient of variation of x
$E(X)$	Expected value of a variable
E_D	Dilatometer modulus
E_i	Intact rock modulus
E_m	Rock mass modulus
F	Factor of safety
$g(X)$	Limit state function
GSI	Geological strength index
HCV	Highest conceivable value
I_{s50}	Point load index
k	Hydraulic conductivity
kD	Horizontal stress index from dilatometer
LCV	Lowest conceivable value
M_k	k^{th} moment about the mean
N, n	Number of items
N	Standard Penetration Test blow count
p	Probability of success in binomial trial
PI	Plasticity index
P_u	Probability of unsatisfactory performance
Q	Rock mass quality index
Q_n	Nominal load
q_c	Cone penetration resistance
q_t	Cone penetration resistance corrected for pore pressure effects

Variable	Definition
R	Return period
R_n	Nominal resistance
r_x	Range of a variable
r_{xy}	Sample correlation coefficient
RQD	Rock quality designation
RMR	Rock mass rating
s	Sample standard deviation
s^2	Sample variance
s_u	Undrained shear strength
t	Time
T_R	Exposure period
w	Water content
$\bar{x}$	Sample mean
x_{max}	Maximum value
x_{min}	Minimum value
x_P	Percentile value for which a fraction of the data, P, are smaller
z	Depth below the ground surface
β	Reliability index
δ_h, δ_v	Scale of fluctuation in the horizontal and vertical directions
φ	Resistance factor for LRFD
ϕ'	Effective stress friction angle
γ	Load factor for LRFD
γ_τ	Total unit weight
γ_δ	Dry unit weight
λ	Rate for Poisson and exponential distributions
μ	Population mean
σ	Population standard deviation
σ^2	Population variance

Variable	Definition
σ_{ci}	Unconfined compressive strength of rock

7-6 SUGGESTED READING.

Topic	Reference
Probability and statistics in civil engineering	Benjamin, J. R. and Cornell, C. A. 1970. *Probability, Statistics, and Decision for Civil Engineers*. Courier Corporation.
Probability and statistics in geotechnical engineering	Baecher, G. B. and Christian, J. T. 2005. *Reliability and statistics in geotechnical engineering*. John Wiley & Sons.
Methods of plotting data	Tukey, J. W. (1977). *Exploratory Data Analysis*. Addison-Wesley, Reading, MA.
Geotechnical risk analysis	Fenton, G. A. and Griffiths, D. V. 2008. Risk assessment in geotechnical engineering. New York: John Wiley & Sons.
Uncertainty of geotechnical parameters	Phoon, K. K. and Kulhawy, F. H. 1999. “Characterization of geotechnical variability.” *Canadian Geotechnical Journal*, 36(4), 612-624.
	Phoon, K. K. and Kulhawy, F. H. 1999. “Evaluation of geotechnical property variability.” *Canadian Geotechnical Journal*, 36(4), 625-639.
	ISSMGE-TC304. 2021. *State-of-the-Art Review of Inherent Variability and Uncertainty in Geotechnical Properties and Models*. Ed. Ching, J. and Schweckendiek, T., ISSMGE, 220 pp.
Application of reliability to geotechnical problems	Duncan, J. M. 2000. “Factors of safety and reliability in geotechnical engineering.” *Journal of Geotechnical Engineering*, 126(4), 307-316.
Reliability and risk analysis of dams and levees	Wolff, T. F, Hassan, A., Khan, R., Ur-Rasul, I. and Miller, M. 2004. *Geotechnical Reliability of Dam and Levee Embankments, ERDC/GSL CR-04-1*, USACE, Washington D.C
	USBR and USACE. 2019. *Best Practices in Dam and Levee Safety Risk Analysis*. Risk Management Center, Denver, CO.
LRFD for shallow foundations	Paikowsky, S. G. 2010. *LRFD design and construction of shallow foundations for highway bridge structures (Vol. 651)*. Transportation Research Board.
LRFD for deep foundations	Paikowsky, S. G. 2004. *Load and resistance factor design (LRFD) for deep foundations (Vol. 507)*. Transportation Research Board.

APPENDIX A. REFERENCES

Aboshi, H., Kuwabara, M., and Mizuno, Y. 1991. “Present state of sand compaction pile in Japan." *Deep Foundation Improvements: Design, Construction, and Testing,* ASTM International, West Conshohocken, PA, 32-46.

Alwarawi, A. S., Leo, C. J., Liyanpathirana, D. S., and Sigdel, L. D. 2021. “A spreadsheet-based technique to calculate the passive pressure based on the log-spiral method,” *Computers and Geotechnics*, 130(3):103926.

American Concrete Institute (ACI). 2014. *Building Code Requirements for Structural Concrete, ACI 318-14*, ACI, Farmington Hills, MI.

American Association of State Highway and Transportation Officials (AASHTO). 2020. *LRFD Bridge Design Specifications*, 9th edition, AASHTO, Washington, DC.

AASHTO. 2021. *T272 Standard Method of Test for One-Point Method for Determining Maximum Dry Density and Optimum Moisture*. AASHTO.

American Concrete Institute (ACI). 2002. *Suggested Analysis and Design Procedures for Combined Footings and Mats, ACI 336.2R-88*, ACI.

American Petroleum Institute (API). 1993. *Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms – Load and Resistance Factor Design. API Recommended Practice 2A-LRFD (RP 2A-LRFD).* 1st Edition.

API. 2011. *Geotechnical and Foundation Design Considerations. ANSI/API Recommended Practice 2GEO.* American Petroleum Institute, Washington, DC.

American Society of Civil Engineers (ASCE). 2017. *Minimum design loads and associated criteria for buildings and other structures: ASCE/SEI 7-16.* ASCE, Reston, VA.

American Wood Preservers Institute (AWPI). 2002. *Timber Pile Design and Construction Manual*. Timber Piling Council, American Wood Preservers Institute, Birmingham, AL.

Anderson, D. G., Martin, G. R., Lam, I. P., and Wang, J. N. 2008. *Seismic Design and Analysis of Retaining Walls, Buried Structures, Slopes and Embankments, NCHRP Report 611*. Transportation Research Board, National Cooperative Highway Research Program, Washington, D.C.

Ang, A. H., and Tang, W. H. 1975. *Probability concepts in engineering planning and design, basic principles.* Vol. 1, John Wiley & Sons Inc.

Arellano, D. E. 2019. "Lightweight Fill Applications & Considerations." *50th Annual Southeastern Transportation Geotechnical Engineering Conference*, Chattanooga, TN.

Arulrajah, A., Disfani, M. M., Maghoolpilehrood, F., Horpibulsuk, S., Udonchai, A., Imteaz, M., and Du, Y. J. (2015). "Engineering and environmental properties of foamed recycled glass as a lightweight engineering material." *Journal of Cleaner Production*, 94, 369-375.

Ashour, M., Norris, G., and Pilling, P. 1998. "Lateral loading of a pile in layered soil using the strain wedge model." *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 124(4), 303-315.

ASTM International. 2021. A722/A722M-18 Standard Specification for High-Strength Steel Bars for Prestressed Concrete. West Conshohocken, PA; ASTM International.

ASTM International. 2018. D1586 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils. West Conshohocken, PA; ASTM International.

ASTM International. 2019. D2216 Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. West Conshohocken, PA; ASTM International.

ASTM International. 2017. D2487 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)." West Conshohocken, PA; ASTM International.

ASTM International. 2018. D3385-18 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer. West Conshohocken, PA; ASTM International.

ASTM International. 2022. D4542-22 Standard Test Methods for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer. West Conshohocken, PA; ASTM International.

ASTM International. 2016. D4718/D4718M-15 Standard Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles. West Conshohocken, PA; ASTM International.

ASTM International. 2020. D4719-20 Standard Test Methods for Prebored Pressuremeter Testing in Soils. West Conshohocken, PA; ASTM International.

ASTM International. 2020. D5080-20 Standard Test Method for Rapid Determination of Percent Compaction. West Conshohocken, PA; ASTM International.

ASTM International. 2020. D5778-20 Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils. West Conshohocken, PA; ASTM International.

ASTM International. 2016. D6635-15 Standard Test Method for Performing the Flat Plate Dilatometer. West Conshohocken, PA; ASTM International.

ASTM International. 2023. D8167/D8167M-23 Standard Test Method for In-Place Bulk Density of Soil and Soil-Aggregate by a Low-Activity Nuclear Method (Shallow Depth). West Conshohocken, PA; ASTM International.

ASTM International. 2007. D1143-07 Standard Test Methods for Deep Foundation Elements Under Static Axial Compressive Load. West Conshohocken, PA; ASTM International.

ASTM International. 2007. D3689-07 Standard Test Methods for Deep Foundation Elements Under Static Axial Tensile Load. West Conshohocken, PA; ASTM International.

ASTM International. 2011. D3080/D3080M-11 Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. West Conshohocken, PA; ASTM International. (Withdrawn 2020)

ASTM International. 2012. D1557-12e1 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3)). West Conshohocken, PA; ASTM International.

ASTM International. 2012. D698-12e2 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3)). West Conshohocken, PA; ASTM International.

ASTM International. 2013. D6467-13e1 Standard Test Method for Torsional Ring Shear Test to Determine Drained Residual Shear Strength of Cohesive Soils. West Conshohocken, PA; ASTM International.

ASTM International. 2014. D4546-14e1 Standard Test Methods for One-Dimensional Swell or Collapse of Soils. West Conshohocken, PA; ASTM International.

ASTM International. 2015. D1556/D1556M-15e1 Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method. West Conshohocken, PA; ASTM International.

ASTM International. 2015. D2167-15 Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method. West Conshohocken, PA; ASTM International.

ASTM International. 2015. D2850-15 Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils. West Conshohocken, PA; ASTM International.

ASTM International. 2016. D1883-16 Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils. West Conshohocken, PA; ASTM International.

ASTM International. 2016. D4644-16 Standard Test Method for Slake Durability of Shales and Other Similar Weak Rocks. West Conshohocken, PA; ASTM International.

ASTM International. 2016. D2166/D2166M-16 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. West Conshohocken, PA; ASTM International.

ASTM International. 2016. D4253-16e1 Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table. West Conshohocken, PA; ASTM International.

ASTM International. 2016. D4254-16 Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density. West Conshohocken, PA; ASTM International.

ASTM International. 2016. 5084-16a Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter. West Conshohocken, PA; ASTM International.

ASTM International. 2017. D4318-17e1 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. West Conshohocken, PA; ASTM International.

ASTM International. 2017. D6913/D6913M-17 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. West Conshohocken, PA; ASTM International.

ASTM International. 2017. D7928-17 Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis. West Conshohocken, PA; ASTM International.

ASTM International. 2017. D2937-17e2 Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method. West Conshohocken, PA; ASTM International.

ASTM International. 2017. D6938-17a Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth). West Conshohocken, PA; ASTM International.

ASTM International. 2018. D4221-18 Standard Test Method for Dispersive Characteristics of Clay Soil by Double Hydrometer. West Conshohocken, PA; ASTM International.

ASTM International. 2018. D4944-18 Standard Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester. West Conshohocken, PA; ASTM International.

ASTM International. 2020. D2435/D2435M-11(2020) Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading. West Conshohocken, PA; ASTM International.

ASTM International. 2020. D4647/D4647M-13(2020) Standard Test Methods for Identification and Classification of Dispersive Clay Soils by the Pinhole Test. West Conshohocken, PA; ASTM International.

ASTM International. 2020. D4767-11(2020) Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils. West Conshohocken, PA; ASTM International.

ASTM International. 2020. D6572-20 Standard Test Methods for Determining Dispersive Characteristics of Clayey Soils by the Crumb Test. West Conshohocken, PA; ASTM International.

ASTM International. 2020. D7181-20 Standard Test Method for Consolidated Drained Triaxial Compression Test for Soils. West Conshohocken, PA; ASTM International.

Aubeny, C. P. and Lytton, R. L. 2003. “Shallow Slides in Compacted High Plasticity Clay Slopes.” *Journal Geotechnical and Geoenvironmental Engineering*, 130(7), 717-727.

Ayyub, B. M. and McCuen , R. H. 2016. *Probability, Statistics, and Reliability for Engineers and Scientists*. CRC Press.

Azam, G. and Wang, M. C. 1991. “Bearing Capacity of Strip Footing Supported by Two-Layer c-phi Soils.” *Transportation Research Record*, 1331.

Baecher, G. B. and Christian, J. T. 2005. *Reliability and statistics in geotechnical engineering*. John Wiley & Sons.

Barden, L. and Sides, G. R. 1970. "Engineering behavior and structure of compacted clay," *Journal of the Soil Mechanics and Foundations Division*, 96(SM4), 1171-1200.

Barksdale, R. D. (1987). *State of the art for design and construction of sand compaction piles, Technical Report REMR-GT-4*, USACE Waterways Experiment Station, Vicksburg, MS.

Barton, N. and Kjærnsli, B. 1981. "Shear strength of rockfill." *Journal of the Geotechnical Engineering Division*, 107(7), 873-891.

Bay, J. A. 2003. "A summary of the research on pile driving vibrations." *Proceedings of the Pile Driving Contractors Association 7th Annual Winter Roundtable*, Atlanta, GA.

Bazett, D. J. and Foxall, R. G. 1972. "Control of Underwater Earthwork at Hugh Keenleyside (Arrow) Dam." *Underwater Soil Sampling, Testing, and Construction Control*, ASTM Special Technical Publication 501, ASTM International.

Benjamin, J. R. and Cornell, C. A. 1970. *Probability, Statistics, and Decision for Civil Engineers*. Courier Corporation.

Benson, C. H., and Trast, J. M. 1995. "Hydraulic Conductivity of Thirteen Compacted Clays." *Clays and Clay Minerals*, 43(6), 669–681.

Berezantzev, V. G., Khristoforov, V. S., and Golubkov, V. N. 1961. "Load bearing capacity and deformation of piled foundations." *Proc., 5th Int. Conf. Soil Mechanics and Foundation Engineering*, Paris, France.

Boscardin, M. D. and Cording, E. J. 1989. "Building Response to Excavation-Induced Settlement," *Journal of Geotechnical Engineering*, 115(1), 1-21.

Bowles, J. E. 1996. *Foundation Analysis and Design*, 5th Edition. McGraw-Hill Companies, Inc., New York, NY

Brandon, T. L., Duncan, J. M., and Gardner, W. S. 1990. "Hydrocompression Settlement of Deep Fills." *Journal of Geotechnical Engineering*, 116(10), 1536-1548.

Brandon, T. L.; Rose, A. T.; and Duncan, J. M. 2006. "Drained and Undrained Strength Interpretation of Low-Plasticity Silt," *Journal of Geotechnical and Geoenvironmental Engineering*, 132(2), 250-257.

Bray, J. D., Zekkos, D., and Merry, S. M. 2008. "Shear strength of municipal solid waste," *Proc. International Symposium on Waste Mechanics*, ASCE, 44–75.

Bray, J. D., Zekkos, D., Kavazanjian, E., Athanasopoulos, G. A., and Riemer, M. F. 2009. "Shear strength of municipal solid waste," *Journal of Geotechnical and Geoenvironmental Engineering*, 135(6), 709–722.

Breitenbach, A. J. 1993. "Rockfill placement and compaction guidelines." *Geotechnical Testing Journal*, 16(1), 76-84.

Brettmann, T. and Duncan, J. M. 1996. "Computer application of CLM lateral load analysis to piles and drilled shafts." *Journal of Geotechnical Engineering*, 122(6): 495-498.

Briaud, J.-L. 2008. "Case histories in soil and rock erosion: Woodrow Wilson Bridge, Brazos River Meander, Normandy Cliffs, and New Orleans Levees." *Journal Geotechnical Geoenvironmental Engineering*, 134(10), 1425-1447.

Briaud, J.-L. 2013. *Geotechnical Engineering: Unsaturated and Saturated Soils*, Wiley, Hoboken, NJ.

Briaud, J.-L. and Tucker, L. 1984. "Piles in sand: a method including residual stresses." *Journal of Geotechnical Engineering*, Vol. 10(11), 1666-1680.

Brinch Hansen, J. 1953. *Earth Pressure Calculations*, Danish Technical Press, Institution of Danish Civil Engineers, Copenhagen.

Brinch Hansen, J. 1957. "Foundations of structures – (a) General subjects and foundations other than piled foundations, General Report." *Proc. of 4th Intl. Conf. Soil Mech. Found. Engr.*, Vol. II, 441-447.

Brinch Hansen, J. 1961. *A General Formula for Bearing Capacity, Bulletin No. 11*. Danish Geotechnical Institute, Copenhagen.

Brinch Hansen, J. 1970. *A Revised and Extended Formula for Bearing Capacity, Bulletin No. 28*. Danish Geotechnical Institute, Copenhagen.

Brinch Hansen, J. 1963. Discussion of "Hyperbolic stress-strain response: cohesive soils." *Journal for Soil Mechanics and Foundation Engineering*, 89(SM4), 241-242.

Broms, B. B. 1964a. "Lateral resistance of piles in cohesive soils." *Journal of the Soil Mechanics and Foundations Division*, 90(SM2), 27-63.

Broms, B. B. 1964b. “Lateral resistance of piles in cohesionless soils.” *Journal of the Soil Mechanics and Foundations Division*, 90(SM3), 123-156.

Broms, B. B. 1965. “Design of laterally loaded piles.” *Journal of the Soil Mechanics and Foundations Division*, 91(SM3), 79-99.

Broms, B. B. 1966. “Methods of calculating the ultimate bearing capacity of piles – a summary.” *Soils-Soils*, 5(18-19), 21-32.

Brooker, E. W. and Ireland, H. O. 1965. “Earth Pressure At-Rest Related to Stress History.” *Canadian Geotechnical Journal*, 11(1), 1-15.

Brown M. J. and Powell, J. J. M. 2013. “Comparison of Rapid Load Test Analysis Techniques in Clay Soils.” *Journal of Geotechnical and Geoenvironmental Engineering*, 139(1), 152-161.

Brown, A. C., Dellinger, G. F., El-Mohtar, C., Zornberg, J. G., and Gilbert, R. B. 2014. *Long-Term Performance of a Drilled Shaft Retaining Wall in Expansive Clay. Research Report FHWA/TX-13/0-6603-2*. Center for Transportation Research. University of Texas at Austin.

Brown, D. A. and Bollman, H. T. 1993. “Pile-Supported Bridge Foundations Designed for Impact Loading.” *Appended Document to the Proceedings of Design of Highway Bridges for Extreme Events*, Crystal City, VA, 265-281.

Brown, J. D. and Meyerhof, G. G. 1969. "Experimental study of bearing capacity in layered clays." *Proc. 7th ICSMFE*, Mexico City, Mexico.

Brown, P. P. 1963. Discussion of “Field Study of Cellular Cofferdams,” Transactions of ASCE, Paper No. 3426, Vol. 128, Part 1.

Brown, R. P. 2001. *Predicting the Ultimate Axial Resistance of Single Driven Piles*. PhD Dissertation, Department of Civil Engineering, The University of Texas at Austin, 168 pp.

Bryant, L., Mauldon, M., and Mitchell, J. K. 2003. *Geotechnical Problems with Pyritic Soil and Rock, CGPR #30*, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA, 157 pp.

Burland, J. B. 1970. “Discussion, Session A.” *Proc. Conf. on In Situ Investigations in Soil and Rocks*, British Geotechnical Society, London, UK, 61-62.

Bursey, A.; Duncan, J. M.; and Smith, C. J. (2006). *A Review of Building Code Requirements and Engineering Practice for Expansive Soils, CGPR #39*, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA, 30 pp.

Bustamante, M. and Gianesselli, L. 1982. “Pile bearing capacity prediction by means of static penetrometer CPT.” *Proc., 2nd European Symposium on Penetration Testing (ESOPT II)*, Vol. 2, 493-500.

Button, S. J. 1953. “The bearing capacity of footing on a two-layer cohesive subsoil.” *Proc. 3rd ICSMFE*, 1, 332-335.

Caicedo, B., Yamin, L., Giraldo, E., Coronado, O., and Soler, N. 2002. “Geomechanical properties of municipal solid waste in Dona Juana sanitary landfill.” *Proc. of the Fourth International Congress on Environmental Geotechnics*, Rio De Janeiro, Brazil, A.A. Balkema, Vol. 1, 177-182.

Caltrans. 2020. “Vertical Ground Anchors.” *Caltrans Geotechnical Manual*.

Canadian Geotechnical Society. 1978. “Excavations and Retaining Structures.” *Canadian Foundation Engineering Manual*, Part 4.

Caquot, A. and Kerisel, F. 1948. *Tables for the Calculation of Passive Pressure, Active Pressure and Bearing Capacity of Foundations*, Gauthier-Villars, Paris.

Carson, A. 1965. *Foundation Construction*, McGraw-Hill Book Co.

Castellanos, B. A. and Brandon, T. L. 2019. “Fully Softened Shear Strength: Application, Measurement, and Correlations.” *Proc. XVI Pan-American Conference on Soil Mechanics and Geotechnical Eng.*, Cancun, MX, 81–88.

Castellanos, B. A., Brandon, T. L., and VandenBerge, D. R. 2016. “Use of fully softened shear strength in slope stability analysis.” *Landslides*, 13(4), 697–709.

Caterpillar. 2000. *Handbook of Rippability*, 12th Edition, Caterpillar, Inc.

Cedergren, H. 1997. *Seepage, Drainage, and Flow Nets*, 3rd Ed., Wiley-Interscience, 496 pp.

Charles, J. A. and Soares, M. M. 1984. “The stability of slopes in soils with nonlinear failure envelopes.” *Canadian Geotechnical Journal*, 21(3), 397-406.

Chen, Y.-J. and Kulhawy, F. H. 1993. “Undrained strength interrelationships among CIUS, UU, and UC tests.” *J. Geotech. Geoenviron. Eng.*, 119(11): 1732-1750.

Chen, Y.-J. and Kulhawy, F. H. 2002. “Evaluation of drained axial capacity for drilled shafts.” *In Proc. Deep Foundations, Geotechnical Special Technical Publication 116*, 1200-2014, ASCE, Reston, VA.

Chen, Y.-J., Lin, S.-S., Chang, H-W., and Marcos, M. C. 2011. “Evaluation of side resistance capacity for drilled shafts.” *Journal of Marine Science and Technology*, Vol. 19(2), 210-221.

Cheng, Y. M. 2004. “Technical note, N_q factor for pile foundations by Berezantzev.” *Geotechnique*, 54(2), 149-150.

Cheng, Y. M. 2005. “Discussion, N_q factor for pile foundations by Berezantzev.” *Geotechnique*, 55(6), 493-494.

Chi, C.M. and Lin, Z.S. 2020. “The bearing capacity evaluations of a spread footing on single thick stratum or two-layered cohesive soils.” *Journal of Marine Science and Engineering*, 8(11), 853, 19 pp.

Chin, F.K., 1978. “Diagnosis of pile condition.” *Proc. 6th Southeast Asian Conference on Soil Engineering,* Bangkok, SEAGS Geotechnical Engineering, 9(2) 85-104.

Ching, J. and Noorzad, A. 2021. “Statistics for transformation uncertainties.” *State-of-the-art Review of Inherent Variability and Uncertainty*, ISSMGE, Technical Committee 304.

Christian, J. T. and Baecher, G. B. 1999. “Point-estimate method as numerical quadrature.” *J. of Geotechnical and Geoenvironmental Engineering*, 125(9), 779.

Clough, G. W. and Davidson. 1977. “Effects of Construction on Geotechnical Performance,” *Ninth International Conference on Soil Mechanics and Foundation Engineering*, Tokyo, Japan.

Clough, G. W. and O’Rourke, T. D. 1990. “Construction Induced Movements of In situ Walls.” *Proc. of Conf. on Design and Performance of Earth Retaining Structures, ASCE Geotech. Special Pub. No. 25*, Cornell University, Ithaca, NY, 439-470.

Clough, G. W., Smith, E. M., and Sweeney, B. P. 1989. “Movement Control of Excavation Support Systems by Iterative Design.” *Proc., Foundation Engineering: Current Principles and Practices*, Vol. 2. ASCE, 869-884.

Coduto, D. P., Kitch, W. A., and Yeung, M. 2016. *Foundation Design: Principles and Practices*, 3rd Edition, Pearson, New York, NY.

Coduto, D. P., Yeung, M. C. R., and Kitch, W. A. 2011. *Geotechnical Engineering: Principles and Practices*. Prentice Hall.

Coleman, D. M. and Arcement, B. J. 2002. “Evaluation of design methods for auger cast piles in mixed soil conditions.” *International Deep Foundations Congress*, Orlando, FL, ASCE, Reston, VA.

Cornell, C. A. 1969. “A probability-based structural code.” *Journal American Concrete Institute*, 66(12), 974-985.

Coulomb, C. A., 1776. “An Attempt to Apply the Rules of Maxima and Minima to Several Problems of Stability Related to Architecture,” *Mémoires de l’Académie Royale des Sciences*, Paris, France, 343-382.

Daniel, D. E. 1984. “Predicting hydraulic conductivity of clay liners.” *Journal of Geotechnical Engineering*, 110(2), 285-300.

Das, B. 2022. *Principles of Geotechnical Engineering*. 10th Edition, Cengage Learning, Inc., Boston, MA.

Davis, E. H. and Booker, J. R. 1973. “The effect of increasing strength with depth on the bearing capacity of clays.” *Geotechnique*, 23(4), 551-563.

Davis, F.J, 1953. “Quality control of earth embankments.” *Proc. of 3rd ICSMFE*.

Davisson, M. T. 1970. “Lateral load capacity of piles.” *In Proc., 49th Annual Meeting of the Highway Research Board*, Washington, DC, 104-112.

Davisson, M. T. and Robinson, K. E. 1965. “Bending and buckling of partially embedded piles.” *In Proc, 6th International Soil Mechanics and Foundation Engineering Conference*, Vol. 2, 243-246.

Davisson, M.T. 1972. “High Capacity Piles.” *In Proc. Soil Mechanics Lecture Series on Innovations in Foundation Construction*, American Society of Civil Engineers, ASCE, Illinois Section, Chicago, IL, 81-112.

Decker, J. B., Rollins, K. M., Ellaworth, J. C., 2008. “Corrosion rate evaluation and prediction for piles based on long-term field performance.” *J. Geotech. Geoenviron. Eng.*, 134(3), 341-351.

DeepEX. 2021. *Combined Sheet Pile Walls Software*, Deep Excavation LLC, New York, NY.

Deere, D. U. and Deere, D. W. 1989. *Rock Quality Designation (RQD) After Twenty Years*, U. S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Deere, D. U. and Patton, F. D. 1971. “Slope Stability in Residual Soils”. *Proc., Fourth Pan American Conference on Soil Mechanics and Foundation Engineering*, San Juan, Puerto Rico, ASCE, Vol. 1, 87-1 70.

Deo. P., Wood, L. E., and Lovell, C.W. 1972. *Use of Shale in Embankments, Joint Highway Research Report 14*, Purdue Univ.

Department of Defense (DoD). 2021. *DOD Dictionary of Military and Associated Terms*. https://irp.fas.org/doddir/dod/dictionary.pdf.

DiBernardo, A. and Lovell, C. W. 1979. *The effect of laboratory compaction on the compressibility of compacted highly plastic clay: Interim Report, Publication FHWA/IN/JHRP-79/03*, Joint Highway Research Project, INDOT and Purdue Univ., West Lafayette, IN.

DiGioia, A. M. and Nuzzo, W. L. 1972. “Fly ash as structural fill.” *Journal of the Power Division*, 98(1), 77-92.

Dixon, N., Langer, U., Gotteland, P., 2008. “Classification and mechanical behavior relationships for municipal solid waste: study using synthetic waste.” *Journal of Geotechnical and Geoenvironmental Engineering*, 134(1), 79–90.

Doherty, P. and Gavin, K. 2011. “The shaft capacity of displacement piles in clay: a state of the art review.” *Geotech. Geol. Eng.*, Springer, DOI 10.1007/s10706-010-9389-2.

Dubbe, D. D., Usmen, M. A., and Moulton, L. K. 1984. “Expansive Pyritic Shales.” *Transportation Research Board 36*, Washington D.C.

Duncan, J. M. 2000. “Factors of safety and reliability in geotechnical engineering.” *Journal of Geotechnical Engineering*, 126(4), 307-316.

Duncan, J. M. and Buchignani, A. 1976. *An engineering manual for slope stability studies*, University of California, Berkeley, Department of Civil Engineering.

Duncan, J. M. and Buchignani, A. L. 1987. *An Engineering Manual for Settlement Studies, Report #2*, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA.

Duncan, J. M. and Bursey, A. 2006. *Settlement of Valley Fills, CGPR #41*, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA.

Duncan, J. M., Brandon, T. L., and VandenBerge, D. R. 2011. *Report of Workshop on Shear Strength for Stability of Slopes in Highly Plastic Clays, CGPR #67*, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA.

Duncan, J. M., Evans, L. T., and Ooi, P. S. K. 1994. “Lateral load analysis of single piles and drilled shafts.” *Journal of Geotechnical Engineering*, 120(5), 1018-1033.

Duncan, J. M., Williams, G. W., Sehn, A. L., and Seed, R. B. 1991. “Estimation of Earth Pressures due to Compaction,” *Journal of Geotechnical Engineering*, 117(12), 1833-1847.

Duncan, J. M., Williams, G. W., Sehn, A. L., and Seed, R. B. 1991. Closure to “Estimation of Earth Pressures due to Compaction,” *Journal of Geotechnical Engineering*, 117(12), 1172-1177.

Duncan, J. M., Wright, S. G., and Brandon, T. L. 2014. *Soil Strength and Slope Stability*, 2nd ed. Wiley, Hoboken, NJ.

Ebeling, R. M. and Morrison, E.E. 1992. “The Seismic Design of Waterfront Retaining Structures,” *US Army Technical Report ITL-92-11, US Navy Technical Report NCEL TR-939*, USACE Waterways Experiment Station, Vicksburg, MS.

Eden, W. J. and Kuboto, J. K. 1962. “Some Observations on the Measurement of Sensitivity of Clays,” *Proceedings of the American Society for Testing and Materials*, Vol. 61, 1239-1249.

Edil, T. B. and Wang, X. 2000. “Shear Strength and Ko of Peats and Organic Soils,” *Geotechnics of High Water Content Materials, ASTM STP 1374*, T. B. Edil and P. J. Fox, Eds., ASTM, West Conshohocken, PA, 209-225.

Eid, H.T., Stark, T.D., Douglas, W.D., and Sherry, P.E. 2000. “Municipal solid waste slope failure waste and foundation properties,” *Journal of Geotechnical and Geoenvironmental Engineering*, 126(5), 397-407.

Eslami, A., and Fellenius, B. H. 1997. “Pile Capacity by Direct CPT and CPTu Methods Applied to 102 Case Histories.” *Canadian Geotechnical Journal*, 34(6), 880-898.

European Committee for Standardization. 1999. *Execution of Special Geotechnical Work - Sheet-pile Walls,* Standard EN 12063.

Evans, L. T. Jr. and Duncan, J. M. 1982. *Simplified Analysis of Laterally Loaded Piles. Report No. UCB/GT/82-04*, University of California, Berkeley, CA.

Fellenius, B. H. 1988. “Unified design of piles and pile groups.” *Transportation Research Record 1169*, 75-82.

Fellenius, B. H. 2021. “Basics of Foundation Design, Electronic Edition.” Accessed May 1, 2021. http://www.fellenius.net.

Fenton, G. A. and Griffiths, D. V. 2008. *Risk Assessment in Geotechnical Engineering*. New York: John Wiley & Sons.

Federal Highway Administration (FHWA). 1978a. *Design and Construction of Compacted Shale Embankments*. Offices of Research and Development, Washington, D.C.

FHWA. 1978b. *Guidelines For Cone Penetration Test, Performance, and Design, FHWA-TS-78-209*. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 145 pp.

FHWA. 1978c. *Lateral Support Systems and Underpinning, Volume I: Design And Construction*, https://rosap.ntl.bts.gov/view/dot/14528.

FHWA. 1984. *Handbook on Design of Piles and Drilled Shafts Under Lateral Load, FHWA-IP-84-11*. U.S. Department of Transportation, Federal Highway Administration, Office of Implementation, Washington, D.C.

FHWA. 1986. *Behavior of Piles and Pile Groups Under Lateral Load, FHWA-RD-85-106*. U.S. Department of Transportation, Federal Highway Administration, Office of Engineering and Highway Operations Research and Development, Washington, D.C

FHWA. 1991. *Rock Blasting and Overbreak Control, FHWA-HI-92-001*. National Highway Institute, McLean, VA.

FHWA. 1993. *SPILE: A Microcomputer Program for Determining Ultimate Vertical Static Pile Capacity. FHWA-SA-92-044*. U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 1999a. *Drilled Shafts: Construction Procedures and Design Methods. FHWA-IF-99-025.* U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 1999b. *Ground Anchors and Anchored Systems. Geotechnical Engineering Circular No. 4. Publication FHWA-IF-99-015.* Federal Highway Administration, Washington, D.C.

FHWA. 2000. *Soils and Foundations Workshop Reference Manual, FHWA HI-00-045.* U.S. Department of Transportation, National Highway Institute, Federal Highway Administration, Washington, DC.

FHWA. 2001a. *Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures – Reference Manual*. Arlington, VA.

FHWA. 2001b. *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines, NHI-00-043.* National Highway Institute, Office of Bridge Technology.

FHWA. 2002a. E*valuation of Soil and Rock Properties, Geotechnical Engineering Circular No. 5, FHWA-IF-02-034)*. Federal Highway Administration. Office of Bridge Technology.

FHWA. 2002b. *Soils and Foundations Workshop Reference Manual, 2nd Edition, FHWA HI-88-009.* U.S. Department of Transportation, National Highway Institute, Federal Highway Administration, Washington, DC.

FHWA. 2005. *Micropile Design and Construction. Reference Manual for NHI Course 132078: FHWA-NHI-05-039*. U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2007. *Design and Construction of Continuous Flight Auger Piles, Geotechnical Engineering Circular No. 8, FHWA-HIF-07-03*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2008. *Earth Retaining Structures, FHWA NHI-07-071*. U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2009a. *Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance, 3th Edition, Volumes 1 and 2. Hydraulic Engineering Circular No. 23, FHWA-HIF-09-111 and FHWA-HIF-09-112*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2009b. *Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Volumes I and II, FHWA-NHI-10-024 and FHWA-NHI-10-025*, National Highway Institute, Washington, D.C.

FHWA. 2012a. *Evaluating Scour at Bridges, 5th Edition. Hydraulic Engineering Circular No. 18, FHWA-HIF-12-003*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2012b. *Stream Stability at Highway Structures, 4th Edition. Hydraulic Engineering Circular No. 20, FHWA-HIF-12-004*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2015. *Soil Nail Walls Reference Manual, FHWA NHI-14-007*. U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2016. *Design and Construction of Driven Pile Foundations. Geotechnical Engineering Circular No. 12, FHWA-NHI-16-009*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2017a. *Geotechnical Site Characterization, Geotechnical Engineering Circular No. 5*. U.S. Department of Transportation - Federal Highway Administration, Washington, DC.

FHWA. 2017b. *Ground Modification Methods Reference Manual – Volumes I and II, Geotechnical Engineering Circular No. 13, FHWA-NHI-16-009*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2018a. *Drilled Shafts: Construction Procedures and Design Methods, Geotechnical Engineering Circular No. 10, FHWA-NHI-18-024*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2018b. *Design, Analysis, and Testing of Laterally Loaded Deep Foundations that Support Transportation Facilities, Geotechnical Engineering Circular No. 9, FHWA-HIF-18-031*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

FHWA. 2021. *Tech Brief: Scour considerations within AASHTO LRFD Design Specifications, FHWA-HIF-19-060*, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

Filz, G. M. 1992. *An experimental and analytic study of earth loads on rigid retaining walls*. Dissertation submitted in partial fulfillment for the degree of Doctor of Philosophy, Department of Civil Engineering, Virginia Tech, 345 pp.

Franklin, A. J. 1981. “A shale rating system and tentative applications to shale performance.” *Shales and Swelling Soils, Transportation Research Record 790*, National Research Council, Washington, D.C. 2-12.

Frossard, E. Hu, W., Dano, C., and Hicher, P.Y. 2012. “Rockfill shear strength evaluation: a rational method based on size effects.” *Géotechnique*, 2012, 62(5), 415-427.

Gabr, M.A. and Valero, S.N. 1995. “Geotechnical properties of municipal solid waste.” *Geotechnical Testing Journal*, ASTM 18 (2), 241–251.

Gabr, M.A., Hossain, M.S., Barlaz, M.A., 2007. “Shear strength parameters of municipal solid waste with leachate recirculation.” *Journal of Geotechnical and Geoenvironmental Engineering*, 133(4), 478–884.

Garcia-Bengochea, I., 1978. *The relation between permeability and pore size distribution of compacted clayey silts, Publ. JHRP-78-4*. Joint Highway Research Project, INDOT and Purdue Univ., West Lafayette, IN.

Giroud, J.-P. 1972. "Settlement of rectangular foundation on soil layer." *Journal of the Soil Mechanics and Foundations Division*, 98(SM1), 149-154.

Gould, J. P., 1954. *Compression Characteristics of Rolled Fill Materials in Earth Dams, TM 648*, U.S. Department of Interior Bureau of Reclamation, Denver, CO.

Gray, H. 1958. "Contribution to the Analysis of Seepage Effects in Backfills," *Geotechnique*, 8(4), 166-170.

Greenfield, M. and Filz, G. M. 2009. *Downdrag and Drag Load on Piles, CGPR #56*, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA.

Gregory, G. H. 1993. *Effect of Geogrid Reinforcement on Seepage Through Earth-Fill Dam Cores*. Masters Thesis, South Dakota School of Mines, Rapid City SD.

Gregory, G. H. 2006. *Shear Strength, Creep and Stability of Fiber-Reinforced Soil Slopes*. Dissertation submitted in partial fulfillment for the degree of Doctor of Philosophy, Oklahoma State Univ., Oklahoma City, OK.

Griffiths, D. V. 1999. "Computation of bearing capacity on layered soils." *Proc. 4th Intl. Conf. Numer. Methods Geomech.*, Edmonton.

Griffiths, D. V. 1982. "Computation of bearing capacity factors using finite elements." *Geotechnique*, 32(3), 195-202.

Grisolia, M. and Napoleoni, Q., 1996. "Geotechnical characterization of municipal solid waste: choice of design parameters." *Proc. of the Second International Congress on Environmental Geotechnics*, Osaka, Japan, A.A. Balkema, Vol. 2, 641–646.

Grisolia, M., Napoleoni, Q., and Tangredi, G., 1995. "The use of triaxial tests for the mechanical characterization of municipal solid waste." *Proc. of the Sardinia '95, Fifth International Landfill Symposium*, Vol. 2, Cagliari, Italy, 761–767.

GRL Engineers. 2013. "CAPWAP Models, Procedures, Parameters, Performance." Presentation materials from PDCA Professors' Driven Pile Institute (PDPI) meeting, Utah State University, Logan, UT.

Guan, Z., Ching, Y.-C., Wang, Y., Aladejare, A., Zhang, D. and Ching, J. 2021. "Site-specific statistics for geotechnical properties." *State-of-the-art Review of Inherent Variability and Uncertainty*, ISSMGE, Technical Committee 304.

Harr, M.E. 1987. *Reliability-Based Design in Civil Engineering*. McGraw-Hill, New York.

Hasofer, A. M. and Lind, N. C. 1974. "Exact and invariant second-moment code format." *Journal of the Engineering Mechanics Division*, 100(1), 111-121.

Hassouna, M.E. and Shenouda, W. K., 1970. "Filling and compaction of sand by deep vibrators and vibrorollers in the High Aswan Dam." *Proc. 10th International Congress on Large Dams*, Montreal, Vol. V, 411-432.

Hatami, K., Gregory, G. H., and Garland, G. S. 2018. *Guidelines for the Use of Fiber Reinforced Soil (FRS) in Highway Construction*. Southern Plains Transportation Center, Univ. of Oklahoma, Norman, OK.

Hetenyi, M. 1948. *Beams on Elastic Foundation*, Univ. of Michigan. Ann Arbor.

Hilf, J. W. 1956. *A rapid method of construction control for embankments of cohesive soil, Engrg. Monograph*, US Bureau of Reclamation, Denver, Colo.,(26), 1-29.

Hilf, J. W. 1991. “Compacted fill.” *Foundation Engineering Handbook*, 2nd Edition, Ed. H.-Y. Fang, Springer Nature, 249-316.

Hoek, E. and Bray, J. 1981. *Rock Slope Engineering*. 3rd Ed., Institute of Mining and Metallurgy, London, UK.

Hoek, E., Carranza-Torres, C., and Corkum, B. 2002. “Hoek-Brown failure criterion – 2002 Edition.” *Proc. North American Rock Mechanics Society Meeting*, Toronto, Canada.

Hoek, E., Wood D. and Shah S. 1992. “A modified Hoek–Brown Criterion for Jointed Rock Masses.” *Proc. Rock Characterization, Symp. Int. Soc. Rock Mech.: Eurock ’92*. J. A. Hudson Ed., Brit. Geotech. Soc., London, 209–214.

Hogentogler, C. A. 1936. “Essentials of soil compaction,” *Proc. of the Highway Research Board, 16th Annual Meeting*, Washington, D. C., R. W. Crum Ed., 309-316.

Holscher, P., Brassinga, H., Brown, M., Middendorp, P., Profittlich, M., and Tol, F. 2012. *Rapid Load Testing on Piles – Interpretation Guidelines*, CRC Press/ Baalkema, Leiden, 104 pp.

Holtz, R. D. 1989. “Treatment of problem foundations for highway embankments.” NCHRP Synthesis No. 147, Transportation Research Board, National Research Council, Washington, D.C., 72 pp.

Holtz, R. D., Kovacs, W. D., and Sheahan, T. C. 2011. *An Introduction to Geotechnical Engineering*, 2nd Ed. Prentice Hall, Upper Saddle River, NJ, 853 pp.

Hough, B. K. 1959. “Compressibility as the basis for soil bearing value.” *Journal for Soil Mechanics and Foundation Division*, 85(4), 11-40.

Houston, S. L., Houston, W. N., Zapata, C. E., and Lawrence, C. 2001. “Geotechnical engineering practice for collapsible soils.” *Unsaturated soil concepts and their application in geotechnical practice*, 333-355.

Huber, K. A., 1997. *Design of Shale Embankments*. Virginia Highway Research Council, Virginia Department of Transportation.

Hughes, S.A. 2001. “Scour and scour protection.” *Coastal Infrastructure Design, Construction and Maintenance Training: Chapter 4 - Design of Maritime Structures*, USACE, Vicksburg, MS.

Ingold, T. S. 1979. “Retaining Wall Performance During Backfilling,” Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, GT5, 1979.

International Code Council (ICC). 2015. 2015 International Building Code. Accessed November 17, 2022. codes.iccsafe.org/content/IBC2015P4

International Society for Rock Mechanics (ISRM). 1978. "Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses," *International Journal of Rock Mechanics*, 15, 319-368.

Jaky, J. 1944. “The Coefficient of Earth Pressure at Rest,” *Journal of the Society of Hungarian Architects and Engineers*, Vol. 7, pp. 355 – 358.

Jamiolkowski, M., Ladd, C. C., Germaine, J. T., and Lancellotta, R. 1985. “New developments in field and laboratory testing of soils.” *Proc. 11th Int. Conf. on Soil Mechanics and Foundation Engineering*, 1, 57-154.

Jardine, R. J., Standing, J. R., Jardine, F. M. , Bond, A. J., and Parker, E. 2001. “A competition to assess the reliability of pile prediction methods.” *Proc. 15th Intl. Conf. Soil Mech. Found. Engr.,* Istanbul, Turkey.

Jennings, J.K. and Knight, K. 1975. “The additional settlement of foundation due to collapse of sandy subsoils on wetting.” *Proc. 4th Intl. Conf. Soil Mech. Found. Engr.*

Jessberger, H. L. and Kockel, R., 1993. “Determination and assessment of the mechanical properties of waste materials.” *Proc. Sardinia ‘93, Fourth International Landfill Symposium*, S. Margherita di Pula, Cagliari, Italy, 1383–1392.

Johnson, J. M. and Lovell, C. W. 1979. *The effect of laboratory compaction on the shear behavior of a highly plastic clay after saturation and consolidation : interim report, Publication FHWA/IN/JHRP-79/07*, Joint Highway Research Project, INDOT and Purdue University, West Lafayette, Indiana.

Johnson, S. J.,, Compton, J. R., and Ling, S. C. 1972. "Control for underwater construction." *Underwater Soil Sampling, Testing, and Construction Control, ASTM STP 501*, ASTM, Philadelphia, PA.

Justason, M.D. 1997. *Report of Load Testing at the Taipei Municipal Incinerator Expansion Project*, Taipei City, Taiwan.

Kavazanjian, E. 2001. "Mechanical properties of municipal solid waste." *Proc. Sardinia 2001, Eighth International Waste Management and Landfill Symposium*, S. Margherita di Pula, Cagliari, Italy, V.3, 415–424.

Keller Moretrench American Corporation. 1954. *General Instructions for the Installation and Operation of Pumps and Wellpoint Systems.* Rockaway, NJ.

Kerisel, J. and Absi, E. 1990. *Active and passive earth pressure tables*. Balkema, Rotterdam, The Netherlands.

Kim, S. G., Duncan, J. M., and Rojiani, K. B. 1991. *Engineering Manual for Walls and Abutments*, Virginia Tech Civil Engineering Report, Blacksburg, VA.

Kitazume, M. 2005. *The sand compaction pile method*. CRC Press.

Konya, C., and Walter, E.J. 2006. *Rock Blasting and Overbreak Control*, 4th Edition, Montville, OH: Intercontinental Development Corporation, Inc.

Kraft, L. M., Ray, R. P., and Kagawa, T. 1981. "Theoretical t-z curves." *Journal of the Geotechnical Division*, ASCE, Reston, VA.

Kramer, S. L. 1996. *Geotechnical Earthquake Engineering*. Prentice-Hall, 653 pp.

Kulhawy, F. H. 2017. "Foundation engineering, geotechnical uncertainty, and reliability-based design." *Geotechnical Safety and Reliability*, 174-184.

Kulhawy, F. H. and Trautmann, C. H. 1996. "Estimation of in-situ test uncertainty." *Uncertainty in the geologic environment: From theory to practice*, ASCE, 269-286.

Kulhawy, F. H., Duncan, J. M., and Seed, H. B. 1969. *Finite Element Analyses of Stresses and Movements in Embankments During Construction, Report No. TE 69-4*, Office of Research Services, University of California Berkeley.

Kulhawy, F.H. and Mayne, P.W. 1990. *Manual on Estimating Soil Properties for Foundation Design, Report EL-6800*, Electric Power Research Institute, Palo Alto, CA.

Kulhawy, F.H., Prakoso, W. A., and Akbas, S. O. 2005. “Evaluation of capacity of rock foundation sockets.” *Proc. Alaska Rocks, 40th U. S. Symposium on Rock Mechanics: Rock Mechanics for Energy, Mineral and Infrastructure Development in the Northern Regions*, American Rock Mechanics Association.

Lacroix, Y., Esrig, M. I., and Luschem, U. 1970. “Design, Construction and Performance of Cellular Cofferdams,” *Lateral Stresses in the Ground and Design of Earth Retaining Structures*, ASCE, Cornell University, 1970.

Lacy, H. S. and Gould, J. P. 1985. “Settlement from pile driving in sands.” *Vibration Problems in Geotechnical Engineering*, Special Technical Publication, ASCE, Reston, VA.

Lade, P.V. 2010. “The mechanics of surficial failure in soil slopes.” *Engineering Geology*, 114(1-2), 57-64.

Landva, A. O. and La Rochelle, P. 1983. “Compressibility and Shear Characteristics of Radforth Peats,” *Testing of Peats and Organic Soils*, ASTM STP 820, P. M. Jarrett, Ed., ASTM, 157-191.

Landva, A. O., Korpijaakko, E. O., and Pheeney, P. E. 1983. “Geotechnical Classification of Peats and Organic Soils,” *Testing of Peats and Organic Soils*, ASTM STP 820, P. M. Jarrett, Ed., ASTM, 37-51.

Lee, D.M. 1992. *The angles of friction of granular fills.* PhD dissertation, Univ. of Cambridge.

Lee, L. T. 2001. "Geotechnical properties and sediment characterization for dredged material models," *DOER Technical Notes Collection (ERDC TN-DOER-N13)*, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. www.wes.army.mil/el/dots/doer/

Leps, T. M. 1970. “Review of shearing strength of rockfill.” *Journal of the Soil Mechanics and Foundations Division*, 96(4), 1159-1170.

Low, B. K. and Tang, W. H. 1997. “Efficient reliability evaluation using spreadsheet.” *Journal of Engineering Mechanics*, 123(7), 749-752.

Maitland, J. K. 1977. *Behavior of Cellular Bulkheads in Deep Sands*. Ph. D. Dissertation submitted at Oregon State University, Corvallis, Oregon.

Maitland, J. K. and Schroeder, W. L. 1979. “Model study of circular sheetpile cells.” *Journal of the Geotechnical Engineering Division*, 105(7), 805-821.

Mana, A. I. and Clough, G. W. 1981. "Prediction of movements for braced cuts in clay." *Journal of the Geotechnical Engineering Division*, 107(6), 759-777.

Mansur, C. and Kaufman, R. 1961. "Dewatering." *Foundation Engineering*, Ed. Leonards, McGraw Hill, 514 pp.

Marchetti, S. 2006. "Origin of the flat dilatometer." *Proc. 2nd International Conf. the Flat Dilatometer*, Washington, DC, 2-5).

Marinos, P. and Hoek, E. 2000. "GSI: A Geological Friendly Tool for Rock Mass Strength Estimation." *Proc. GeoEng 2000, Intl. Conf. Geot. Geol. Engr.*, Melbourne, 1422-1446.

Marsal, R. J. 1967. "Large scale testing of rockfill materials." *Journal of the Soil Mechanics and Foundations Division*, 93(2), 27-43.

Marschi, N. D., Chan, C. K., and Seed, H. B. 1972. "Evaluation of properties of rockfill materials." *Journal of the Soil Mechanics and Foundations Division*, 98(1), 95-114.

Martin, R. E. 2001. "Foundations in Weathering Profiles from Igneous and Metamorphic Rocks." *ASCE Geo-Institute Specialty Conference*, Virginia Tech, VA.

Martin, R.E. 1977. "Estimating Foundation Settlements in Residual Soils." *Journal of Geotechnical Engineering Division*, 103(GT3), 197-212.

Martin, R.E. 1987. "Settlement of Residual Soils.", *Proc. Foundations and Excavations in Decomposed Rock of the Piedmont Province*, ASCE, 1-14.

Masad, E., Taha, R., Ho, C., and Papagiannakis, T. 1996. "Engineering properties of tire/soil mixtures as a lightweight fill." *Geotechnical Testing Journal*, 19, 297-304.

Matlock, H. 1970. "Correlations for design of laterally loaded piles in soft clay." *Proc. Offshore Technology Conference*, Vol. 1, Houston, TX.

Matsuzawa, H., Ishibashi, I., and Kawamura, M. 1985. "Dynamic soil and water pressures of submerged soils." *Journal of Geotechnical Engineering*, 111(10), 1161-1176.

Mayne, P. W. 1985. "A review of undrained strength in direct simple shear." *Soils and Foundations*, 25(3), 64-72.

Mayne, P. W. and Kulhawy, F. H. 1982. "K_0 – OCR Relationships in Soil," *Journal of the Geotechnical Division*, 108(60, 851 – 872.

Mays, T. W. 2015. *Design Guide for Pile Caps*, Concrete Reinforcing Steel Institute, Schaumburg, Il.

Mazurkiewicz, B.K. 1980. *Design and Construction of Dry Docks*. Trans Tech Publications, Rockport, MA.

McCarthy, D. F. 2007. *Essentials of Soil Mechanics and Foundations: Basic Geotechnics*. Prentice Hall.

McCook, D. K. and Shanklin, D. W. 2000. "NRCS experience with field density test methods including the sand-cone, nuclear gage, rubber balloon, drive-cylinder, and clod test." *Constructing and Controlling Compaction of Earth Fills*, ASTM Special Technical Publication 1384, 72-92.

McGregor, J. and Duncan, J.M. 1998. *Performance and Use of the Standard Penetration Test in Geotechnical Engineering Practice, CGPR #12*. Center for Geotechnial Practice and Research, Virginia Tech, Blacksburg, VA.

McGuire, M. P. and VandenBerge, D. R. (2017). "Interpretation of shear strength uncertainty and reliability analyses of slopes." *Landslides*, 14(6), 2059-2072.

McVay, M.C., Kuo, C.L., and Guisinger, A.L., 2003. *Calibrating Resistance Factor in the Load and Resistance Factor Design of Statnamic Loading Test*. Project No. 4910450482312, Final Report, University of Florida, 129 pp.

Menard L. 1955. Travail personnel sur le pressiometre, Ecole nationale des ponts et chaussees, Paris.

Merifield, R. S., Sloan, S. W., and Yu, H. S. 1999. "Rigorous plasticity solutions for the bearing capacity of two-layered clays." *Geotechnique*, 49(4), 471-490.

Meyerhof, G. G. 1951. "The ultimate bearing capacity of foudations." *Geotechnique*, 2(4), 301-332.

Meyerhof, G. G. 1953. "Some recent foundation research and its application to design." *The Structural Engineer*, 31(6), 151-167.

Meyerhof, G. G. 1957. "The ultimate bearing capacity of foundations on slopes." *Proc. 4th Intl. Conf. Soil Mech. Found. Engr.*, Vol. 1, 384-386.

Meyerhof, G. G. 1963. "Some recent research on the bearing capacity of foundations." *Canadian Geotechnical Journal*, 1(1), 16-26.

Meyerhof, G. G. 1974. "Ultimate bearing capacity of footings on sand layer overlying clay." *Canadian Geotechnical Journal*, 11(2), 223-229.

Meyerhof, G. G. 1976. “Bearing capacity and settlement of pile foundations.” *Journal of the Geotechnical Engineering Division*, 102(GT3), 197- 228.

Meyerhof, G. G. and Hanna, A. M. 1978. “Ultimate bearing capacity of foundations on layered soils under inclined load.” *Canadian Geotechnical Journal*, 15(4), 565-572.

Middendorp, P., Bermingham, P. and Kuiper, B. 1992. “Statnamic load testing of foundation piles.” *Proc. 4th Intl. Conf. Appl. Stresswave Theory to Piles*, Balkema Publishers, A.A., The Hague, The Netherlands, 581-588.

Milovic, D. M. 1965. "Comparison between the calculated and experimental values of the ultimate bearing capacity." *Proc. 6th ICSMFE*, Montreal, 142-144.

Mitchell, J. K. and Soga, K. 2005. *Fundamentals of soil behavior*. John Wiley & Sons, New York, NY.

Mitchell, J. K., Hooper, D. R., and Campenella, R. G. (1965). “Permeability of compacted clay.” *Journal of the Soil Mechanics and Foundations Division*, 91(4), 41-65.

Mokwa, R. L. and Duncan, J. M. 2001a. “Experimental evaluation of lateral-load resistance of pile caps.” *Journal of Geotechnical and Geoenvironmental Engineering*, 127(2), 185-192.

Mokwa, R. L. and Duncan, J. M. 2001b, “Laterally Loaded Pile Groups and p-y Multipliers,” *Proc. Geo-Institute Conference 2001: A Geo-Odyssey, Geotechnical Special Publication Number 113*, ASCE.

Mononobe, N and Matsuo, H. (1929). “On the Determination of Earth Pressures during Earthquakes,” *Proc. World Engineering Congress*, 9 pp.

Muhs, D.R. 2013. “Loess and its Geomorphic, Stratigraphic, and Paleoclimatic Significance in the Quaternary.” *Treatise on Geomorphology, Vol 11, Aeolian Geomorphology.* Ed.: Shroder, J. F., Lancaster, N., Sherman, D.J., and Baas, A.C.W., San Diego: Academic Press, 149-183.

Mullins, G., Lewis, C., and Justason, M. 2002. “Advancements in Statnamic Data Regression Techniques.” *Proc. Deep Foundations 2002: An International Perspective on Theory, Design, Construction, and Performance*, *GSP No.116*, ASCE, Vol. 2, 915-930.

Narin, W. A. and Mitchell, J. K. 1994. “Soil improvement by blasting.” *Journal of Explosive Engineering*, 12(3), 34-41.

Natural Resource Conservation Service (NRCS). 2022. "Chapter 4 Engineering Classification of Rock Materials." *Part 631 Geology National Engineering Handbook*.

NCHRP (National Cooperative Highway Research Program). 2018. *Manual on Subsurface Investigations, Publication No. CRP Project 21-20*. Transportation Research Board, National Academies of Science Engineering, and Medicine, Washington, DC.

NCHRP. 1991. *Manuals for the Design of Bridge Foundations, Report 343*. Transportation Research Board, National Academies Press, Washington, DC.

NCHRP. 1997a. *Design and Construction Guidelines for Downdrag on uncoated and Bitumen-Coated Piles, Report 393*. Transportation Research Board, National Academies Press, Washington, DC.

NCHRP. 1997b. *Dynamic Effects of Pile Installations on Adjacent Structures, NCHRP Synthesis 253*, Transportation Research Board, Washington, DC.

NCHRP. 2006. *Innovative Load Testing Systems, NCHRP 21-08*. Transportation Research Program, Washington, D.C., 148 pp.

NCHRP. 2010. *Intelligent Soil Compaction Systems, Report 676*. Transportation Research Board, National Academies of Science Engineering, and Medicine, Washington, D.C.

NCHRP. 2015. *Current Practices for Design and Load Testing of Large Diameter Open-End Driven Pipe Piles, NCHRP Report 20-05, Topic 45-05*. Transportation Research Board, Washington, DC.

NeSmith, W. M. 2002. “Static capacity analysis of augered, pressure-injected displacement piles.” *Proc. Deep Foundations: An International Perspective on Theory, Design and Performance*, ASCE, Reston, VA.

Noorany, I. and Stanley, J. V. 1994. “Settlement of compacted fills caused by wetting.” *Proc. Vertical and Horizontal Deformations of Foundations and Embankments*, 1516-1530.

Noorany, I., Gardner, W. S., Corley, D. J., and Brown, J. L. 2000. “Variability in field density tests.” *Constructing and Controlling Compaction of Earth Fills*, ASTM Special Technical Publication 1384, 58-71.

Nordlund, R. L. 1963. “Bearing capacity of piles in cohesionless soils.” *Journal of the Soil Mechanics and Foundations Division*, 89(SM3), 1-35.

Nordlund, R. L. 1979. “Point bearing and shaft friction of piles in sand.” *Proc. 5th Annual Fundamentals of Deep Foundation Design*, St. Louis, MO.

Norris, G. M. 1986. “Theoretically based BEF laterally loaded pile analysis.” *Proc. 3rd Intl. Conf. Num. Methods in Offshore Piling*, Paris, France.

Norrish, N. I. and Wyllie, D. C. 1996. “Chapter 15, Rock Slope Stability Analysis.” *Special Report Number: 247. Landslides: Investigation and Mitigation*, TRB, 391-425.

Nowak, A. S. 1995. “Calibration of LRFD bridge code.” *Journal of Structural Engineering*, 121(8), 1245-1251.

O’Rourke, T. D. 1981. “Ground Movements Caused by Braced Excavations,” *Journal of the Geotechnical Engineering Division*, 107(GT9), 1159-1178.

Occupational Safety and Health Administration (OSHA). 2020. *CFR Part 1926, Subpart P, Excavations, with Appendices A - F*. https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926SubpartP.

Ohio Department of Transportation (ODOT). 2010. *Supplement 1015 Compaction Testing of Unbound Materials*. https://www.dot.state.oh.us/Divisions/ConstructionMgt/OnlineDocs/2013MOP/Supplements/S_1015.htm.

Okabe, S. 1926. “General theory on earth pressure and seismic stability of retaining wall.” *J. of Japan Soci. of Civil Engineers*, 10(6), 1277-1323.

Olson, R. E. 1963, "Effective Stress Theory of Soil Compaction", *Journal of the Soil Mechanics and Foundations Division*, 89(SM2), 27-45.

Olson, S. M. 2002. *Liquefaction Analysis of Level and Sloping Ground Using Field Case Histories and Penetration Resistance*. Ph.D. Thesis, University of Illinois at Urbana-Champaign, IL.

Oriard, L. L. 1987. “Resolution of Some Common Problems in Highway Blasting,” *Transportation Research Record, Issue Number 1119*, Washington, D.C., 119-125.

OSHA. 2020. "Section V: Chapter 2 Excavations: Hazard Recognition in Trenching and Shoring." *OSHA Technical Manual*. https://www.osha.gov/otm/section-5-construction-operations/chapter-2.

Ostadan, F. 2005. “Seismic Soil Pressure for Building Walls – an Updated Approach,” *Journal of Soil Dynamics and Earthquake Engineering*, 25, 785-793

Ovesen, N. K. 1962. *Cellular Cofferdams Calculation Method and Model Tests*, *Bulletin 14*, Danish Geotechnical Institute, Copenhagen.

Pandey, R. K. and Tiwari, R. P. 2015. "Physical Characterizations and Geotechnical Properties for Municipal Solid Waste," *IOSR Journal of Mechanical and Civil Engineering*, 12(1), 15-21.

Pastore, E. I. 1995. "Weathering Profiles." Proc. Conference on Soil Mechanics and Foundation Engineering, 363-364.

Pastore, E.L., 1995. "Weathering profiles." *Proc. Panamerican Conference on Soil Mechanics and Foundation Engineering*, ISSMFE, Vol. 1, 353-364.

Peck, R. B. 1969. "Deep excavations and tunneling in soft ground, State-of-the-art report," *7th International Conference on Soil Mechanics and Foundation Engineering*, Mexico City, Mexico, State-of-the-Art Volume, 225-290.

Perko, H. A. 2009. *Helical Piles: A Practical Guide to Design and Installation*. Wiley, Hoboken, NJ.

Perloff, W. H. and Baron, W. 1976. *Soil Mechanics Principles and Applications*, Ronald Press Co., New York.

Phoon, K. K. and Kulhawy, F. H. 1999a. "Characterization of geotechnical variability." *Canadian Geotechnical Journal*, 36(4), 612-624.

Phoon, K. K. and Kulhawy, F. H. 1999b. "Evaluation of geotechnical property variability." *Canadian Geotechnical Journal*, 36(4), 625-639.

Porter, O. 1943. "Foundations for flexible pavements." *Proc. of 22nd Annual Meeting of the Highway Research Board*, Highway Research Board, 100-143.

Portland Cement Association (PCA). 1952. "Concrete Crib Retaining Walls." *Concrete Information No. St. 46*, Chicago, IL.

PCA. 1992. *PCA Soil Primer*. Skokie, IL.

Post-Tensioning Institute (PTI). 1996. *Recommendations for Prestressed Rock and Soil Anchors*, 3rd ed., Phoenix, Arizona.

Poulos, H.G. 1989. "Pile behaviour – theory and application." *Geotechnique*, 39(3): 365-415.

Prandtl, L. 1920. "Über die Härte plastischer Körper." Nachr. Ges. Wiss. Goettingen, Math.-Phys. Kl., 74-85.

Proctor, R. R. (1933). "Fundamental Principles of Soil Compaction," *Engineering News-Record*, 111(9), 245-248.

Randolph, M. F. and Murphy, B. S. 1985. "Shaft capacity of driven piles in clay. *Proc. 17th Annual Offshore Technology Conference*, Houston, TX.

Rankine, W. J. M. 1857. "On the Stability of Loose Earth," *Transactions of Royal Society*, London, England, Vol. 147, Part 1, 9-27.

Rausche, F. and Goble, G.G. 1979. "Determination of pile damage by top measurements." *Behavior of Deep Foundations. American Society for Testing and Materials, ASTM STP 670*, R. Lundgren, Editor, 500-506.

Rausche, F. and Webster, S. 2007. "Behavior of cylinder piles during pile installation." *Proc. Geo-Denver: Contemporary Issues in Deep Foundations, Geotechnical Special Technical Publication 158*, ASCE, Reston, VA.

Reddy, K. R., Hettiarachchi, H., Gangathulasi, J., and Bogner, J. 2011, "Geotechnical Properties of Municipal Solid Waste at Different Phases of Biodegredation," *Waste Management,* 31, 2275–2286.

Reddy, K.R., Hettiarachchi, H., Gangathulasi, J., Bogner, J., and Lagier, T. 2009. "Geotechnical properties of synthetic municipal solid waste," *International Journal of Geotechnical Engineering*, 3(3), 429–438.

Reese, L. C. and Matlock, H. 1956. "Non-dimensional solutions for laterally loaded piles with soil modulus assumed proportional to depth." Proc. *8th Texas Conf. Soil Mech. Found. Engr*. Association of Drilled Shaft Contractors, Dallas, TX.

Reese, L. C. and O'Neil, M. W. 1989. "New design method for dilled shafts from common soil and rock tests." *Proc. Foundation Engineering: Current Principles and Practices, Geotech. Special Tech. Publ. 22*, ASCE, Reston, VA, 1026-1039.

Reese, L. C., Wang, S. T., Isenhower, W. M., Arrellaga, J. A., and Hendrix, J. 2004. *LPILE Plus Version 5 Technical Manual*. Ensoft, Austin, TX.

Richards, R. J. and D. Elms. 1979. "Seismic Behavior of Gravity Retaining Walls," *Journal of the Geotechnical Engineering Division*, 105(GT4), 449-464.

Richart, F. E., and Schmertmann, F. 1957. "The effects of seepage on the stability of sea walls." *Coastal Engineering Procedings*, 6, 48.

Robertson, P. K. 2009. "Interpretation of cone penetration tests—a unified approach." *Canadian Geotechnical Journal*, 46(11), 1337-1355.

Robinette, M. D. and Duncan, J. M. 2005. *Pile Group 2.0 – A Spreadsheet for Laterally Loaded Pile Groups*, *CGPR #33*. Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA.

Rollins, K. M. and Rogers, G. W. 1994. "Mitigation measures for small structures on collapsible alluvial soils." *Journal of Geotechnical Engineering*, 120(9), 1533-1553.

Rollins, K. M., Clayton, R. J., Mikesell, R. C., and Blaise, B. C. 2005. "Drilled shaft side friction in gravelly soils." *J. Geotech. Geoenviron. Eng.*, 13(8), 987-1003.

Romanoff, M. 1962. "Corrosion of steel pilings in soils." *Journal of Research of the National Bureau of Standards – C. Engineering and Instrumentation*, Vol.66C(3), 223-244.

Rosenblueth, E. 1975. "Point estimates for probability moments." *Proc. of the National Academy of Sciences*, 72(10), 3812-3814.

Rosenblueth, E. and Esteva, L. 1972. "Reliability analysis for some Mexican codes." *American Concrete Institute*, Detroit.

Rosenqvist, I. T. 1953. "Considerations on the Sensitivity of Norwegian Quick-Clays," *Geotechnique*, 3, 195-200.

Rowe, P. W., Stroyer, Browzin, and Tschebotarioff. 1952. "Anchored Sheet Pile Walls," *Proc. Institution of Civil Engineers*, 1(1), 27-70.

Rowe, R. K. and H. H. Armitage. 1987a. "Theoretical solutions for axial deformation of drilled shafts in rock." *Canadian Geotechnical Journal*, 24, 114-125.

Rowe, R. K. and H. H. Armitage. 1987b. "A design method for drilled piers in soft rock." *Canadian Geotechnical Journal*, 24, 126-142.

Salgado, R. 2006. "The role of analysis in pile design." *Modern Trends in Geomechanics, Springer Proc. Physics*, Vol. 106, 521-540.

Salgado, R. 2008. *The Engineering of Foundations*. McGraw Hill, New York, NY.

Satyanarayana, B. and Garg, R. K. 1980. "Bearing capacity of footings on layered c-ϕ soils." *Journal of the Geotechnical Engineering Division*, 106(7), 819-824.

Schmertmann, J. H. 1970. "Static Cone to Compute Static Settlement Over Sand," *Journal of the Soil Mechanics and Foundations Division*, 96(SM3), 1011-1043.

Schmertmann, J. H. 1989. “Density tests above zero air voids line.” *Journal of GeotechnicalEngineering*, 115(7), 1003-1018.

Schmertmann, J. H., Hartman, J. P., and Brown, P. R. 1978. “Improved strain influence factor diagrams,” *Journal of Geotechnical Engineering Division*, 104(GT8), 1131-1135.

Schroeder, W. L. and Maitland, J. K. 1979. "Cellular bulkheads and cofferdams." *Journal of Geotechnical Engineering Division*, 105(7), 823-837.

Schroeder, W. L., Marker, D. K., and Khuayjarernpanishk, T. 1977. "Performance of a cellular wharf." *Journal of Geotechnical Engineering Division*, 103(GT3), 153-168.

Seed, H. B. and R. V. Whitman. 1970. “Design of Earth Retaining Structures for Dynamic Loads.” *Proc. ASCE/SEI Specialty Conference on Lateral Stresses in the Ground and Design of Earth-Retaining Structures*, 103-147.

Seed, H. B., Mitchell, J. K., and Chan, C. K. 1960. “The strength of compacted cohesive soils.” *Research conference on the strength of cohesive materials*, ASCE, Boulder, CO, 877-964.

Seelye, E. E. 1956. *Foundations: Design and Practice*, John Wiley & Sons, Inc., New York.

Sehn, A. E. 1990. *Experimental Study of Earth Pressures on Retaining Structures.* Dissertation submitted in partial fulfillment for the degree of Doctor of Philosophy, Department of Civil Engineering, Virginia Tech, 347 pp.

Sellmeijer, J. B., Cools, J. P. A. E., Decker, J. and Post, W. J. 1995. “Hydraulic Resistance of Steel Sheet Pile Joints.” *Journal of Geotechnical Engineering*. 121(2), 105-110.

Sherard, J. L. 1953. *Influence of Soil Properties and Construction Methods on the Performance of Homogenous Earth Dams*, *TM-645*, United States Bureau of Reclamation.

Sherard, J. L. 1986. “Hydraulic fracturing in embankment dams.” *Journal of Geotechnical Engineering*, 112(10), 905-927.

Siegel, T.C., Lamb, R., Dasenbrock, D., and Axtell, P.J. 2013. “Alternative design approach for drag load and downdrag with the LRFD framework.” *Proc. 38th Annual Conference on Deep Foundations*, Phoenix, AZ, 23-39.

Siegel, T.C., Lamb, R., Dasenbrock, D., Axtell, P. J. 2014. “Neutral plane method for drag force of deep foundations and the AASHTO LRFD Bridge Design Specifications.” *Proc. Univ. of Minnesota Annual Geotechnical Conference*.

Skempton, A. W. 1942. “An investigation of the bearing capacity of a soft clay soil.” *J. Inst. Civil Eng.*,18, 307.

Skempton, A. W. 1964. “Long-term Stability of Clay Slopes.” *Géotechnique*, 14(2), 77–102.

Skempton, A. W. 1970. “First-time Slides in Overconsolidated Clays,” *Géotechnique*, 20(3), 320-324.

Skempton, A. W. 1977. “Slope Stability of Cuttings in Brown London Clay.” *9th Intl. Conf. Soil Mech. Geotech. Engr*. Tokyo, Japan, 261-270.

Skempton, A. W. and Golder, H. Q. 1948. “Practical examples of the $\phi = 0$ analysis of stability of clays.” *Proc. 2nd Intl. Conf. Soil Mech. Found. Engr.*, Vol. 2, 63-70.

Sleep, M., Duncan, J. M., Hickerson, H., and Ritter, K. 2009. *Geotechnical Considerations for Organic Soils and Peat, CGPR #58*, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA, 25 pp.

Sleep, M.D. and Duncan, J.M. 2014. *Manual for Geotechnical Engineering Reliability Calculations (2nd edition), CGPR #76*. Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA.

Smith, E. A. L. 1960. “Pile driving analysis by the wave equation.” *Journal of the Soil Mechanics and Foundations Division*, 86(4), 35-61.

Soleimanbeigi, A. and Edil, T. B. 2015. “Compressibility of recycled materials for use as highway embankment fill.” *Journal of Geotechnical and Geoenvironmental Engineering*, 141(5), 04015011.

Soleimanbeigi, A., Edil, T. B., and Benson, C. H. 2014. “Engineering properties of recycled materials for use as embankment fill.” *Geo-Congress 2014: Geo-characterization and Modeling for Sustainability*, 3645-3657.

Sotelo, M. J., Mazari, M., Garibay, J., and Nazarian, S. 2014. “Variability of moisture content measurement devices on subgrade soils.” *Geo-Congress 2014: Geo-characterization and Modeling for Sustainability*, 1425-1432.

Sowers, G. F. 1977. Closure to “Failures in Limestones in Humid Subtropics.” *Journal of the Geotechnical Engineering Division*, 103(GT7), 807-813.

Sowers, G. F. 1979. *Introductory Soil Mechanics and Foundations: Geotechnical Engineering*. Macmillan & Co, New York, New York.

Sowers, G.F. 1963. “Engineering Properties of Residual Soil Derived from Igneous and Metamorphic Rocks.” *Proc. Second Pan American Conference on Soil Mechanics and Foundation Engineering*, Brazil, Vol. 1, 39-61.

Stagg, K. G. and Zienkiewicz, O. C. 1968. *Rock Mechanics in Engineering Practice*. John Wiley & Sons, New York, 442 pp.

Szypcio, Z. and Dołżyk, K. 2006. “The bearing capacity of layered subsoil.” *Studia Geotechnica et Mechanica*, 28(1), 45-60.

Terzaghi, K. 1943. *Theoretical Soil Mechanics*. John Wiley and Sons, Inc., New York, NY.

Terzaghi, K. 1944. “Ends and Means in Soil Mechanics." *Engineering Journal of Canada*, Vol. 27, 608.

Terzaghi, K. 1945. "Stability and Stiffness of Cellular Cofferdams," *American Society of Civil Engineers, Transactions*, Vol 110, Paper No. 2253, 1083-1202.

Terzaghi, K. 1954. “Anchored Bulkheads,” *American Society of Civil Engineers, Transactions*, Vol. 119, Paper No. 2720, 1243-1280.

Terzaghi, K. and Peck, R. B. 1967. *Soil Mechanics in Engineering Practice*, 2nd Ed. Wiley and Sons, Inc., New York, NY.

Terzaghi, K., Peck, R. B., and Mesri, G. 1996, *Soil Mechanics in Engineering Practice*, 3rd Ed. John Wiley & Sons, Inc., New York.

Timchenko, A., Shidlovskaya, A. and Briaud, J.-L. 2021. “Tolerable risk chart.” *Proc. of 20th Intl. Conf. Soil Mech. Geotech. Engr*.

Tinjum, J. M., Benson, C. H., and Blotz, L. R. 1997. “Soil-water characteristic curves for compacted clays.” *Journal of Geotechnical and Geoenvironmental Engineering*, 123(11), 1060-1069.

Tomlinson, M. J. 1994. *Pile Design and Construction Practice*, 4th Ed. E & FN Spon, London, England.

Transportation Research Board (TRB). 1990. *Guide to Earthwork Construction, State of the Art Report 8*, National Research Council, Washington, D.C.

Troxler Labs. 2019. *Troxler Model 3430 and 3440 Moisture Density Gauges*. Research Triangle Park, NC.

Tschebotarioff, G.P. 1973. *Foundations, Retaining and Earth Structures*, 2nd Ed., McGraw-Hill, New York.

Tsiambaos, G. and Saroglou, H. (2010). "Excavatability Assessment of Rock Masses Using the Geological Strength Index (GSI)." *Bulletin of Engineering Geology and the Environment*, 69(1), 13-27.

Turnbull, W. J. and Foster, C. R. 1956. "Stabilization of materials by compaction." *Journal of the Soil Mechanics and Foundations Division*, 82(2), 1-23.

Unified Facilities Criteria (UFC). 2004. *Dewatering and Ground Control, UFS 3-220-05*. US Department of Defense, Washington, DC.

UFC. 2012. *General Criteria for Waterfront Construction, UFC 4-151-10*, US Department of Defense, Washington, DC.

UFC. 2021. *Geotechnical Engineering With Change 1, UFC 3-220-01*, US Department of Defense, Washington, DC.

UFC. 2022. *Soil mechanics (DM 7.1), UFC 3-220-10*, US Department of Defense, Washington, DC.

United States Army Corps of Engineers (USACE). 1960. "Appendix B, The Unified Soil Classification System." *Characteristics of Soil Groups Pertaining to Roads and Airfields. Technical Memorandum 3-357*. Waterways Experiment Station, Vicksburg, MS.

USACE. 1980. *Civil Works Construction Specifications for Wire Mesh Gabions, Slope and Channel Protection, CE 02541*, Department of the Army, Washington, DC, 17 pp.

USACE. 1983a. *Dewatering and Groundwater Control, TM 5/818-5/AFM 88-5.* Department of the Army, Washington, DC.

USACE. 1983b. *Procedures for Foundation Design of Buildings and Other Structures (Except Hydraulic Structures), TM 5/818-1/AFM 88-3*. Department of the Army, Washington, DC.

USACE. 1989. *Design of Sheet Pile Cellular Structures, Cofferdams, and Retaining Structures, EM 1110-2-2503*, Department of the Army, CECW-EP, 186 pp.

USACE. 1991. *Design of Pile Foundations. Engineer Manual: EM 1110-2-2906*, Department of the Army, Washington, DC.

USACE. 1994a. *Design of Sheet Pile Walls, EM 1110-2-2504*. Department of the Army, CECW-EP, 75 pp.

USACE. 1994b. *Test Quarries and Test Fills, EM 1110-2-2301*. Department of the Army, Washington, D.C.

USACE. 1995a. *Construction Control for Earth and Rock-Fill Dams, EM 1110-2-1911*. Department of the Army, Washington, D.C.

USACE. 1995b. *Design of Coastal Revetments, Seawalls, and Bulkheads, EM 1110-2-1614.* Department of the Army, CECW-EH-D, 110 pp.

USACE. 2001. *Geotechnical Investigations, EM 1110-1-1804.* Department of the Army, Washington, D.C.

USACE. 2004. *General Design and Construction Considerations for Earth and Rock-Fill Dams, EM 1110-2-2300*. Department of the Army, Washington, D.C.

USACE. 2012. *LPILE Method for Evaluating Bending Moments in Batter Piles Due to Ground Settlement for Pile-Supported Floodwalls in New Orleans and Vicinity. Report W912P8-07-D-0062*, US Army Corps of Engineers, Washington, DC.

USACE. 2014. *Safety of Dams – Policy and Procedures, EM 1110-2-1156*, Department of the Army, Washington, D.C.

USACE. 2020. *Geotechnical System Response Curves for Risk Assessments, ETL 1110-2-588*, Department of the Army, Washington, D.C.

United States Department of Agriculture (USDA). 2010. *Wood Handbook: Wood as an Engineering Material*, *General Technical Report: FPL-GTR-190*, Forest Products Laboratory, Madison, WS.

United States Steel (USS). 1984. *Steel Sheet Piling Design Manual*. Updated and reprinted by the US Dept. of Transportation/FHWA, 135 pp.

United States Bureau of Mines (USBM). 1971. *Blasting Vibrations and Their Effect on Structures*. United States Department of the Interior.

United States Bureau of Reclamation (USBR). 1960. *Petrographic and Engineering Properties of Loess, Engineering Monograph No. 28.*

USBR. 1987. *Design of Small Dams*. 3rd Edition, United States Department of the Interior.

USBR. 1988. *Bureau Case History of Loess Cut Slopes in Nebraska, GR-88-3*. United States Department of the Interior.

USBR. 1992. *Characteristics and Problems of Collapsible Soils.* United States Department of the Interior.

USBR. 1998. *Earth Manual, Part 1*. 3rd Ed., Earth Sciences and Research Laboratory, Technical Service Center, Denver, CO., 348 pp.

USBR. 2012. "Chapter 10: Embankment Construction." *Design Standards No. 13 Embankment Dams*, Technical Service Center.

USBR and USACE. 2019. *Best Practices in Dam and Levee Safety Risk Analysis*. Risk Management Center, Denver, CO.

VandenBerge, D. R., Castellanos, B. A., and McGuire, M. P. 2018. "Comparison and Use of Failure Envelopes for Slope Stability," *Geotechnical and Geological Engineering*, https://doi.org/ 10.1007/s10706-018-0742-1.

VandenBerge, D. R., Duncan, J. M., and Brandon, T. L. 2015. *Consolidated-Undrained Strength of Compacted Clay, CGPR #83*, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA, 128 pp.

VandenBerge, D. R., Duncan, J. M., and Brandon, T. L. 2017. "Practical considerations for measuring the shear strength of compacted clay," *Proc. GeoFrontiers 2017*.

VandenBerge, D. R., Esser, A. J., and Bumpas, K. 2015. "An overview of sustainability applied to earth structures," *Proc. IFCEE 2015*, 2707-2716

VandenBerge, D. R., McGuire, M. P., and Castellanos, B. A. 2018. *Linear and Nonlinear Effective Stress Shear Strength Envelopes from Triaxial Test Data*, Center for Geotechnical Practice and Research, Virginia Tech, Blacksburg, VA, 57 pp.

VandenBerge, D. R., McGuire, M. P., and Castellanos, B. A. 2020. "Effective Stress Failure Envelope Forms and Parameter Variability." *Geo-Congress 2020: Modeling, Geomaterials, and Site Characterization*, ASCE, Reston, VA, 236-246.

VandenBerge, D. R.; Brandon, T. L.; and Wielputz, M. P. 2017. "Highly organic fill for levee stability berms," *Geotechnical Testing Journal*, ASTM, 38(3), 1-13.

Vanmarcke, E. H. 1977. “Probabilistic modeling of soil profiles.” *Journal of the Geotechnical Engineering Division*, 103(11), 1227-1246.

Vaughan, P. R. 1985. “Mechanical and Hydraulic Properties of In-Situ Residual Soils.” *General Report, Session 2, First International Conference on Geomechanics in Tropical, Lateritic and Saprolitic Soil*, Brasilia, 231–263.

Vesić, A. S. 1973. “Analysis of ultimate loads of shallow foundations.” *Journal of the Soil Mechanics and Foundations Division*, 99(1), 45-73.

Vesic, A. S. 1975. “Bearing capacity of shallow foundations.” *Foundation Engineering Handbook.* Ed. Winterkorn and Fang), Van Nostrand Reinhold, New York, NY, 121-147.

Vesic, A. S. 1977. *Design of Pile Foundation, Synthesis of Highway Practice No. 42*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC.

Vilar, O. and Carvalho, M. 2004. “Mechanical properties of municipal solid waste.” *ASTM Journal of Testing and Evaluation*, 32(6), 1–12.

Wan, C. F. and Fell, R. 2004. “Investigation of rate of erosion of soils in embankment dams.” *Journal of Geotechnical and Geoenvironmental Engineering*, 130(4), 373-380.

Weaver T.J. and Rollins, K.M. 2010. “Reduction factor for the unloading point method at clay sites.” *Journal of Geotechnical and Geoenvironmental Engineering*, 136(4), 643-646.

Wesley, L.D. 2009. “Behavior and Geotechnical Properties of Residual Soils and Allophane Clays,” *Works and Projects*, 6, 5-10.

Wesley, L.D. 2010. *Geotechnical Engineering in Residual Soils*. John Wiley, New York, NY.

Whitman, R. V. 1970. “Hydraulic fills to support structural loads.” *Journal of the Soil Mechanics and Foundations Division*, ASCE, 96(1), 23-47.

Whitman, R. V. 1991. “Seismic design of earth retaining structures.” *Proc. Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, St. Louis, Missouri.

Wiles, T. T. 1988. *A Shale Durability Rating System Based on Shear strength.* Masters thesis, Univ. of Missouri-Rolla, Rolla, MO.

Wiss, J. F. 1981. “Construction vibrations: state-of-the-art.” *Journal of the Geotechnical Engineering Division*, 107(2), 167-181, ASCE, Reston, VA.

Wolff, T. F, Hassan, A., Khan, R., Ur-Rasul, I. and Miller, M. 2004. *Geotechnical Reliability of Dam and Levee Embankments, ERDC/GSL CR-04-1*, USACE, Washington D.C.

Wolosick, J. R. and Scott, R. F. 2012. “Design and applications for anchored earth retention systems.” Proc. ADSC IFCEE Geo-Construction Conference, San Antonion, TX, 55-75.

Wong, K. S. and Goh, A. T. C. 2002. “Basal heave stability for wide excavations.” *Geotechnical Aspects of Underground Construction in Soft Ground*. Kastner, Emeriault, Dias, and Guilloux, Eds., Specifique, Lyon.

Wood, J. H. 1973. *Earthquake-Induced Soil Pressures on Structures, Report EERL 73-05*. California Institute of Technology, Pasadena, CA.

Wyllie, D. C. 1999. *Foundations on Rock*, 2nd Ed., E & FN Spon, London, UK.

Wyllie, D. C. 2017. *Rock Slope Engineering: Civil Applications*, 5th Edition, CRC Press; New York, NY.

Wyllie, D. and Norrish, N. 1996. “Chapter 18 – Stabilization of rock slopes.” *Landslides: Investigation and Mitigation, Transportation Research Board Special Report Number 247*. National Research Council, Washington, D.C.

Xanthakos, P. P., Abramson, L. W., and Bruce, D. A. 1994. *Ground Control and Improvement*, Wiley.

Zelada, G. A. and Stephenson, R. W. 2000. “Design methods for auger CIP piles in compression.” *Proc. New Technological and Design Developments in Deep, Foundations, Geotechnical Special Publication 100*, 418-432, ASCE, Reston, VA.

Zhu, M. 2004. “Bearing capacity of strip footings on two-layer clay soil by finite element method.” *Proc. of ABAQUS Users' Conference*, Vol. 787.

Zola, S. P. and Boothe, P. M. 1960. “Design and construction of Navy's largest drydock.” *Journal of the Waterways and Harbors Division*, 86(1), 53-84.

This Page Intentionally Left Blank

APPENDIX B. VERIFICATION EXAMPLES

This appendix contains seven extended examples of the types of analyses presented in this manual, particularly from Chapters 4 to 7. The purpose of these examples is twofold. First, the examples provide the opportunity to present longer and more complete design calculations than is possible in the body of the manual. The second purpose is related to geotechnical software. Many designs are completed using software; however, the results can be difficult to verify. It is hoped that these examples will allow a user to verify their use of geotechnical software for relatively simple conditions prior to the application of such software to more complex design scenarios.

B-1 EXAMPLE 1 – CANTILEVER CUT WALL.

B-1.1 Description of the Problem.

A land development project requires a 15 ft vertical grade change in medium dense sandy soil. A reinforced concrete cantilever retaining wall has been selected to accomplish the grade change. A road will pass along the top of the wall that imposes a live load of 250 psf. The finished grade behind the wall will be approximately level and a drainage system will be incorporated behind the wall to avoid the development of water pressures acting on the wall. For frost considerations, the retaining wall must bear 3 ft below the final grade at the base of the wall.

B-1.2 Goals and Limitations of the Analysis.

The goal of this analysis is to size the geometry of the cantilever retaining wall for geotechnical stability considerations. Structural design of the wall and global stability analysis is outside the scope of this example. The geotechnical design of the wall will be approached using allowable stress design (ASD); however, the design checks can readily be applied within a Load and Resistance Factor Design (LRFD) framework. The analysis is approached using the following assumptions and performance requirements:

- The wall must have adequate resistance to overturning as evaluated by the eccentricity of the resultant force acting on the base of the wall. Since the wall is bearing on soil, the resultant force must be located within the middle third of the base of the wall.
- The wall must have a factor of safety against sliding on the foundation soil, F_{SL}, of at least 1.5.
- The wall must have a factor of safety against bearing capacity failure, F_{BC}, of at least 3.0.
- For structural considerations, the thickness of the top of the wall stem (t_2) is assumed to be equal to 1 ft, the thickness of the bottom of the wall stem (t_1) is assumed to be equal to 1.5 ft, and the thickness of the base of the wall (d) is

assumed to be equal to 2 ft. In this example, these thicknesses are considered to be appropriate for the type of concrete, grade of steel, steel area ratio, height of wall, and imposed forces.

- Passive resistance in front of the wall will be conservatively ignored in the stability calculations.
- For overturning and sliding checks, it is assumed that the traffic pressure does not act over the wall heel. For the check of bearing capacity, the traffic pressure is included. These assumptions increase the conservatism in the analyses.
- The lateral force imposed on the wall by the traffic pressure (P_{h1}) can be represented by an equivalent result force acting at half of the wall height, $0.5H$, as measured above the base of the wall.
- The horizontal component of the earth force (P_{h2}) is greater than zero. The vertical component of the earth force (P_v) is assumed toequal to zero. This is justified for translational wall movement by an assumption that an active wedge over the wall heel and the active wedge behind the wall heel move vertically together and therefore do not transfer shear force (Figure).
- The lateral earth force can be represented by an equivalent result force acting at one third of the wall height, $H/3$, as measured above the base of the wall.

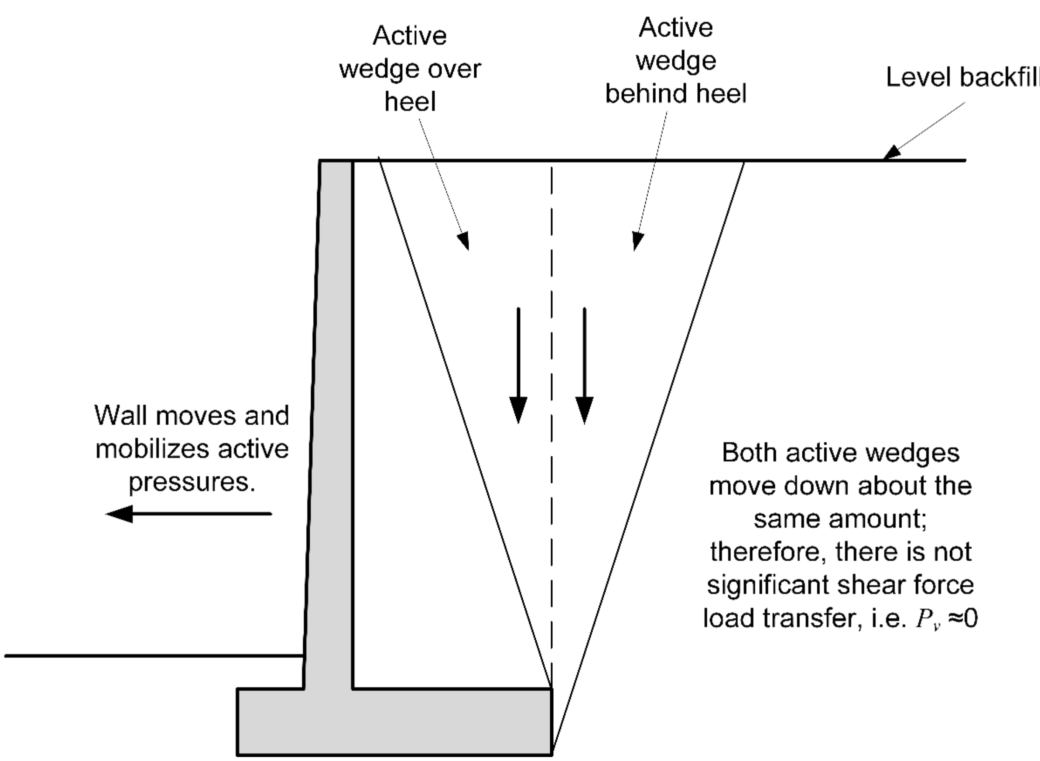


Figure B-1 Rationale for Assumption of No Vertical Earth Force

Based on these assumptions, the proposed cantilever retaining wall the geometry shown in Figure B-2. The unknown dimensions include: the width of the wall footing (B), the width of the heel (b_h), and the width of the toe (b_t). These dimensions will be determined by performing stability checks for overturning, sliding, and bearing capacity. These dimensions are related by:

$$B = b_t + t_1 + b_h \, .$$

If the width of the toe is assumed to be equal to 2 ft, the width of the footing becomes the only unknown since t_1 has been set equal to 1.5 ft for structural design reasons. The design process can be repeated using other assumptions regarding the wall geometry to determine which design makes the most efficient use of concrete.

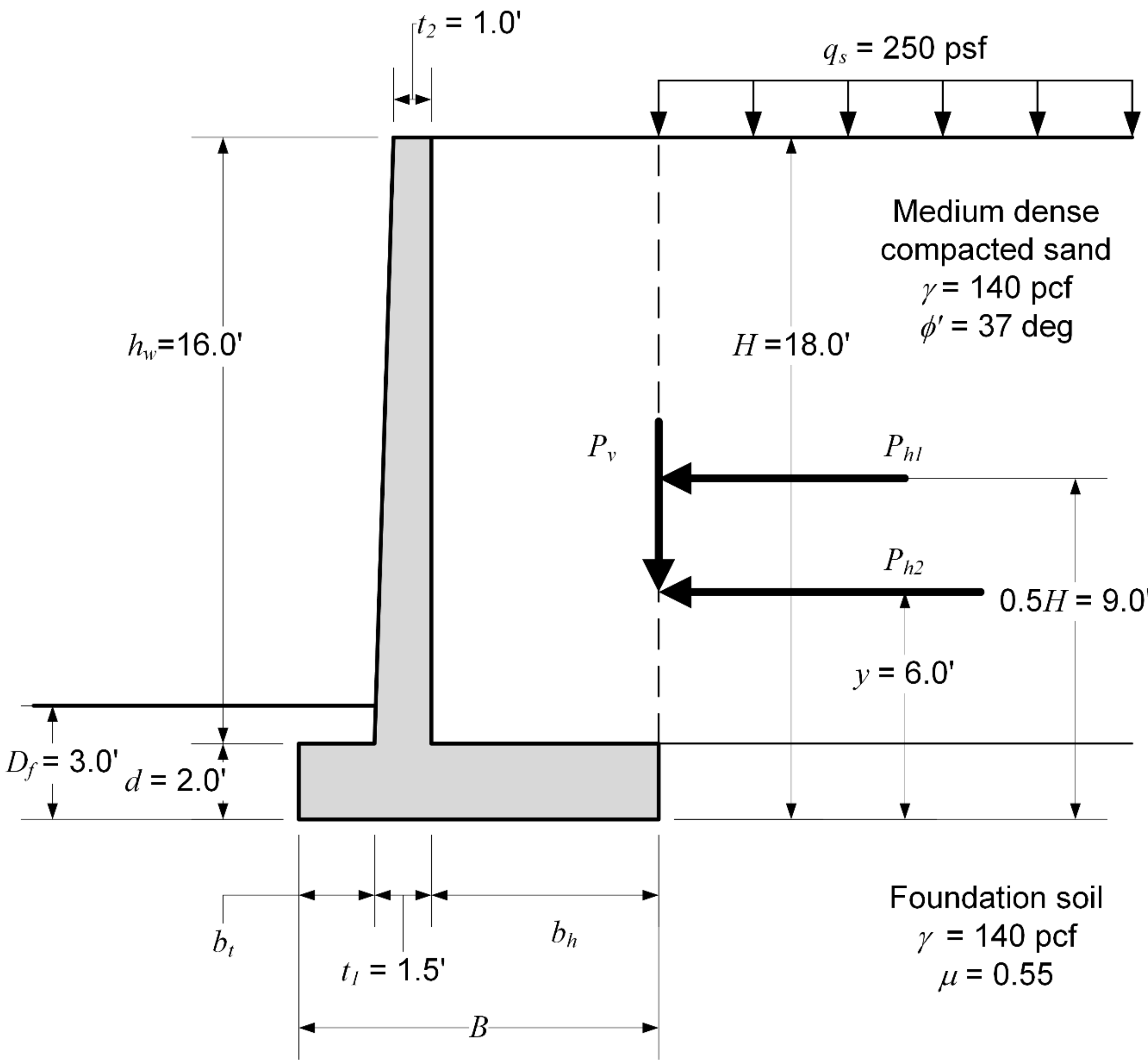


Figure B-2 Geometry of the Proposed Cantilever Retaining Wall

B-1.3 Evaluation of Forces and Moments.

The values of the lateral forces P_{h1} and P_{h2} depicted in Figure B-2 are determined assuming that the wall moves enough by sliding and/or rotation to mobilize the active condition. For the backfill having the properties given in Figure B-2, application of Rankine earth pressure theory produces a value for the active earth pressure coefficient equal to 0.25. It has already been assumed above that the vertical earth force, P_v, equals zero.

The backfill and a traffic pressure equal to 250 psf produce the following lateral forces per linear foot of wall:

$$P_{h1} = q_s K_A H = (250\,psf)(0.25)(18\,ft) = 1{,}125\,lb/ft$$

$$P_{h2} = 0.5 K_A \gamma H^2 = 0.5(0.25)(140\,pcf)(18\,ft)^2 = 5{,}670\,lb/ft$$

Assuming the unit weight of concrete is 150 pcf, the weight of the wall footing (W_f) per linear foot equals:

$$W_f = d \cdot \gamma_c \cdot B = (2\,ft)(150\,pcf)B = (300B)\,lb/ft$$

and the weight of the stem equals the sum of the weights of the uniform (W_{s1}) and tapered (W_{s2}) portions of the stem:

$$W_{s1} = t_2 \cdot h_w \cdot \gamma_c = (1\,ft)(16\,ft)(150\,pcf) = 2400\,lb/ft$$

$$W_{s2} = \frac{(t_1 - t_2)h_w}{2}\gamma_c = \frac{(1.5\,ft - 1\,ft)(16\,ft)}{2}(150\,pcf) = 600\,lb/ft\,.$$

The weight of the soil over the heel equals:

$$W_{bf} = h_w \cdot b_h \cdot \gamma = (16\,ft)(B - 3.5\,ft)(140\,pcf) = 2,240 \cdot (B - 3.5\,ft) = 2,240B - 4560\,(lb/ft)\,.$$

The weight of the soil over the toe equals:

$$W_{ff} = (D_f - d) \cdot b_t \cdot \gamma = (3\,ft - 2\,ft)(2\,ft)(140\,pcf) = 280\,lb/ft\,.$$

Vertical equilibrium requires that the vertical component of the reaction on the base of the wall (R) equals:

$$R = W_f + W_{s1} + W_{s2} + W_{bf} + W_{ff} + E_v = 2,540 \cdot B - 4560\ (lb/ft).$$

Table B-1 summarizes these forces, their moment arms with respect to rotation about the toe of the wall, and moments. The moment arm of the reaction force (x_0) is defined in Figure B-3.

The primary task at this point in the design is the selection of B to meet the overturning, sliding, and bearing capacity criteria. Two approaches can be taken. The width can be selected by trial and error, realizing that B is typically 50 to 70% of H. It is also possible to derive equations that can be solved for B based on the design criteria. Both will be illustrated in this example.

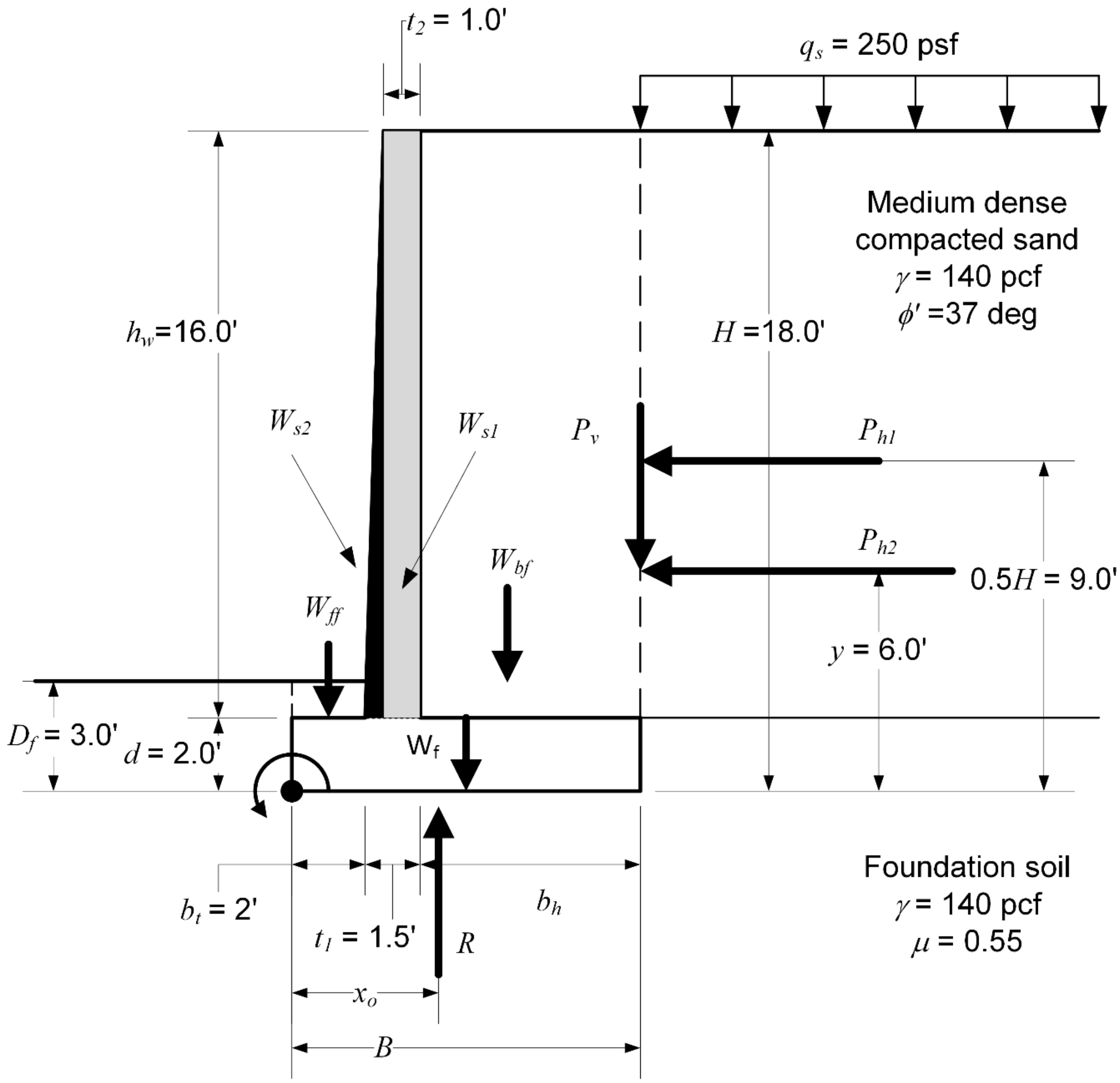


Figure B-3 Forces for Wall Stability Analysis

B-1.4 Overturning.

Using the forces and moments provided in Table B-1, the moment about the toe equals

$$\sum M_{toe} = 48985 - 1270 \cdot B^2 + 2540 \cdot B \cdot x_0 - 4560 \cdot x_0$$

The wall is acceptable with respect to overturning when R is located within the middle third of the base of the wall. The minimum value of x_0 from the toe that satisfies this requirement is equal to $B/3$. Substituting $B/3$ for x_0 enables the minimum width that satisfies the overturning requirement to be found by satisfying moment equilibrium:

$$\sum 0 = 48985 - 1520 \cdot B - 423.33 \cdot B^2$$

Solving this quadratic equation for B yields a minimum width equal to 9.11 ft.

Table B-1 Forces and Moments for Wall Stability Analysis

Force ID	Force (lb/ft)	Moment Arm Relative to the Wall Toe (ft)	Moment (ft-lb)
P_{h1}	1125	9	10125
P_{h2}	5670	6	34020
W_f	$300(B)$	$-B/2$	$-150 \cdot B^2$
W_{s1}	2,400	$-(b_t+(t_1-t_2)+0.5t_2) = -3$	-7200
W_{s2}	600	$-(b_t+2(t_1-t_2)/3) = -2.33$	-1400
W_{bf}	$2240(B-3.5)$	$-(B+b_t+t_1)/2 = -(B+3.5)/2$	$-1120 \cdot (B^2-12.25)$
W_{ff}	280	$-b_t/2 = -1$	-280
R	$2540(B)-4{,}560$	x_0	$x_0 \cdot (2{,}540 \cdot B-4560)$

B-1.5 Sliding

The sliding check is performed by comparing the mobilized horizontal shear load on the base of the wall (P_H) to the available shear resistance (T) as shown in Figure 4-27. In this case, the mobilized shear load equals:

$$P_H = P_{h1} + P_{h2} = 6795\, lb/ft$$

and the available resisting shear force equals:

$$T = R \cdot \tan\delta = \left(2540 \cdot B - 4560\right)\left(0.55\right) = 1397 \cdot B - 2508 \;\left(lb/ft\right).$$

The factor of safety against sliding equals:

$$F_{SL} = \frac{T}{P_H} = \frac{1397 \cdot B - 2508}{6795} = 0.2056 \cdot B - 0.3691.$$

If F_{SL} is set equal to 1.5, this equation can be solved for B equal to 9.09.

B-1.6 Bearing capacity

Unlike the checks of overturning and sliding, it is conservative to include the surcharge over the heel of the wall, if this is possible to occur, in the bearing capacity check. The inclusion of the surcharge over the heel changes the forces W_{bf} and R.

The weight of the soil and the surcharge over the heel equals

$$W_{bf+q} = b_h \cdot \left(h_w \cdot \gamma + q_s\right) = \left(B - 3.5ft\right)\left[\left(16ft\right)\left(140pcf\right) + 250psf\right] = 2490\left(B - 3.5ft\right)\ \left(lb/ft\right)$$

The moment arm associated with W_{bf+q} is the same as W_{bf} and is equal to $-(B+3.5)/2$. The moment produced by W_{bf+q} is equal to $-1245(B^2-12.25)$.

The reaction on the base of the wall with the addition of the surcharge over the heel equals:

$$R = W_f + W_{s1} + W_{s2} + W_{bf+q} + W_{ff} + E_v = 2,790 \cdot B - 5435\ \left(lb/ft\right)$$

The moment produced by R is equal to $x_0 \cdot (2790 \cdot B - 5435)$.

Using the forces and moments provided in Table B-1, substituting W_{bf+q} and R that include the surcharge over the toe, the moment about the toe equals

$$\sum M_{toe} = 50,516 - 1395 \cdot B^2 + 2790 \cdot B \cdot x_0 - 5435 \cdot x_0$$

Moment equilibrium requires that

$$x_0 = \frac{1395 \cdot B^2 - 50,516}{2790 \cdot B - 5435}$$

where the value of x_0 will be found using bearing capacity theory.

The Meyerhof method was selected for the analysis of bearing capacity. The backfill loads cause the pressure on the base of the foundation to be eccentric and inclined. The uniform applied bearing pressure using the equivalent footing approach is:

$$q_{gross} = \frac{R}{2x_0} = \frac{2790 \cdot B - 5435}{2x_0}.$$

The load inclination can be found based on the normal and shear forces on the base,

$$\theta = \tan^{-1}\left(\frac{P_H}{R}\right) = \tan^{-1}\left(\frac{6795}{2790 \cdot B - 5435}\right)$$

For soil with a friction angle of 37 degrees, the Meyerhof bearing capacity factors are N_q = 42.92 and N_γ = 53.27. The inclination factors are found according to:

$$i_q = \left(1-\theta/90\right)^2 \text{ and } i_\gamma = \left(1-\theta/\phi'\right)^2$$

The bearing capacity for the foundation with the inclined load is found as:

$$q_{ult} = D_f \cdot \gamma \cdot N_q \cdot i_q + 0.5\left(2x_0\right)\cdot \gamma \cdot N_\gamma \cdot i_\gamma = \left(3ft\right)\left(140pcf\right)\left(42.92\right)i_q + x_0\left(140pcf\right)\left(53.27\right)i_\gamma .$$

Substituting known parameter values and dividing q_{ult} by F_{BC} of 3.0 gives the allowable bearing pressure:

$$q_{allow} = 6009 \cdot \left(1-\theta/90\right)^2 + 2486 \cdot x_0 \cdot \left(1-\theta/\phi'\right)^2$$

Setting q_{gross} equal to q_{allow} and solving for B results in:

$$B = 1.782x_0^2 \cdot \left(1-\theta/\phi'\right)^2 + 4.308x_0 \cdot \left(1-\theta/90\right)^2 + 1.948$$

Trial widths (B_{trial}) can be selected and used to calculate x_0 and θ. These can then be used to calculate B. An iterative process or spreadsheet can be used to the solution where B = B_{trial}. This solution technique results in B equal to 7.68 ft as shown in Table B-2 and in Figure B-4.

Table B-2 Implicit Solution for Footing Width with Desired F_{BC}

Assumed B_{trial} (ft)	Calculated based on B_{trial}		Resulting B_{calc} (ft)	Difference
	x_0 (ft)	θ (deg)		
7.50	1.805	23.686	6.920	-0.580
7.55	1.856	23.497	7.130	-0.420
7.60	1.906	23.312	7.343	-0.257
7.65	1.956	23.129	7.559	-0.091
7.70	2.006	22.949	7.779	0.079
7.75	2.055	22.771	8.002	0.252
7.80	2.104	22.596	8.228	0.428
7.85	2.153	22.424	8.458	0.608
7.90	2.201	22.254	8.691	0.791
7.95	2.248	22.086	8.927	0.977
8.00	2.296	21.921	9.167	1.167
Using Solver				
7.68	1.983	23.032	7.677	0.000

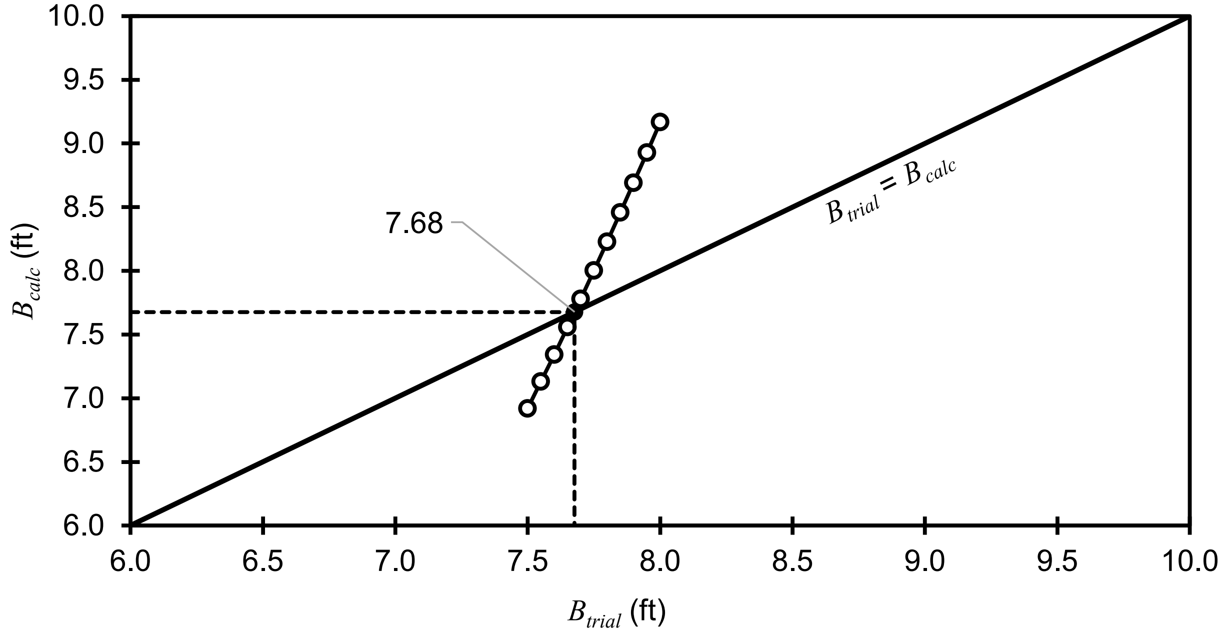


Figure B-4 Graphical Implicit Solution for Footing with Desired F_{BC}

B-1.7 Conclusions from the Analysis.

Table B-3 summarizes the minimum footing widths that meet the stability requirements with respect to overturning, sliding, and bearing capacity. This analysis shows that the footing width is controlled by overturning stability in this case.

Table B-3 Summary of Minimum Footing Widths Meeting Stability Requirements

Stability check	Required B (ft)
Overturning (x_0=B/3)	9.11
Sliding (F_{SL} = 1.5)	9.09
Bearing capacity (F_{BC} = 3)	7.68

Based on these stability checks, a design footing width equal to 9.5 feet is satisfactory.

Table B-4 provides the stability checks using the design value of B equal to 9.5 ft. Since the minimum required widths for overturning and sliding are close, both the overturning check and sliding checks are close to the minimum requirements for the design value of B. However, the design value of B is considerably greater than the minimum required value of 7.68 ft for bearing capacity, which gives the expected result of a factor of safety that significantly exceeds 3.0.

Table B-4 Summary of Stability Checks for Example 1

Stability check for B = 9.5 ft	Outcome
Overturning	$F_{SL} = 1.58 > 1.5$
Sliding	$x_0/B = 0.35 > 1/3$
Bearing capacity	$F_{BC} = 6.35 > 3$

B-1.8 Additional Comments on Overturning Factor of Safety.

Overturning resistance can also be checked using a factor of safety for overturning, F_{OT}, defined as the ratio of stabilizing moments to destabilizing moments about the toe of the wall. Referring to Table B-1, the absolute value of the moments having a negative sign according to the adopted sign convention are stabilizing moments that are located in the numerator of the factor of safety calculation. The moments in Table B-1 having a positive sign are destabilizing moments that are located in the denominator of the factor of safety calculation. Note that the moment from R is neglected in this calculation as:

$$F_{OT} = \frac{\text{Resisting moments}}{\text{Driving moments}} = \frac{1270 \cdot B^2 - 4840}{44145} = 2.49$$

For the design base width of 9.5 ft, F_{OT} is 2.49. It is instructive to consider how this factor of safety interacts with the design criterion requiring R to be in the middle third of the footing base. Recognizing that the resultant vertical force acting on the base of the wall is a destabilizing moment, the state of limit equilibrium corresponds to the resultant being located at the toe of the wall, i.e. x_0 = 0, as shown in Figure B-5.

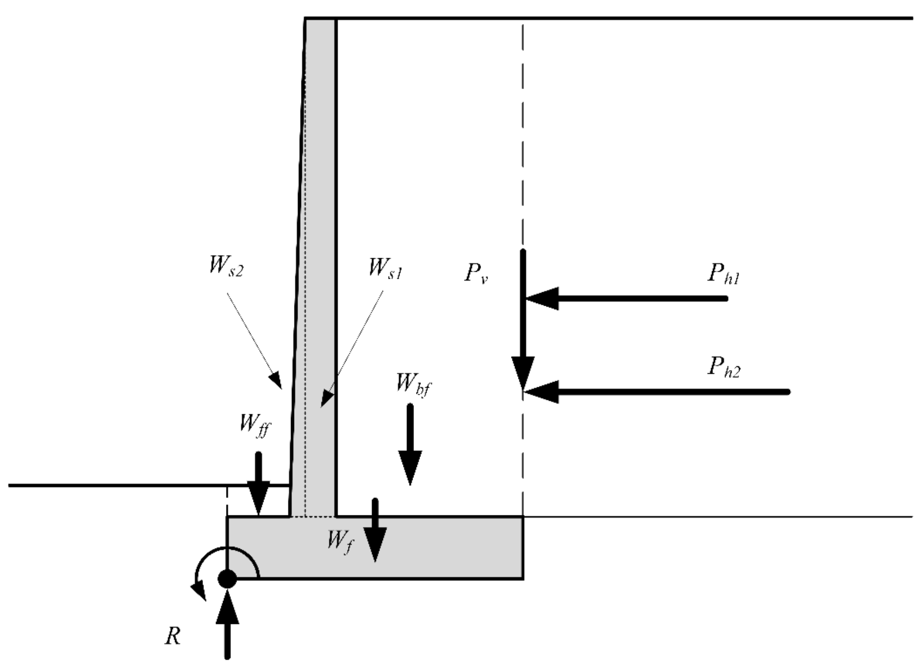


Figure B-5 Retaining Wall Conditions with F_{OT} = 1

For this condition with x_0 = 0 ft, the wall will have F_{OT} = 1. For this example, a footing having a width of 6.21 ft corresponds to F_{OT} = 1, which is found by solving:

$$\sum M_{toe} = 48{,}985 - 1270 \cdot B^2 + 2540 \cdot B \cdot x_0 - 4560 \cdot x_0 = 0$$
$$48{,}985 = 1270 \cdot B^2$$

The position of the reaction is related to F_{OT} according to

$$x_0 = a\left(\frac{W}{W + P_v}\right)\left(1 - \frac{1}{F_{OT}}\right) \quad \text{(xx)}$$

where W equals the sum of W_{ff}, W_f, W_{bf}, W_{s1}, and W_{s2} and a is the moment arm for W found by dividing the sum of the moments produced by wall and soil over the heel by the sum of the weights of the wall and soil over the heel. For the current example, E_v = 0 and a equals 5.61 resulting in:

$$x_0 = 5.61(1 - 1/2.49) = 3.36$$

For F_{OT} equal to 2.49, x_0 = 3.36 and x_0/B = 0.353.

B-2 EXAMPLE 2 – ANCHORED CUT WALL.

B-2.1 Description of the Problem.

An anchored bulkhead is needed for a land reclamation project that will provide a landside elevation that is 24 ft higher than the dredge line on the waterside (Figure B-6). The bulkhead will be anchored using a single row of anchors. The anchors will consist of horizontal steel tierods spaced every 6 ft and connected to a continuous concrete deadman located behind the bulkhead. The tierod elevation is established 1-ft above the water elevation so the tierod can be placed in the dry.

The site is sandy and dredged onsite soils will be used as fill. Due to tidal effects, the waterside water elevation is to be considered 2 ft below the landside water elevation. Figure B-6 provides relevant material properties, including the interface friction angle between the soil and sheetpile, δ.

During the service life of the project, industrial activities will impose ground pressures that can be modeled as a uniform surcharge equal to 500 psf.

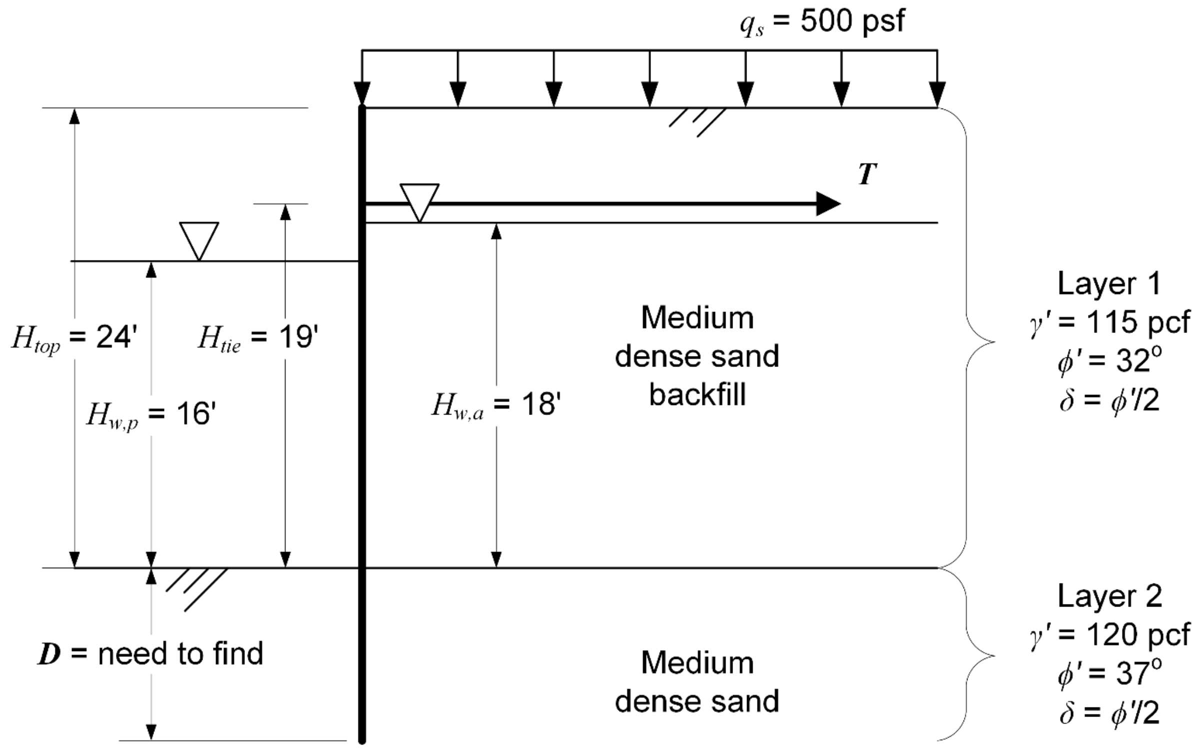


Figure B-6 Proposed Anchored Bulkhead in Sand

B-2.2 Goals and Limitations of the Analysis.

The goals of this analysis are to determine an appropriate steel sheetpile section, minimum embedment of the sheetpile, and size of the continuous anchor needed to provide adequate resistance. The Free Earth Support (FES) Method is applied to this example with the following assumptions and performance requirements:

- Allowable stress design will be applied using factored strengths for the evaluation of passive resistance of the embedded sheetpile and deadman anchor. A factor of safety equal to 2.0 is applied to determine the available resistance. This factor of safety accounts for typical uncertainty and variability with respect to soil properties as well the lateral displacements required to mobilize resistance.
- The sheetpile embedment determined by moment equilibrium calculations will be increased by 20% to account for the potential for scour and future dredging.
- Log spiral earth pressure theory is applied to estimate passive resistance while Rankine earth pressure theory is applied to estimate active pressures.
- This analysis ignores the reduction of the sheetpile section due to corrosion over the service life of the bulkhead.
- The selection of an acceptable tierod section, connections, turnbuckles, and wales are important design aspects that are not included in this example.

B-2.3 Calculation of Lateral Pressures and Forces.

Table B-5 summarizes the active and passive earth pressure coefficients used in the analysis. Because Rankine theory is used for active pressures and the ground surface behind the bulkhead is level, there is no vertical component to the active pressure. Therefore, the coefficient of horizontal active earth pressure ($K_{A,h}$) is equal to K_A. Because log spiral earth pressure theory is used for passive pressure and the interface friction angle is greater than zero, there is a vertical component to the passive pressure and the coefficient of horizontal passive earth pressure coefficient ($K_{P,h}$) must be found.

Table B-5 Earth Pressure Coefficients Used in the Design

Soil Layer	ϕ' (deg)	Rankine Active, K_A	Factored Friction Angles		Factored Passive Resistance
			ϕ'^* (deg)	δ^* (deg)	$K_{P,h}$
		$K_A = \dfrac{1-\sin\phi'}{1+\sin\phi'}$	$\phi'^* = \tan^{-1}\left(\dfrac{\tan\phi'}{F}\right)$	$\delta^* = \phi'^*\left(\dfrac{\delta}{\phi'}\right)$	$K_{P,h} = K_P\cos\left(\delta^*\right)$
1	32	0.31	17.4	8.7	2.1
2	37	0.25	20.6	10.3	2.4
Find log-spiral K_P using Equation 4-12: $\ln K_P = \ln\left(\dfrac{1+\sin\phi'^*}{1-\sin\phi'^*}\right)\left[1.443\left(\dfrac{\delta}{\phi'}\right)\sin\phi'^*+1\right]$					

Figure B-7 shows the distribution of earth pressures and net water pressure on both sides of the sheetpile. The pressures are divided into simple triangular and rectangular shapes to simplify the calculation of forces and moments. Table B-6 presents a summary of the pressure calculations. The vertical stresses listed in the table equal the incremental change in vertical effective stress at the top and bottom of the numbered shape that form the pressure distribution, $\Delta\sigma'_{v,top}$ and $\Delta\sigma'_{v,bot}$, respectively. The horizontal effective stresses at the top and bottom of each shape, $\Delta\sigma'_{h,top}$ and $\Delta\sigma'_{h,bot}$, respectively, are found by multiplying by the appropriate value of K_A or $K_{P,h}$.

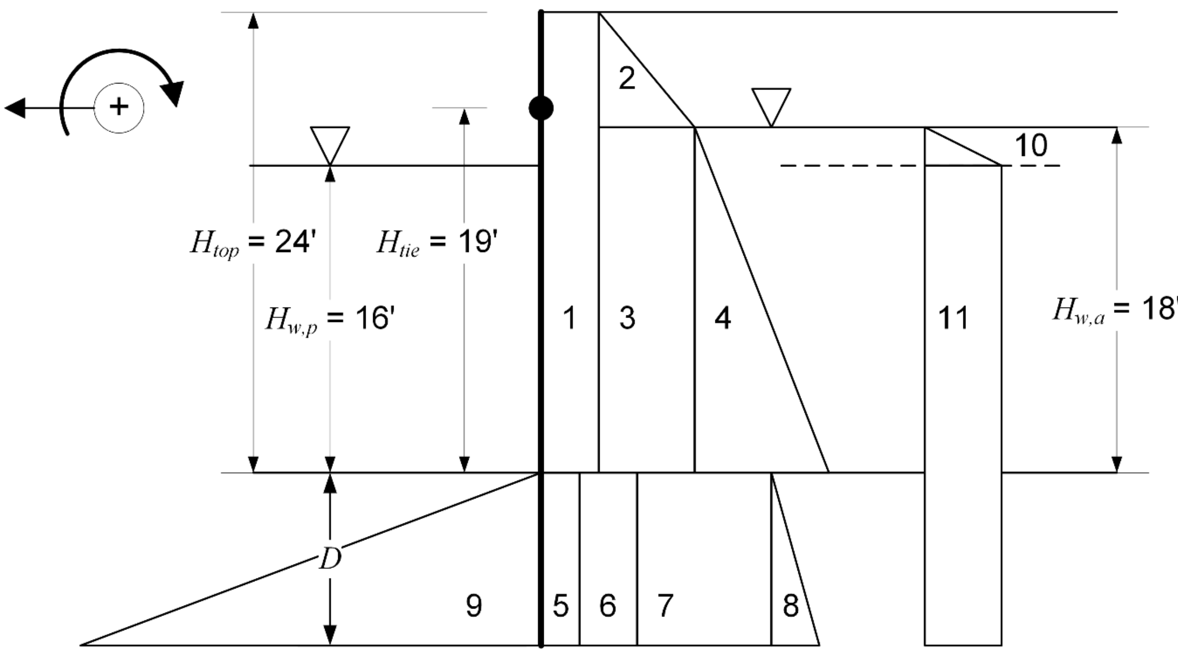


Figure B-7 Distribution of Earth and Water Pressures on the Sheetpile

Table B-6 Summary of Lateral Pressure and Force Calculations

Force ID	$\Delta\sigma'_{v,top}$ (psf)	$\Delta\sigma'_{v,bot}$ (psf)	K[A]	$\Delta\sigma'_{h,top}$ (psf)	$\Delta\sigma'_{h,bot}$ (psf)	h_{shape} (ft)	ΔP (lb/ft)
1	500	500	0.31	155	155	24	3720
2	0	690	0.31	0	214	6	642
3	690	690	0.31	214	214	18	3850
4	0	947	0.31	0	294	18	2642
5	500	500	0.25	125	125	D	$125 \cdot D$
6	690	690	0.25	172	172	D	$172 \cdot D$
7	947	947	0.25	237	237	D	$237 \cdot D$
8	0	57.6(D)	0.25	0	14.4(D)	D	$7.2 \cdot D^2$
9	0	57.6(D)	-2.4	0	-138(D)	D	$-69.1 \cdot D^2$
10	0	125	1	0	125	2	125
11	125	125	1	125	125	16+D	$125 \cdot (D+16)$

[A] The sign applied to K establishes the direction of the force as defined in Figure.

The lateral force due to each numbered shape that forms the lateral pressure distribution is found by:

$$\Delta P = \left(\frac{\Delta\sigma'_{h,top} + \Delta\sigma'_{h,bot}}{2} \right) \cdot h_{shape}$$

where:
h_{shape} = the height of each numbered shape.

B-2.4 Embedment of Sheet Pile and Tie Rod Force.

The embedment of the sheetpile is found by computing moment equilibrium about the elevation of the tierod. Referring to the numbered shapes in Figure B-7 and Table B-6, the elevation of the centroid of each component, y, relative to the dredge line is listed in Table B-7. Calculating the centroid as a separate step simplifies making changes to the tierod elevation in the design. The moment arm about the tierod elevation is equal to the difference between the elevation of the tierod and the elevation of the centroid for each component of the lateral force, i.e. $H_t - y$. The moment about the tierod elevation is found by multiplying the force listed in Table B-6 by the moment arm. The embedded depth of the sheetpile is found by summing moments and satisfying moment equilibrium. Calculations can be performed using an iterative guess and check technique or application of an implicit solving algorithm in a spreadsheet, e.g. Solver macro in MS Excel. Figure B-8 shows the sum of moments versus sheetpile embedment.

Table B-7 Summary of Moment Calculations

Force ID	Elevation of Centroid Relative to Dredge Line, y (ft)	Moment Arm at Tierod Elevation (ft)	Moment (ft-lbs)
1	H_{top} / 2 = 12	$H_t - y$ = 19-12 = 7	26,040
2	$H_{w,a}$ + (H_{top} - $H_{w,a}$) / 3 = 20	-1	-642
3	$H_{w,a}$ / 2 = 9	10	38,500
4	$H_{w,a}$ / 3 = 6	13	34,346
5	-D / 2	19+D / 2	125(D)(19+D/2)
6	-D / 2	19+D / 2	172(D)(19+D/2)
7	-D / 2	19+D / 2	237(D)(19+D/2)
8	-(2/3)D	19+(2/3) D	7.2(D^2)(19+(2/3)D)
9	-(2/3)D	19+(2/3) D	-69.1(D^2)(19+(2/3)D)
10	$H_{w,p}$ + ($H_{w,a}$ - $H_{w,3}$)/3 = 16.67	2.33	291
11	($H_{w,p}$ + D) / 2 - D =(16 + D) / 2 - D	19+D-(16+D)/2	125(D+16)(19+D-(16+D)/2)

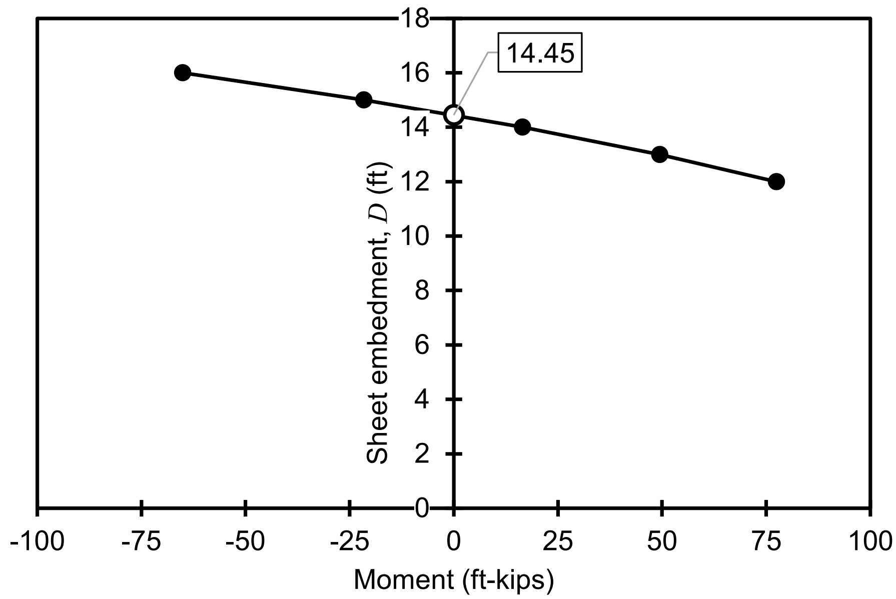


Figure B-8 Sum of Moments versus Trial Values of Sheet Pile Embedment

The calculated sheetpile embedment for this example equals 14.45 ft. This value will be used in subsequent calculation steps; however, a design value is found by increasing the embedment by 20% and rounding up to nearest whole foot. In this case, the design embedment is equal to 18 ft.

With the embedment of the sheetpile known, the magnitude of tierod force is found by satisfying horizontal force equilibrium. This calculation is performed using the embedment equal to 14.45 ft. For the sign convention defined in Figure B-7, the tierod force is equal to -9,568 lb/ft. This value will be used to design the sheeting and deadman in subsequent calculation steps. However, a value for designing the connection of the tierod to the sheetpile and deadman is found by increasing the tierod force by 20% and rounding up to nearest 100 lb/ft. In this case, the connections of the tierod to the sheetpile and deadman should be designed for 11,400 lb/ft. The tierod itself may be designed using the calculated value, with appropriate rounding, e.g. 9,600 lb/ft. For a tierod spacing of 6 ft, the tierod should be designed for a force equal to 58 kips, while the tierod connections should be designed for a force equal to 69 kips.

B-2.5 Selection of Sheet Pile Section.

This section provides the steps need to select an appropriate sheet pile section. The process involves identifying the location of the maximum moment, solving for the maximum moment, applying Rowe's moment reduction described in Section 4-7.2, and selecting a sheet with an adequate section modulus.

B-2.6 Location of Maximum Moment.

The elevation of the maximum moment above the dredge line is found by solving for the elevation of zero shear force. The location of zero shear force is found by integrating the pressure distribution in the direction of the dredge line starting from the top of the bulkhead. The shaded portion of Figure B-9 graphically shows the integration of the pressure distribution from the top of the bulkhead to the elevation of zero shear force, $h_{V=0}$ = 4.57 ft. Figure B-10 plots shear force against height above the dredge line.

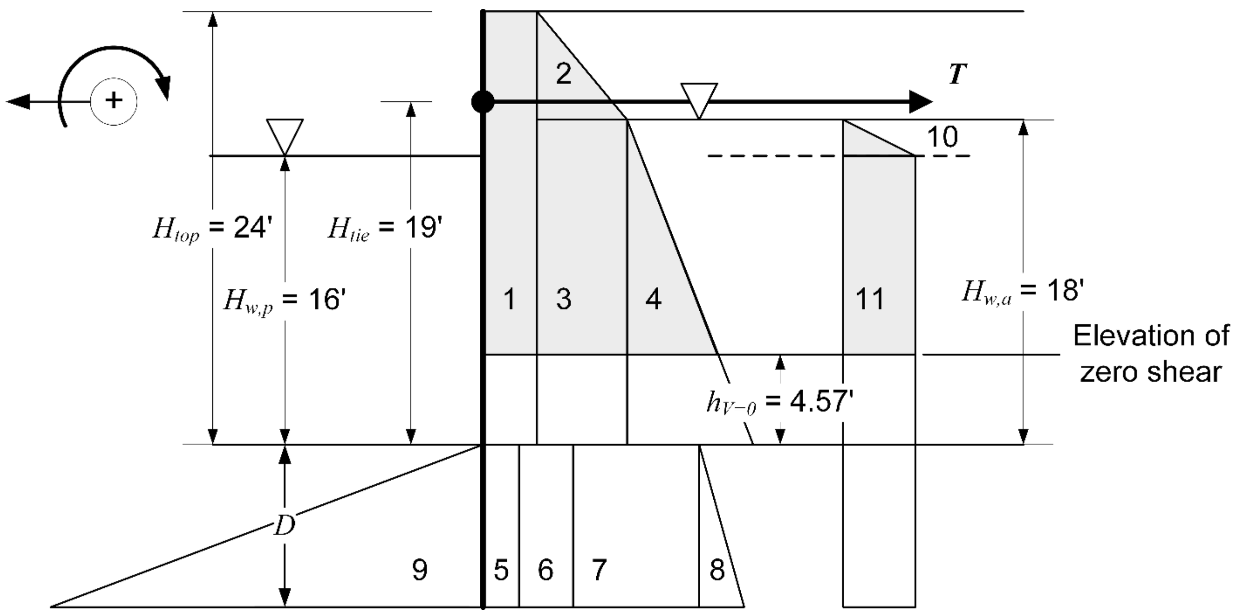


Figure B-9 Integration of Pressure Distribution to Locate Elevation of Zero Shear Force

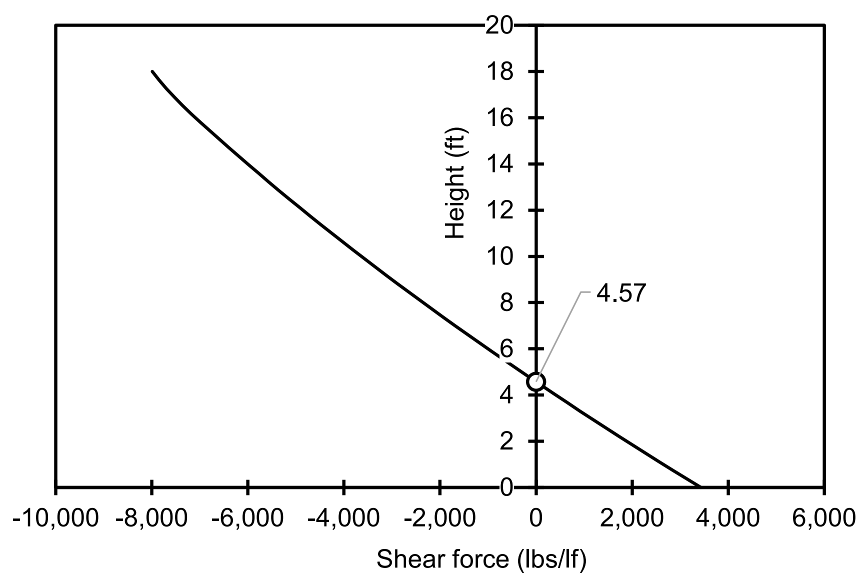


Figure B-10 Shear Force Versus Height Above the Dredge Line

The maximum bending moment in the sheetpile occurs at the elevation of zero shear, $h_{V=0}$, calculated in the previous section. Table B-8 summarizes the integrated loads to the elevation of zero shear as indicated by the shaded region in Figure B-9, the elevation of the centroid of each shaded area component, the moment arm relative to $h_{V=0}$, and the moment. The sum of the components of moment equals the maximum moment, M_{max}, equal to 63.4 ft-kips.

Table B-8 Calculation of the Maximum Bending Moment in the Sheet Pile

Force ID	Force (lb)	Elevation of Centroid Relative to Dredge Line, y (ft)	Moment Arm at $h_{V=0}$ (ft)	Moment (ft-lb)
Tierod	-9,568	19.0	-14.4	138,073
1	3,012	14.3	-9.7	-29,261
2	642	20.0	-15.4	-9,902
3	2,873	11.3	-6.7	-19,292
4	1,471	9.0	-4.5	-6,584
10	125	16.7	-12.1	-1,510
11	1,427	10.3	-5.7	-8,154
			Sum =	63,370

The steel sheetpile selected for the anchored bulkhead must have an elastic section modulus, S, that will keep the steel sufficiently below yield when subjected to the anticipated bending moment. Recall that the bending moment divided by the section modulus gives the bending stress. For this example, a PZ-22 section is selected for consideration. The PZ-22 section has the properties listed in Table B-9.

Table B-9 Properties of the PZ-22 Hot Rolled Steel Sheet Pile

Property	**Value**
Width of sheet	22 in.
Section modulus, S, per sheet	33.1 in^3
Section modulus, S, per foot	18.1 in^3
Moment of interia, I, per sheet	154.7 in^4
Moment of interia, I, per foot	84.4 in^4
Young's Modulus, E	29,000 ksi
Yield stress, f_s	38.5 ksi

Since the sheetpile is flexible and the soil is compressible, the maximum moment is expected to be less than the value calculated in the previous section. The method proposed by Rowe (1952) in Figure 4-36 reduces the maximum calculated moment to a value that is expected for the given stiffness of the steel section and soil. The reduction is based on the flexibility number, which is:

$$\rho = \frac{\left(H_{top} + D\right)^4}{E \cdot I} = \frac{\left[\left(\frac{12in}{1ft}\right)\left(24ft + 14.45ft\right)\right]^4}{\left(29{,}000ksi\right)\left(84.4in^4\right)} = 18.52\frac{in}{lb} \text{ per foot}$$

For medium dense sand, the moment reduction proposed by Rowe (1952) is given by

$$\frac{M_{design}}{M_{max}} = \frac{2.03}{\ln \rho} - 0.076 = \frac{2.03}{\ln\left(18.52\right)} - 0.076 = 0.62$$

Applying the moment reduction to the maximum moment calculated in the previous section yields a design moment equal to

$$M_{design} = M_{max}\left(\frac{M_{design}}{M_{max}}\right) = 63.4ft - k\left(0.62\right) = 39.3ft - k$$

The required section modulus per linear foot of bulkhead is equal to

$$S_{req} = \frac{M_{design}}{f_s} = \frac{39.3ft - k\left(12\,in/ft\right)}{38.5ksi} = 12.25in^3 \text{ per foot}$$

The PZ-22 sheetpile is an acceptable choice since the provided S equals 18.1 in^3/ft, which exceeds the required value of 12.25 in^3. A lighter-duty sheetpile section should be checked in cases where the section modulus of the candidate sheetpile significantly exceeds the required value. As stated above, this analysis ignores section loss due to corrosion over the service life of the bulkhead.

B-2.7 Design of Continuous Anchor.

Since this particular land reclamation project imposes no spatial constraints behind the bulkhead, the anchor can be placed far enough behind the bulkhead so that the active zone behind bulkhead does not interfere with the passive zone in front of the anchor. As shown in Figure B-11, the anchor should be placed at least 56 ft behind the sheetpile in order to have the potential to develop full resistance (see also Figure 4-39). Note that the inclinations of the active wedge and stable backslope are based on Layer 1 which has the lower friction angle. In Figure B-11, Construction Line 1 defines the active wedge behind the sheetpile, Construction Line 2 defines the inclination of a stable backslope, and Construction Line 3 defines the inclination of passive wedge in front of the anchor.

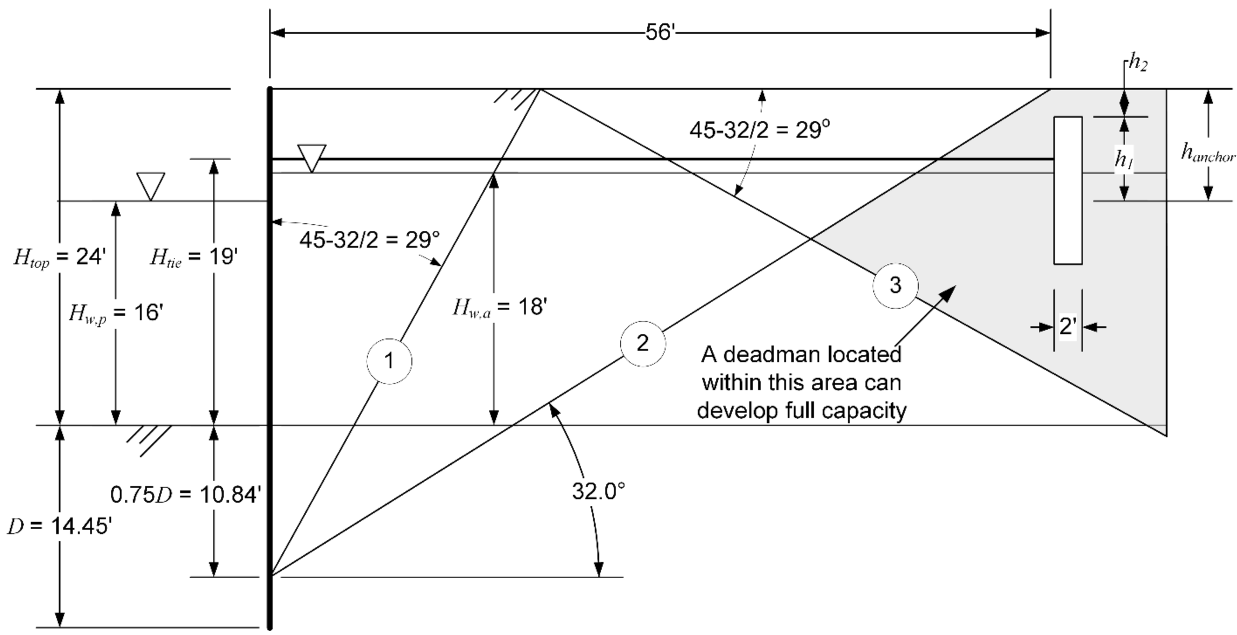


Figure B-11 Location of the Continuous Anchor

Since the deadman is embedded in Layer 1, the unfactored value of K_A of 0.31 (Table B-5) will be used to evaluate active pressure on the opposite side of the tierod force and the factored value of $K_{P,h}$ equal to 2.1 will be used to estimate passive resistance based on an applied factor of safety equal to 2.0 on the shear strength of the soil.

Assume that the anchor is 2 ft thick and made of reinforced concrete. In a complete design, this assumption would be checked as part of the structural design of the anchor. The mobilized vertical force due to interface friction between the anchor and soil is limited by the weight of the anchor. For the Layer 1 sand, the mobilized interface friction angle is limited according Duncan and Mokwa (2001) by:

$$\delta_{mob} = \min\begin{cases} (\delta/\phi')\cdot\phi'^* \\ \tan^{-1}(W_a/T) \end{cases} = \min\begin{cases} 8.7° \\ \tan^{-1}\left(\dfrac{(150\,pcf)(2\,ft)\cdot h_1}{9600\,lb/ft}\right) \end{cases}$$

where
W_a = weight of the concrete anchor per foot and
T = design tierod force per foot.

The minimum anchor height required to allow full mobilization of the factored interface friction is found by rearranging Equation (x)

$$\min h_1 = \frac{9600\,lb/ft}{(150\,pcf)(2\,ft)}\tan(8.7°) = 4.9\,ft$$

The calculations will proceed assuming that h_1 is greater than or equal to 4.9 ft and the embedment of the top of the anchor, h_2, equals 2 ft. With these dimensions, h_1 will be greater than (h_1 + h_2) and the anchor can be treated as extending to the ground surface (see Figure 4-40). These assumptions will be checked at the end of the design.

The net allowable resistance of the anchor, ignoring base sliding resistance, is estimated by the difference between the active and passive earth pressure coefficients, $K_{P,h} - K_{A,h}$, which in this case equals 1.79. Table B-10 summarizes the calculation of the net resistance of the anchor based on the sketch provided as Figure B-12.

Table B-10 Calculation of Net Allowable Anchor Resistance

Force ID	$\Delta\sigma'_{v,top}$ (psf)	$\Delta\sigma'_{v,bot}$ (psf)	$K_{p,h}$-$K_{a,h}$	$\Delta\sigma'_{h,top}$ (psf)	$\Delta\sigma'_{h,bot}$ (psf)	h_{shape} (ft)	ΔP (lb/ft)
12	0	690	1.79	0	1235	6	3705
13	690	690	1.79	1235	1235	h-6	1235(h - 6)
14	0	52.6(h - 6)	1.79	0	94.2(h - 6)	h-6	47.1(h - 6)^2

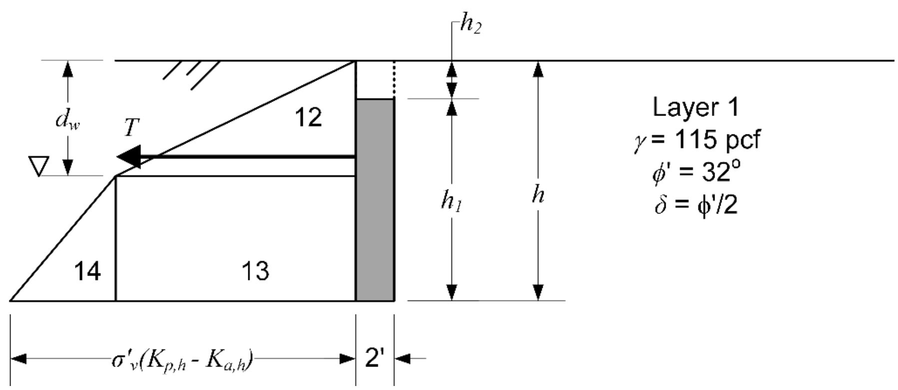


Figure B-12 Net Anchor Resistance to Counteract Tierod Force

The required height of the anchor can be found summing the horizontal forces:

$$\sum F_h = 0 = T - \sum \Delta P = 9600\frac{lb}{ft} - \left[3705\frac{lb}{ft} + (1235\,psf)(h - 6\,ft) + (47.1\,psf)(h - 6\,ft)^2\right]$$

Solving, h equals 10.1 ft. The height of the anchor should be rounded to the nearest half foot for design, which is 10.5 ft in this case. Since h_1 exceeds h/2, it is acceptable to treat the anchor as extending to the ground surface. Since h_1 exceeds 4.9 ft, it is acceptable to assume that wall friction will be unimpeded by the weight of the anchor.

Table B-11 summarizes the design geometry of the anchor based on the analysis provided in this section.

Table B-11 Summary of Anchor Design

Dimension	Value
Total anchor depth, h	10.5 ft
Height of anchor block, h_1	8.5 ft
Depth of embedment, h_2	2 ft
Width	2 ft

The tierod connection is located 5 ft below the ground surface, which is 5.1 ft above the base of the anchor, using the unrounded depth. Ideally, the anchor should connect at the elevation of the net resultant resistance force. Table B-12 summarizes the calculation of the elevation of the resultant force relative to the base of the anchor. Based on this calculation, the tierod is located about 14 inches higher than the ideal location. Lowering the tierod elevation has implications on the design, including the embedment of the sheetpile. A final design should evaluate the advantages and disadvantages of revising the tierod elevation.

Table B-12 Calculation of the Elevation of the Resultant Force

Force ID	Force (lbs) for h = 10.1ft	Elevation of Resultant Relative to Anchor Base (ft)	Weighting by Force (Force) × (Resultant Elev.)
12	3705	10.1 – 4 = 7.1	3705(7.1) = 26,306
13	5064	(10.1-6)/2 = 2.0	10,128
14	792	(10.1-6)/3 = 1.4	1,109
$y_{resultant}$ = (26,306+10,128+1,109)/(3705+5064+792) = 3.93 ft			

B-2.8 Conclusions from the Analysis.

Table B-13 summarizes all of the design parameters determined in this example. Any changes to the problem require revisiting all calculated parameter values.

Table B-13 Summary of Anchored Bulkhead Design Example

Design Element	Design Parameter	Value
Sheet Pile	Sheetpile section	PZ-22
	Total length (H+D)	24+18 = 42 ft
	Embedment (D)	18 ft
	Position of tierod above pile tip	19+18 = 37 ft
Concrete Deadman Anchor	Depth to base of anchor, h	10.5 ft
	Height of anchor, h_1	8.5 ft
	Depth to top of anchor, h_2	2 ft
	Width of anchor	2 ft
Tierod	Spacing	6 ft
	Length	56 ft
	Force	58 kips
	Connection force	69 kips

B-3 EXAMPLE 3 – BEARING CAPACITY OF SHALLOW FOUNDATIONS.

B-3.1 Description of the Problem.

Three rows of footings are proposed for construction of a building on a site with medium to stiff consistency overconsolidated clay. The footings will be designed for the vertical loads indicated in Figure B-13. The design properties of the clay are provided in Table B-14. The depth to the bearing grade of the footings, D_f, is equal to 3 ft below the final ground surface for frost and shrink/swell considerations.

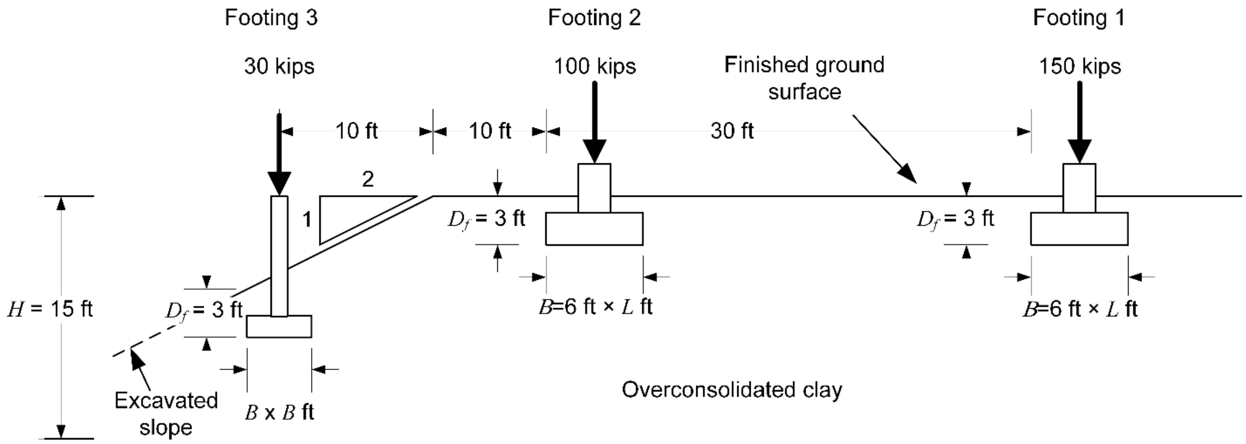


Figure B-13. Three Rows of Footings – Example 3

Table B-14 Design Properties of Overconsolidated Clay

Condition	Unit weight, γ (pcf)	Shear Strength Parameters
Short term (undrained)	115	ϕ = 0 deg, s_u = 1000 psf
Long Term (drained)		ϕ' = 30 deg, c' = 0 psf

B-3.2 Goals and Limitations of the Analysis.

Where applicable, the Meyerhof (1957, 1963) and Hansen (1970) methods will be used to evaluate the unknown dimensions of the three footings in order to have a factor of safety against bearing capacity failure, F_{BC}, of at least 2.5 for short-term and long-term conditions. It is assumed that the clay can be modeled as a saturated undrained soil in the short term and a drained soil in the long term that does not require correction for the presence of the water table. It is further assumed that the footings are spaced far enough away from each other that they can be treated as isolated footings. This example does not consider geotechnical design for settlement and structural design. Because the Footings 2 and 3 are on or near the 2H:1V slope, global stability analysis should also be performed as part of the overall footing design. For example, treating the slope in a long-term drained case as an infinite slope reveals that the slope is only marginally stable using the design strength parameter values.

$$F_{global} = \frac{\tan 30°}{0.5} = 1.15 .$$

The remainder of this example will consider the effects of the slope on bearing capacity. However, the controlling factor for this design is more likely the global stability of the slope itself.

B-3.3 Bearing Capacity Equations.

The generalized gross bearing capacity equation expressed using the notation found in Chapter 5 is as follows

$$q_{ult} = c \cdot N_c \cdot \psi_c + \sigma_{zD} \cdot N_q \cdot \psi_q + 0.5 \cdot B \cdot \gamma \cdot N_\gamma \cdot \psi_\gamma$$

where
N_c, N_q, N_γ = bearing capacity factors that are a function of friction angle,
c = the effective stess cohesion for drained conditions or s_u for undrained conditions,
σ_{zD} is the effective or total vertical stress at the bearing grade,
B = footing width,
γ = representative unit weight, and
$\psi_c,\ \psi_q,\ \psi_\gamma$ = correction factors for the combined effect of complicating conditions.

Applying the desired minimum factor of safety and removing the self weight of the footing and overlying soil, ignoring the difference between the unit weight of concrete and soil, yields the allowable net bearing capacity

$$q_{net,all} = \frac{q_{ult}}{F_{BC}} - \sigma_{zD} .$$

Table B-15 presents the bearing capacity factors according to Meyerhof (1951) and Brinch Hansen (1970) as calculated from Figure 5-5 for short and long-term conditions.

Table B-15 Bearing Capacity Factors for the Example 3

Condition	Theory	N_c	N_q	N_γ
Short term (undrained) $\phi = 0°$	Meyerhof	5.14	1.00	0
	Brinch Hansen	5.14	1.00	0
Long term (drained) $\phi' = 30°$	Meyerhof	30.14	18.40	15.67
	Brinch Hansen	30.14	18.40	15.07

Because N_q equals 1.0 and N_γ equals zero for the undrained case, the net allowable bearing capacity equation reduces to

$$q_{all,net} = \frac{s_u N_c \psi_c}{F_{BC}} + \sigma_{zD}\left(\frac{\psi_q}{F_{BC}} - 1\right)$$

where
s_u is the undrained strength.

Because the shear strength of the clay in the drained condition is represented by a purely frictional material, i.e. $c' = 0$, the net allowable bearing capacity equation for drained conditions reduces to:

$$q_{all,net} = \sigma_{zD}\left(\frac{N_q \psi_q}{F_{BC}} - 1\right) + \frac{B \cdot \gamma \cdot N_\gamma \cdot \psi_\gamma}{2F_{BC}}.$$

When conditions do not match the assumptions used for the theoretical development of the bearing capacity equation, Meyerhof (1951) and Brinch Hansen (1970) use correction factors applied to the bearing capacity factors. In the current example, the relevant corrections are for footing shape, s_i, and depth, d_i, and ground inclination gi, where the subscript i is assigned characters c, q, or γ to denote which bearing capacity factor the correction is applied to. Recall from Section 5-3.3 that the correction factors are usually multiplied with the exception of the undrained case for Brinch Hansen's method.

The evaluation of the correction factors for each footing is presented in the subsections that follow. In the case of Footing 2, which is located close to the top of the slope, a special form of the bearing capacity equation presented in chart form by Meyerhof (1957) will be applied to account for the effects of the slope.

Applying known parameter values, the net allowable bearing pressure for undrained conditions for both Meyerhof and Brinch Hansen theories yields:

$$q_{all,net} = \frac{(1000\,psf)(5.14)\psi_c}{2.5} + (3\,ft)(115\,pcf)\left(\frac{\psi_q}{2.5} - 1\right) = 2056\psi_c + 138\psi_q - 345.$$

Applying known parameter values and a value of N_γ equal to 15.67, the net allowable bearing pressure for drained conditions according to Meyerhof (1951) yields:

$$q_{all,net} = (3\,ft)(115\,pcf)\left(\frac{18.4\psi_q}{2.5} - 1\right) + \frac{B(115\,pcf)(15.67)\cdot\psi_\gamma}{2(2.5)} = 2539\psi_q + 360B\cdot\psi_\gamma - 345$$

Using a value of N_γ equal to 15.07 according to Brinch Hansen (1970) gives:

$$q_{all,net} = (3\,ft)(115\,pcf)\left(\frac{18.4\psi_q}{2.5} - 1\right) + \frac{B(115\,pcf)(15.07)\cdot\psi_\gamma}{2(2.5)} = 2539\psi_q + 347B\cdot\psi_\gamma - 345\,.$$

These equations provide the basis for sizing footings 1, 2, and 3 with respect to bearing capacity. The design of Footing 1 is presented in Section B-3.4, the design of Footing 2 is presented in Section B-3.5, and the design of Footing 3 is presented in Section B-3.6. To illustrate a range of design approaches, the dimensions of Footing 1 will be determined by directly solving for B, while Footings 2 and 3 will use an iterative approach.

B-3.4 Footing 1 – Located Far from the Top of the Slope.

Footing 1 imposes a vertical design load, Q, equal to 150 kips that is distributed over the bearing area to produce the design bearing pressure,

$$q_{net} = \frac{Q}{B\cdot L} = \frac{150{,}000\,lb}{6\,ft\cdot L} = \frac{25000}{L} \text{ (psf).}$$

The design bearing pressure must not exceed the allowable bearing capacity, $q_{net} \le q_{all,net}$.

According to Meyerhof (1957), the bearing capacity of a footing is not affected by the inclination of the slope when it is located behind the top of the slope a distance of at least 2 to 6 times the width of the footing, depending on the inclination of the slope, the shear strength of the soil, and the embedment depth of the footing. Since Footing 1 is 6 ft wide and is located 40 ft from the top of the slope, which is 6.7 times the width of the footing, it can be assumed that the bearing capacity evaluation of Footing 1 does not need to consider the slope and the applicable bearing capacity corrections are limited to footing shape and depth. Table B-16 presents Meyerhof's (1951) corrections for shape and depth

Table B-16. Meyerhof Corrections for Footing Shape and Depth

Correction	Undrained, $\phi = 0$	Drained, $\phi' = 30°$, $K_P = 3$
Shape	$s_c = 1 + 0.2(B/L) = 1 + 0.2(6\text{ ft})/L = 1 + 1.2/L$ $s_q = 1$	$s_q = s_\gamma = 1 + 0.1(B/L)K_P$ $s_q = s_\gamma = 1 + 0.1(6\text{ ft}/L)(3) = 1 + 1.8/L$
Depth	$d_c = 1 + 0.2(D_f/B) = 1 + 0.2(3\text{ ft})/L = 1 + 0.6/L$ $d_q = 1$	$d_q = d_\gamma = 1 + 0.1(D_f/B)(K_P)^{0.5}$ $d_q = d_\gamma = 1 + 0.1(3\text{ft}/6\text{ ft})(3)^{0.5} = 1.087$
Combined	$\psi_c = [1 + 0.2(B/L)][1 + 0.2(D_f/B)]$ $\psi_c = [1 + 1.2/L][1 + 0.6/L]$ $\psi_q = 1$	$\psi_q = \psi_\gamma = [1 + 0.1(B/L)K_P][1 + 0.1(D_f/B)(K_P)^{0.5}]$ $\psi_q = \psi_\gamma = [1 + 1.8/L][1.087]$

Applying Meyerhof's corrections for footing shape and depth for undrained conditions results in:

$$q_{all,net} = 2056\psi_c + 138\psi_q - 345 = 2056\left(1+1.2/L\right)\left(1+0.6/L\right)+138\left(1\right)-345\,.$$

Setting the net bearing pressure equal to the net allowable and solving for L results in:

$$\begin{aligned}&q_{net} \le q_{all,net}\\ &\frac{25000}{L} \le 2056\left(1+1.2/L\right)\left(1+0.6/L\right)-207\\ &L \ge 10.84\ ft\end{aligned}$$

This footing length produces a net bearing pressure of 2.31 ksf.

Applying Meyerhof's corrections for footing shape and depth for drained conditions results in:

$$\begin{aligned}q_{all,net} &= 2539\psi_q + 360B\cdot\psi_\gamma - 345\\ q_{all,net} &= 2539\left(1+1.8/L\right)\left(1.087\right)+360(6\,ft)\left(1+1.8/L\right)\left(1.087\right)-345\\ q_{all,net} &= 5108\left(1+1.8/L\right)-345\end{aligned}$$

(psf)

Equating the net and net allowable bearing pressures:

$$\frac{25000}{L} \le 5108\left(1+1.8/L\right)-345 \;\; \rightarrow \;\; L \ge 3.32\ ft$$

This footing length produces a bearing pressure of 7.53 ksf. Since the required length is less than the width, the width of Footing 1 is oversized with respect to drained bearing capacity according to Meyerhof. If this case controlled the size of the footing, the calculations would need to be repeated with the lesser footing dimension assigned as the width.

Table B-17 presents Brinch Hansen's (1970) corrections for shape and depth.

Table B-17. Brinch Hansen Corrections for Footing Shape and Depth

Correction	Undrained, $\phi = 0$	Drained, $\phi' = 30°$, $K_P = 3$
Shape	$s_c = 1 + 0.2(B/L)$ $s_c = 1 + 0.2(6\text{ ft})/L = 1+1.2/L$	$s_q = 1 + \sin(\phi')(B/L) = 1+\sin(30)(6\text{ ft}/L) = 1+3/L$ $s_\gamma = 1 - 0.4(B/L) = 1 - 0.4(6\text{ ft}/L) = 1 - 2.4/L$
Depth	$d_c = 0.4(D_f/B) = 0.4(3\text{ ft})/L = 1.2/L$	$d_q = 1+2\cdot\tan(\phi')(1-\sin(\phi'))^2\cdot(D_f/B)$ $d_q = 1+2\cdot\tan(30)(1-\sin(30))^2\cdot(3\text{ ft}/6\text{ ft}) = 1.144$ $d_\gamma = 1$
Combined	$\psi_c = [1 + 0.2(B/L)]+0.4(D_f/B)$ $\psi_c = (1+1.2/L) + 1.2/L = 1+2.4/L$	$\psi_q = [1 + \sin(\phi')(B/L)][1+2\cdot\tan(\phi')(1-\sin(\phi'))^2\cdot(D_f/B)]$ $\psi_q = (1+3/L)(1.144) = 1.144 + 3.43/L$ $\psi_\gamma = [1 - 0.4(B/L)][1] = 1 - 2.4/L$

Applying Brinch Hansen's corrections for footing shape and depth for undrained conditions results in:

$$q_{all,net} = 2056\psi_c + 138\psi_q - 345 = 2056\left(1 + 2.4/L\right) + 138\left(1\right) - 345 = 1849 + 4934/L$$

Setting the net bearing pressure equal to the net allowable and solving for L results in:

$$\begin{aligned} &25000/L \le 1849 + 4934/L \\ &L \ge 9.97\ ft \end{aligned}$$

This footing length produces a bearing pressure of 2.51 ksf.

Applying Brinch Hansen's corrections for footing shape and depth for drained conditions results in:

$$\begin{aligned} q_{all,net} &= 2539\psi_q + 347B \cdot \psi_\gamma - 345 = 2539\left(1.144 + 3.43/L\right) + 347\left(6\,ft\right)\left(1 - 2.4/L\right) - 345 \\ q_{all,net} &= 4642 - 3712/L \end{aligned}$$

Equating the net and net allowable bearing pressures:

$$25000/L \le 4642 - 3712/L \ \rightarrow\ L \ge 4.58\,ft$$

The minimum footing length required to support the design load produces a bearing pressure of 5.46 ksf. As with the analysis using Meyerhof's bearing capacity theory, the required footing length is less than the width in this case, which indicates that the footing width is oversized with respect to drained bearing capacity. If this case controlled the sizing of the footing, the calculations would need to be repeated with the lesser footing dimension assigned as the width.

In summary, the minimum footing length is equal to 10.84 ft to achieve an F_{BC} of at least 2.5 as determined according to Meyerhof (1951) for the undrained case. For design with respect to bearing capacity, the footing should be sized with B equal to 6 ft and L equal to 11 ft.

B-3.5 Footing 2 – Located Close to the Top of the Slope.

Footing 2 is near the top of the slope and the effects on bearing capacity must be considered. Brinch Hansen's theory does not include a correction for a footing near the top of a slope. The method by Leshchinsky and Xie will be used.

Leshchinsky and Xie (2017) provided bearing capacity reduction factors for saturated undrained conditions. Their method requires that the following ratios be calculated:

$$\frac{\gamma H}{s_u} = \frac{\left(115\,pcf\right)\left(15\,ft\right)}{1000\,psf} = 1.725,\quad \frac{B}{H} = \frac{6\,ft}{15\,ft} = 0.4,\quad \frac{b}{B} = \frac{10\,ft}{6\,ft} = 1.7$$

Interpolation is required by selecting values from Table 5-9 as shown in Table B-18. The boldface values are interpolated.

Table B-18 Interpolation of Bearing Capacity Factors for Sloping Conditions

Bearing Capacity Reduction Factor, RC_{slope}						
b/B	$\gamma H/s_u = 0$			$\gamma H/s_u = 2$		
	$\beta = 0°$	$\beta = 26°$	$\beta = 30°$	$\beta = 0°$	$\beta = 26°$	$\beta = 30°$
1.25	1	---	0.94	1	---	0.92
1.7	**1**	**0.985**	**0.983**	**1**	**0.98**	**0.977**
1.88	1	---	1	1	---	1

Meyerhof Bearing Capacity Factor, $N_{\gamma,slope}$			
β (deg)	$D_f / B = 0$	$D_f / B = 0.5$	$D_f / B = 1$
0	15	---	60
26	**14.1**	**31.4**	**48.7**
30	14	---	47

Further interpolating for $\gamma H/s_u$ = 1.725 from Table B-18 yields RC_{slope} = 0.981. The ultimate and allowable bearing capacity are found as:

$$q_{ult} = 5.14 \cdot s_u \cdot RC_{slope} = 5.14\left(1000\,pcf\right)\left(0.981\right) = 5042\,psf$$

$$q_{all,net} = \frac{5042\,psf}{2.5} = 2017\,psf$$

The allowable bearing pressure can be considered a net value because the N_q term was neglected when q_{ult} was calculated. The required value of L can be found as:

$$q_{net,all} \geq q_{net}$$

$$2017\,psf \geq \frac{100000\,lb}{\left(6\,ft\right)L}$$

$$L \geq 8.26\,ft$$

For undrained conditions, the footing should be sized with a length of 8.5 ft.

For drained conditions with c' = 0, the chart solution by Meyerhof (1957) must be used. The following ratios are required:

$$b/B = 1.7$$

$$D_f/B = 3\,ft/6\,ft = 0.5$$

Values from Figure 5-8 are summarized in Table B-18. Interpolation for the 2H1V slope and embedment results in the boldface values in the table and $N_{\gamma,slope}$ = 31.4.

The ultimate and allowable bearing capacities for drained conditions are found as:

$$q_{ult} = 0.5 \cdot \gamma \cdot B \cdot N_{\gamma,slope} = 0.5(115pcf)(6ft)(31.4) = 10833psf$$

$$q_{all,net} = \frac{10833psf}{2.5} - (3ft)(115pcf) = 3988psf$$

As for Footing 1, the net allowable bearing pressure for drained conditions is higher than for undrained. Thus, the length of 8.5 ft obtained for undrained conditions should be used.

B-3.6 Footing 3 – Located on the Slope.

Footing 3 will be designed as a square footing for a bearing pressure equal to

$$q_{net} = \frac{Q}{B^2} = \frac{30000\,lb}{B^2} \text{ (psf).}$$

Footing 3 is located on the 2H:1V slope. Brinch Hansen (1970) provides correction for the effect of the slope on bearing capacity, which are implemented using simple equations. Footing 3 will be designed by selecting both B and iteratively changing B until the net bearing pressure is less than the allowable value. An initial guess of 2 ksf was selected to size Footing 3, which yields dimensions of:

$$B^2 \geq \frac{30000\,lb}{2000\,psf} = 15 \;\rightarrow\; B = 4ft\,.$$

Table B-19 presents Brinch Hansen's (1970) correction factors for both undrained and drained conditions. Applying Brinch Hansen's corrections for footing shape, depth, and ground inclination for undrained conditions and B = 4 ft results in:

$$q_{all,net} = \frac{5.14 s_u \cdot \psi_c + \sigma_{zD} N_q}{F_{BC}} - \sigma_{zD} = \frac{5.14(1000psf)(1.319)}{2.5} + (345psf)\left(\frac{1}{2.5} - 1\right) = 2505psf\,.$$

Table B-19 Corrections for Footing Shape, Depth, and Ground Inclination (Brinch Hansen 1970)

Correction	Undrained, $\phi = 0$	Drained, $\phi' = 30°$, $K_P = 3$
Shape	$s_c = 1 + 0.2(B/L)$ $s_c = 1 + 0.2(1) = 1.2$	$s_q = 1 + \sin(\phi')(B/L) = 1 + \sin(30)(1) = 1.5$ $s_\gamma = 1 - 0.4(B/L) = 1 - 0.4(1) = 0.6$
Depth	$d_c = 0.4(D_f/B) = 0.4(3\text{ ft})/4 = 0.3$	$d_q = 1 + 2\cdot\tan(\phi')(1-\sin(\phi'))^2\cdot(D_f/B)$ $d_q = 1 + 2\cdot\tan(30)(1-\sin(30))^2\cdot(3\text{ ft}/4\text{ ft}) = 1.217$ $d_\gamma = 1$
Ground	$g_c = \beta / 147 = 26.6/147 = 0.181$	$g_q = g_\gamma = [1-0.5\tan(\beta)]^2 = [1-0.5\tan(26.6)]^2 = 0.563$
Combined	$\psi_c = 1.2 + 0.3 - 0.181 = 1.319$	$\psi_q = (1.5)(1.217)(0.563) = 1.028$ $\psi_\gamma = (0.6)(1)(0.563) = 0.338$

The allowable net bearing pressure is greater than the net bearing pressure for B = 4 ft. A smaller size could be tried; however, drained conditions will be evaluated first. Applying Brinch Hansen's corrections for footing shape, depth, and ground inclinations for drained conditions and B = 4 ft results in:

$$q_{all,net} = \frac{\sigma_{zD} N_q \psi_q + 0.5B \cdot \gamma \cdot N_\gamma \psi_\gamma}{F_{BC}} - \sigma_{zD}$$

$$q_{all,net} = \frac{(345)(18.4)(1.028) + 0.5(4\,ft)(115\,pcf)(15.07)(0.338)}{2.5} - (345\,psf) = 2734\,psf$$

The footing size of B = 4 ft is also acceptable for drained conditions, and a smaller size can be attempted. Table B-20 summarizes some of the calculations for other footing sizes. Footing 3 can be sized for B = 3.5 ft, which produces a bearing pressure of 2.45 ksf. This is higher than the bearing pressure for Footing 3 because the Leshchinsky and Xie method conservatively ignores shape factors and depth factors.

Table B-20 Iterative Sizing of Footing 3

B (ft)	q_{net} (psf)	Undrained		Drained			Acceptable?
		ψ_c	$q_{all,net}$ (psf)	ψ_q	ψ_γ	$q_{all,net}$ (psf)	
4	1875	1.319	2505	1.026	0.338	2729	Y
3.75	2133	1.339	2546	1.039	0.338	2731	Y
3.5	2449	1.362	2593	1.053	0.338	2737	Y
3.25	2840	1.388	2647	1.069	0.338	2749	N

B-3.7 Conclusions from the Analysis.

Table B-21 summarizes the bearing capacity analyses presented in this example. The sizing of Footings 1 and 2 with respect to bearing capacity was controlled by the short-term undrained case, which is expected for soil which gains strength by consolidation as drainage occurs. For Footing 3, the net allowable bearing pressure was approximately equivalent for both undrained and drained conditions.

Table B-21 Summary of Bearing Capacity Analyses – Example 3

Analysis	Footing 1 Far from Slope (Q=150 kips)	Footing 2 Near Top of Slope (Q=100 kips)	Footing 3 On Slope (Q=30 kips)
Short term, Meyerhof	6 ft × 11 ft, 2.27 ksf		
Short term, Brinch Hansen	6 ft × 10 ft, 2.50 ksf		3.5 ft × 3.5 ft, 2.45 ksf
Short term, Leshchinsky & Xie		6 ft × 8.5 ft, 1.96 ksf	
Long term, Meyerhof	6 ft × 3.5 ft, 7.14 ksf	6 ft × 4.25 ft, 3.92 ksf	
Long term, Brinch Hansen	6 ft × 4.75 ft, 5.26 ksf		3.5 ft × 3.5 ft, 2.45 ksf
Design	6 ft × 11 ft, 2.27 ksf	6 ft × 8.5 ft, 1.96 ksf	3.5 ft × 3.5 ft, 2.45 ksf

B-4 EXAMPLE 4 – MAT FOUNDATION DESIGN.

B-4.1 Description of the Problem.

A proposed 10-story building with underground parking is to be supported by a rectangular mat foundation having plan dimensions of 120 ft by 160 ft (Figure 1). The site is level with an exterior finished grade of El. 215 ft. The site conditions enable the bearing grade of the mat to be set at an elevation of El. 200 ft. In addition to providing space for parking, the excavation will reduce expected settlements since some of the weight of the new structure will be offset, or compensated, by the weight of the excavated material.

The subsurface exploration performed for the project indicates that the subsurface consists of the four strata listed in Table B-22. It is known that Stratum 4 continues for several hundred feet. The design groundwater elevation is El. 195 ft.

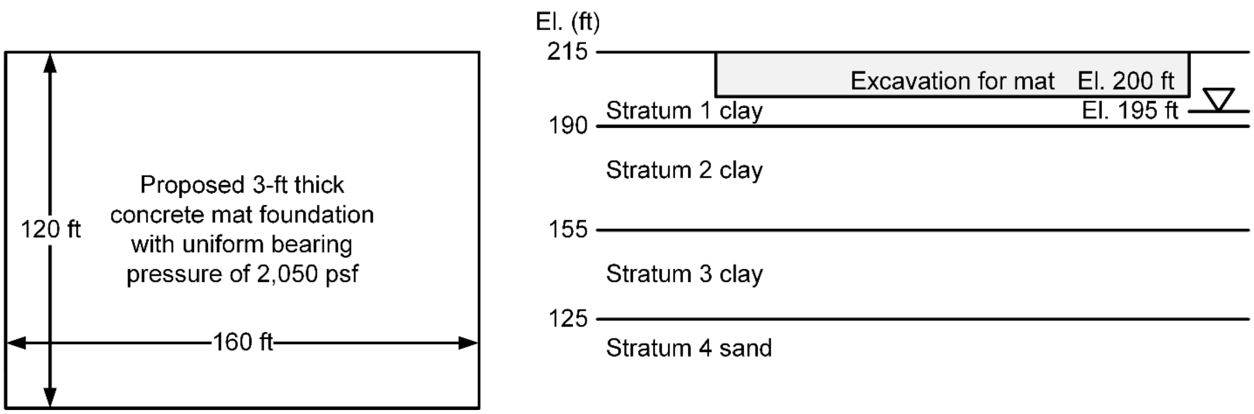


Figure B-14 Plan and Profile of Site

Table B-22 Subsurface Profile

Stratum	Description	Depth (ft)		Soil Properties			
		Top	Bottom	γ (pcf)	$C_{\varepsilon c}$	$C_{\varepsilon r}$	OCM (ksf)
1	Medium to stiff lean clay	0	25	110	0.07	0.007	2
2	Medium stiff lean clay	25	60	115	0.10	0.010	2
3	Very stiff lean clay	60	90	125	0.05	0.005	6
4	Dense fine to coarse sand	90	--				

The design of total unit weight (γ), modified compression index ($C_{\varepsilon c}$), modified recompression index ($C_{\varepsilon r}$), and overconsolidation margin (OCM) listed in Table B-22 are based on interpretation of in-situ and lab testing information as well as prior experience with the local geology. The OCM quantifies the preconsolidation and is equal to the difference between the preconsolidation stress and the current vertical effective stress at any depth. The soil properties in Table B-22 reflect the soil prior to the excavation and foundation construction. Additionally, Atterberg limits testing suggests that the Strata 1-3 clays generally have plasticity index values less than 30.

The concrete mat foundation will be 3 ft thick and support a regular grid of columns on a 25 ft spacing. The columns will impose design loads of 1,000 kips each on the mat. Based on the self-weight of the mat and uniform distribution of the column load with each column's tributary area, the bearing pressure of the mat is equal to:

$$q_{net} = (3\,ft)(150\,pcf) + \frac{1000000\,lb}{(25\,ft)^2} = 2050\,psf\ .$$

The 15-ft deep excavation in Stratum 1 soil associated with accessing the bearing grade (El. 200 ft) from the ground surface (El. 215 ft) reduces the total vertical stress on the bearing grade by 1,650 psf. It is conservatively assumed that the excavation is left open long enough for the excess pore pressures generated by the excavation to fully dissipate and the effective vertical stresses in the ground to be reduced and be in equilibrium with the excavation prior to construction of the mat. The reduction in effective vertical stress due to the excavation causes the Stratum 1-3 clays to heave according to the swell ratio, which is assumed to be equal to the recompression ratio. It is further assumed that all settlement occurs after application of the full bearing pressure, i.e. no settlement occurs during construction. This assumption is conservative, particularly for immediate settlement, which occurs simultaneously with loading.

B-4.2 Goals and Limitations of the Analysis.

The first goal of this analysis is to estimate ultimate settlements of the mat foundation due to immediate elastic distortion under loading and time-dependent consolidation. The potential for secondary compression over the service life of the foundation is not considered in this analysis. Compression of the Strata 1-3 clays is considered while compression of the Stratum 4 sand is assumed to be small enough to ignore.

The second goal of the analysis is to estimate the modulus of subgrade reaction for the service loading condition based on the results of the settlement analysis.

The analysis is performed at the plan view location of the center of the mat. A full analysis of the mat foundation for geotechnical and structural design would likely involve evaluating settlement and the modulus of subgrade reaction at multiple locations.

B-4.3 Immediate Settlement.

Immediate settlement, s_i, of the compressible clay soils of Strata 1-3 is due to distortion, i.e. shape change rather than volume change, of the clay due to the finite loaded area of the mat foundation. Immediate settlement calculations of this type are typically performed by approximating the soils that undergo distortion as a linear elastic material that experiences a uniform strain due to an applied uniform bearing pressure. The calculations require estimates of the Young's modulus, E_s, of the layers experiencing distortion as well as an estimate of the thickness of material that experiences the uniform strain. When multiple layers are present, a single composite estimate of Young's modulus can be estimated using the weighing method by layer thickness proposed by Bowles (1996). This approach does not weight layers by proximity to the bearing grade and soil profiles commonly become stiffer with depth, so care should be used when evaluating which layers to include in the calculation. The thickness of the soil experiencing the average strain is estimated by multiplying the width of the loaded area, B, by two influence factors, μ_0 and μ_1 (see Section 5-4.5).

Estimates of Young's modulus are almost always imprecise and often do not directly consider stress-strain nonlinearity. Since immediate settlement occurs with loading, the clay soils are best represented as being undrained. In this example, Young's modulus for undrained conditions is estimated using the correlation with undrained strength, OCR, and plasticity index proposed by Duncan and Buchignani (1987) as presented in Figure 8-51 of UFC 3-220-10 (UFC 2022). The Strata 1 to 3 clays generally have a plasticity index less than 30 and are slightly overconsolidated, so a ratio of Young's Modulus to undrained strength equal to 600 is a reasonable estimate. Because no direct measurements of shear strength are available, undrained strength is estimated using the correlation proposed by Jamiolkowski et al. (1985) using a fitting parameter, m, equal to 0.8. Expressing the effect of the OCR in terms of a constant value of OCM, yields:

$$s_u \approx 0.23 \cdot \sigma'_z \cdot OCR^{0.8} \approx 0.23 \cdot \sigma'_z \cdot \left(\frac{1 + OCM}{\sigma'_z} \right)^{0.8}$$

Combining the relationship among undrained strength, vertical effective stress, and OCM, with the ratio of undrained Young's modulus to undrained strength equal to 600 produces the following relationship:

$$E_{s,u} \approx 600 \cdot s_u \approx 138\sigma'_z \cdot \left(\frac{1 + OCM}{\sigma'_z} \right)^{0.8}$$

Application of the relationship above with the vertical effective stress at the middle of each stratum prior to construction and the estimates of OCM given in Table B-22 produces the estimates of Young's Modulus provided in Table B-23. For Stratum 1, the vertical stress is evaluated at the midpoint between the bearing grade of the mat foundation and the bottom of the layer at a depth of 20 ft below the ground surface.

The weighed average modulus value is equal to:

$$E_{s,u} = \frac{(509ksf)(10ft) + (661ksf)(35ft) + (1281ksf)(30ft)}{75ft} = 889ksf$$

Table B-23 Calculated Vertical Stresses, *OCR*, and Modulus at Layer Midpoints

Stratum	σ'_z (ksf)	*OCM* (ksf)	*OCR*	$E_{s,u}$ (ksf)
1	2.20	2	1.9	509
2	3.27	2	1.6	661
3	4.89	6	2.2	1281

The values of influence factors, μ_0 and μ_1, are found using the charts found in Figure 5-29. Based on the geometric ratios and interpretation of the charts presented in Figure B-15, the values of the influence factors, μ_0 and μ_1, are taken to equal 0.97 and 0.2, respectively. Using the estimated value of Young's modulus, influence factors, and bearing pressure, the estimated immediate settlement of the mat is equal to:

$$s_i = \mu_0 \mu_1 B\left(\frac{q}{E_{s,u}}\right) = (0.97)(0.2)(120ft)\left(\frac{2.05ksf}{889ksf}\right)\left(\frac{12in}{1ft}\right) = 0.64 \rightarrow \approx 0.7in.$$

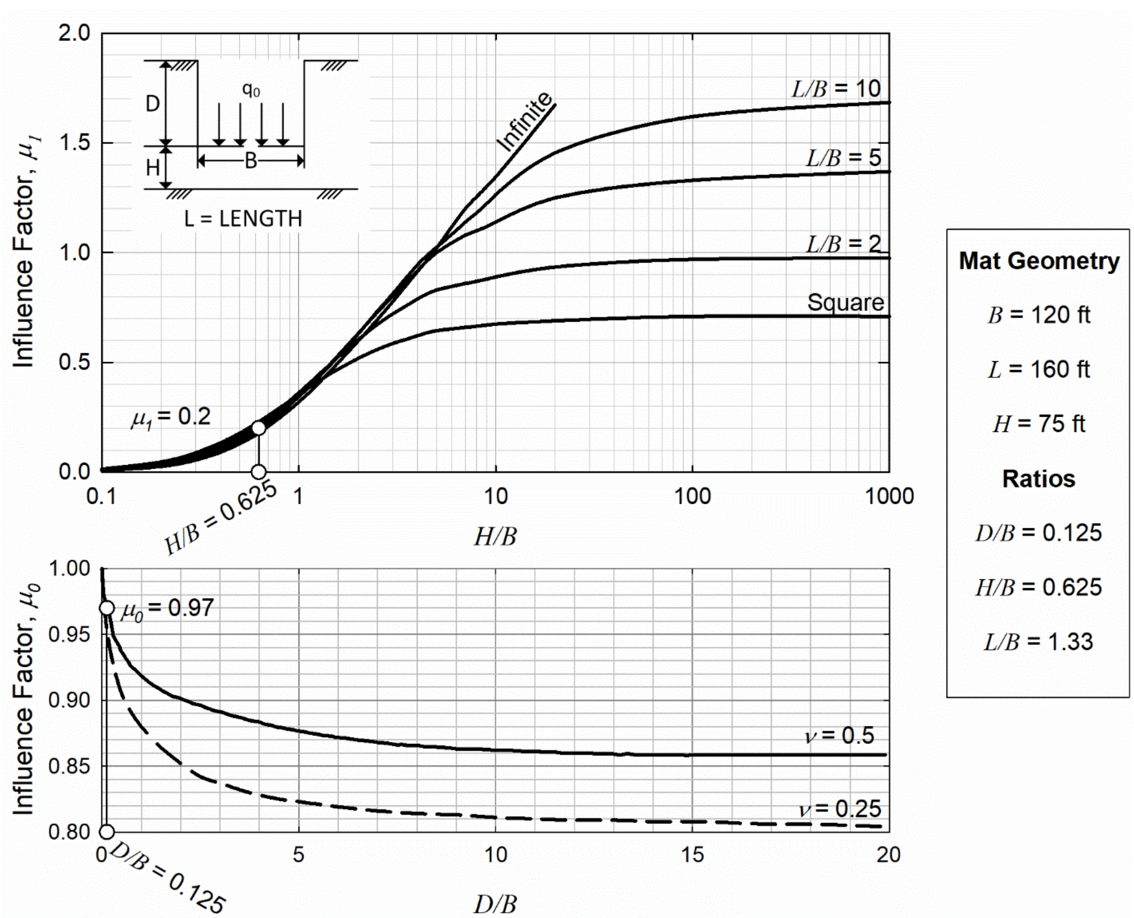


Figure B-15 Intepretation of Influence Factors for Elastic Settlement

B-4.4 Primary Consolidation.

Ultimate primary consolidation, s_c, of the compressible clay soils of Strata 1 to 3 is due to changes in effective stress from the foundation loading, incorporating the effects of the excavation on the stress history of the soils, i.e. preconsolidation stress. While commercial software and spreadsheet analysis of consolidation allow discretization of the compressible soils into a great number of thin layers, a relatively small number of layers having thickness that increases with depth from the bearing grade can produce results that closely match analyses using highly-discretized profiles. In this case ten sublayers are used as shown in Table B-24 along with the evaluation of the total and effective vertical stresses at the mid-depth of each layer prior to making the excavation for the foundation.

Table B-24 Evaluation of Initial Stresses Prior to Construction

Sublayer	Stratum	Top El. (ft)	Bottom El. (ft)	Thickness (ft)	Midpt. El. (ft)	γ_t (pcf)	At Mid-Depth σ_{z0} (psf)	At Mid-Depth u (psf)	At Mid-Depth σ'_{z0} (psf)
Excavated		215	200	15	207.5	110	825	0	825
1	1	200	195	5	197.5	110	1925	0	1925
2	1	195	190	5	192.5	110	2475	156	2319
3	2	190	185	5	187.5	115	3038	468	2570
4	2	185	175	10	180.0	115	3900	936	2964
5	2	175	165	10	170.0	115	5050	1560	3490
6	2	165	155	10	160.0	115	6200	2184	4016
7	3	155	145	10	150.0	125	7400	2808	4592
8	3	145	135	10	140.0	125	8650	3432	5218
9	3	135	125	10	130.0	125	9900	4056	5844

Table B-25 presents values of preconsolidation stress for each layer (σ'_p) found by adding the OCM to the initial vertical effective stress from Table B-24. Changes in total vertical stress due to the excavation and foundation loading are estimated using Boussinesq elastic solutions for stress changes below the corner of a flexible rectangular-loaded area as presented in Table 4-2 in UFC 3-220-10 (UFC 2022). Stress changes due to the excavation are represented by $\Delta\sigma_{ze}$ and stress changes due to the foundation construction and loading are represented by $\Delta\sigma_{zl}$. The effective vertical stress after the excavation, σ'_{ze}, is the initial effective stress used in the strain calculations and the final effective stress, σ'_{zf}, is equal to the sum of σ'_{ze} and $\Delta\sigma_{zl}$.

Strain due to ultimate consolidation settlement is found according to:

$$\varepsilon_{z,ult} = C_{\varepsilon r} \log\left(\frac{\min\left(\sigma'_p, \sigma'_{zf}\right)}{\sigma'_{ze}}\right) + C_{\varepsilon c} \log\left(\frac{\max\left(\sigma'_p, \sigma'_{zf}\right)}{\sigma'_c}\right).$$

Table B-25 Evaluation of Preconsolidation Stress and Stress Changes

Sublayer	Stratum	***OCM*** **(psf)**	σ'_c **(psf)**	$\Delta\sigma_{ze}$ **(psf)**	σ'_{ze} **(psf)**	$\Delta\sigma_{zl}$ **(psf)**	σ'_{zf} **(psf)**
1	1	2000	3925	-1650	275	2050	2325
2	1	2000	4319	-1648	671	2048	2719
3	2	2000	4570	-1642	927	2040	2968
4	2	2000	4964	-1621	1343	2013	3357
5	2	2000	5490	-1563	1927	1942	3869
6	2	2000	6016	-1476	2540	1834	4374
7	3	6000	10592	-1368	3224	1700	4924
8	3	6000	11218	-1251	3967	1555	5521
9	3	6000	11844	-1134	4710	1409	6119

Table B-26 summarizes the ultimate strain and compression, ΔH_{ult}, of each sublayer. The sum of the sublayer compressions equals the ultimate consolidation settlement, $\delta_{c,ult}$. In this case, the consolidation settlement is approximately 2.4 inches.

Table B-26 Strain and Compression Calculations

Sublayer	Stratum	$C_{\varepsilon c}$	$C_{\varepsilon r}$	$\varepsilon_{z,ult}$	Thickness (ft)	ΔH_{ult} **(ft)**
1	1	0.070	0.007	0.0065	5	0.032
2	1	0.070	0.007	0.0043	5	0.021
3	2	0.100	0.010	0.0051	5	0.025
4	2	0.100	0.010	0.0040	10	0.040
5	2	0.100	0.010	0.0030	10	0.030
6	2	0.100	0.010	0.0024	10	0.024
7	3	0.050	0.005	0.0009	10	0.009
8	3	0.050	0.005	0.0007	10	0.007
9	3	0.050	0.005	0.0006	10	0.006
					$\delta_{c,ult} = \Sigma\Delta H$ (ft) =	0.195

B-4.5 Modulus of Subgrade Reaction.

The modulus of subgrade reaction is calculated for two conditions: 1) considering the immediate settlement response of the loaded mat foundation and 2) considering the additional time-dependent settlement from primary consolidation.

The modulus of subgrade reaction for the immediate response of the loaded mat foundation, k_s, is found by:

$$k_s = \frac{q}{s_i} = \frac{2.05 ksf}{0.7\, in.}\left(\frac{1000\, lb}{1\, k}\right)\left(\frac{1\, ft^2}{144\, in^2}\right) = 20.3\, pci\,.$$

Including the time-depending settlement from primary consolidation further reduces the modulus of subgrade reaction, k_{sc}. Using a value for s_i equal to 0.7 inches, a value for s_c equal to 2.4 inches, and a bearing pressure equal to 2.05 ksf (14.24 psi) produces:

$$k_{sc} = \frac{q}{s_i + s_c} = \frac{14.24\, psi}{0.7\, in + 2.4\, in} = 4.6\, pci\,.$$

B-4.6 Conclusions from the Analysis.

Settlement of the proposed mat foundation was calculated. The immediate and consolidiation settlements are summarized in Table B-27. The subgrade reaction moduli are also provided.

Table B-27 Summary of Estimated Settlements and Subgrade Reaction Moduli

Design Parameter	Value
Immediate settlement, s_i	0.7 inches
Consolidation settlement, s_c	2.4 inches
Immediate modulus of subgrade reaction, k_s	20.3 pci
Long-term modulus of subgrade reaction, k_{sc}	4.6 pci

B-5 EXAMPLE 5 ‑ PILE GROUP CAPACITY AND SETTLEMENT.

B-5.1 Description of the Problem.

A bridge pier will be supported on concrete driven piles. The soil profile consists of normally consolidated soft clay overlying overconsolidated stiff clay as shown in Figure B-16. The proposed construction includes placement of 8 ft of new fill of broad lateral extent.

The bridge pier will require a foundation capable of supporting a permanent unfactored static axial compressive load acting on the pile cap equal to 1,500 kips and an additional 600 kips due to transient vertical live loads. Lateral loads, uplift, and moments are not considered in this example.

Square precast prestressed concrete (PPC) piles having a 12-inch side length are selected for the project due to sourcing and transport considerations. The supplier produces piles up to a maximum length of 70 ft using 5,000 psi concrete that have a factored structural resistance in compression, P_r, equal to 200 kips. The piles will be installed in a square array with a center-to-center spacing of 3-ft and tied together in a 3.5-ft thick reinforced concrete cap. The weight of the cap and overlying soil should be added to the unfactored permanent loads considered in this analysis.

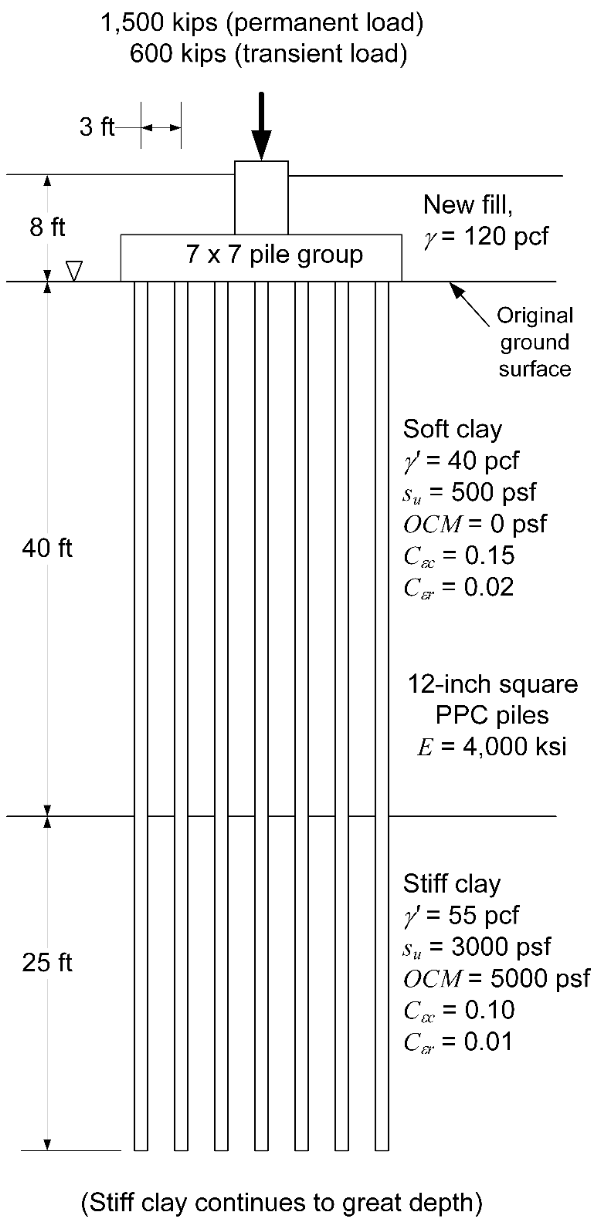


Figure B-16 Proposed Pile Group in Soft and Stiff Clay

B-5.2 Goals and Limitations of the Analysis.

The goal of this analysis is to check the proposed length and number of PPC piles against the geotechnical strength limit state and a serviceability limit with respect to settlement. The performance requirements as well as assumptions and simplifications are listed below:

- The geotechnical strength limit state is checked using load factors equal to 1.25 for permanent loads and 1.75 for transient loads. The geotechnical resistance for individual piles is estimated using the Alpha Method with a resistance factor equal to 0.35. Block failure of the group is checked using a resistance factor equal to 0.60.
- The structural strength limit state for the axial pile capacity is checked using load factors equal to 1.25 for permanent loads and 1.75 for transient loads
- The serviceability limit state with respect to settlement considers unfactored permanent loads only. Analysis results where 50% of the transient live loads are included in addition to the permanent loads are also presented. A limit on ultimate settlement of the pile cap equal to 3 inches is selected based on considerations for acceptable angular distortion and post construction settlement. Time rate of settlement analysis is not part of this example.
- Settlement analysis is limited to elastic shortening of the piles above the neutral plane and consolidation of clay soils below the neutral plane. Stress shielding and soil stiffening effects of the piles and cap are conservatively ignored.

The analysis will utilize the neutral plane method to evaluate the maximum load in the pile for the structural strength limit state check and to position the equivalent footing for the settlement analysis.

B-5.3 Trial Dimensions.

This example is performed for a square arrangement of 49 piles having a trial length below the pile cap equal to 65 ft. It is assumed that additional pile length to account for cutoff and embedment in the cap can be included within the 70 ft maximum length constraint. The cap is buried and will remain in contact with the ground.

For this arrangement, a cap width and length equal to 21 ft accommodates the piles with an allowance of 1 ft between the edge of the pile and the edge of the cap. The weight of the cap and overlying soil, $W_{cap+soil}$, is equal to:

$$W_{cap+soil} = \left(21ft\right)^2\left[\left(3.5ft\right)\left(0.15kcf\right)+\left(8ft-3.5ft\right)\left(0.12kcf\right)\right] = 470\,kips\ .$$

The permanent load from the superstructure acting on the pile cap plus the weight of the cap and the overlying soil equals the unfactored permanent load acting on the pile group:

$$Q_{g,d} = 1500\,kips + 470\,kips = 1976\,kips\,.$$

B-5.4 Geotechnical Strength Limit State Analysis.

For the trial dimensions described in Section 1-7.3, the pile group must resist a factored load equal to

$$Q'_g = (1.25)(1976\,kips) + (1.75)(600\,kips) = 3520\,kips\,.$$

Nominal shaft resistance for the soft and stiff clays is evaluated according to the Alpha method described in Section 6-5.4.2. As shown in Figure B-17, interpreted values of α for the soft and stiff clay, α_{soft} and α_{stiff}, are equal to 1.0 and 0.5, respectively. Fully-mobilized shaft friction per unit area for the soft and stiff clay, $f_{s,soft}$ and $f_{s,stiff}$ respectively, is equal to

$$f_{s,soft} = \alpha_{soft} \cdot s_{u,soft} = 1.0 \cdot (500\,psf) = \pm 500\,psf$$
$$f_{s,stiff} = \alpha_{stiff} \cdot s_{u,stiff} = 0.5 \cdot (3000\,psf) = \pm 1500\,psf$$

where the positive and negative signs indicate that shaft friction can be positive (shaft resistance) or negative (drag force), depending on the location of the neutral plane.

It possible that the soft clay will be dragged into a portion of the stiff clay and reduce shaft resistance. A length of pile equal to 10 times the width, in this case 10 ft, below top of the stiff clay is assigned a value of α according to Equation 6-9 in Section 6-5.4.2 based on guidance by Tomlinson (1980). For the current example,

$$f_{s,transition} = 0.28 \cdot s_{u,stiff} \left(\frac{s_{u,stiff}}{P_a}\right)^{-0.44} = 0.28(3000\,psf)\left(\frac{3000\,psf}{2116\,psf}\right)^{-0.44} = \pm 720\,psf\,.$$

Based on this approach, the load transfer per unit length of shaft, Δp, for the soft clay, stiff clay, and transition zone is equal to:

$$\Delta p_{soft} = 4 \cdot B \cdot f_{s,soft} = 4(1\,ft)(500\,psf) = \pm 2000\,lb/ft = \pm 2\,k/ft$$
$$\Delta p_{transition} = 4 \cdot B \cdot f_{s,transition} = 4(1\,ft)(720\,psf) = \pm 2900\,lb/ft = \pm 2.9\,k/ft$$
$$\Delta p_{stiff} = 4 \cdot B \cdot f_{s,stiff} = 4(1\,ft)(1500\,psf) = \pm 6000\,lb/ft = \pm 6\,k/ft$$

where B is the width of the square pile. For the sign convention adopted here, positive values of Δp indicate load transfer from the pile to the soil, i.e. resistance, and negative values of Δp indicate load transfer from the soil to the pile, i.e. drag force.

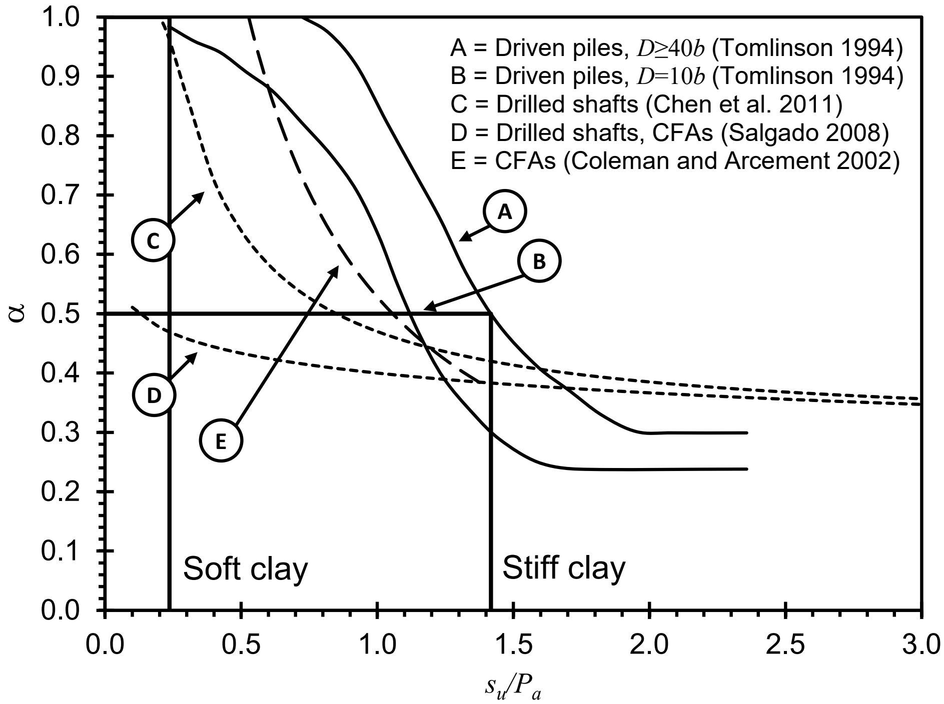


Figure B-17 Interpretation of Alpha Factor

For the total embedded length of the pile, the nominal shaft resistance equals:

$$R_s = (40\,ft)(2\,k/ft) + (10\,ft)(2.9\,k/ft) + (15\,ft)(6\,k/ft) = 199\,kips$$

and the nominal base resistance equals:

$$R_b = 9 \cdot s_u \cdot B^2 = 9 \cdot (3000\,psf) \cdot (1\,ft)^2 = 27000\,lb = 27\,kips.$$

The total nominal pile resistance, R_n, is equal to 226 kips. Because the pile cap is in contact, the group efficiency factor (η_g) is equal to 1.0 (Table 6-26). The resistance factor is equal to 0.35, and the factored combined single pile capacity for is equal to

$$n\left(\eta_g R_{r,s}\right) = 49\left(1.0 \cdot 0.35 \cdot 226\,kips\right) = 3876\,kips.$$

Since the pile group includes more than 4 piles, a 20% reduction to the resistance factor is not needed. The resistance against block failure is checked according to

$$R_{n,gblock} = 2 \cdot L \cdot (B + Z) \cdot s_{u,1} + B \cdot Z \cdot s_{u,2} \cdot N_c$$

where L, B, and Z are the pile group dimensions provided in Figure 6-15 and N_c is the bearing capacity factor found by:

$$N_c = 5\left(1+0.2\frac{18ft}{18ft}\right)\left(1+0.2\frac{60ft}{18ft}\right)=10 \rightarrow \text{Use maximum value of } N_c = 9$$

The weighted average shear strength along the sides of the block, $s_{u,1}$, is found by

$$s_{u,1} = \frac{s_{u,soft}L_{soft} + s_{u,stiff}L_{stiff}}{L_{soft}+L_{stiff}} = \frac{(0.5ksf)(40ft)+(3ksf)(20ft)}{60ft} = 1.33ksf$$

and the shear strength at the base of the block, $s_{u,2}$, is equal to 3 ksf.

Using these values, the nominal resistance again block failure is equal to

$$\begin{aligned} R_{n,gblock} &= 2\cdot(60ft)\cdot(18ft+18ft)(1.33ksf)+(18ft)(18ft)(3ksf)(9)=14494\,kips \\ R_{r,gblock} &= 0.6(14494\,kips)=8696\,kips \end{aligned}.$$

After applying a reduction factor equal to 0.6 for resistance to block failure, the combined single pile capacity is determined to control the capacity of the group:

$$R_{r,g} = \min\begin{cases} n(\eta_g R_{r,s}) = 3876\,kips \\ R_{r,gblock} = 8696\,kips \end{cases} = 3876\,kips$$

The geotechnical strength limit state is checked by comparing the factored resistance to the factored load acting on the pile group. The trial design is adequate with respect to the geotechnical strength limit state because the factored resistance is greater than or equal to the factored resistance:

$$3876\,kips = R_{r,g} \geq Q'_g = 3520\,kips\,.$$

B-5.5 Neutral Plane Analysis.

The unfactored permanent load and resistance curves for the trial design are shown in Figure B-18. The load curve was generated by computing the permanent load acting on the top of each pile and adding the accumulated drag force according to the due to negative skin friction according to

$$P_z = Q_d - \sum \Delta p_{soil}\cdot z_{soil}$$

where:
P_z = load in the pile as a function of depth,

Q_d = unfactored permanent load acting on top of a single pile,
Δp_{soil} = unit load transfer for each soil layer, and
z_{soil} = the depth below the top of each soil layer.

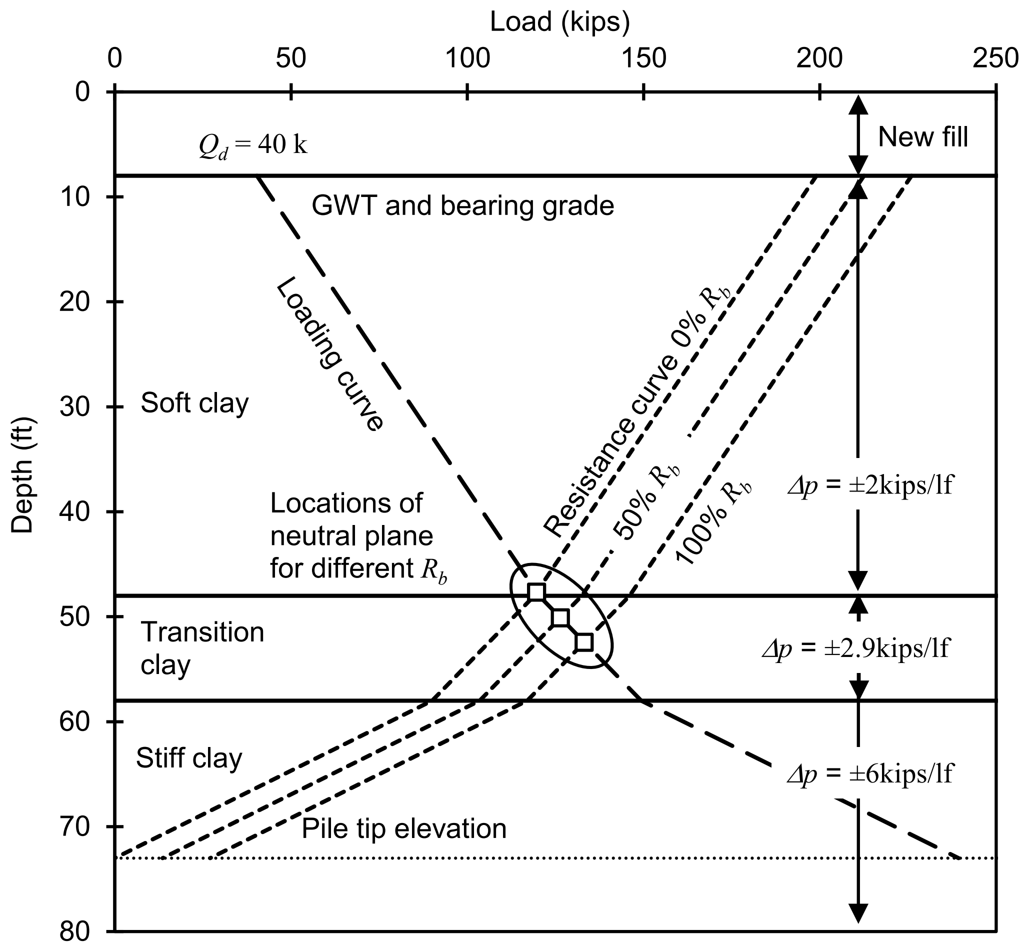


Figure B-18 Load and Resistance Curves

Based on the adopted sign convention, values of Δp_{soil} are negative. In this example, each pile is assumed to carry equal load; therefore, for 49 piles the load equals

$$Q_d = \frac{1976\,kips}{49} = 40\,kips\,.$$

The resistance curves shown in Figure B-18 were generated by computing the nominal single-pile geotechnical resistance and subtracting the accumulated resistance along the pile according to

$$R_z = R_n - \sum \Delta p_{soil} \cdot z_{soil}$$

where:
R_z = nominal geotechnical resistance as a function of depth.

Based on the adopted sign convention, values of Δp_{soil} are positive. To address uncertainty about the mobilization of base resistance, resistance curves are provided for 0%, 50%, and 100% mobilization of base resistance as recommended by Siegel et al. (2013).

The neutral plane is located at the intersection of the load curve with the resistance curve. The maximum load in the pile occurs at the neutral plane. It is apparent from Figure B-18 that mobilization of base resistance increases the depth of the neutral plane. The depth of the neutral plane is also increased by reducing the load applied to the top of the pile and increasing the penetration depth of the pile. As shown in Section 6-5.8.4, the estimated settlement increases as the position of the neutral plane moves closer to the top of the pile.

Table B-28 summarizes the key information used to generate and interpret the load and resistance curves for the trial pile design. The curves change with changes to the design, e.g. changes to the size, number, and/or length of piles.

Table B-28 Key Values for Load and Resistance Curves

Depth below ground surface, z (ft)	Loading curve values (kips)	Resistance curve values (kips), $R_b = 0\%$	Resistance curve values (kips), $R_b = 50\%$	Resistance curve values (kips), $R_b = 100\%$
8	40	199	213	226
48	120	119	133	146
58	149	90	104	117
73	239	0	14	27
Depth to neutral plane below ground surface, z_{np} (ft)		48	50	52
Max load in the pile, P_{max} (kips)		120	126	133

B-5.6 Structural Strength Limit State Analysis.

The factored structural resistance of the pile in compression, P_r, is equal to 200 kips as given in Section B-5.1. The factored resistance must be greater than or equal to the factored permanent load, including the largest drag force estimated by the neutral plane analysis in Section B-5.5. The check performed using Equation 6-80 in Section 6-7.4 shows that the trial design is acceptable with respect to the structural strength limit state:

$$1.25 \cdot Q_d + 1.1\left(Q_{np} - Q_d\right) \leq P_r$$
$$1.25\left(40\,kips\right) + 1.1\left(133\,kips - 40\,kips\right) \leq 200\,kips$$
$$152\,kips \leq 200\,kips$$

B-5.7 Settlement Analysis.

Settlement of the pile cap is evaluated considering consolidation of the clay below the neutral plane and elastic compression of the piles above the neutral plane.

The ultimate consolidation settlement of the clay below the neutral plane is estimated using an equivalent footing located at the neutral plane. The vertical stress in the soil below the footing is increased due to the weight of the new fill and the unfactored permanent load shed from the piles to the ground. As stated in Section B-5.2, this analysis conservatively ignores the effects that piles can have on the ground which tend to stiffen the soil, i.e. decrease compressibility, and shield the soil within the pile group from increases in stress due to surface loads.

As demonstrated in Section B-5.2, the position of the neutral plane depends on many factors, including the degree to which base resistance is mobilized. The details of the settlement analysis assuming 50% mobilization of base resistance are presented here; however, settlements for 0% and 100% mobilization are also provided. Estimated settlement decreases as the assumed mobilization of base resistance increases.

For 50% mobilization of base resistance, the neutral plane is located 50 ft below the final ground surface. The equivalent footing positioned at the neutral plane has dimensions B and L equal to 18 ft based on the 7x7 square arrangement of piles on a 3-ft center-to-center spacing. Table 29 provides the boundaries, initial thickness, H_0, and average vertical effective stress ($\sigma'_{z,0}$) for ten compressible sublayers located below the footing. The boundaries for the sublayers were chosen to concentrate thin layers at the top of the profile where changes in stress are largest and to terminate the overall profile considered in the analysis at the depth where the stress change due to the equivalent footing falls below 10% of the initial vertical effective stress as recommended by FHWA (2016).

Table B-29 Delineation of Compressible Soil Profile and Initial Vertical Stress

Sublayer	z_{top} (ft)	H_0 (ft)	z_{bot} (ft)	z_{mid} (ft)	$\sigma'_{z,0}$ (psf)
1	50	1	51	50.5	1737.5
2	51	2	53	52	1820
3	53	2	55	54	1930
4	55	4	59	57	2095
5	59	4	63	61	2315
6	63	6	69	66	2590
7	69	6	75	72	2920
8	75	8	83	79	3305
9	83	8	91	87	3745
10	91	8	99	95	4185

The position of the neutral plane is below the bottom of the soft clay. Thus only the stiff clay is represented in the settlement analysis with properties given in Figure B-16. For each sublayer, Table B-30 presents the preconsolidation stress (σ'_c), stress change due to placement of the new fill ($\Delta\sigma_{z,fill}$), stress change due to the pile group loads ($\Delta\sigma_{z,piles}$), final effective stress ($\sigma'_{z,f}$), vertical strain ($\varepsilon_{z,ult}$), and compression (ΔH). Strain calculations are performed according to:

$$\varepsilon_{z,ult} = C_{\varepsilon r}\log\left(\frac{\min\left(\sigma'_p,\sigma'_{zf}\right)}{\sigma'_{z0}}\right) + C_{\varepsilon c}\log\left(\frac{\max\left(\sigma'_p,\sigma'_{zf}\right)}{\sigma'_p}\right).$$

Table B-30 Consolidation Settlement Calculations

Sublayer	σ'_c (psf)	$\Delta\sigma_{z,fill}$ (psf)	$\Delta\sigma_{z,piles}$ (psf)	σ'_{zf} (psf)	$\varepsilon_{z,ult}$	H_0 (ft)	ΔH (ft)
1	6737.5	960	5774	8471	0.0158	1	0.016
2	6820	960	4940	7720	0.0111	2	0.022
3	6930	960	4083	6973	0.0058	2	0.012
4	7095	960	3162	6217	0.0047	4	0.019
5	7315	960	2350	5625	0.0039	4	0.015
6	7590	960	1709	5259	0.0031	6	0.018
7	7920	960	1235	5115	0.0024	6	0.015
8	8305	960	895	5160	0.0019	8	0.015
9	8745	960	653	5358	0.0016	8	0.012
10	9185	960	498	5643	0.0013	8	0.010
						$\Sigma\Delta H =$	0.15

The sum of the sublayer compressions provides the estimated magnitude of ultimate consolidation settlement, $\delta_{c,ult}$, equal to 0.15 ft (1.9 in).

The elastic compression of the piles above the neutral plane is due to the permanent load applied to the pile and the drag force. Elastic compression is evaluated by discretizing the pile into intervals of length that can be reasonably modeled by an average axial load, $P_{z,avg}$. The compression of each interval is estimated according to

$$\Delta L = \frac{P_{z,avg}\cdot L_0}{E\cdot A}$$

where:
L_0 = initial length of the interval of pile above the neutral plane,
E = Young's Modulus of the pile material, and
A = area of the pile cross section.

Table B-31 summaries the elastic compression calculations. The magnitude of elastic compression, δ_e, is estimated to equal 0.006 ft (0.1 in), which is an amount that is arguably smaller than what can be estimated using simple elastic methods.

Table B-31 Estimated Elastic Compression of the Piles above the Neutral Plane

Sublayer	z_{top} (ft)	L_0 (ft)	z_{bot} (ft)	z_{mid} (ft)	$P_{z,bot}$ (kips)	$P_{z,top}$ (kips)	$P_{z,avg}$ (kips)	ΔL (ft)
1	8	40	48	28	120	40	80	0.0056
2	48	2	50	49	126	120	123	0.0004

The total estimated settlement for the trial design, assuming 50% mobilization of base resistance is equal to 2.0 inches, which is below the limit of 3 inches. For the case of 0% base resistance, the settlement increases slightly to 2.1 inches and for the case of 100% base resistance, the estimated settlement remains equal to 2.0 inches. Therefore, the settlement is not significantly sensitive to the mobilization of base resistance for the conditions considered in the analysis.

B-5.8 Conclusions from Analysis.

Based on the analysis provided herein, a square arrangement of 49 piles having an embedded length of 65 ft below the bottom of the pile cap is satisfactory with respect to the geotechnical limit state (Section B-5.4), structural strength limit state (Section B-5.6), and serviceability limit state with respect to settlement (Section B-5.7).

However, if a portion of the transient live load is included in the neutral plane and settlement analysis, the depth of the neutral plane decreases. If the neutral plane is located within the soft clay, the estimated settlement can increase significantly. For example, for the case where 50% of the transient load is included in the neutral plane and settlement analysis, i.e. the unfactored load on each pile is 46.5 kips, and it is assumed that 0% of base resistance is mobilized, the neutral plane moves from the previously-estimated depth of 50 ft to a depth of 46 ft, which is 2 ft above the bottom of the normally-consolidated soft clay. The combination of the increased load on each pile and the shallower neutral plane, increases the estimated settlement from 2 inches to 4.8 inches, which exceeds the serviceability limit of 3 inches. The majority of the additional settlement is due to compression of the normally-consolidated soft clay below the neutral plane. However, if the stiffening effects of the piles are taken into account, for example by placing the equivalent footing at the bottom of the piles, the estimated settlement decreases from 4.8 inches to 1.9 inches.

Therefore, designers should carefully consider the characterization of subsurface conditions, the loads used, and assumptions made for this type of analysis. It is also important to consider the potential for stress overlap from nearby loads, e.g. adjacent pile caps.

B-6 EXAMPLE 6 – LATERAL LOAD ANALYSIS.

B-6.1 Description of the Problem.

For the pile-supported bridge pier considered in Example 5, evaluate the serviceability state limit with respect to lateral deflection of the pile cap due to an applied longitudinal shear load of 300 kips, i.e. a shear load parallel to the bridge span. The 300 kip load is comprised of a 100 kip permanent load and a 200 kip transient load. Transverse shear loads and applied moments are equal to zero in this example. Figure B-19 provides useful information for this example.

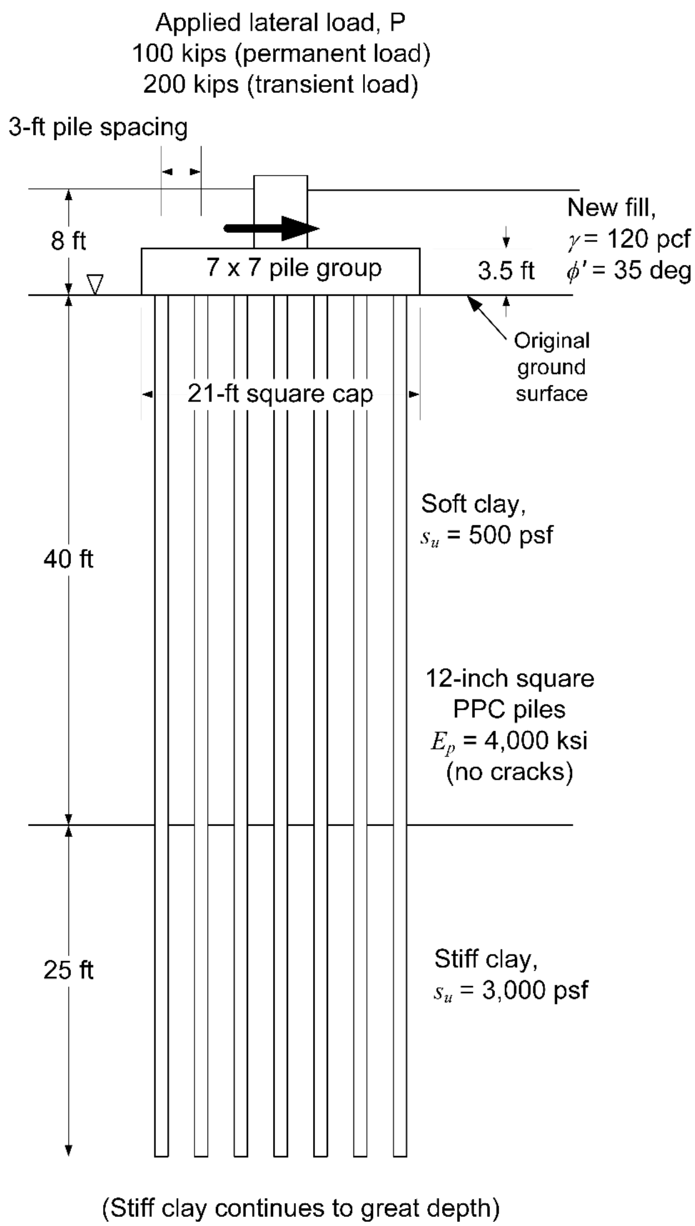


Figure B-19 Laterally Loaded Pile Group in Soft and Stiff Clay

B-6.2 Goals and Limitations of the Analysis.

The goal of this analysis is to determine whether the trial pile design analyzed in Example 6 satisfies the geotechnical strength limit state and serviceability limit state with respect to lateral deflection of the pile cap. The performance requirements as well as assumptions and simplifications are listed below:

- Both the geotechnical strength and service limit states only consider the application of shear load at the cap elevation, i.e. no moment is applied to the cap. The geotechnical resistance of the piles and pile cap are unfactored for both limit states. For the geotechnical strength limit state, the inverse of the resistance factor, equal to 0.8, is applied to the factored load, i.e. 1/0.8 = 1.25 (see Section 6-6.2.1).
- The geotechnical strength limit state is evaluated using load factors equal to 1.25 for permanent loads and 1.75 for transient loads. In actual design, factored load demands are typically determined using an iterative process of structural modeling and foundation response.
- The serviceability limit state with respect to lateral deflection is evaluated using unfactored loads. The limit on lateral deflection of the pile cap is equal to 0.5 inches based on consideration of negative impacts on the superstructure and alignment of the pier.
- The response of the pile group is modeled using the Characteristic Load Method (CLM) (Section 6-6.4.3) as adapted to pile groups (Section 6-6.5).
- The piles are modeled using a constant bending stiffness, i.e. nonlinear effects from concrete cracking are not considered. In this case, this assumption is deemed reasonable since the deflection limit is small. Furthermore, the effects of axial load on bending resistance and lateral deflection are not considered.
- The response of the pile cap is modeled using Rankine earth pressure theory and the simplified hyperbolic load-deflection relationship presented in Section 6-6.5.
- The piles are embedded a minimum of 12 inches into the pile cap; however, the degree of fixity is unknown.
- Scour and seismic considerations are not addressed in this example.

This analysis includes estimating the maximum bending moment developed in the piles for the serviceability limit state. This moment is not the value used to evaluate the structural strength limit state.

B-6.3 Characteristic Load Method Analysis

The CLM is suitable for modeling long piles in uniform ground. Since the pile length exceeds $18 \cdot b$ (18ft), the piles meet the minimum length requirement of the CLM. Since the upper $8 \cdot b$ (8ft) of the pile is in uniform soft clay, the ground conditions meet the uniform ground requirement of the CLM.

B-6.3.1 Calculation of p-Multiplier

Due to pile-soil-pile interaction, the softening of the p-y response of the ground is captured using a weighted average p-multiplier. There are 7 rows of piles aligned perpendicular to the applied lateral load. Table B-32 summarizes calculation of the weighted average p-multiplier as proposed by Mokwa (1999) using the equations in Table 6-38 for a normalized spacing, s/b, equal to 3.

Table B-32 Calculation of Weighted p-Multiplier

p-Multiplier	Equation and Result
1st row	$p_m = 0.06(3) + 0.64 = 0.82$
2nd row	$p_m = 0.11(3) + 0.34 = 0.67$
3rd row	$p_m = 0.14(3) + 0.16 = 0.58$
4th – 7th rows	$p_m = 0.16(3) + 0.04 = 0.52$
Average: $p_m = (0.82 + 0.67 + 0.58 + 0.52 + 0.52 + 0.52 + 0.52) / 7 = 0.593$	

B-6.3.2 Calculation of the Characteristic Load and Moment.

The characteristic load and moment are calculated for the PPC pile in soft clay according to equations provided in Table 6-29 in Section 6-6.4.3. These equations require finding the ratio (R_I) of the moment of inertia of the pile section (I_p) to the moment of inertia of a solid circular section (I_{circ}). For an uncracked solid square section,

$$R_I = \frac{I_p}{I_{circ}} = \left(\frac{64}{\pi b^4}\right)\left(\frac{b^4}{12}\right) = 1.70$$

Applying the conditions considered in this example, the characteristic load equals:

$$P_c = 7.34(12\,in)^2(4000 ksi)(1.70)\left(\frac{(500\,psf)(0.593)}{(4000\,ksi)(1.70)(144000\,psf/ksi)}\right)^{0.68} = 265\,kips$$

and the characteristic moment equals:

$$M_c = 3.86(12\,in)^3(4000 ksi)(1.70)\left(\frac{(500\,psf)(0.593)}{(4000\,ksi)(1.70)(144000\,psf/ksi)}\right)^{0.46} = 45457\,in-kips\ .$$

B-6.3.3 Lateral Resistance of the Pile Cap.

The embedded pile cap is assumed to mobilize some amount of passive resistance on the leading face, full active pressure on the trailing face, and no shear resistance on the sides and base (Figure B-20). The resistance provided by the pier is also ignored.

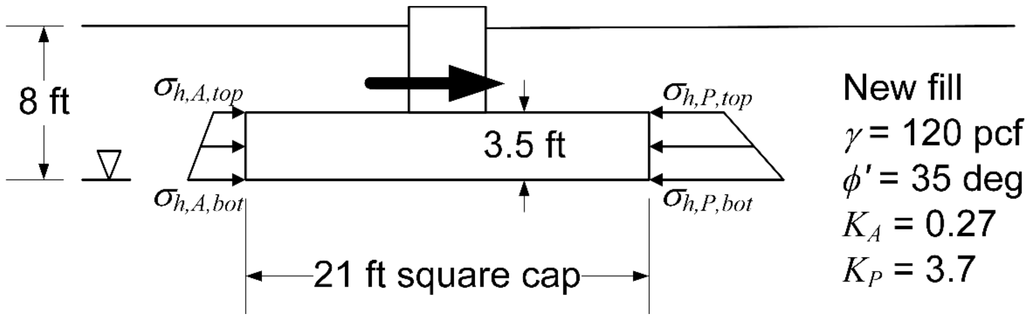


Figure B-20 Development of Active and Passive Pressures on Pile Cap

For the sand surrounding the pile cap having a friction angle of 35 degrees, the Rankine active and passive coefficients are equal to 0.27 and 3.7, respectively. As mentioned in Section 6-6.5, the use of Rankine earth pressure theory results in a conservative (in some cases excessively conservative) estimate of passive resistance. Table B-33 presents the fully-mobilized active and passive pressures and calculation of the active and passive earth forces.

Table B-33 Pile Cap Pressure Calculations

Calculation	Active side	Passive side
Pressure at top of cap	$\sigma'_{h,a,top}$ = 0.27(4.5 ft)(120 pcf) = 146 psf	$\sigma'_{h,p,top}$ = 1998 psf
Pressure at bottom of cap	$\sigma'_{h,a,bot}$ = 259 psf	$\sigma'_{h,p,bot}$ = 3552 psf
Fully-mobilized lateral earth force	P_a = 0.5(146+259 psf)(3.5 ft)(21 ft)(1 k/1000 lb) = 15 kips	P_p = 204 kips

Assuming that active resistance is fully mobilized by any pile cap deflection and passive resistance is mobilized according to the simplified hyperbolic relationship presented in Section 6-6.5, the resistance provided by the pile cap is equal to

$$P_{cap,mob} = \left[\max \begin{cases} 15\,kips \\ 204\,kips\left(\dfrac{y_t}{0.85y_t + 0.006(3.5\,ft)(12\,in/ft)}\right) \end{cases} \right] - 15\,kips$$

where:
y = average pile cap deflection in inches.

B-6.3.4 Lateral Deflection at the Geotechnical Strength Limit State.

Since the mobilization of cap resistance is a function of deflection, the geotechnical strength limit state is evaluated by incrementally increasing deflection up to a failure criterion defined by a deflection equal to 10% of the pile width. In this case, 1.2 inches of deflection defines the strength limit state. The lateral load at the deflection limit is P_{limit}. The trial design is acceptable if P_{limit} equals or exceeds the factored load multiplied by the inverse of the resistance factor, P'' or:

$$P_{limit} \leq \frac{1}{\varphi} P_{factored} = P"$$

$$P" = \left(\frac{1}{0.8}\right)\left[(1.25)(100\,kips) + (1.75)(200)\,kips\right]$$

A version of Equation 6-67 in Section 6-6.4.3 adapted to the pile group is used to estimate the lateral resistance provided by the piles as a function of deflection.

$$P_{t,group} = (49\,piles)\left(265\frac{kips}{pile}\right)\left(\frac{1}{a}\frac{y_t}{12\,in}\right)^{\frac{1}{n}}.$$

Values for the constants a and n are given in Table 6-31. For piles in clay, the constants a and n are equal to 50 and 1.822, respectively, for a free head condition and 14 and 1.846, respectively, for a fixed head condition.

The average deflection of the pile cap is assumed to equal the deflection at the top of the pile. The combined lateral resistance of the piles and cap, $P_{cap+piles}$, as a function of deflection is found by:

$$P_{cap+piles} = (49\,piles)\left(265\frac{kips}{pile}\right)\left(\frac{1}{a}\frac{y_t}{12\,in}\right)^{\frac{1}{n}} + \left[\max\left\{\begin{array}{c} 15\,kips \\ 204\,kips\left(\dfrac{y_t}{0.85y_t + 0.252}\right)\end{array}\right.\right] - 15\,kips$$

A series of values of y_t can be assumed and the corresponding lateral resistance is calculated. Figure B-21 shows the development of lateral resistance as a function of deflection for the cases of 0% and 100% fixity. In both cases, the resistance at the failure criterion of 1.2 inches of deflection exceeds the maximum load, indicating that the trail design is acceptable with respect to the geotechnical strength limit state. While rotational restraint is not required to satisfy the geotechnical strength limit state in this example, it is apparent that rotational restraint contributes significantly to the overall lateral stiffness. If a free head condition is present, cap resistance is required to meet the deflection criteria.

B-6.3.5 Lateral Deflection at the Service Limit State.

Figure B-22 shows that the unfactored lateral load of 300 kips produces lateral deflections less than 0.5 inches, regardless of fixity. Cap resistance must be considered to meet this criterion for a free head condition.

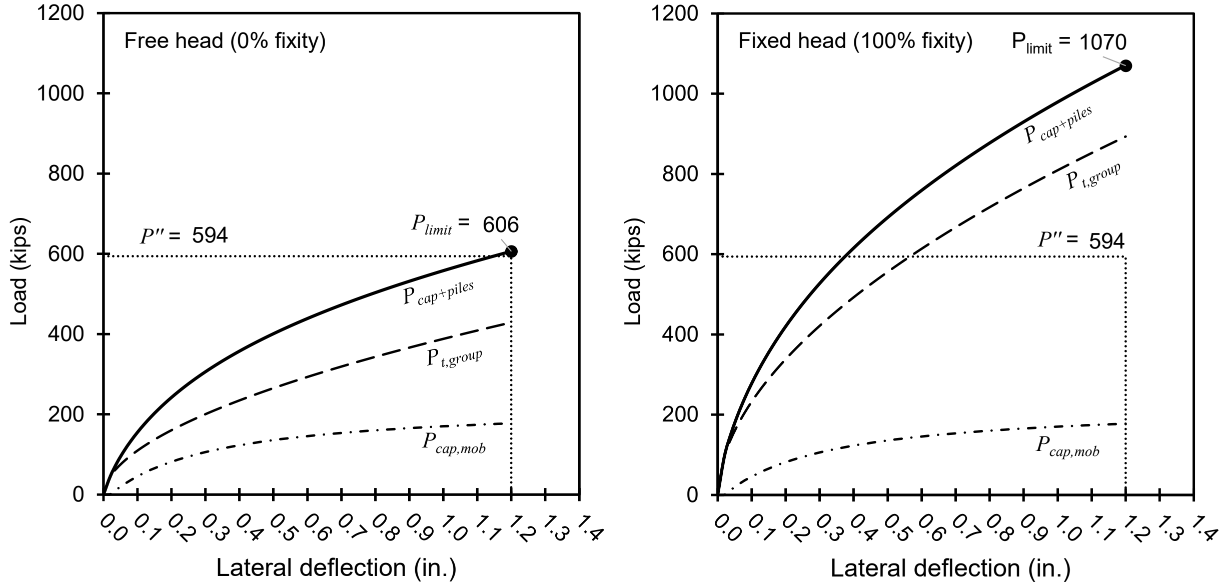


Figure B-21. Load-Deflection Relationship with Strength Limit State Check

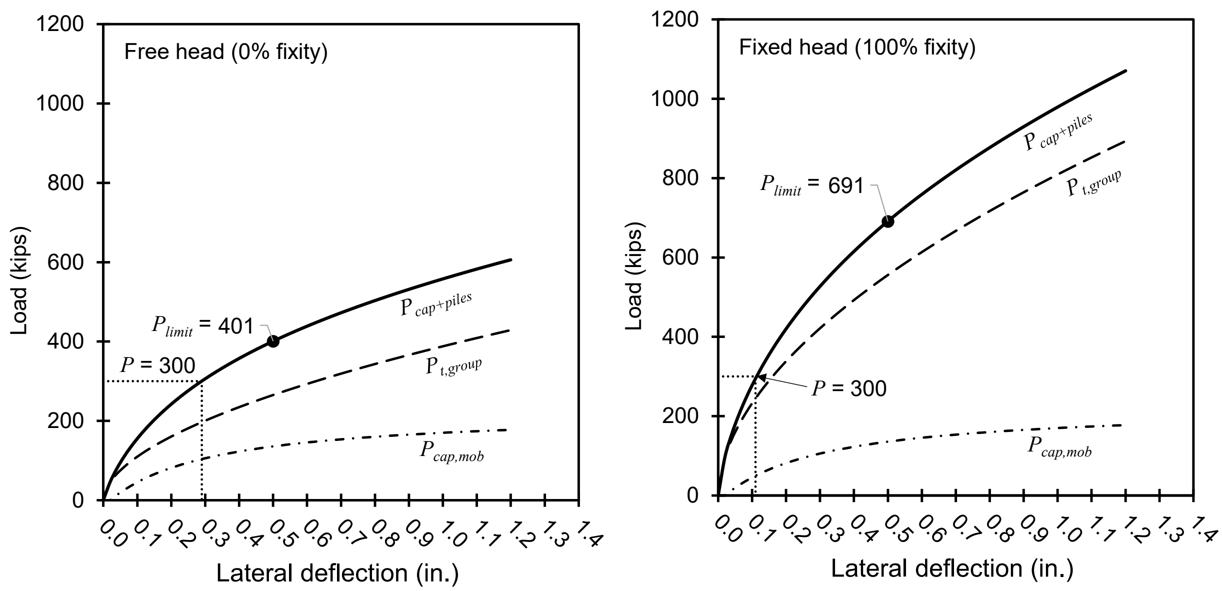


Figure B-22. Load-Deflection Relationship with Service Limit State Check

B-6.3.6 Calculation of Maximum Moment under Service Conditions.

The maximum moments in the piles at the service limit state are found using Equation 6-71 in Section 6-6.4.3. Use of a single weighted p-multiplier to account for group effects implicitly assumes that all piles in the group carry equal load. The maximum moments are corrected for group effects using the moment scaling factors provided in Section 6-6.5. This correction estimates the maximum moment in the corner piles of the lead row, which are expected to experience the highest moments in the pile group. For this example, the equation is:

$$M_{\max} \approx a \cdot M_c \left(\frac{P_t}{P_c} \right)^n \approx a\left(45457\, in - kip\right)\left(\frac{P_t}{265\, kips} \right)^n$$

where for piles in clay:
a = 0.855 for a free head and 0.782 for a fixed head and
n = 1.288 for a free head and 1.249 for a fixed head.

At the service limit state of 0.5 inch deflection, the resistance provided by the pile group is equal to 265 kips. Because the normalized pile spacing is equal to 3, a correction equal to 1.20 (see Section 6-6.5) is applied to estimate the maximum moment for the corner piles in the lead row. With these considerations, the maximum moment in the piles for a free head condition is equal to:

$$M_{\max,corner} = \left(\frac{1.2}{12\, in/ft} \right)\left(0.855\right)\left(45457\, in - kip\right)\left(\frac{259\, kips}{\left(265\, kips / pile\right)\left(49\ piles\right)} \right)^{1.288} = 26\, ft - kip$$

For fixed head conditions, similar calculations estimate a maximum moment equal to 69 ft-kips at the service limit state deflection of 0.5 inches.

Under service conditions, where an unfactored load of 300 kips is anticipated, the load-deflection relationships provided in Figures B-21 and B-22 can be interpreted to extract the portion of the resistance provided by the piles, $P_{t,group}$. Alternatively, the equation for $P_{cap+piles}$ can be solved for y_t corresponding to the unfactored load and that value of y_t can be used to find $P_{t,group}$. Table B-34 summarizes the values of y_t, $P_{t,group}$, and $M_{max,corner}$ for the applied unfactored load.

Table B-34 Deflection, Lateral Pile Load, and Maximum Moment due to Unfactored Loading

Parameter	Free head (0% fixity)	Fixed head (100% fixity)
y_t	0.29 in.	0.11 in.
$P_{t,group}$	197 kips	249 kips
$M_{max,corner}$	18 ft-kips	25 ft-kips

B-6.4 Conclusions from the Analysis.

Based on this analysis, the trial pile design satisfies the geotechnical strength limit state and the serviceability limit state with respect to lateral deflection. Given that the piles are embedded in the cap 1 ft, there is some amount of rotational restraint that can be justified in the design. Referring to Table B-34, the contribution of rotational restraint means that lateral deflection is expected to be less that 0.29 inches.

B-7 EXAMPLE 7 – RELIABILITY ANALYSIS OF A RETAINING WALL.

B-7.1 Description of the Problem.

A concrete, cantilever gravity retaining wall is being designed as shown in Figure B-23. The parameters shown in Table B-35 were assumed to be random variables with the properties provided. Note that the uncertainty in concrete unit weight is being used as a proxy for both the material variation and uncertainty in the structural dimensions. Any covariance between the parameters is being ignored.

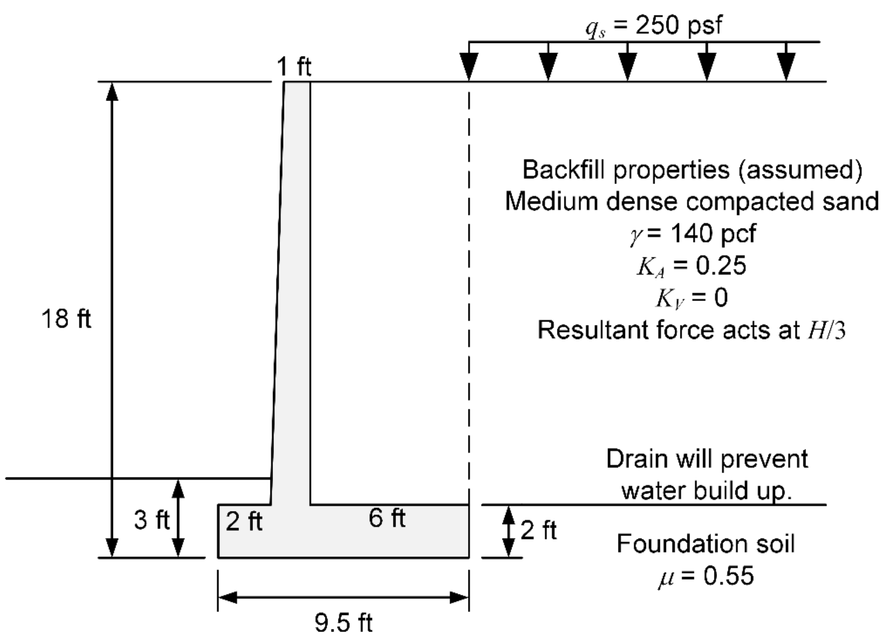


Figure B-23 Proposed Cantilever Retaining Wall

All four methods discussed in Chapter 7 will be used to evaluate the reliability of the wall design for overturning, sliding, bearing capacity, and settlement. Each section will focus on one of the methods and provide comparative results from the others.

Table B-35 Probabilistic Material Properties for Wall Design

Parameter or RV	Mean	Std. Dev.	*COV*	Comment
Backfill unit weight	140 pcf	16 pcf	11.4%	Table 7-4: Assumed value indicates high uncertainty
Backfill earth pressure coefficient	0.25	0.04	16%	Table 7-4: Assumed value indicates high uncertainty. Based on typical COV for friction angle.
Surcharge	250 psf	50 psf	20%	Judgment. Similar to load factor of 1.2.
Concrete unit weight	150 pcf	5 pcf	3.3%	High quality formwork and QA/QC will result in low uncertainty.
Base friction coefficient	0.55	0.07	13%	Table 7-4: Assumed value with moderate to high uncertainty. Based on typical COV for friction angle.
Wall height	18 ft	0.2 ft	1.1%	High quality construction will result in low uncertainty in wall dimensions.
All RV were assumed to be normally distributed.				

B-7.2 Overturning.

For overturning, a wall supported on soil must either meet a minimum factor of safety (F_{OT}) or the resultant must be within the middle one-third of the wall base. If the latter requirement is used, the entire base will be under compression, and the F_{OT} will typically far exceed 1.5. F_{OT} reaches unity as x_0 approaches zero, which means the limit state function can be defined as:

$$g(x) = x_0$$

where:
x_0 = horizontal distance of the resultant from the toe of the wall.

Using the mean values, the resultant is 3.35 ft from the toe, which is close to the middle one-third critierion. However, a positive value of the limit state function indicates a safe condition for overturning, even though values lower than $B/3$ indicate some loss of compression below the base. The approximate FOSM approach was used to evaluate overturning with the calculations summarized in Table B-36. Each of the five RV that affects overturning was systematically varied up or down one standard deviation. The difference in the limit state function for each pair of variation was divided by two and squared as an estimate of the variance from that variable. The square root of the sum of the individual variances gives an estimate of the standard deviation of the limit state function.

The reliability index is calculated as:

$$\beta_{x_0} = \frac{\mu_{x_0}}{\sigma_{x_0}} = \frac{3.35}{0.385} = 8.72\,.$$

Table B-36 FOSM Approximation for Retaining Wall Example

Trial	γ_c (pcf)	γ_t (pcf)	q_s (psf)	K_a	H (ft)	x_N (ft)	$(\Delta g(x)/2)^2$
1	155	140	250	0.25	18	3.36	0.00002
2	145	140	250	0.25	18	3.35	
3	145	156	250	0.25	18	3.39	0.00207
4	145	124	250	0.25	18	3.30	
5	150	140	300	0.25	18	3.25	0.01071
6	150	140	200	0.25	18	3.46	
7	150	140	250	0.29	18	2.99	0.13026
8	150	140	250	0.21	18	3.71	
9	150	140	250	0.25	18.2	3.28	0.00482
10	150	140	250	0.25	17.8	3.42	
						Sum:	0.14788
						Estimated standard deviation of $g(x)$:	0.38456

•

The corresponding probability of overturning is (assuming a normal distribution for $g(x)$):

$$P_u = 1 - \Phi(8.72) = \text{Negligible}.$$

The P_u values are very small, indicating that an overturning failure is very unlikely for this case. The value of F_{OT} for the mean values is 2.49.

Table B-37 Summary of Probabilities of Unsatisfactory Overturning Resistance

Method	β_{x0}	P_u
FOSM by derivatives	6.45	6×10^{-11}
Approximte FOSM	8.72	Negligible
Point Estimate	8.69	Negligible
Hasofer Lind	7.41	6×10^{-14}
Monte Carlo (100,000 trials)	No failures encountered	
Calculations assume a normal distribution of x_0.		

B-7.3 Sliding.

The factor of safety against sliding at the mean values is 1.58. The reliability will be assessed by calculating the FOSM derivatives directly and using the Hasofer-Lind method. Sliding resistance depends on the weight and volume of the wall and backfill. The concrete volumes are $V_{c,base}$ = 19 ft^3/ft and $V_{c,stem}$ = 20 ft^3/ft. The soil volumes are V_{bf} = 96 ft^3/ft (backfill) and V_{ff} = 2 ft^3/ft (soil above toe).

The limit state function will be expressed as:

$$g\left(x\right)=F_{SL}-1=\frac{\gamma_c\mu\left(V_{c,base}+V_{c,stem}\right)+\gamma_t\mu\left(V_{bf}+V_{ff}\right)}{q_sK_aH+0.5\gamma_tK_aH^3}-1=\frac{39\gamma_c\mu+98\gamma_t\mu}{q_sK_aH+0.5\gamma_tK_aH^3}-1$$

Evaluating the first derivatives of *g(x)* with respect to each variable at the mean values:

$$\frac{\partial g}{\partial\gamma_c}=\frac{39\mu}{q_sK_aH+0.5\gamma_tK_aH^2}=\frac{39\left(.55\right)}{\left(250\,psf\right)\left(0.25\right)\left(18\,ft\right)+0.5\left(140\,pcf\right)\left(.25\right)\left(18\right)^2}=3.157\times10^{-3}\,ft^3\,/\,lb$$

$$\frac{\partial g}{\partial\gamma_t}=\frac{98\mu}{q_sK_aH+0.5\gamma_tK_aH^2}=\frac{98\left(.55\right)}{\left(250\,psf\right)\left(0.25\right)\left(18\,ft\right)+0.5\left(140\,pcf\right)\left(.25\right)\left(18\right)^2}=7.932\times10^{-3}\,ft^3\,/\,lb$$

$$\frac{\partial g}{\partial\mu}=\frac{39\gamma_c+98\gamma_t}{q_sK_aH+0.5\gamma_tK_aH^2}=\frac{\left(39\right)\left(150\,pcf\right)+\left(98\right)\left(140\,pcf\right)}{\left(250\,psf\right)\left(0.25\right)\left(18\,ft\right)+0.5\left(140\,pcf\right)\left(.25\right)\left(18\right)^2}=2.88$$

$$\frac{\partial g}{\partial q_s}=\frac{-\left(39\gamma_c+98\gamma_t\right)\mu K_aH}{\left(q_sK_aH+0.5\gamma_tK_aH^2\right)^2}=\frac{-\left(\left(39\right)\left(150\,pcf\right)+\left(98\right)\left(140\,pcf\right)\right)\left(0.55\right)\left(0.25\right)\left(18\right)}{\left[\left(250\,psf\right)\left(0.25\right)\left(18\,ft\right)+0.5\left(140\,pcf\right)\left(.25\right)\left(18\right)^2\right]^2}=-1.05\times10^3\,ft^2\,/\,lb$$

$$\frac{\partial g}{\partial K_a}=\frac{-\left(39\gamma_c+98\gamma_t\right)\mu}{\left(q_sH+0.5\gamma_tH^2\right)K_a{}^2}=\frac{-\left(\left(39\right)\left(150\,pcf\right)+\left(98\right)\left(140\,pcf\right)\right)\left(0.55\right)}{\left[\left(250\,psf\right)\left(18\,ft\right)+0.5\left(140\,pcf\right)\left(18\right)^2\right]\left(0.25\right)^2}=-6.336$$

$$\frac{\partial g}{\partial H}=\frac{-\left(39\gamma_c+98\gamma_t\right)\mu\left(q_sK_a+\gamma_tK_aH\right)}{\left(q_sK_aH+0.5\gamma_tK_aH^2\right)^2}$$

$$=\frac{-\left(\left(39\right)\left(150\,pcf\right)+\left(98\right)\left(140\,pcf\right)\right)\left(0.55\right)\left(\left(250\right)\left(0.25\right)+\left(140\,pcf\right)\left(0.25\right)\left(18\,ft\right)\right)}{\left(\left(250\,psf\right)\left(0.25\right)\left(18\,ft\right)+0.5\left(140\,pcf\right)\left(.25\right)\left(18\right)^2\right)^2}=-.1614\,ft^{-1}$$

The mean value of the limit state function is estimated by:

$$\mu_{g(x)}=F_{SL}\Big|_{MV}-1=1.58-1=0.58\,.$$

The estimated variance of the limit state function is:

$$\sigma_{g(x)}^2 \approx \left(\frac{\partial g}{\partial \gamma_c}\right)^2 \sigma_{\gamma_c}^2 + \left(\frac{\partial g}{\partial \gamma_t}\right)^2 \sigma_{\gamma_t}^2 + \left(\frac{\partial g}{\partial \mu}\right)^2 \sigma_{\mu}^2 + \left(\frac{\partial g}{\partial q_s}\right)^2 \sigma_{q_s}^2 + \left(\frac{\partial g}{\partial K_a}\right)^2 \sigma_{K_a}^2 + \left(\frac{\partial g}{\partial H}\right)^2 \sigma_{H}^2$$

$$\sigma_{g(x)}^2 \approx \left(3.076\times10^{-3}\,pcf^{-1}\right)^2\left(5\,pcf\right)^2 + \left(7.892\times10^{-3}\,pcf^{-1}\right)^2\left(16\,pcf\right)^2 + \left(2.88\right)^2\left(0.07\right)^2$$

$$+\left(1.05\times10^{-3}\,psf^{-1}\right)^2\left(50\,psf\right)^2 + \left(6.336\right)^2\left(0.04\right)^2 + \left(0.1596\,ft^{-1}\right)^2\left(0.2\,ft\right)^2$$

$$\sigma_{g(x)}^2 \approx 0.125$$

$$\sigma_{g(x)} \approx 0.354$$

The reliability index is:

$$\beta_{F_{SL}} = \frac{\mu_{g(x)}}{\sigma_{g(x)}} = \frac{1.58-1}{0.354} = 1.64\,.$$

Table B-38 Summary of Probabilities of Unsatisfactory Sliding Resistance

Method	β_F	P_u
FOSM – derivatives	1.64	5%
Taylor Series – approximate derivatives	1.67	4.7%
Point Estimate	1.84	3.3%
Hasofer Lind	2.22	1.3%
Monte Carlo (100,000 trials)	2.22	1.3%
Calculations assume a normal distribution of F_{SL}.		

B-7.4 Bearing Capacity.

For the analysis of bearing capacity, the Meyerhof method was selected. The backfill loads cause the pressure on the base of the foundation to be eccentric and inclined. The applied bearing pressure (q_{net}) using the equivalent footing approach is:

$$q_{net} = \frac{R}{2\cdot x_0}$$

where:
R = vertical component of the load on the footing (including the surcharge) and
x_0 = horizontal distance of R from the toe of the wall.

Using the mean values of the parameters, R is 21,070 lb/ft and x_0 is 3.58 ft (different from the overturning analysis above because the surcharge has been included). The applied bearing pressure is 2945 psf.

The load inclination (θ) can be found based on the vertical reaction and the horizontal reaction (T):

$$\theta = \tan^{-1}\left(\frac{T}{R}\right)$$

The bearing capacity for the foundation with the inclined load is found as:

$$q_{ult} = \sigma_{zD} \cdot N_q \cdot i_q + 0.5 \cdot B' \cdot N_\gamma \cdot i_\gamma$$

where:
σ_{zD} = vertical stress at footing depth at toe = (3 ft)(140 pcf) = 420 psf,
$B' = 2x_0$,
Nq and N_γ = Meyerhof bearing capacity factors = function of friction angle,
i_q = inclination factor = $(1 - \theta / 90)^2$, and
i_γ = inclination factor = $(1 - \theta / \phi')^2$.

Using the mean values, B' is 7.16 ft, N_q = 33, N_γ = 37, i_q = 0.64, and i_γ = 0.24. The resulting ultimate bearing capacity is 13338 psf. The calculated factor of safety for the mean values is 4.53.

The inclination factors and bearing capacity factors both have complex dependence on the random variables. A closed-form expression of the factor of safety will be cumbersome to manipulate, so the direct FOSM and Hasofer-Lind methods will not be considered for bearing capacity. Note that Filz and Navin (2006) present a simplified version of Hasofer-Lind that does not require a closed-form solution but for brevity is not presented here.

The approximate FOSM approach was performed first. The results are presented in Table B-39 for all six RV.

Table B-39 Approximate FOSM Analysis of Bearing Capacity

Variable	F+	F-	$(\Delta g(x)/2)^2$	Percentage of Variance
γ_t (pcf)	4.53	4.53	2.4 x 10-6	0%
γ_c (pcf)	4.65	4.38	0.017	0.4%
ϕ' (deg)	5.22	2.84	1.42	35%
q_s (psf)	6.73	4.78	0.948	23.4%
K_a	3.43	5.98	1.63	40.2%
H (ft)	4.33	4.73	0.390	1.0%
		Estimated Variance of F:	4.05	
		Estimated Standard Deviation of F:	2.01	
		Reliability Index (Assuming F is normally distributed):	1.75	
		Probability F < 1 (Assuming F is normally distributed):	4%	

The unit weights of the concrete and soil have very little effect on the variance as shown in the final column. For simplicity, these RV will be considered deterministic in the example of the Point Estimate method. For the four remaining RV, a total of $2^4 = 16$ cases must be analyzed for the Point Estimate method as demonstrated in the following table. If the factor of safety is assumed to be normally distributed, the reliability index is 1.48 and the probability of F < 1 is 6.9%.

Table B-40 Point Estimate Analysis of Bearing Capacity

Trial	ϕ' (deg)	q_s (psf)	K_A	H (ft)	q_{app} (psf)	q_{ult} (psf)	F_{BC}	P	$P \times F_{BC}$	$P \times (F_{BC})^2$
1	32	200	0.21	17.8	2590	10440	4.03	0.0625	0.252	1.016
2	38	200	0.21	17.8	2590	28089	10.85	0.0625	0.678	7.353
3	32	300	0.21	17.8	2723	10043	3.69	0.0625	0.231	0.850
4	38	300	0.21	17.8	2723	26975	9.91	0.0625	0.619	6.134
5	32	200	0.29	17.8	3071	7404	2.41	0.0625	0.151	0.363
6	38	200	0.29	17.8	3071	19507	6.35	0.0625	0.397	2.521
7	32	300	0.29	17.8	3284	7064	2.15	0.0625	0.134	0.289
8	38	300	0.29	17.8	3284	18479	5.63	0.0625	0.352	1.979
9	32	200	0.21	18.2	2660	10001	3.76	0.0625	0.235	0.883
10	38	200	0.21	18.2	2660	26844	10.09	0.0625	0.631	6.364
11	32	300	0.21	18.2	2802	9619	3.43	0.0625	0.215	0.737
12	38	300	0.21	18.2	2802	25763	9.20	0.0625	0.575	5.285
13	32	200	0.29	18.2	3211	7034	2.19	0.0625	0.137	0.300
14	38	200	0.29	18.2	3211	18382	5.73	0.0625	0.358	2.049
15	32	300	0.29	18.2	3445	6717	1.95	0.0625	0.122	0.238
16	38	300	0.29	18.2	3445	17414	5.05	0.0625	0.316	1.597

Subtotals =	5.40	37.96
Estimated mean =	5.40	
Estimated variance = 37.96 – 5.40^2 =	8.79	
Estimated standard deviation =	2.96	

Monte Carlo simulation was performed in a spreadsheet for all six RV. The RAND() function generates a value on the interval (0,1) which can be treated as a cumulative probability.

Combined with the mean and standard deviation of each RV, random values of each RV were determined using the inverse normal function as:

$$x_i = \Phi^{-1}\left(RAND,\ \mu_x,\ \sigma_x\right) = NORMINV\left(RAND(),\ \mu_x,\ \sigma_x\right)$$

These values were placed in a spreadsheet row followed by all of the calculated moments, dimensions, forces, and bearing capacity factors. The values of q_{net} and q_{ult} are then calculated for each trial and the ratio is determined to find the factor of safety.

An additional column is added which records a "1" every time $F < 1$. The total number of trials for which $F < 1$ divided by the total number of trials is equal to the estimated probability of $F < 1$. For this particular case, the spreadsheet calculated 10,000 trials each time a value was changed. Ten sets of trials were completed resulting in 100,000 trials total. The combined probability of $F < 1$ was 0.57%, which is lower than predicted by the other methods when F is assumed to be normally distributed.

Table B-41 Monte Carlo Analysis of Bearing Capacity

Method	Normally Distributed F		Lognormally Distributed F	
	β	$P(F<1)$	β	$P(F<1)$
Approximate FOSM	1.75	4.0%	3.35	0.04%
Point Estimate	1.45	6.9%	3.03	0.12%
Monte Carlo	$P(F<1) =$ 0.57%			

In order to investigate this further, one set of 10,000 trials was divided into bins of factor of safety, and a histogram of the frequency was plotted in Figure B-24. The distribution of F is markedly skewed, and visually appears to be lognormal. This could be checked using statistical methods but has not bee completed here.

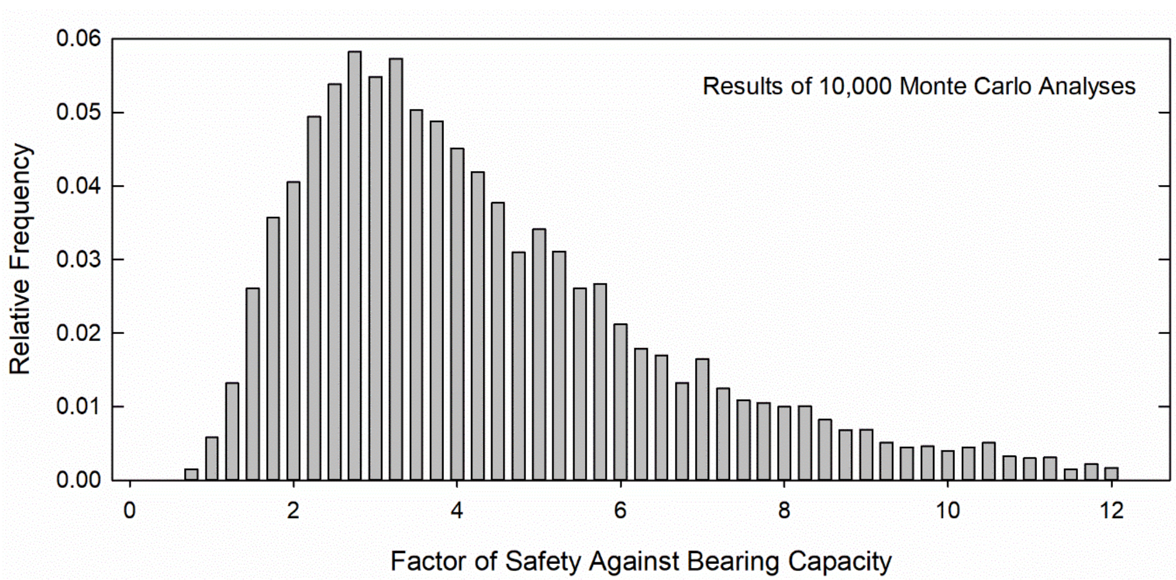


Figure B-24 Distribution of the Factor of Safety from a Subset of the Monte Carlo Analysis of Bearing Capacity

If the Taylor Series and Point Estimate methods are interpreted as lognormal, the probability of $F < 1$ becomes 0.04% and 0.12%, respectively, which is less than the value determined by Monte Carlo. This indicates that the actual distribution of F is something between normal and lognormal for this problem. This tendency results from the fact that q_{net} and q_{ult} both have additive (tends toward normal) and multiplicative (tends toward lognormal) components.

In addition, the bearing capacity factors are highly non-linear, and the approximate FOSM and Point Estimate methods would only be expected to produce an approximate estimate of β.

B-7.5 Conclusions from Analysis.

The reliability analyses are for the retaining wall example are summarized in Table B-42. The probability of unsatisfactory performance for sliding is relatively high. To evaluate risk, an estimate of the cost of repair or the potential for loss of life would be required. The high value of P_u for sliding may indicate that the mean factor of safety of 1.58 is too low considering the large uncertainty in some of the input parameters. Another factor to consider for the probabilities in Table B-42 is the time scale. Probabilities and risk are often reported on an annual basis; however, none of the loading factors in this design include timing. Thus, the reported values can be taken as applying over the life of the structure rather than yearly probabilities.

Table B-42 Summary of Probabilistic Stability Checks for Wall Design

Failure Mode	Reliability Index	Probability of Unsatisfactory Performance	Comments / Observations
Overturning – resultant location	6 to 9	Negligible	F assumed to be normally distributed Close agreement between methods
Sliding factor of safety	1.6 to 2.2	5% to 1.3%	F assumed to be normally distributed Hasofer-Lind and Monte Carlo agreed. Other methods underestimate β.
Bearing capacity factor of safety	2.5 to 3	0.6%	Distribution of F appears to fall between normal and lognormal but closer to lognormal based on Monte Carlo simulation.

APPENDIX C. GLOSSARY

Active condition – Stress state in which the soil's shear strength is fully mobilized by lateral movement away from the soil mass, resulting in a corresponding reduction in lateral stress.

Adhesion – Undrained strength of the interface between the soil and a structural material, such as a wall or foundation.

Aeolian soil – Material transported and deposited by wind.

Aggregate columns – Cylindrical columns of gravel constructed in the ground to support loads and/or promote drainage. Borderline technology between ground improvement and deep foundation constructed by drilling a shaft in the ground and backfilling with aggregate.

Aleatory uncertainty – see natural variability.

Allowable bearing pressure – Highest bearing pressure that does not exceed the factored bearing capacity and produces estimated settlements below the design criteria. Often rounded down to a multiple of 500 or 1000 psf.

Alluvial soil – Material transported and deposited by a river or stream.

Alpha Method – Deep foundation static capacity analysis method which finds a coefficient, α, that can be multiplied by the undrained shear strength to determine the unit shaft resistance. The α coefficient accounts for differences in soil disturbance and adhesion caused by soil properties and pile geometry.

Angular distortion – Differential vertical movement between two points divided by distance separating the points.

Apparent earth pressure diagrams – Pressure diagrams semi-empirically drawn to encompass the earth pressures measured in excavations. Actual pressures are likely lower at many depths.

Asperity – Undulation or irregularity in rock fractures. Asperity angle is added to the frictional resistance of rock surfaces.

At-rest condition – Stress state resulting from loading under conditions of no lateral strain.

Autocorrelation – Correlation of a property with the same property at a different point in space or time.

Backward erosion piping (BEP) – Progressive erosion of soil into an internal void or pipe by seepage flow. BEP starts at the downstream or exit end of the flow path.

Basal heave – Tendency of the bottom of an excavation to move upward because of the weight of the soil adjacent to the excavation.

Batter pile – Driven pile installed at an angle to provide lateral as well as axial resistance.

Bearing surface – Interface between the base of a foundation and the underlying soil. The bearing surface is usually horizontal.

Bent – A intermediate support for bridge spans, consisting of the piles and cap.

Beta Method – Deep foundation static capacity analysis method which finds a coefficient, β, that can be multiplied by the vertical effective stress to determine the unit shaft resistance. The β coefficient combines the effects of the horizontal earth pressure coefficient and the interface friction between the soil and pile.

Bin wall – Wall constructed from corrugated steel panels that are bolted together and filled with coarse-grained soils.

Biogeotechnics – Practice of leveraging or mimicking natural biological processes to improve the engineering behavior of a soil.

Blast densification – Use of explosives to cause densification of coarse-grained deposits with little fines.

Blast furnace slag – By-product of iron production. Air-cooled slag is solidified under atmospheric conditions and is angular and vesicular. Expanded slag is solidified using water which increases cellular nature. Granulated slag is chilled quickly forming a glassy product.

Block (group) failure – Bearing failure of a group of deep foundation elements along the sides and at the base of the group.

Borrow – Source of material for an engineered fill.

Bottom heave – Upward movement of the base of an excavation caused by a high upward gradient that exceeds the critical gradient of the soil, a.k.a., a quick condition.

Box and whisker plot – A diagram depicting the mean, median, specified percentiles, and extreme values of a sample.

Box shoring – Timber trench support method that uses horizontal timbers to support the soil. Applicable in any soil. Only limited in depth by the structural strength and size of the timber.

Buckling – Failure mode for unbraced length of piles in compression. Primarily a concern for unsupported piles extending through air, voids, water, and/or liquefied soil.

Bulkhead – Waterfront structure used to allow a change in elevation and access to a body of water.

Bulk-Infill Grouting – Ground improvement technology that uses large quantities of cementitious grout to fill subsurface voids.

Bulking – In the context of earthwork, an increase in soil volume by excavation, transport, and compaction to a different dry unit weight than the borrow material.

Cantilever flexible wall – Flexible wall that relies solely on passive earth pressure for support rather than anchors or bracing.

Cantilever movement – Horizontal movement of the top of a deep excavation wall. Occurs prior to installation of support system

Case Method – Real time use of wave equation analysis and measurements of pile strain and acceleration during driving to estimate nominal pile resistance, hammer and drive system performance, driving stresses, and pile integrity.

Cellular cofferdams – Structures constructed from sheet piles driven in a variety of geometries and filled with soil. Cofferdams perform many purposes, such as creating dewatered construction areas, lock walls, retaining structures, mooring structures, and spillway weirs.

Cellular concrete – Manufactured, preformed foam mixed with cement slurry and pumped into place. Can be pervious.

Chemical grouting or injection – Ground improvement technology that uses grout with no suspended particles to bond soil particles and fill voids. Strengthens the soil and reduces hydraulic conductivity.

Chemical soil stabilization – Ground improvement technology that uses chemical admixtures to reduce plasticity, reduce water content, and/or chemically bound soil or aggregate particles. Admixtures are often lime, portland cement, fly ash, or byproducts.

Clay – Soil particles passing a No. 200 (75-μm) sieve that exhibit plasticity (putty-like properties) within a range of water contents, and considerable strength when air dried.

Clay-sized fraction – The portion of the soil which is finer than 0.002 mm. This is not a viable measure of the plasticity of the material or its characteristics as a clay.

Clearing – In the context of earthwork, the removal of vegetation, trash, debris, and topsoil from the ground surface.

Close (tight) shoring – Timber trench support method that uses continuous upright timbers to support the soil. Useful where seepage and cave-ins are expected.

Coarse-grained soil – Soil that contains more than 50% particles retained on a No. 200 (75 µm) sieve.

Coefficient of variation – Standard deviation of a variable divided by the mean value.

Cohesion intercept – Intercept of a linear failure envelope with the shear stress axis. Can be expressed in terms of either total or effective stress.

Cohesionless soils – Typically used as a synonym for coarse-grained soils. Also an official term in OSHA classification.

Cohesive soils – An overly simplistic term typically used to refer to clayey fine-grained soils because these soils cohere at low normal stress. Also an official term used by in OSHA classification.

Collapse index – Relative collapse from inundation at a stress of 4000 psf.

Collapse potential – Strain caused by wetting at any stress level.

Collapsible soil – Material characterized by a metastable structure that undergo an abrupt collapse when they are inundated. Exhibits large compressive volume change upon wetting.

Colluvial soil – Material transported and deposited by gravity, often found in the vicinity of slopes.

Column-supported embankments – Earth fill supported by a foundation reinforced with vertical elements. The base of the embankment may include a load transfer platform of geosynthetic reinforced soil and/or crushed stone.

Combined footing – Footing supporting more than one column load.

Compaction – Removal of air from soil by temporary application of a mechanical load, such as rolling, tamping, or vibration.

Compaction control – QA process coupled with in-depth testing and observation of the earthwork process appropriate to an owner’s representative.

Compaction grouting – Generally shallow ground improvement technology in which grout is pumped into the ground to displace and compact soil around the created grout bulb.

Compaction plane – Diagram that compares trends in compacted soil behavior that vary with dry unit weight and water content. The dry unit weight vs. water content relationship (a.k.a. compaction curve, Proctor curve, moisture density curve) is plotted on the compaction plane.

Compactive effort – Work performed on soil per unit volume during compaction.

Compensated foundation – Design method used to support heavy structures over compressible strata and reduce settlement. In this approach, the weight of the structure is balanced, completely or partially, by soil that is permanently excavated from the building footprint.

Competent person – Someone capable of identifying hazards or unsafe working conditions who also possesses authority to take corrective measures. See OSHA (2020) Paragraph 652(a)(1)(ii) for the legal definition of competent person.

Compression wave – Seismic wave in which the particles move longitudinally or in the same direction as the wave propagation.

Concentrated leak erosion – Erosion of soil particles at an interface in the soil at which a concentrated flow has developed.

Concrete diaphragm wall – retaining wall system constructed from overlapping concrete wall panels.

Continuous flight auger column – Deep foundation element constructed by inserting a continuous auger into the ground in one continuous operation, after which the hole is filled with grout or concrete under pressure. Reinforcing steel is pushed into the uncured concrete.

Continuous footing – Footing supporting two or more columns in a row or a wall. Continuous foundations are used under wall loads and when the distance between columns is sufficiently close that individual footings can be combined.

Controlled compacted fill – Use of a controlled compaction process to create a soil mass that is more rigid and uniform than most natural soils.

Correlation length – Distance in space or time within which a property is significantly correlated with itself.

Counterfort – Structural support member between the stem and base of a cast-in-place gravity retaining wall. The counterfort provides moment resistance to the stem without increasing the thickness of the entire stem.

Creep – Time-dependent deformation of a soil at a constant effective stress.

Crib wall – Wall constructed of timber or precast concrete beams. Interlocking precast concrete beams are available for rapid wall construction.

Critical height– Maximum height that a vertical excavation in clay soil will stand without support for short term conditions.

Cross-hole sonic logging – Integrity testing method that measures travel time of waves between a transmitter and a receiver in two access tubes embedded in the foundation. Typically used in drilled shafts. Only tests the portion of the foundation between the access tubes.

Cross-lot bracing – Structural element that supports an excavation by spanning between two sides of the excavation.

Cumulative density function – Function defining the probability that a continuous random variable is less than or equal to a particular value.

Cumulative distribution – Plot of the number of observations that are less than a particular value.

Cumulative mass function – Function defining the probability that a discrete random variable is less than or equal to a particular value.

Cut wall – Retaining structure that is inserted into the ground, followed by excavation to create the grade separation.

Dampproofing – Material applied to foundation walls that resists the passage of water under no hydrostatic pressure.

Deadman anchor – Buried discrete or continuous element that uses passive earth pressure to resist anchor forces.

Decision tree – Risk assessment tool that combines probabilities and consequences in graphical form. Decisions are made at each branch between options with different costs or consequences.

Deep and mass mixing – Ground improvement technology that creates strong, stiff elements or zones by mixing soil and cement with a mixing tool from the ground surface. Can extend to significant depth.

Deep dynamic compaction – Compaction of existing soil by dropping a large weight from substantial height. Useful for compacting existing deep coarse-grained fills or loose soils.

Deep foundation – Foundation with a depth to width ratio more than about five.

Deep inward movement – Horizontal movement of a laterally supported deep excavation that occurs near the base of the excavation. This type of movement may be associated with basal heave movement.

Deflocculation – Separation of clay particles caused by moving water or chemical reagents.

Degree of saturation – Ratio of the volume of water to the volume of voids, which is typically expressed as a percent.

Depth to fixity – Depth at which a laterally loaded pile experiences minimal rotation or translation. Can also refer to the unbraced pile length used in buckling calculations.

Desiccated – Fine-grained soil that has been dried, usually below the shrinkage limit, resulting in cracks.

Design point – In reliability analysis, the point on the limit state function that is most likely to occur based on the distributions of all the random variables. The design point defines the reliability of the design.

Deterministic – In the context of geotechnical calculations, the assumption that the input parameters take on a particular value or trend for each soil or rock unit, rather than being defined statistically.

Dewatering – Process where water is pumped from a foundation excavation or pumped from a pervious soil stratum with the purpose of lowering the water table. Allows construction below grade without water in the excavation.

Dip – In layered geologic material, the angle between the layering and the horizontal plane.

Discontinuity – Natural break in a rock mass, such as a joint, fault, or bedding plane.

Dispersive clays – Clays comprised of minerals that contain a high percentage of dissolved sodium in the pore water and are thus very susceptible to concentrated leak erosion.

Drag force – Vertical load transferred to pile by negative skin friction.

Drained – In the context of shear strength and soil mechanics, a condition in which all excess porewater pressures caused by changes in stress or boundary condition have dissipated by water flow and volume change. Does not imply that the soil is unsaturated.

Dredged soils – Excavated or pumped materials that are obtained from below a water surface, mainly from the maintenance of navigable waterways and harbors.

Drilled displacement piles – Deep foundation element similar to a continuous flight auger column but constructed with an auger that displaces the soil laterally as it is inserted.

Drilled shaft – Deep foundation element constructed by drilling a shaft in the ground, which is subsequently filled with reinforced concrete.

Drivability - Ability of a hammer and drive system to drive a pile efficiently without damaging the pile.

Driven pile – Preformed deep foundation element that is hammered or vibrated into the ground.

Driving stress – Axial stress in driven piles during the driving process.

Dry method – Drilled shaft construction that uses an open shaft without drilling slurry. The shaft will often be cased.

Dry of optimum – Compaction to a combination of water content and dry unit weight to the left of the line of optimums. Dry of optimum can also refer to compaction at a water content lower than the optimum water content for a particular energy.

Dry unit weight – Weight of solids per unit volume.

Dynamic formulae – Methods to estimate the capacity of a driven pile from the measured blow count or pile set. These formulae produce highly variable results.

Earth pressure coefficient – Nominally, the ratio of horizontal to vertical effective stress.

Earthwork – The process of changing the topography of the ground to accommodate construction and to provide drainage.

Eccentricity – A loading condition that results in an unbalanced foundation bearing pressure as a result of nonconcentric loading or applied moment.

Effective stress – Stress state that controls soil strength and compressibility. Effective stress found by subtracting the pore pressure from the total stress.

Effective stress analysis - Analysis of stability or deformation that uses effective stresses. Synonymous with drained analysis.

Electro-osmosis – Ground improvement technology that uses an electrical gradient to promote water flow in soil, particularly to promote consolidation.

Encapsulation – Method of protecting moisture sensitive soils from large fluctuations in moisture content, particularly below pavements. The soil can be fully or partially encapsulated.

End-of-construction – Design scenario for conditions immediately following the application of the full structural load. Fine-grained soils are typically assumed to be undrained in this condition.

End-result specifications – Specifications requiring that a particular threshold value or acceptable range be achieved for the parameter of interest, such as dry unit weight and water content for earth fill or concrete compressive strength for foundations.

Epistemic uncertainty – See knowledge uncertainty.

Equivalent fluid unit weight – Product of the soil unit weight and earth pressure coefficient. Used to calculate horizontal pressure with the same methodology as for hydrostatic fluids. The concept is commonly used by structural engineers.

Equivalent footing – In the context of shallow foundations, the reduced dimensions that define a bearing area for which the resultant soil reaction is centered (non-eccentric). In the context of deep foundations, the depth at which the foundation load is assumed to beginning shedding to the supporting soil or rock.

Event tree – Risk assessment tool used to evaluate complex chains of conditional probabilities starting at an initiation point with a specific probability. Branches extend at each intermediate node.

Expanded clay shale (ECS) – Synthetic, vitrified aggregate produced by heating clay or claystones. Often used as aggregate in lightweight concrete. Can degrade under steel-tracked equipment.

Expansive shale – Sedimentary rock composed of clay minerals that can swell when exposed to water.

Expected value – Summation of any function times the probability mass function (discrete) or probability density function (continuous) over the full range of the random variable. The expected value of a random variable is the mean.

Exposure period – Length of time being considered in a design.

External uncertainty – See natural variability.

Externally-supported – Retaining system that uses anchors or tiebacks within the soil that are external to the excavation.

Factor of safety – Ratio of capacity to demand, often expressed in terms of shear strength divided by shear stress or failure load divided by applied load.

Fault tree – Risk assessment tool that starts with outcomes and assesses events required to reach those outcomes.

Fiber reinforcement – Use of fibers mixed with soil to improve shear strength. The fiber materials include natural, fiberglass, and plastic.

Field test section – Full-scale field compaction test to determine the appropriate procedure for a particular combination of site conditions and fill material. May be used to develop a method specification. Can also refer to a test grouting program.

Fill preloading – Practice of using an earth fill to promote consolidation and strengthening of soil prior to construction of the final structure, a.k.a., surcharging.

Fill wall – Retaining structure for which the wall is constructed and subsequently backfilled, creating grade separation. Rigid walls and MSE walls classify as fill walls.

Filter cake – Bentonite that collects on the side of a drilled shaft from the bentonite slurry.

Fine-grained soil – Soil that contains 50% or more particles passing a No. 200 (75 μm) sieve.

Fissures – Cracks or joints in soil, typically clay, resulting from stress relief and passive failure caused by unloading.

Fixed earth support – Analysis method for flexible structures that assumes no movement of the tip of the wall. Less commonly used than free earth support.

Fixed head condition – Condition where full rotational restraint is applied to the top of a laterally loaded deep foundation element. The maximum moment occurs at the restraint at the top of the element.

Flexible foundation – Foundation system that does not meet the requirements for rigid foundations.

Flexible retaining structures – Primarily vertical structural elements that are inserted prior to excavation. Structures may be braced or anchored. See also cut walls.

Floating foundation – See compensated foundation.

F-N chart – Risk assessment diagram that plots the annual probability of a consequence (F) against the consequence (N). Usually has regions that define acceptable and unacceptable risks.

Foamed glass aggregate (FGA) – Synthetic aggregate produced by heating recycled glass. Closed and open cell FGA available.

Force polygon – A vector diagram of the forces on a free body, used to graphically evaluate equilibrium.

Free earth support – Analysis method for flexible structures which assumes tip deflection can occur. Tends to overpredict the bending moments in the structure. Techniques are available to correct the bending moment.

Free head condition – Condition where no rotational restraint is applied to the top of a laterally loaded deep foundation element. The maximum moment occurs below the top of the element.

Friction angle – Inclination of a linear failure envelope in shear stress versus normal stress space. Can be expressed in terms of either total or effective stress.

Full-displacement pile – Deep foundation element that compresses the surrounding soil during driving or drilling to allow for the volume of the pile, such as closed-end piles or piles that form plugs.

Fully softened shear strength – Drained shear strength condition used to account for the effects of weathering, stress relief, and progressive failure in moderate to high plasticity clays. Fully softened shear strength is empirically equal to the peak shear strength of the clay in a normally consolidated state.

Gabion – Compartmented, rectangular containers made of heavily galvanized steel or polyvinylchloride (PVC) coated wire. Filled with stone from 4 to 8 inches in size. Used for control of bank erosion and stabilization as well as earth retaining structures.

Gamma-gamma logging – Integrity testing method that uses a gamma ray detector to determine the unit weight of the concrete from a single access tube.

General shear failure – Bearing failure along a well-defined slip surface that extends below and beyond the edges of a footing. Typical of stiff saturated clays and relatively dense coarse-grained soils.

Geofoam – Blocks manufactured from expanded polystyrene (EPS) or extruded polystyrene (XPS), typically installed in large blocks.

Geologic Strength Index – Measure of rock strength based on the rock mass structure and the surface condition.

Geosynthetic – Polymer material used with soil or rock for a geotechnical purpose.

Geosynthetic reinforcement – Geosynthetic used to provide tensile resistance in geotechnical structures, often used in slopes, pavement subgrades, and behind walls.

Geotextile – Permeable geosynthetic made like a textile and used for separation, filtration, or reinforcement. Geotextiles can be made using both woven and nonwoven manufacturing processes.

Glacial till – An accumulation of debris, deposited beneath, at the side (lateral moraines), or at the lower limit of a glacier (terminal moraine). Material lowered to the ground surface in an irregular sheet by a melting glacier is known as a ground moraine. Also known as boulder clay.

Global stability – Equilibrium condition for retaining walls that considers slip surfaces that complete by-pass the wall structure and any reinforcing or anchors.

Granular – A common synonym for coarse-grained soils.

Gravel – Soil with more than 50% coarse-grained particles and more gravel than sand-sized particles.

Gravel-sized – Soil particle size between 4.75 mm and 75 mm (3 in.).

Grid foundation – Foundation system formed by intersecting continuous footings.

Gross bearing pressure – The total load applied to the foundation divided by the area of the bearing surface.

Ground anchor – Structural element used to transmit tensile force to soil or rock.

Ground improvement – Means of modifying the ground with the purpose of improving one or more properties, such as shear strength, compressibility, or hydraulic conductivity.

Grubbing – Removal of stumps, heavy root mats, and buried objects.

Hard driving – Pile driving to refusal on rock or very dense soil, or penetrating an obstruction.

Hazard – A condition that has the potential to cause damage to or loss to personnel, equipment, or property.

Hazard curve – Relationship between the rate of exceedance and the magnitude of the hazard.

Hazard function – The probability that an event occurs (per time) assuming that the event has not occurred up to the given time.

Helical piles – Deep foundation element with relatively low capacity consisting of a steel bar with circular steel bearing plates.

High-strain dynamic testing – Integrity testing method that employs wave equation analysis to detect pile length and defects. Typically used with driven piles.

Histogram – Bar graph with intervals on one axis that span the range of the plotted property. The total height of the bars equals the number of observations in the sample.

Hydraulic conductivity – Discharge velocity of water through a unit area under a unit hydraulic gradient. Can also be viewed as a coefficient of proportionality relating seepage velocity to hydraulic gradient. Often called permeability in geotechnical engineering practice.

Hydraulic fill – Fill placed using flowing water. Cannot be compacted during placement. Hydraulic fill tends to be weaker and more compressible than compacted fills.

Hydraulic shoring – Aluminum hydraulic cylinder braces and heavy plywood (Finform) sheets used to support excavations.

Hydrocompression – Compressive volume change that occurs as a result of wetting, which is particularly a concern in relatively thick compacted fills.

Hydrodynamic – Water pressure exerted by moving water, specifically by seismic excitation.

Hydrostatic – Water pressure exerted under conditions of no flow or movement.

In situ – Latin for “in the original position,” which refers to soil or rock that remains in place in the ground. Used with testing to refer to measurements that are made in the ground and do not require a soil sample to be obtained.

Integrity testing – Method used to detect and evaluate damage and/or defects in a deep foundation.

Intelligent compaction – Use of instrumented compaction equipment to provide a measure of the stiffness of the compacted soil during compaction. In order to fully implement, the equipment should automatically modify operation based on the stiffness measurements.

Interface friction angle – Arctangent of the coefficient of friction between the soil and a structural material, such as a wall or foundation.

Interlock – Connection between individual adjacent sheet piles.

Internal erosion – Movement of soil particles from within the soil structure by flowing water.

Internal uncertainty – See knowledge uncertainty.

Internally-supported – Retaining system that uses structural supports that are internal to the excavation.

Jet grouting – Grouting method that uses high pressure jets on the tooling to break apart the soil, followed by the insertion of cementitious grout.

Jet-eductor well – Dewatering system that uses a high-pressure nozzle to create a vacuum at the bottom of the well, which draws groundwater to the well.

Jetting – Pile driving aided by loosening sand and gravel soils with a high-pressure water nozzle on a probe.

Karst – Terrain usually formed from the dissolution of rocks such as limestone, dolomite, and gypsum. It normally contains an underground drainage system connected to sinkholes and caves.

Kneading compaction – Method of applying compactive effort that shears the soil using a roller with pads or feet that exert very high contact pressure. Usually used for fine-grained soils.

Knowledge uncertainty – Uncertainty that occurs from lack of knowledge, information, or understanding; a.k.a., epistemic or internal uncertainty.

Kurtosis – Fourth moment of a distribution about the mean.

Lacustrine soil – Material deposited within lakes by waves, currents, and organo-chemical processes. Deposits consist of unstratified organic clay or clay in central portions of the lake and typically grade to stratified silts and sands in peripheral zones.

Laterites – Residual soils rich in iron formed in hot and humid climates (tropical regions). The cementing action of iron oxides and hydrated aluminum oxides makes dry laterites extremely hard. The high content of iron oxide makes many laterites to be rusty-red in color. Laterites are usually developed after significant weathering of the parent rock.

Leads – Frame used to guide driven pile during driving. Leads can be either fixed or swinging.

Lightweight fill – Alternative fill materials with lower unit weights than natural mineral soils.

Limit state function – Mathematical expression that defines the boundary between satisfactory and unsatisfactory performance.

Line of optimums – Curve connecting the peaks of a series of compaction (a.k.a. Proctor or moisture density) curves for different compactive efforts.

Liquefaction – A variety of phenomena affecting saturated cohesionless soils, in which positive excess pore pressures approach the total normal stress, causing partial or complete loss of shear strength. Liquefaction phenomena are typically divided into two categories: flow liquefaction and cyclic mobility (liquefaction in place).

Load and resistance factor design – Method that applies probabilistically-calibrated factors separately to the pertinent loads and resistances. In general, the factored load must be lower than the factored resistance.

Load factor – Multiplicative factor used to increase the calculated or measured nominal demand to an acceptable level for design. Factor accounts for uncertainty in the method used to determine the demand.

Load transfer – Process by which resistance is mobilized along the shaft and at the base of a deep foundation by movement of the foundation element.

Local shear failure – Bearing failure where plastic shear failure below the foundation transitions to compression of the adjacent soil. Slip surfaces do not extend to the ground surface beyond the footing.

Loess – A wind deposited, calcareous, unstratified deposit of silt or sandy or clayey silt traversed by a network of vertical tubes formed by the decay of root fibers. Loess slopes have the ability to withstand vertical cuts.

Logarithmic spiral – In the context of soil mechanics, a spiral-shaped slip surface having a radius that increases exponentially based on the friction angle of the soil.

Long pile – Slender deep foundation that behaves as a flexible member with no base rotation or translation.

Low wall – Short retaining wall that may require less detailed design and defined as less than 12 feet in this manual.

Low-strain dynamic testing – Integrity testing methods that use relatively low energy, such as sonic echo and impulse response.

Mat foundation – Foundation in which the weight of the structure is distributed across the entire footprint of the structure. Typically supports columns in several rows in each direction. Foundation covers an area of at least 75 percent of the total structure area.

Maximum dry unit weight – Dry unit weight at the peak of a compaction (a.k.a. Proctor or moisture density) curve for a particular amount of compactive effort.

Maximum void ratio – Loosest state that the soil can sustain with a regular structure. Typically used for coarse-grained soils with little fines.

Mean recurrence interval – see return period.

Measurement value (MV) – Indicator used in the intelligent compaction process, such as soil stiffness, modulus, or roller vibration characteristics.

Mechanical subgrade stabilization – Improvement of unstable soils by drying and recompaction and/or mixing with stronger or more stable soil.

Mechanically stabilized earth wall (MSEW) – Reinforced soil mass with a face inclined at 70° or more. Usually has a facing element of precast blocks or wire baskets.

Method specifications – Requirement that the contractor use a particular process, such as fill placement, lift thickness, equipment type, equipment speed, water content, and number of passes in the context of earthwork.

Micropiles – Small diameter (≤ 12 inches) foundation elements that are bored and grouted. Many variations are possible with respect to casing, drilling technique, grout delivery, and grouting phases.

Minimum void ratio – Densest state that the soil can sustain with a regular structure. Typically used for coarse-grained soils with little fines.

Model uncertainty – Uncertainty associated with the theoretical or mathematical model used to idealize a scenario.

Modulus of subgrade reaction – Ratio of the bearing pressure to the corresponding settlement with units of force per cubic length.

Moment – In the context of probability, summation over the full range of the random variable of the probability mass function (discrete) or probability density function (continuous) multiplied by the distance from the origin or mean. Analogous to area moments from mechanics.

Moment reduction – Method for correcting the overconservative moment predicted by the free earth support method.

Municipal solid waste (MSW) – Common items that are used and thrown away from residential and commercial sources. Also called trash or garbage.

Natural variability – Variations that result from physical randomness. Describes variability at various locations at the same time or variations in time and space; a.k.a., aleatory or external uncertainty.

Negative skin friction – Load transferred from the soil to a deep foundation element when the soil moves down relative to the element from consolidation, secondary compression, or vibration-induced densification.

Net bearing pressure – Gross bearing pressure minus the existing vertical overburden pressure at the foundation bearing elevation.

Net pressure diagram – Plot of the calculated difference between the pressure on each side of a wall.

Neutral plane – The elevation along a deep foundation at which no relative displacement occurs between the foundation element and the soil. The maximum compressive load in the foundation occurs at the neutral plane.

Non-displacement pile – Deep foundation element constructed without displacing soil, such as a drilled shaft or micropile.

Nonplastic – Soil that moves immediately from a semi-solid to a liquid state as the water content increases. Exhibited by difficulty rolling a plastic limit thread or performing the liquid limit test.

Normally consolidated soil – Soil for which the current effective stress state is the highest stress experienced by that soil following deposition.

One-third rule – Methodology that selects design parameters such that one-third of the data lies to the conservative side of the selected parameters.

Optimum water content – Water content at the peak of a compaction (a.k.a. Proctor or moisture density) curve for a particular amount of compactive effort.

Overconsolidated soil – Soil that has been previously consolidated to a higher effective stress state than the current stress state. Possesses a relatively low void ratio for the current stress state.

Oversize – Large particles within a test volume that interfere with the preparation of the test specimen or the performance of the test. This interference does not mimic field conditions. In the context of compaction, the large particles prevent adequate compaction of the finer soil fraction in the mold.

Oversleeves – Steel tubes used to extend hydraulic shoring braces to increase trench width.

Overturning – Equilibrium condition for retaining walls that considers wall rotation about a point on the wall, typically the toe.

Parallel gradation – Soil sample for which the grain size distribution has been shifted to have 100% passing the largest allowable particle size but maintaining the shape of the distribution. Created to facilitate laboratory testing.

Passive condition – Stress state in which the soil's shear strength is fully mobilized by lateral movement toward the soil mass and a corresponding increase in lateral stress.

Peak particle velocity (PPV) – Highest velocity generated by blasting in the direction of the wave propagation.

Plasticity – Measure of a soil's ability to interact with water. High plasticity soils require a large change in water content to move from a solid state to a liquid state.

p-multiplier – Empirical coefficients used to reduce the force or reaction of particular piles in a pile group as a result of group interactions.

Population – In the context of statistics, the set of all possible outcomes for a particular situation.

Post grouting – Grout pumped to the base of a drilled shaft to premobilize base resistance by reducing the void ratio of the underlying soil or creating a grout bulb at the base.

Power function – Nonlinear failure envelope used to represent shear strength with two or more parameters.

Predrilling - Pile driving aid in which an auger is used to drill a pilot hole for the pile.

Prefabricated vertical drains – Drain with a rectangular cross-section and geotextile sleeve that is inserted into the ground to shorten the drainage path for consolidation.

Pressure slab and walls – Floor slab and exterior foundation walls that are designed to retain and resist permeation and pressure from an elevated water level adjacent to the structure.

Presumptive bearing pressure – Allowable bearing pressure selected without explicit calculation of bearing capacity and/or settlement.

Probability density function – The function equal to the derivative of the cumulative density function at each value of a continuous random variable.

Probability mass function – Discrete function defining the probability that a random variable is equal to particular value.

Proctor test – Standardized test method for determining the maximum dry unit weight and optimum water content for a particular soil. Two compactive efforts are standardized by ASTM – Standard and Modified.

Proof rolling – Systematic trafficking of the subgrade by a loaded dump truck or roller. The purpose is to find instability and inconsistency in the subgrade or fill.

Punching shear – Bearing failure dominated by compression of the soil below the footing and vertical shear along the sides of the footing.

Pushover analysis – Repeated lateral load calculations that determine lateral top of pile deflections for a range of specified loads or the loads required to cause a range of top of pile deflections.

p-y curve – Constitutive model for lateral loading that relates soil reaction or load (p) to deflection (y).

Pyritic shale – Sedimentary rock containing sulfur that can form pyrite when exposed to the atmosphere and water, commonly dark gray to black and Devonian in age.

Quality assurance (QA) – Control testing completed by an entity other than the contractor, often the owner's representative.

Quality control (QC) – Control testing completed by the contractor.

Quick clay – Clay with a sensitivity greater than about eight.

Raker – Structural element that supports an excavation by transmitting load from the wall to the base of the excavation; a.k.a., raking braces.

Random variable – Variable that maps outcomes from a sample space to the real line.

Rapid drawdown – Design scenario for rapid lowering of water adjacent to a slope. Consolidated undrained shear strength is appropriate for this condition for soils with moderate to low hydraulic conductivity.

Rapid impact compaction – Method of compacting soil that drops a large weight many times per minute using an excavator as an alternative to deep dynamic compaction.

Rapid load test – Method to assess the capacity of a deep foundation that uses a dynamic load from a propellant or a dropped mass to load a foundation. The results must be interpreted to determine the failure load. Does not require reaction piles.

Rate of exceedance – Inverse of the return period in units of 1/time.

Record samples – In the context of earthwork, block or other intact samples of fill that can be used for laboratory characterization testing.

Reinforced soil slope – Reinforced soil mass with a face inclined flatter than 70°.

Relative compaction – Ratio of the compacted dry unit weight of a fill to a reference unit weight, typically the maximum dry unit weight for a particular compactive effort, such as Standard or Modified Proctor.

Relative density – Parameter used to quantify the density of a coarse-grained soil relative to the loosest and densest states. It is calculated as the ratio of the difference between the maximum void ratio and current void ratio to the difference between the maximum and minimum void ratios.

Relative water content – Algebraic difference between the compacted water content of a fill to a reference water content, typically the optimum water content for a particular compactive effort, such as Standard or Modified Proctor.

Relaxation – In the context of deep foundations, the reduction in pile resistance over time as negative driving-induced pore pressures dissipate.

Reliability – Probability that a design will perform in a satisfactory manner.

Reliability index – Number of standard deviations separating the mean value of a limit state function from the unsatisfactory condition.

Relieved slab and walls – Floor slab and exterior foundation walls that use a drainage system to relieve pressures from an elevated water level adjacent to the structure. Requires dampproofing.

Residual shear strength – The lowest drained shear strength of a soil that is achieved by shear displacement along a failure plane until particle alignment is achieved. This term is normally reserved for fine-grained soils. Residual conditions are often associated with slickensides forming on the failure plane.

Residual soils – Soil deposit formed by physical and chemical weathering of parent rocks in-place or from weathering of volcanic ash deposits.

Resistance factor – Multiplicative factor used to reduce the calculated or measured nominal capacity to an acceptable level for design. Accounts for uncertainty in the method used to determine the capacity.

Resultant – Reaction force acting on a structure or soil mass.

Return period – The mean amount of time between the return of a particular hazard; a.k.a., mean recurrence interval.

Rigid foundation – Foundation system for which the loads cause a ratio of differential to total settlement ratios less than or equal to 0.1.

Rippability – Ability to excavate rock directly using tracked equipment or an excavator. Rippability is dependent on the size of the equipment.

Riprap – Cobbles and boulders used as a slope protection to prevent scour. Size varies with classification.

Risk – Product of the probability of an adverse event multiplied by its consequence.

Risk assessment – Quantification and description of the nature, likelihood, and magnitude of risk in a systematic, evidence-based manner.

Rock fill – Fill containing at least 30% clean rock with a grain size greater than ¾-inch and containing less than 15% fines.

Running soils – Soils with no ability to hold a vertical face that will flow or cave into the excavation if unsupported, such as clean, dry coarse-grained soils. Seepage can cause running soil conditions.

Sample – In the context of statistics, a set of observations or measurements.

Sample space – See also population.

Sand – Soil with more than 50% coarse-grained particles and more sand-sized than gravel-sized particles.

Sand compaction piles – Columns of soil compacted in loose sand or soft clay using a driven installation pipe.

Sand-sized – Particle size between 0.075 mm and 4.75 mm.

Scale of fluctuation – Distance over which the soil properties are strongly correlated.

Scaled distance – Measure of the distance from a blasting charge to a structure that is corrected by the weight of the charge.

Scalped gradation – Soil sample for which all particles larger than a particular grain size have been removed to facilitate a particular laboratory testing method.

Scour – Loss of soil by erosion due to the drag force of moving water. Clear water scour occurs when the upstream bed material is not being actively transported and deposited. Live bed scour refers to a condition where the upstream bed material is transported and deposited to partially replenish eroded materials.

Secant pile wall – Retaining wall constructed from overlapping drilled shafts.

Sensitivity – Ratio of the peak undrained shear strength to the remolded undrained shear strength.

Service limit state – Design condition pertaining to the functionality or ability of the structure to remain useful.

Settlement – Downward movement of a structure.

Setup – In the context of deep foundations, the increase in pile resistance over time as driving-induced positive pore pressures dissipate.

Shallow foundation – Foundation with a depth to width (D/B) ratio less than about five, a.k.a., spread foundation, footing, or footer.

Shear strength – A measure of the shear stress sustained by a soil or rock at a state of shear failure. The shear stress on the failure plane and the maximum principal stress difference are two common measures of shear strength.

Shear wave – Seismic wave in which the particles move in the direction perpendicular to wave propagation.

Sheepsfoot roller – A type of kneading compactor with long tines or feet. Equipment replaced by tamping foot rollers in modern practice.

Sheet piling – Interlocking structural sections that are pushed or driven into the ground, often used for cut-type retaining walls. Cross-sectional shape varies based on usage. Most commonly steel but also available in plastic and timber.

Short pile – A deep foundation that can be considered rigid when laterally loaded. The rigid foundation element will rotate or translate at the base when loaded.

Shrinkage – In the context of earthwork, a reduction of soil volume by compaction to a higher dry unit weight than the borrow material.

Shrinkage factor – A factor multiplied by the final fill volume to account for shrinkage or bulking during the earthwork process.

Signal matching – Use of wave equation analysis along with strain gauges and accelerometers to estimate nominal pile resistance, hammer and drive system performance, driving stresses, and pile integrity.

Silt – Nonplastic or slightly plastic soil particles passing a No. 200 (75-µm) sieve that exhibit little or no strength when air dried. For classification of silty soils, refer to ASTM D2487.

Silt-sized – Soil particle size between 0.002 mm and 0.075 mm.

Simulation – Use of a complex, representative mathematical model to represent and calculate the performance of a design. Typically uses a numerical method such as finite element, finite difference, or Monte Carlo.

Skeleton shoring – Timber trench support method that uses discontinuous upright members and is applicable when running soils are not expected. Can be used to depths up to 20 feet.

Skew – Third moment of a distribution about the mean.

Sliding – Equilibrium condition for retaining wall and shallow foundations that considers movement parallel to the bearing surface.

Slurry cutoff wall – Subsurface barrier created by filling an excavated trench with a mixture of cement, bentonite, and/or soil. May be solely for seepage reduction or have structural components.

Soft driving – Pile driving through soft soil prior to reaching a competent bearing layer.

Soil nail (drilled) – Soil stabilization technique that drills and grouts a horizontal or inclined reinforcing elements in place. Soil nails are not prestressed or tension tested.

Soil nail (screw-in) – Soil stabilization technique that uses helical anchors as horizontal or inclined soil reinforcing elements. The anchors are installed by screwing into the ground. Soil nails are not prestressed or tension tested.

Soil nail (shoot in) – Soil stabilization technique that shoots a horizontal or inclined reinforcing elements into the soil. Depth of penetration and size of the nail are relatively limited; anchors are not grouted in place. Soil nails are not prestressed or tension tested.

Soldier pile and lagging – Retaining wall system with discrete vertical structural elements (soldier piles or soldier beams) and horizontal elements (lagging) that transfer load from the retained soil. Vertical elements are embedded deeper than the lagging to develop resistance to applied load. Most of the retained load arches to the piles.

Specific gravity of solids – Ratio of the density of the solids to the density of water.

Spudding – Practice of driving a heavy pile through an obstruction to make a hole for a production pile.

Static capacity analysis – Analytical method to estimate the axial capacity of a deep foundation element.

Static liquefaction – Behavioral condition in which soil liquefies as a result of an applied static shear stress in loose sands and non-plastic silts. Can occur when excavations are made in loose contractive sand deposits that were formed by sluicing or hydraulic fill.

Static load test – Method to assess the capacity and performance of a deep foundation in which a full-scale element is statically loaded after installation and the deformation is monitored. Results must be interpreted to determine the failure load. Requires reaction piles or anchors.

Stochastic – Random variation in time and space.

Sulfidic soil and rock – Geomaterials containing sulfur in various forms. Has the potential to be expansive when exposed to water and the atmosphere.

Surcharge – In the context of retaining wall or excavation design, a uniform pressure applied to the ground surface in many design calculations to represent live loading. In the context of earth fill or foundations, see Fill preloading.

Talus – A loose, colluvial deposit of rock debris located at the base of a cliff or mountain.

Tangent pile wall – Retaining wall constructed from adjacent but not overlapping drilled shafts. Due to the construction method, the wall may have gaps between the piles.

Telescopic shoring – Timber trench support method used for very deep trenches, which consists of nested trenches that decrease in width as the trench depth increases.

Thermal integrity profiling – Integrity testing method for drilled shafts that uses embedded temperature sensors to monitor the curing temperature of the concrete. Temperature patterns can be used to infer presence of defective concrete.

Tie back – Ground anchor installed through a retaining wall system to provide restraining force and/or moment. Tie backs are post-tensioned to reduce or eliminate the displacement required to develop capacity.

Timber shoring – A temporary structure made of wood used to support a trench.

Tire derived aggregate (TDA) – Lightweight construction material obtained by shredding or chipping scrap tires; a.k.a, tire shreds. The particle size usually ranges from 0.5 inches to 12 inches. TDA has been used in a wide range of projects, including lightweight embankment fill, landslide repair or stabilization, retaining wall backfill, roads, vibration mitigation, among others.

Top down method – Construction method where the retaining wall system is installed as the excavation progresses.

Total stress – Stress state that includes normal stresses from all sources, both soil contact forces and pore pressures.

Total stress analysis – Analysis of stability or deformation that only considers total stresses and represents shear strength in terms of total stress. Often synonymous with undrained analysis.

Total unit weight – Weight of solids plus liquids per unit volume.

Trench shield – A rigid prefabricated steel support system used in lieu of other types of shoring, which extends from the bottom of the excavation to the ground surface; a.k.a. trench box.

Two-thirds rule – Method in which a design parameter is selected such that one-third of the data lies to the conservative side of the selected parameter. Two thirds of the data falls on the other side of the selected value.

Ultimate bearing capacity – Gross bearing pressure that the soil or rock can withstand at the point of incipient plastic failure.

Ultimate limit state – Design condition pertaining to collapse.

Uncontrolled fill – Fill consisting of soil, rock, or other materials that are placed without control of material type, lift thickness, or compaction energy. The fill may contain industrial and domestic wastes, ash, slag, chemical wastes, building rubble, and refuse.

Underpinning – Installation of foundation elements below an existing structure that provides structural support when the bearing elevation of the existing foundations is higher than the bottom of an adjacent excavation.

Undrained – In the context of soil mechanics, a condition in which excess pore pressure caused by changes in stress or boundary condition is present. Commonly refers to the state immediately after loading where dissipation of excess pore pressures has not yet occurred.

Undrained shear strength – Strength measure of soil sheared without allowing excess pore pressures to dissipate. No volume change occurs during undrained shear of saturated specimens.

Unit base resistance – Deep foundation axial resistance at the base of the element per unit area.

Unit shaft resistance – Deep foundation axial resistance along the side of the element per unit area.

Vacuum preloading – Use of a vacuum to promote consolidation. The vacuum is applied within a sealed system to promote water flow to vertical drains.

Vibratory compaction – Method of applying compactive effort that uses a vibrating mass, which is usually used for coarse-grained soils.

Vibro-compaction – Densification of coarse-grained soils using a probe inserted into the ground and vibrated at different frequencies.

Vibro-concrete columns – Vertical elements created using a vibrating probe that penetrates the soil, delivers concrete to the base of the element, and expands the concrete through repeated penetration.

Void ratio – Ratio of the volume of voids to volume of solids.

Walk out – In the context of earthwork, the ability of tamping foot rollers to penetrate less and less into the fill as the fill becomes well-compacted.

Waste – The volume of soil lost in the earthwork process

Water content – Ratio of the weight of water to weight of solids, typically expressed as a percent. Can be expressed in terms of mass rather than weight.

Waterproofing – Material applied to foundation walls that resists the passage of water under hydrostatic pressure.

Wave equation analysis – Numerical approach that uses the characteristics of the pile, drive system, and hammer to evaluate nominal resistance and driveability, as well as hammer and drive system selection.

Wellpoint – Dewatering system that pumps water from the ground through a perforated well.

Wet method – Drilled shaft construction that uses a slurry mixture of water and bentonite or polymer to maintain shaft stability.

Wet of optimum – Compaction to a combination of water content and dry unit weight to the right of the line of optimums. Wet of optimum can also refer to compaction at a water content higher than the optimum water content for a particular energy.